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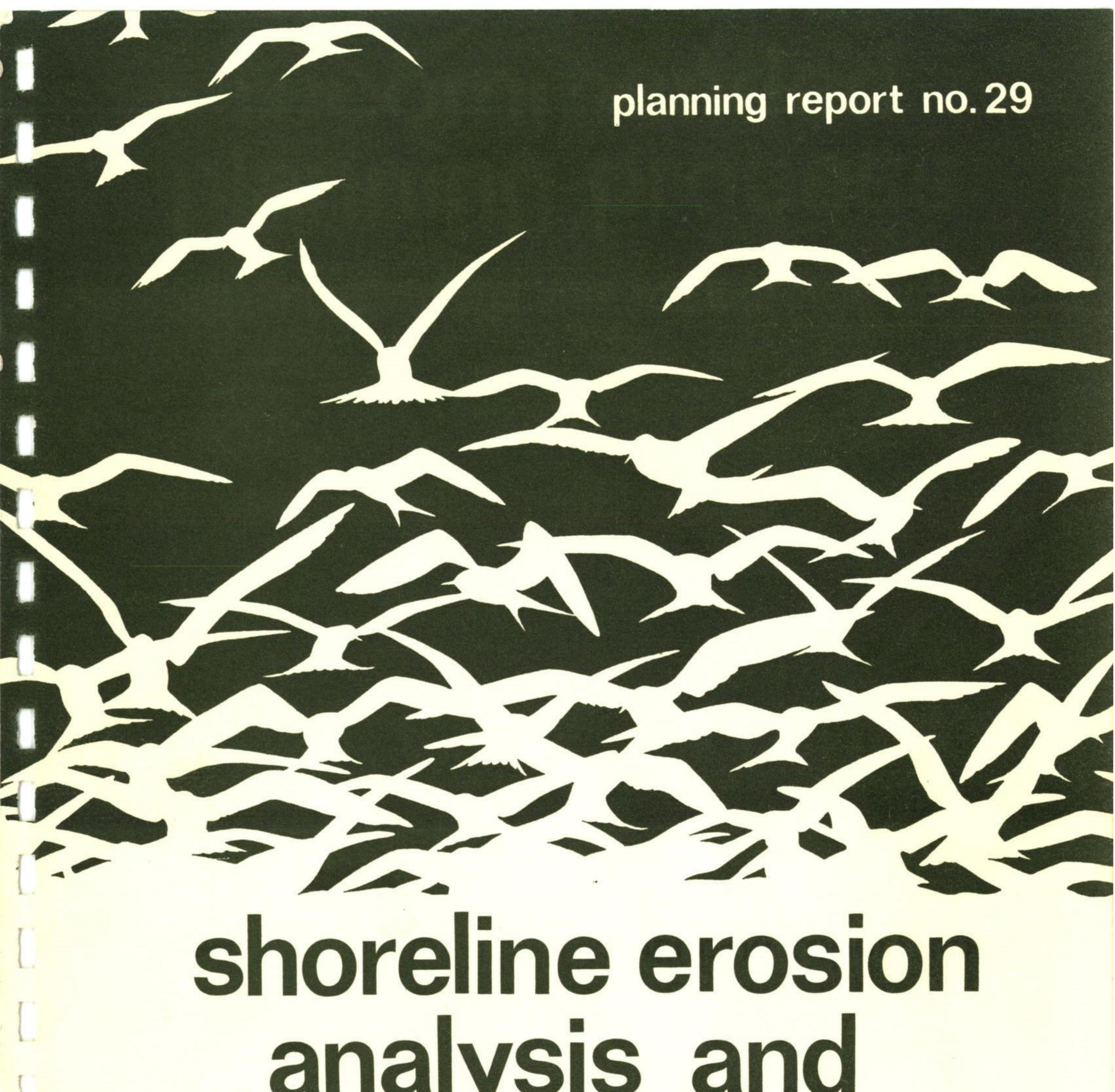

shoreline erosion analysis and recommended planning process

the connecticut coastal area management program

SHORELINE EROSION ANALYSIS
AND RECOMMENDED PLANNING PROCESS

State of Connecticut
Department of Environmental Protection
Coastal Area Management Program

June, 1979

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P R E F A C E

The Connecticut Coastal Area Management Program was established in August, 1974, under the auspices of the Federal Coastal Zone Management Act of 1972 (CZMA). The CZMA was passed by Congress in response to a perceived need for wise and balanced planning and management of the nation's coastal resources. The Act gave the country's thirty-five coastal and Great Lakes states and territories the opportunity and financial means to develop planning programs for their shorelines. Although participation in the planning effort is voluntary all coastal states have participated in the program.

The CZMA provides federal funding for eighty percent of the cost of designing a coastal management program, provided the state complies with certain broad procedural guidelines. Four years are allowed for the planning process; at the end of that time the state must submit a final management plan for federal approval in order to qualify for continued funding to implement its plan and recommendations.

Connecticut's program is now in its fourth year of planning. During the planning effort the program, under the guidance of an Advisory Board, has prepared recommendations for the possible implementation of a coastal management program. This planning report contains an analysis of shoreline erosion and a recommended planning process designed to mitigate the impacts of erosion on Connecticut's coast. The erosion planning process and analysis are intended to fulfill the shoreline erosion planning requirements of the CZMA.

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INTRODUCTION

For as long as man has lived on and utilized the northern shore of Long Island Sound, shoreline erosion and its impacts have been of concern. In 1955 the state legislature declared:

> "...that because of the occurrence of severe storms accompanied by winds up to hurricane force, abnormal high tides and tide flooding, the lives and property of residents and other persons within areas exposed to such hazards are endangered and that in the interests of public health, safety and welfare it is necessary to minimize...loss of life, property and revenue...."

The legislature further defined exposed (hazard) areas as:

> "...Land areas fronting on the ocean, or on bays, inlets and coves, or bordering on rivers in which tides occur, that are subject to the full force of storms; or land areas in direct contact with storm waves, including banks, bluffs, cliffs, promontories and headlands or similar topographical or geological formations, that are subject to erosion through wave action; or open beach areas, including spits, dunes and barrier beaches, that are subject to loss of sand through high waves, strong currents or scouring wave action; or land areas subject to inundation during storms or vulnerable to storm damage because of geographical situation...."

More recently, the Congress of the United States, as part of the Coastal Zone Management Act of 1972 (CZMA), recognized that states, in their efforts to develop coastal management programs, should formulate a "...planning process that can access the effects of shoreline erosion and evaluate management policies and techniques for addressing shoreline erosion."

The need for a comprehensive approach to planning for and managing shore erosion is clear. Our coast is intensely used. Over forty percent of the land within one mile of the shoreline is developed. The economic value of shorefront property and the high recreational use demands placed on sandy beaches, which are most susceptible to erosion, further amplify the significance of the problem. In 1975 the United States Army Corps of Engineers, as part of the Long Island Sound Regional Study, estimated that annual erosion damages incurred along our shores were in excess of $1.8 million (1970 dollars).In addition, approximately ten percent of Connecticut's coast was classified as "critically eroding." These figures and statistics, although indicative of the magnitude and effect of erosion are subject to rapid and considerable variation resulting from the dynamic nature of the shoreline and its physical environment.

In order to continuously evaluate, plan for and minimize the impacts of shoreline erosion, a system of long range observation, analysis and planning is necessary. This system must be based on a firm understanding and knowledge of the *geologic* and *geophysical* factors which have originated and continue to modify our coast.

The purpose of this report is to identify a planning process designed to cope with the problems of shoreline erosion as they pertain to Connecticut and meet the requirements of the CZMA (Appendix A).

First, and most importantly, it presents a current picture of the geology, *geomorphology* and important coastal processes which influence shoreline erosion. Presentation of these features and processes is necessarily brief with emphasis placed on the factors which are most important in producing shoreline change. Secondly, after discussion of the geophysical base, an attempt has been made to quantify the impacts of erosion through a general identification of those portions of our shoreline which are potentially erodible and those areas which are influenced by significant erosion. Subsequent to this general characterization, management alternatives are presented with the objective of enumerating a recommended planning process aimed at mitigating the types of erosion impacts which are experienced along Connecticut's shore. Based on exploration of the existing data base and informational availabilities, recommendations have been developed for further investigation for the purposes of filling in gaps in the research base.

When viewed in context these three elements form the foundation of a long range, resource-based planning process which is needed to adequately evaluate and mitigate shoreline erosion and its impacts on Connecticut.

This planning report is presented in four sections. The initial sections contain a non-technical description of the geologic properties and form of Connecticut's coastline and its interaction with winds, waves and tides, the primary agents of erosion. Subsequently, section three (Erosion Problem) contains a summary of the information presented in the initial sections, various statistics on the nature and extent of shoreline erosion and a discussion of erosion control alternatives. Section four contains the recommended planning process. Those readers interested solely in statistical information and a brief summary of Connecticut's erosion problems are directed to section three.

CONNECTICUT'S SHORELINE

GENERAL DESCRIPTION

Connecticut's coast occupies the northern shore of Long Island Sound -- an elongate, estuarine embayment whose major axis trends west-south-west to east-north-east for a distance of approximately 110 miles between New York City and Westerly, Rhode Island. At its point of maximum width the Sound is twenty-five miles across between New Haven, Connecticut and a point east of Port Jefferson, Long Island on its southern boundary. Long Island Sound is influenced by the Atlantic Ocean at its eastern-most terminus through a channel commonly known as the "Race" and at its western-most end through a more restricted connection with the East River and New York Harbor.

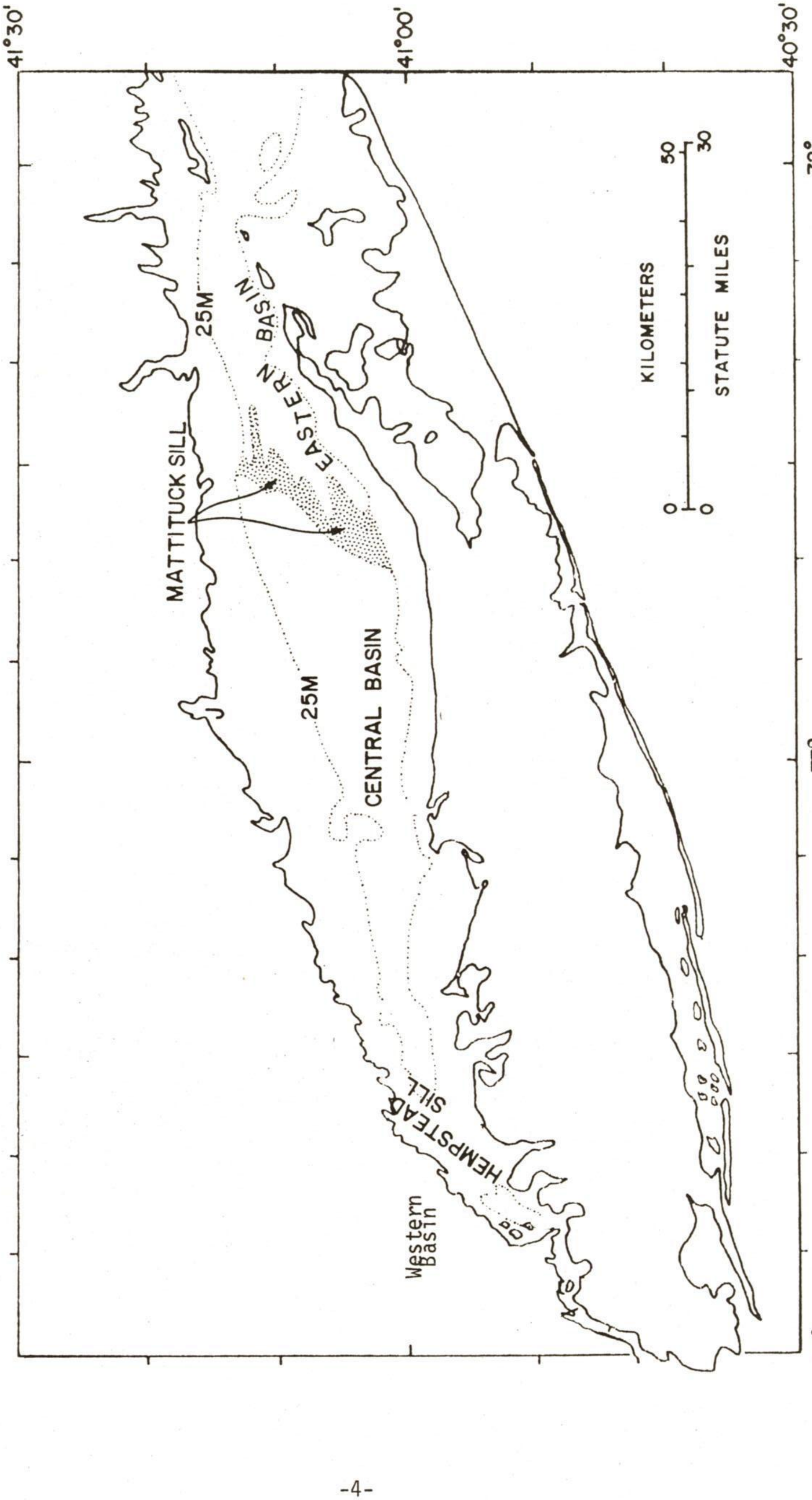
In a general sense, the Sound may be characterized as consisting of three major basins: the eastern basin, which lies between Westerly, Rhode Island and the Mattituck Sill, a submarine ridge extending between Duck Point on Long Island and Hammonasset Point in Connecticut; the central basin, which extends from the Mattituck Sill on the east to the Hempstead Sill on the west and; the western basin, which is bounded by Hempstead Sill on the east and the entrance to the East River on the west (Figure 1).

On the northerly side of the Sound, Connecticut's shoreline extends for almost 280 miles. Two major divisions of the shoreline may be identified on the basis of approximate geographical trends. The first segment trends roughly southwest-northeast between the Byram River in Greenwich and New Haven Harbor. The second trends generally east-west between New Haven Harbor and the Pawcatuck River in Stonington.

Geologically speaking, the northern shore of Long Island Sound may be classified as a submerging, primary coast of glacial deposition. Simply stated, this means that Connecticut's shoreline was originated by non-marine processes and is subsequently being inundated as a result of rising sea level. More specifically, it means that the shoreline is characterized by the occurrence of land forms which were deposited by *glaciation* and more recently submerged.

In a larger sense the present day configuration of the shoreline is really the result of the interaction of a number of climatic, geologic and oceanographic factors. Most important among these factors are: geologic history, including bedrock and glacial geology; physical climatic variables such as wind patterns and storms; and oceanographic phenomena such as waves, tides, tidal currents and variations in sea level. Working over geologic (thousands of years) and human (tens and hundreds of years) time periods these physical forces have formed and will continue to alter the configuration of the present day Connecticut shoreline.

FIGURE 1



LONG ISLAND SOUND BASIN
(source: Hardy, 1971)

GEOLOGIC HISTORY

To a major extent the configuration of all shorelines reflect the geology of the land mass of which they are part. The composition and character of the earth materials which are exposed at the water's edge almost singularly determine the ways in which the coast will respond to wave, wind, storm and tidal action.

In Connecticut two types of geology contribute to the composition of the shoreline. The most recent history of the state is dominated by glacial geology while the pre-glacial character was determined largely by *bedrock* geology.

Bedrock Geology

Connecticut is distinguished by three physiographic regions: two highland masses divided by a central lowland valley (Figure 2). The east and west highland regions have bedrock of slightly different character. However, for the purposes of this discussion, their qualities are very similar and can be considered to be identical. The central valley consists of bedrock very different from the highland regions, but its significance with respect to the shoreline is minimized by its limited exposure at the coast.

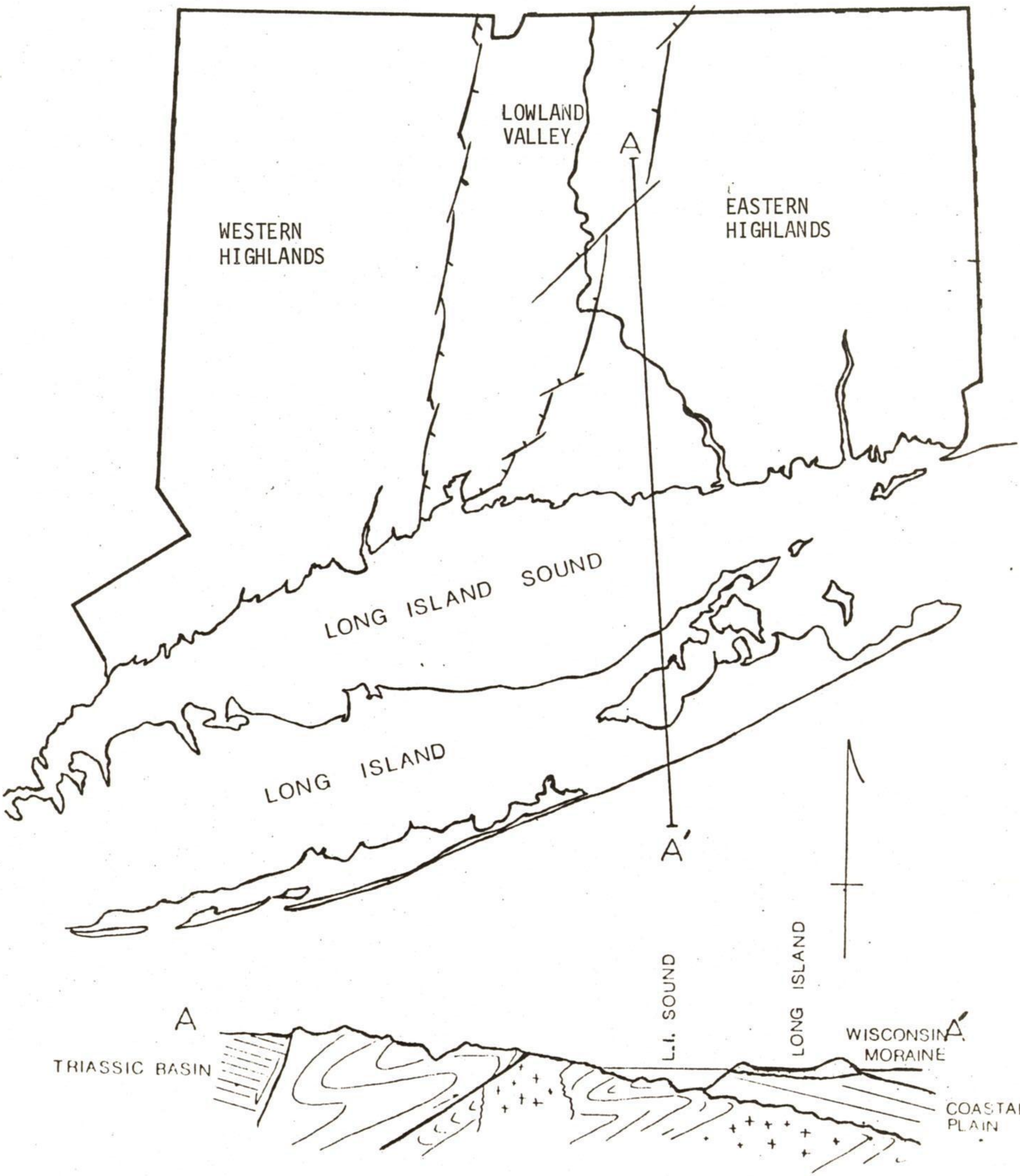
The bedrock of the highland regions consists of folded and faulted metamorphic rocks. The central lowland valley is composed of interbedded sedimentary and *igneous* rocks and is separated from the highlands by a series of faults on its eastern and western boundaries.

At the coast the eastern highlands extend from the Rhode Island border in Stonington to Lighthouse Point in New Haven. The composition of these highlands at the shoreline is variable, although most exposures are dominated by *gneiss*. One igneous rock body, the East Haven granite, extends from Sachem's Head, Guilford west to the highland boundary at Lighthouse Point, (Rodgers, et al, 1956).

The central valley achieves a maximum width of 25 miles at the border between Massachusetts and Connecticut. From there to the shore, the south trending valley tapers to an exposure of five miles in width at New Haven. The low-lying characteristic of the valley has produced a major embayment (New Haven Harbor) which minimizes the effect of the already reduced expanse of the valley upon shoreline configuration. Although most exposures have been covered by extensive artificial fill in the harbor area, the rock unit present at the shoreline is the New Haven Arkose, a reddish brown sandstone.

The western highlands extend from Savin Rock, West Haven to the New York border in Greenwich. The rocks of these highlands differ only slightly from that of the eastern highlands.

FIGURE 2



PHYSIOGRAPHIC REGIONS

OF CONNECTICUT

Glacial Geology

Glaciation has had a dominant influence on the present configuration of Connecticut's shoreline. It has affected the coast through the erosion of the pre-glacial landscape and associated re-deposition of glacially eroded materials. Indirectly, through the storage and release of water as ice in polar ice masses, glaciation continues to control the actual position of the shoreline by regulating global sea level.

Throughout the last 10 million years portions of North America, including New England, have experienced several glacial periods punctuated by warmer inter-glacial periods. A complete and authoritative discussion of glacial geology and its mechanisms are beyond the scope of this planning report. For a detailed presentation of all aspects of glaciation and glacial geology the reader is directed to R.F. Flint's Glacial and Quatenary Geology.

The most recent glacier to affect Connecticut was part of the late Wisconsin Glaciation which reached its greatest extent 18,000 years ago. At its point of maximum development the glacier extended across present day Long Island Sound as indicated by the position of two *moraines* deposited at its margin on Long Island (Figure 3). The Ronkonkoma Moraine of Long Island marks the southern most position of glaciation while the more northerly Harbor Hill Moraine locates a second equilibrium position. During the ensuing retreat of the ice a number of unique glacial materials were deposited as a blanket, or mantle, over the rocky Connecticut landscape. The shoreline area is therefore composed of a number of glacial and bedrock landforms. Their form and composition as modified by marine erosion control coastal configuration.

Glacial Landforms

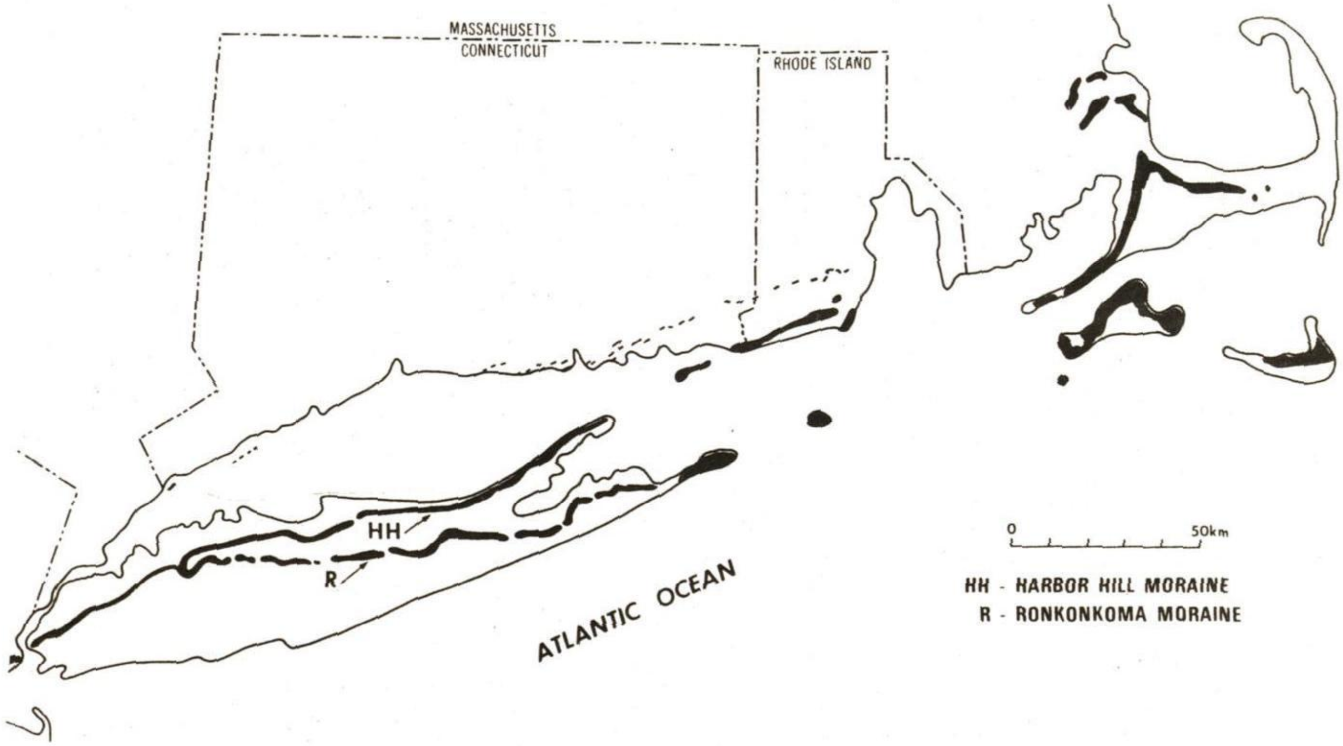
As the late Wisconsin glacier passed over Connecticut it altered the form of the land in several ways. First, it stripped existing vegetation and soils and transported them away in the ice. Second, it altered the bedrock surface. Finally, it deposited material contained in the ice as it advanced and retreated.

During its advance the glacier smoothed out the existing topography. Hills were eroded to a greater degree than the valleys because of the increased friction involved in passing over a topographic high.

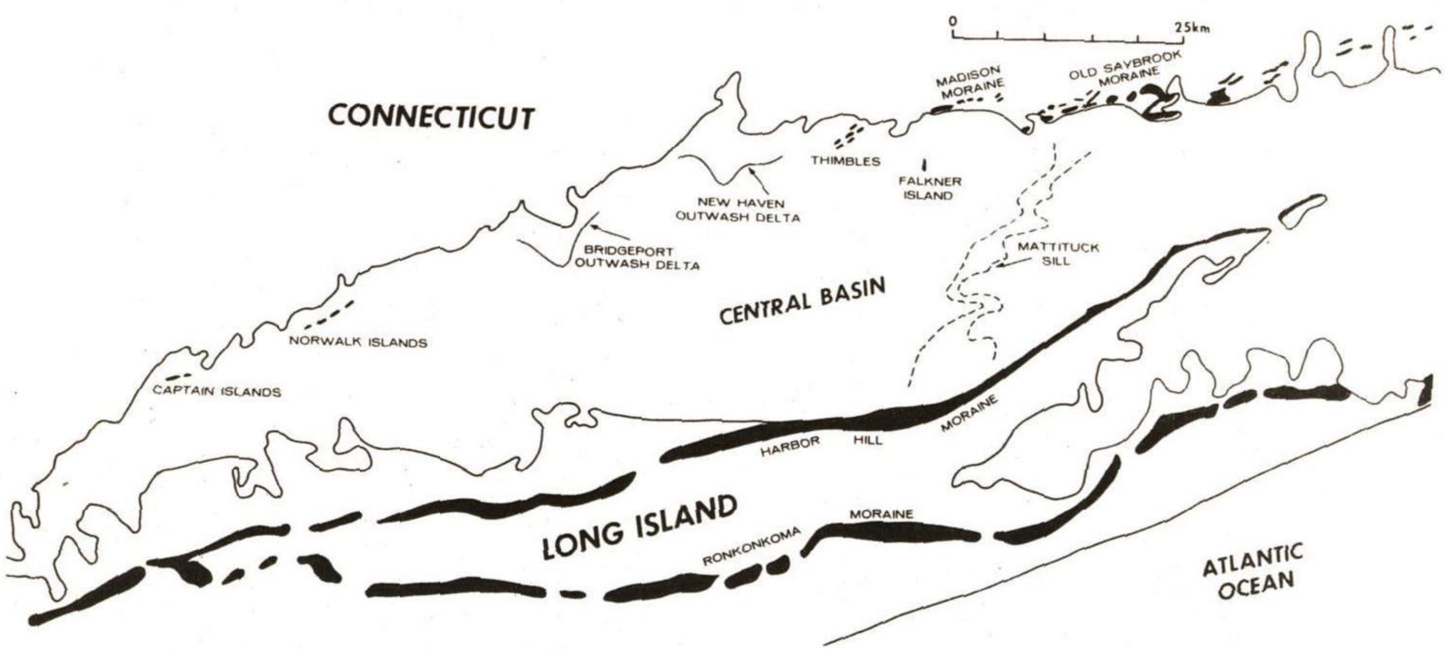
Alterations in the pre-existing bedrock surface caused by glacial advance were generally confined to modifications of pre-existing features. Rarely did glacial ice carve a new valley, especially in southern New England where the ice sheet was 1300 to 1600 feet thick, substantially thinner than to the north.

Till, the material transported in the glacier, was often deposited as elongate hills during glacial advance. The long axes of these hills approximate the direction of glacial movement. Called *drumlins,* these

FIGURE 3



MORAINES OF SOUTHERN
NEW ENGLAND



MORAINES AND OUTWASH DEPOSITS
OF CONNECTICUT AND LONG ISLAND

hills are more common in some regions than in others. Their distribution appears to be controlled by several geologic factors. Drumlins most often formed where hills already existed. These hills acted as traps for further deposition. In such cases the amount of material deposited depends on many factors, but the distribution is relatively consistent. The bedrock deflected the ice up and around the area behind it. This protection allowed deposition to occur there without subsequent erosion. Most drumlins are composed of till which has a high clay concentration. The abundance of these fine grain sizes fills pore space and results in a very compact unit (Flint, 1971). Erodibility varies directly with clay content.

Drumlins in Connecticut are most common in areas of greater preglacial relief. Conditions were evidently optimum for drumlin formation at the far western and eastern ends of the state, and in an area just west of New Haven Harbor. Most of these drumlins have substantial bedrock cores, some of which have been exposed by wave-caused erosion.

As climatic conditions eased and warming occurred, several types of land forms were produced by the ice sheet. One such form is the end moraine, formed at the terminus of the glacier by the deposition of glacial debris during equilibrium conditions. Glacial retreat is a dynamic event. Throughout its existence, the glacier continued to flow, with different velocities and often with a dead ice zone at its margin. During advance, the rate of flow was greater than the rate of melting. During retreat, the rate of melting was greater than the rate of flow. Equilibrium positions occurred when climatic conditions produced a melting rate equal to the flow rate. In these positions end moraines were formed.

Figure 3 shows the distribution of moraines in southern New England. Large continuous moraines resulting from longer periods of equilibrium were formed on Long Island (Ronkonkoma Moraine) and on Long Island and Fishers Island (Harbor Hill Moraine). Both of these features are part of terminal moraines which extend eastward into Rhode Island and appear in Massachusetts on Cape Cod, Martha's Vineyard and Nantucket. North of these extensive units much smaller and less continuous moraines occur at or near shore in Connecticut. The size and disjunct nature of these deposits indicate that a relatively shorter equilibrium period was responsible for their origin. They occur in a band generally less than six miles in width, which is present in the form of islands (Captain Island and Norwalk Islands) in Greenwich and Norwalk and as a segmented land feature extending east from Madison through Old Saybrook and into Rhode Island (Madison and Old Saybrook Moraines). These moraines are present in areas of low local relief which are not dominated by bedrock. Because of their composition, morainal deposits are generally less affected by erosion than till.

Land forms produced by the retreating ice sheet are composed predominantly of outwash, sand and gravel carried away from the glacier by melt water and deposited by glacial streams.

Outwash is the dominant material in valleys where melt water flowed. In regions of low relief, where early deposition in the lower elevations evened out the topography, large outwash plains occur. They are most extensive when deposited on the continental shelf behind a moraine such as those which form Long Island. Most outwash landforms are low sloping plains or valleys, broken occasionally by a hill which is usually composed of till. Outwash is often deposited on top of till, since till was laid down first by the advancing glacier, and because the deposition of till was usually thicker in the valleys.

Two rather extensive outwash deposits occur along the shoreline in the vicinities of New Haven and Bridgeport (Figure 3). Other smaller outwash deposits occur in numerous small stream valleys which intersect the coast. The loosely consolidated sandy, gravelly character of outwash makes it most susceptible to erosion and provides an excellent source of materials for beach development.

PHYSICAL CLIMATE

The physical climate to which Connecticut's shoreline is exposed is a unique assemblage of climatic and oceanographic phenomena. Climatic influences include regional wind patterns and infrequent storms and hurricanes. Oceanographic forces include tides and tidally induced currents and wind generated waves. Although its influence has received somewhat less notice, climatically induced fluctuations in sea level also form an integral component of the physical climate of the shoreline. Acting in concert these physical phenomena produce shoreline changes through their interaction with the geologic materials of the shoreline and are the primary causative agents of erosion.

Tides

Because of its naturally semi-enclosed, embayed form and consequent restricted circulation, Long Island Sound experiences vastly different tidal conditions than those that occur along open ocean shorelines. As in other locations on the east coast, tides in the Sound are primarily *semi-diurnal*. That is, two high and two low tides are experienced in the basin over a period of 24 hours, or more precisely 24 hours and 50 minutues. Long Island Sound tides are produced by astronomical tides occurring in the open ocean. Ocean tides act to force the tidal oscillation of the waters within the Long Island Sound basin. The natural period of oscillation of Long Island Sound is very close to that of the semi-diurnal ocean tide - roughly 12.5 hours. As a result, the geometry of the Sound, which determines its natural period of oscillation, is particularly well tuned to the ocean tide and acts to amplify it. This condition in which the ocean tide at the Race induces the tide within Long Island Sound is referred to as *tidal co-oscillation* (Swanson, 1976). Mean tidal ranges within the Sound vary from 2.7 feet at the eastern terminus to 7.3 feet at Greenwich in the western end. Spring tidal ranges are slightly greater, varying from 3.2 feet to 8.4 feet respectively at the eastern and western ends of the Sound. Diurnal

TABLE 1

TIDAL RANGES FOR SHORELINE

LOCATIONS IN CONNECTICUT

Location (Listed from east to west)	Tidal Range (in feet) Mean	Spring
Stonington	2.7	3.2
New London	2.6	3.1
Waterford	2.7	3.2
Old Saybrook	3.5	4.2
Westbrook	4.1	4.7
Madison	4.9	5.6
Guilford	5.4	6.2
Branford	5.9	6.8
New Haven	6.2	7.1
Milford	6.6	7.6
Stratford	5.5	6.3
Bridgeport	6.7	7.7
Norwalk	7.1	8.2
Stamford	7.2	8.3
Greenwich	7.4	8.5

inequalities (differences in elevation between succeeding high tides or succeeding low tides) are observed within the Sound and may range as high as 0.8 feet. Tidal range within the Sound increases most markedly as th tide progresses through the first 21 miles of the eastern end. An increase in range of 2.6 feet occurs between the Race and Hammonasset Point while an additional range increase of only 2.1 feet is experienced between Hammonasset Point and Great Captain Island, 60 miles west in Greenwich. Table 1 shows tidal range for various locations along the Connecticut shore of Long Island Sound. In addition to monthly and seasonal variations in tides, caused by changes in position of the sun and moon with respect to the earth, atmospheric forces such as winds and waves can function to alter tidal elevations. These alterations, such as wind and wave set up and storm surge, are discussed in succeeding sections.

The most important influences of tides on physical shoreline processes (erosion and deposition) are their effects in producing tidal currents and in controlling the depths of water in shoreline areas which can affect the ways and locations in which waves break and expend erosive energy on the shore.

Tidal Currents

The co-oscillating tide in Long Island Sound produces changes in water surface elevations which in turn induce flowing of water within the basin to accommodate the rising and falling tides. As water level is rising, after low tide, water flows into the basin from the east and tidal currents are said to *flood*. Following high water, as the water's surface falls, currents flow out of the basin from the west and tidal currents *ebb*.

As the tide wave enters Long Island Sound through the Race, between Great Gull Island and Fishers Island, tidal currents begin their flood phase. Flood tidal currents also enter Long Island Sound via Fishers Island Sound, between the eastern tip of Fishers Island and Napatree Point, Rhode Island and through Plum Gut to the west of Great Gull Island. During flood, colder more saline ocean waters enter the Sound as a wedge progressing westward into the basin. Since the colder saline ocean waters are more dense than Sound water the major inflow of water occurs near the bottom. Approximately 20 miles west of the Race the submarine ridge of the Mattituck Sill creates a dam that limits inflowing tidal water. Limited exchange then occurs through a northern notch or low point in the Sill (Hardy, 1971). Maximum (spring) flood tidal currents on the order of 5 knots[1] occur at the Race, from that point westward flood velocities diminish to a maximum of 0.5 knots at the western end of the Sound. Currents flowing into Fishers Island Sound between Fishers Island and Napatree Point reach a maximum velocity of approximately 2.5 knots.

Following high tide, currents begin to ebb and flow out of Long Island Sound to the east. The major portion of outflowing occurs

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[1] A knot is equal to 1 nautical mile per hour or 1.15 statute miles per hour.

at the surface as lighter, less dense Sound water flows out over more dense ocean water. As was the case for flood currents, maximum ebb currents occur at the Race with velocities diminishing toward the western end of the Sound. Maximum ebb tidal currents at the Race are slightly higher than flood currents, since additional freshwater introduced by three major rivers (Connecticut, Housatonic and Thames) and numerous smaller streams increases the volumes of water flowing out of the Sound. In addition, the restricted opening of the Race has a greater influence on ebbing tides and functions to increase the velocity of ebb tidal flow.

Maximum ebb and flood tidal currents occur approximately 3.1 hours after high and low tides respectively. During high and low tides, tidal currents are slack (i.e., no flooding or ebbing occurs).

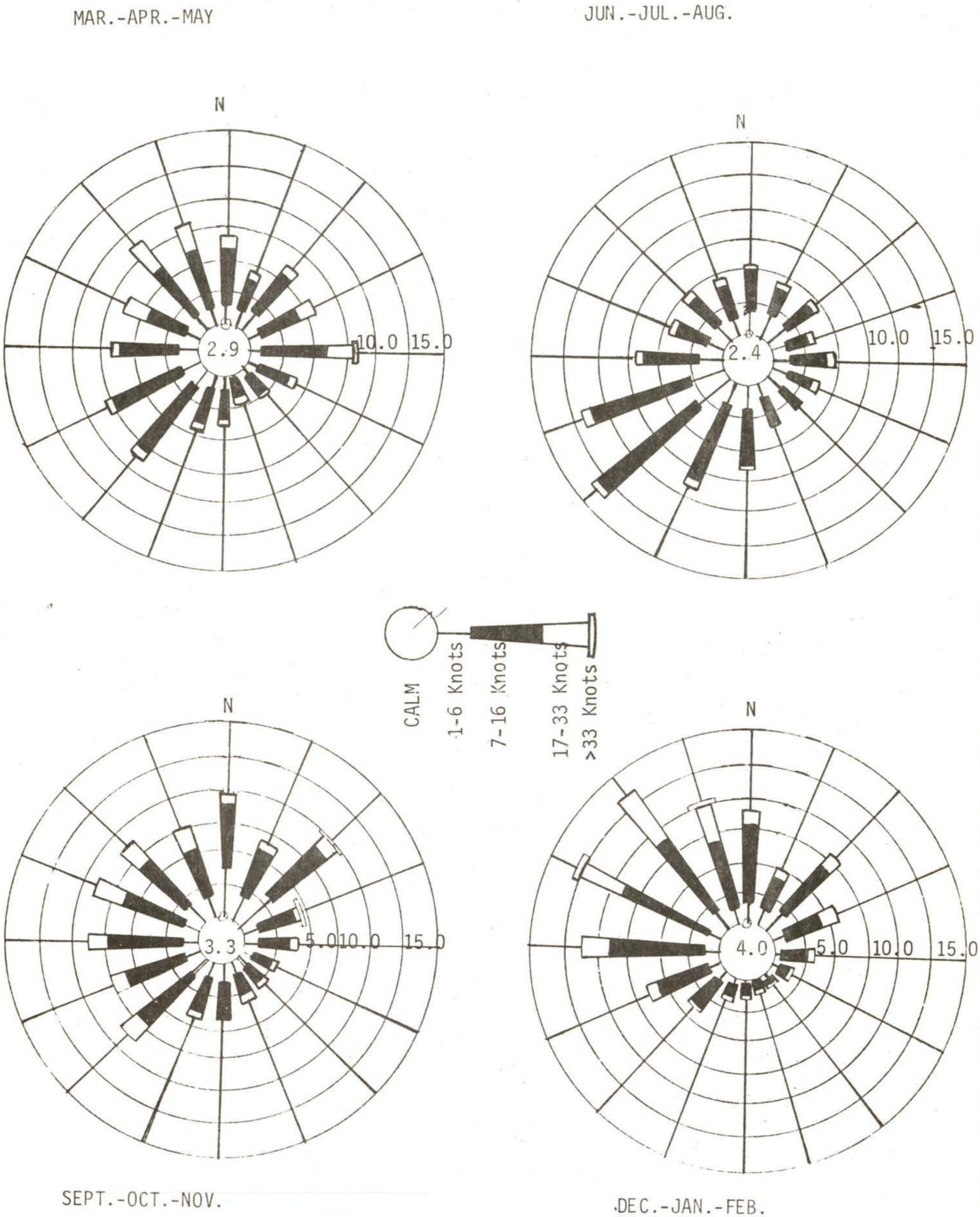
Anomalously high tidal currents are experienced in the central basin at the Housatonic River, and three major headlands: Long Point in Darien, Shippan Point in Stamford, and Greenwich Point. Increased current velocities at the Housatonic River are a result of substantial discharge from the river, while the greater magnitude of currents at the headlands arises from the fact that they project into deeper waters which experience more rapid flows.

Ellis (1961) reports that tidal currents decrease with proximity to shore. However, in areas of large tidal range, such as western Long Island Sound, a greater component of the overall tidal current is directed perpendicular to shore. Other researchers (Farrar, 1977) have indicated that in some shoreline areas, particularly near headlands and river mouths, tidal currents may act to augment transport of materials along shore by waves.

Winds

Wind and regional wind patterns are perhaps the most important feature of the physical environment of Connecticut's shoreline. Wind generates surface waves which cause erosion and transport of shoreline materials. Strong onshore winds also contribute to storm surge (abnormal tidal surface levels) by means of wind set-up. In addition, wind can cause the movement of sand or other loosely consolidated, fine-grained materials on to and off beaches and dunes through *aeolian* transport.

The seasonal distribution of wind patterns for Long Island Sound is shown in Figure 4, "Wind Roses for Bridgeport Airport," which includes measurements of wind velocity and direction made during all weather conditions over the period between 1951 and 1970. Concentric circles are used to indicate the percentage of time a wind with a given velocity blows. Axes radiating from the center of the circles show the direction from which the wind blows. Lines and shaded bars are used to indicate wind velocities in accordance with the key. The figure is representative for the Connecticut shoreline with the exception of the New Haven region.



WIND ROSES FOR BRIDGEPORT AIRPORT
(Source: J. Brumbach, from: Demico, 1977)

The influence of Connecticut's central lowland valley produces a channeling effect which funnels winds in the New Haven vicinity such that a high north-south directional flow occurs there. However, in general, wind patterns in all of the coastal area are dominated by a southwesterly flow in summer and by a northwesterly flow during winter months, with transition between the two in spring and fall.

The wind rose for June, July, and August indicates wind patterns for the summer months. The summer rose shows a high percentage of southwest winds. These winds are the result of the prevailing southwest circulation caused by a high pressure system located near Bermuda (Bermuda High). Wind circulation around the high pressure area is clockwise and causes air masses to move from the southwest along the east coast. Wind velocity during the summer months is very low. No winds greater than 33 knots were recorded and less than 2.5 percent of the total wind blew from the southwest quadrant at velocities between 17 and 33 knots. The most prevalent winds were those with speeds between 7 and 16 knots.

For the months of September, October, and November the wind rose demonstrates the meteorological transition that occurs during the fall. The influence of the Bermuda High is reduced as polar fronts begin to pass through the region from the northwest. The equal dominance of each is illustrated by the even distribution of wind blowing from the northwest and southwest quadrants. The high wind velocity (greater than 33 knots) recorded in the northeast quadrant is the result of hurricanes or northeast storms which are most likely to occur during the early fall.

The winter (December, January, February) wind rose is characterized by dominant northwest flow associated with the polar front. Winter winds are much stronger than the summer winds, showing velocities greater than 33 knots. Winter winds are also more closely concentrated within one quadrant. Northwest winds blow 57 percent of the time during the three winter months, while winds are from the southwest for 47 percent of the three summer months.

Finally, the spring wind rose exhibits the transition between the dominant winter and summer circulation patterns as well as the influence of increased storm activity. The northwest quadrant exhibits the prevalence of dwindling winter winds while the southwest quadrant indicates the beginning of the summer's southwesterly flow of wind. Evidence of strong northeast storm winds is also apparent during the spring months.

The effect of the regional wind climate on the north shore of Long Island Sound is moderated by the orientation of the shoreline. Because Connecticut's coast faces south it is protected from strong northwest winter winds and wind induced waves, since both propagate offshore. During the summer the shoreline is exposed to southwest winds. However, these winds are generally much lower in velocity and generate smaller waves.

Damaging, high velocity winds are regularly associated with low pressure systems and hurricanes. By definition, hurricane winds exceed 64 knots (Davies et al, 1973). The highest velocity (hurricane) winds normally blow from the southeastern or northeastern quadrants where the least resistance is presented by land masses. Winds associated with the 1938 hurricane varied from 5 minute sustained velocities of 60 to 78 knots to gusts of over 87 knots.

Winds associated with low pressure systems can exceed the minimum hurricane value, but this situation occurs only rarely. Maximum gale force (35 to 55 knots) storm winds usually blow from the eastern quadrants where they meet little land resistance. Although lower in velocity, storm winds carry the potential for greater damage because they are usually longer in duration.

Waves

Surface waves are the primary causative agent of erosion along the shoreline. Waves are generated by, and therefore inherit their physical characteristics (length, height and velocity) from the wind which initiates them (Figure 5).

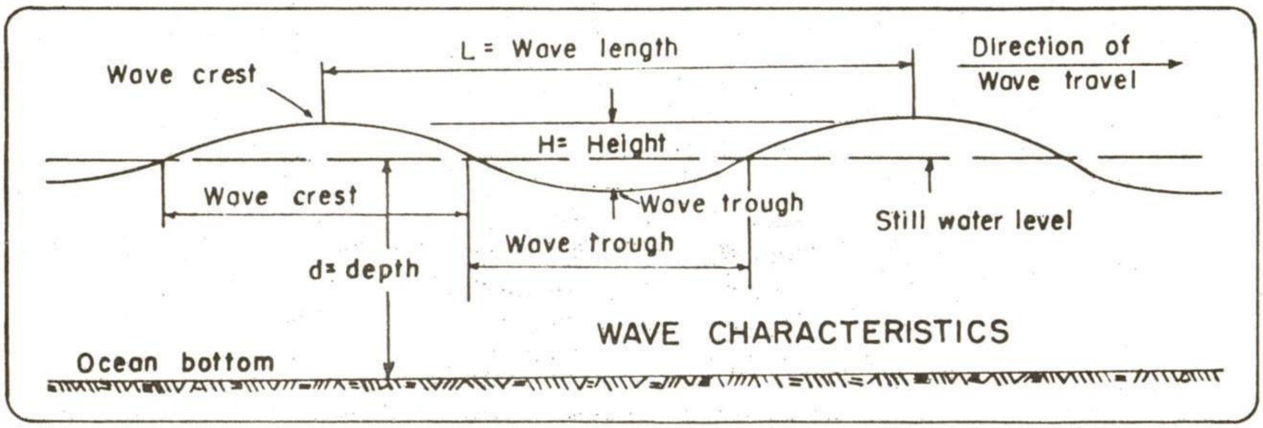


FIGURE 5
(Source: U.S. Army Corps of Engineers, 1975)

The wave generation process is the result of energy transfer from air to water. Waves generated by the wind propagate in the direction to which the wind is blowing. Three factors are important in the generation of waves: the *fetch*, or unobstructed distance of water over which the wind blows; the *duration* or length of time for which the wind blows; and the *intensity*, or velocity with which the wind blows. An increase or decrease in any of these factors results in a corresponding increase or decrease in wave size (height and length). The depth of water at the site of wave generation also exhibits some control on wave size. Generally speaking, wave height cannot exceed four-thirds (4/3) of the water depth before breaking occurs.

From their creation by wind to the point near shore where they first interact with the sea floor, waves travel at a constant velocity which is dependent on the length and period. Wave period is the time required for two successive wave crests to pass a fixed point. Fluid dynamics allow transfer of energy in water with very low loss of energy. Thus, when waves approach shore they possess most of the energy transferred from wind as well as energy from any other similar waves traveling with them.

As waves approach a shoreline they begin to dissipate their energy. When water depth decreases to half the wave length of the approaching wave, the wave begins to frictionally interact with, or "feel" bottom. As depth continues to decrease the wave shoals. Its height increases and its crest becomes steeper. Eventually the wave becomes too steep or the water too shallow and breaking occurs. At this point the wave dissipates or transmits its energy to the shoreline.

The manner in which a wave approaches the shoreline and breaks is a function of the wave's length, height, direction of approach and the shape of the nearshore bottom (bathymetry). In most cases, the nearshore bathymetry is not a regular feature. The irregularity, or differences in water depth along the shoreline, cause a varying degree in the wave's frictional interaction with the bottom along the wave front. As a result, those portions of the wave in shallow water travel more slowly than those portions of the wave in deep water; and the wave front is bent or refracted. Through the process of *refraction*, wave energy may be focused on portions of the shoreline in a manner which is somewhat similar to the way in which a magnifying glass focuses light. Figure 6 illustrates the refraction of waves under the influence of several different types of bathymetry or submarine topography. The lines labeled as *orthogonals* in the figure are drawn perpendicular to the wave front (not shown). Where orthogonals converge, wave energy is focused, where they diverge energy is decreased. Figures 6(b) and (c) show how energy is concentrated by a submarine ridge and dissipated by a submarine canyon. Figure 6(d) shows concentration of energy at headlands and dissipation of energy at bays.

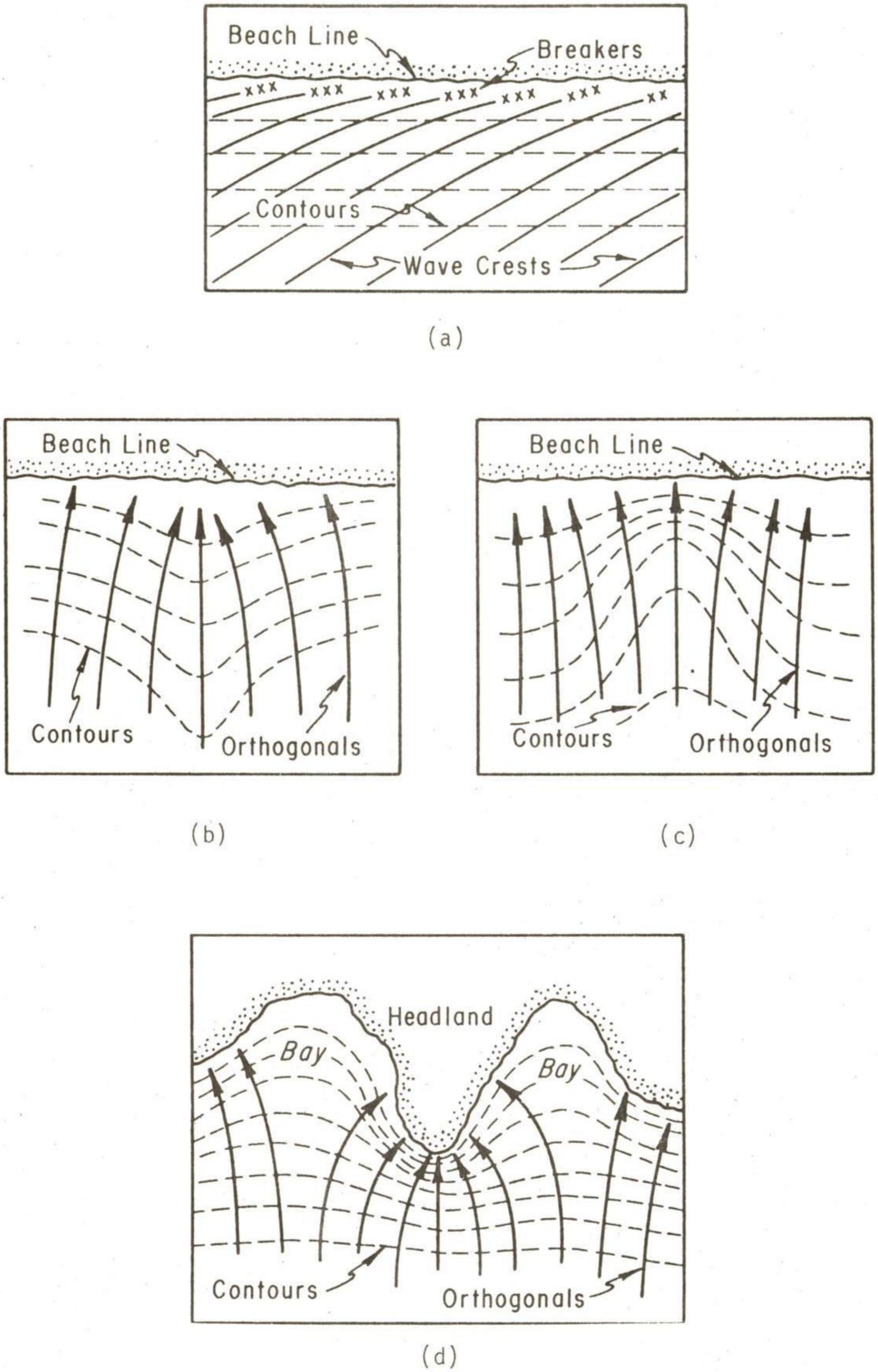
Refraction of waves obliquely approaching a linear beach is indicated by Figure 6(a).

Littoral Transport

Movement of shoreline materials in the nearshore area by waves, tidal currents, and wave induced currents is defined as *littoral transport*. Littoral transport occurs in two ways: transport of material parallel to shore (longshore transport) and movement of material perpendicular to shore (onshore-offshore transport). Material moved by littoral transport is termed *littoral drift*.

Onshore-offshore transport depends on wave steepness. Generally, steeper waves tend to plunge as they break moving material off shore.

FIGURE 6



WAVE REFRACTION
(Source: U.S. Army Corp of Engineers, 1975)

Gently sloping waves, on the other hand, tend to spill as they break transporting materials onshore.

Longshore transport results from the suspension of material by the breaking wave and subsequent movement of the material by the component of wave energy which is directed parallel to shore (Figure 7). The direction of longshore transport is directly related to the direction of wave approach. The magnitude of longshore transport is controlled by wave energy and the angle of wave attack. Due to the variability of wave approach and to seasonal and storm-related variations in wave energy and steepness, the rates and directions of littoral transport vary randomly. However, because of regional weather patterns, which produce similar wave conditions on an average yearly basis, a net or dominant direction of longshore transport is usually evident for most shoreline segments.

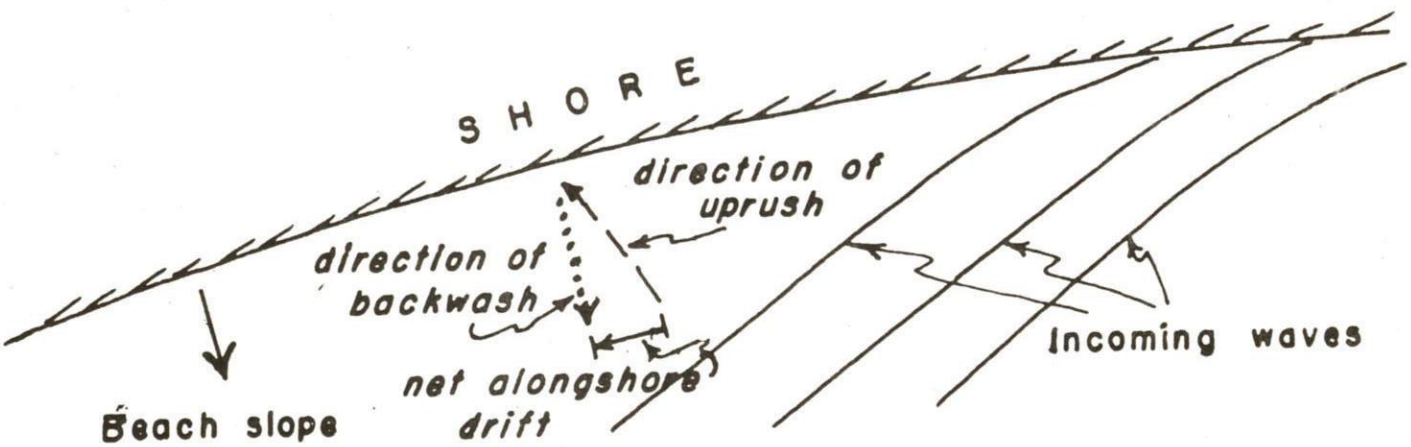


FIGURE 7
Wave Induced Longshore Transport
(Source: Sanders and Ellis, 1961)

Wave Conditions in Long Island Sound

The generation and occurrence of waves in Long Island Sound are primarily localized phenomena. Long Island severely restricts the fetch available for wave generation in the Sound and limits the exposure of Connecticut's shoreline to larger, more powerful waves generated in the open Atlantic Ocean. There is, however, small oceanic influence at the eastern end of the Sound. Ocean swells (long, low waves) from the east-southeast can enter Long Island Sound through the Race. The influence of these waves is limited and affects only the eastern portion of the state's coastline.

Waves in Long Island Sound, because they are generated locally, are normally short and steep, and reflect directly the patterns of local winds (preceding section). Seasonal variation in wind direction elicits similar variation in wave direction. Strong, northwest winter winds form larger waves, which break on the north shore of Long Island but have less affect on

Connecticut's shoreline. Summer winds blow from the southwest, creating onshore waves.

The irregular configuration of the shoreline and the complex and variable nature of the nearshore bathymetry markedly influence wave behavior through the process of wave refraction. Consequently, although regional wind patterns may produce waves which approach the shore from the south in the open Sound, refraction is capable of completely changing the direction of wave approach once the wave enters shallower nearshore waters. As a result each small segment of Connecticut's coast is exposed to differing wave conditions arising from their different configurations.

Table 2 shows observed wave heights and directions of approach recorded at Stratford Point Light Station between October, 1954 and October, 1957. The record is dominated by waves varying in height up to 4 feet. Waves with heights up to 2 feet occurred nearly 90 percent of the time during the period of observation. No recorded waves exceeded 15 feet in height and only once (October, 1955) were waves in excess of 10 feet recorded.

Direction of wave approach is dominated by the southerly quadrants (E, SE, S, SW) with east (E) and southeast (SE) approaching waves generally accounting for the major directions of approach. It is worthy of note that waves rarely approached from west, northwest or northerly directions.

The distribution of wave height as a percentage occurrence over the period of record is shown in Figure 8, along with similar data recorded for other east coast stations. Examination of this information clearly indicates the smaller, lower energy nature of waves in the Sound. The information presented here, for Stratford Point, is not necessarily representative of conditions throughout the Sound. Because of its seaward projecting configuration, its location and the orientation of the shoreline in general, the Point is exposed to a limited degree to waves from the northeast. In addition, local bathymetry and the presence of deeper water near shore probably allow larger waves to approach the shoreline. Other portions of the shore are thought to be more protected, on the average, due to decreasing fetches over the southerly quadrants as the Sound narrows towards the west and east. The period of record (1954-1957) includes only one hurricane event: Hurricane Diane, which passed south of Long Island between August 17th and 20th of 1955. Undoubtedly hurricanes and other low pressure storm systems contribute a preponderance of erosive waves to the Long Island Sound System (see section on storms). Maximum wave heights recorded during the 1938 hurricane ranged from 10 feet at New London to 15 feet at Bridgeport (U.S. Army Corps of Engineers, 1975). Wave heights of this magnitude coupled with abnormally high tides which accompany coastal storms are the most important factor influencing erosion in the coastal environment.

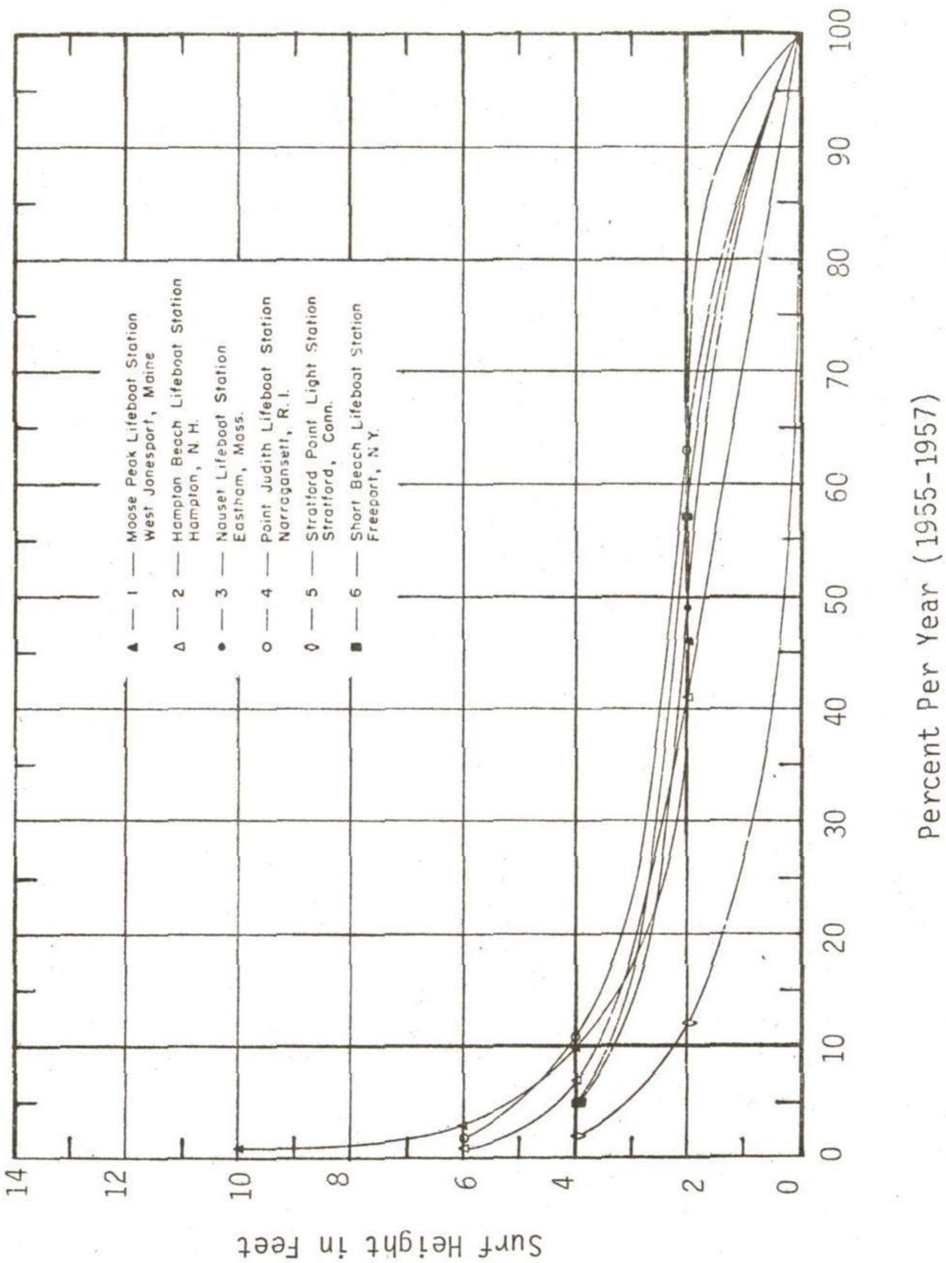
Aside from the information obtained at Stratford Point, virtually no other published information on wave statistics is available for Long Island Sound. This lack of published information is one of the major deficiencies in the physical data base of the Sound.

	SURF HEIGHT IN FEET (%)						PERIOD (SECONDS)	WAVE DIRECTION (%)								
	0-1.9	2-3.9	4-5.9	6-9.9	10-14.9	15 +	Max. Ave. Min.	CALM	N	NE	E	SE	S	SW	W	NW
1954 OCT.	96	3	1				5.2 / 2.3 / 1.5			3	34	31	14	18		
NOV.	87	11	2				5.5 / 3.9 / 2.8			8	24	40	15	13		
DEC.	86	12	2				7.0 / 2.6 / 2.5			8	24	40	15	13		
1955 JAN.	98	2					6.5 / 2.2 / 2.0			5	27	49	14	5		
FEB.	93	6	1				6.0 / 3.8 / 2.0	5		7	19	38	18	13		
MAR.	81	13	5	1			5.8 / 2.8 / 2.0	1		10	36	32	8	13		
APR.	86	14					6.5 / 2.6 / 2.0	1		11	34	25	20	9		
MAY	97.8	2.2					5.2 / 3.0 / 2.0			7.5	20.4	32.3	12.9	26.9		
JUN.	93.4	5.5	1.1				5.3 / 3.2 / 2.0	2.2		12.2	32.2	32.3	8.9	12.2		
JUL.	96	4					4.4 / 3.1 / 1.0			9	34	18	14	25		
AUG.	83	13	3	1			6.1 / 2.3 / 2.2			11	27	29	18	15		
SEP.	87.0	13.0					4.2 / 3.3 / 2.6			12.9	16.5	43.5	17.7	9.4		
OCT.	51.8	26.4	13.6	6.8	1.7		6.2 / 4.0 / 2.2	2.1		3.1	36.5	30.2	16.7	11.4		
NOV.																
DEC.	97.7	2.3					5.3 / 2.7 / 2.2				16	60	17	7		
1956 JAN.	87.1	11.8	1.1				5.3 / 3.5 / 2.0	4		12	4	54	20	6		
FEB.	89.8	8.9	1.3				5.9 / 2.4 / 1.7	21.7		7.5	18.8	36.9	7.6	7.5		
MAR.	79.1	18.7	2.2				5.8 / 2.3 / 1.6	24.4		13.7	22.3	23.6	8.4	7.6		
APR.	86.7	11.1	2.2				5.4 / 1.9 / 1.8	31.0		3.3	14.1	25.8	12.5	13.3		
MAY	93.5	6.5					5.0 / 1.8 / 1.8	31.3		1.5	13.8	19.1	12.2	22.1		

	SURF HEIGHT IN FEET (%)						PERIOD (SECONDS)	WAVE DIRECTION (%)								
	0-1.9	2-3.9	4-5.9	6-9.9	10-14.9	15 +	Max. Ave. Min.	CALM	N	NE	E	SE	S	SW	W	NW
1956 JUN.	100						5.0 / 3.0 / 1.8	37.0		8.2	19.2	13.7	8.9	13.0		
JUL.	91.3	5.4	3.3				5.2 / 3.0 / 1.5	35		4	19	9	10	22		
AUG.	90.3	5.4	4.3				4.8 / 3.1 / 2.0	31		5	18	18	11	17		
SEP.	82.9	14.9	1.1	1.1			5.8 / 2.1 / 2.0	29		6	13	26	15	11		
OCT.	83.3	15.6	1.1				5.3 / 2.3 / 1.9	28		14	19	27	8	4		
NOV.	85.0	11.5	3.5				5.2 / 2.3 / 1.9	23		4	21	25	17	8		
DEC.	86.0	14.0					5.4 / 2.6 / 2.2	20		16	21	19	10	14		
1957 JAN.	92.5	7.5					5.0 / 3.3 / 2.2	44.2		7.5	16.1	16.1	5.3	10.8		
FEB.	89.3	10.7					4.8 / 3.3 / 2.2	52.3		6.0	14.3	17.8	7.2	3.6		
MAR.	86.4	13.6					4.8 / 3.4 / 2.2				24.4	51.2	11.0	13.4		
APR.	92.2	5.6	2.2				5.4 / 3.4 / 2.2			8.9	28.9	37.8	13.3	11.1		
MAY	92.0	8.0					5.5 / 3.1 / 2.1	55	3	4	8	3	7	9	7	4
JUN.	100						3.6 / 2.9 / 2.0	71		1	1	6	6	8	7	
JUL.	99	1.0					9.0 / 3.0 / 2.0	59	1	1		7	9	13	5	5
AUG.	88	12					4.8 / 2.1 / 2.0			8	14	33	27	18		
SEP.	88	12					4.4 / 2.6 / 2.1			6	23	27	23	21		
OCT.	90	8	2				5.4 / 3.3 / 2.2			13	11	16	21	9		
NOV.																
DEC.																

TABLE 2
WAVE DATA FOR STRATFORD POINT
(Source: Helle, 1958)

FIGURE 8



WAVE HEIGHT VS. PERCENT OCCURRENCE
(Source: Helle, 1958)

Littoral Transport in Long Island Sound

The predominantly low energy nature of the Long Island Sound system coupled with a shoreline which is markedly irregular and highly variable in composition, due to its geologic history, is responsible for the development of numerous discrete and segmented patterns of littoral transport along the shoreline. Directions and magnitudes of littoral transport vary continuously Soundwide. No dominant pattern of transport is apparent which would generally characterize the movement of material along, or on or off, the north shore of Long Island Sound. Primarily because of the irregular nature of the shorefront, directions of net longshore transport vary from east to west and include almost all intermediate directions. For instance, on a north-south trending segment of shoreline northerly longshore transport may occur. On an east-west oriented shoreline wave induced movement of material may vary from easterly transport to the opposite westerly transport depending on wave conditions and bathymetry. Net directions of longshore transport were observed and recorded by the U.S. Army Corps of Engineers, for all sections of Connecticut directly fronting on Long Island Sound, during a cooperative study conducted with the state between 1949 and 1958 as a result of field observations throughout the area. This information is far too voluminous to present here. However, it is being tabulated in map form by the Coastal Area Management Program as part of a resource inventory. Appendix B shows an example of this information compiled for the Old Lyme quadrangle.

Onshore-offshore components of littoral transport are less readily specified than the longshore components of littoral transport. Due to seasonal and long term variations in weather conditions, the occurrence of storms, and hence, wave and wave-breaking conditions, no attempt can be made to quantify the effects of this component of littoral transport. However, some general observations are valuable in this regard.

The way in which a wave breaks is a function of the wave's height and length and the slope of the nearshore bottom. Davies et al (1973) note that waves formed in Long Island Sound by local winds (called seas) have short periods and are relatively steep. When these waves break on gently sloping beaches they plunge causing substantial movement of material offshore, and/or along shore. Plunging waves are more likely to cause offshore transport on gently sloping beaches. Long, low waves, on the other hand, are less steep and tend to spill as they break producing onshore transport on gently sloping beaches.

When beach slope is steep the wave breaking process tends to reverse. Steeper seas spill as they break while the more gentle swell tends to plunge during breaking (Sanders and Ellis, 1961). Since wind conditions vary seasonally wave conditions vary seasonally. Under normal open ocean conditions during calmer summer months long low swell exhibits the dominating influence on the shore causing onshore transport. During more severe winter conditions seas dominate causing offshore transport. As a result many authors have noted seasonal beach cycles between "winter" (eroded) and "summer" (accreting) beaches. These terms are actually misnomers since the variation in beach conditions is really related to storm events which may occur without respect to seasons.

In Long Island Sound the importance of beach cycles is further reduced since long low swell is virtually completely excluded from the basin by Long Island. As a result, seas (steep waves) dominate throughout the year and beach cycles have not been shown to occur consistently throughout the Sound.

Several authors have made estimates of net littoral (onshore-offshore and longshore) transport on beach areas in Connecticut. Based on profiling (survey) on Prospect Beach, West Haven conducted between 1956 and 1960, Vesper (1961) estimates that an average of 13,000 cubic yards of material was removed by littoral forces from the shoreline area. Farrar (1977) estimates (on the basis of profiles) that between March of 1976 and February of 1977 more than 14,000 cubic yards of beach material was lost from the shoreline of Hammonasset State Park in Madison. A third study, also conducted by Vesper (1965) over a five year period for Seaside Park in Bridgeport, yielded estimates (from profiles) of approximately 8,000 cubic yards for the volume of material lost from the study area. These case studies indicate a variation in net littoral transport for beach areas in Connecticut which ranges from 8,000 to 14,000 cubic yards per year. However, the range in the estimated figures also points out the tremendous variability in the nature of sediment movement. This variation can most probably be attributed to the differences in orientation of the shoreline at the various locations. Prospect Beach and the beach at Hammonsset State Park are both oriented more nearly north-south while Seaside Park trends approximately east-west. Since Seaside Park is aligned more nearly perpendicular to waves approaching from the dominant southern quadrants, it is apparently more stable than the other north-south trending shorelines. That is, waves approaching the shore at Seaside Park approach at a smaller angle to shore inducing a correspondingly smaller amount of longshore transport. Waves which approach Hammonasset and Prospect from the south do so at a larger angle to shore producing a significantly higher volume of longshore transport. This hypothesis is very basic since,as mentioned earlier, littoral transport is influenced by factors other than orientation such as the shoreline composition, bathymetry and wave breaking conditions.

Storms and Hurricanes

As emphasized in the preceding discussion of waves, the Long Island Sound environment is low energy in comparison to the open ocean. Normal wave attack, resultant littoral transport and tidal currents do not account for all the changes in configuration (erosion and deposition) which occur along the shoreline. While these events have a cumulative effect, their influence is less significant than high energy catastrophic storms and hurricanes. In the Sound the impact of catastrophic events is marked in contrast to the normal low energy environment. In fact most major changes are the result of low pressure storm systems.

Two types of storms are important agents of shoreline erosion on Connecticut's shore: tropical cyclones and frontal storms, most commonly called northeasters. Northeasters originate in mid-latitudes through the interaction of warm and cool air masses. Tropical cyclones, as the name implies, originate in more southerly latitudes and progress west into the Caribbean or north towards the eastern United States. Tropical cyclones of the North Atlantic may be categorized into three divisions according to the National Oceanic and Atmospheric Administration:

1. Tropical depressions (sustained wind speeds of less than 34 knots).

2. Tropical storms (sustained wind speeds of at least 34 knots).

3. Hurricanes (sustained wind speeds of at least 64 knots).

Tropical cyclones are characterized by:

1. Low central barometric pressure.

2. Counterclockwise (cyclonic) circulation of wind about a calmer central core.

3. Large amounts of precipitation.

4. Overall diameter of the circle of influence of up to 1000 miles.

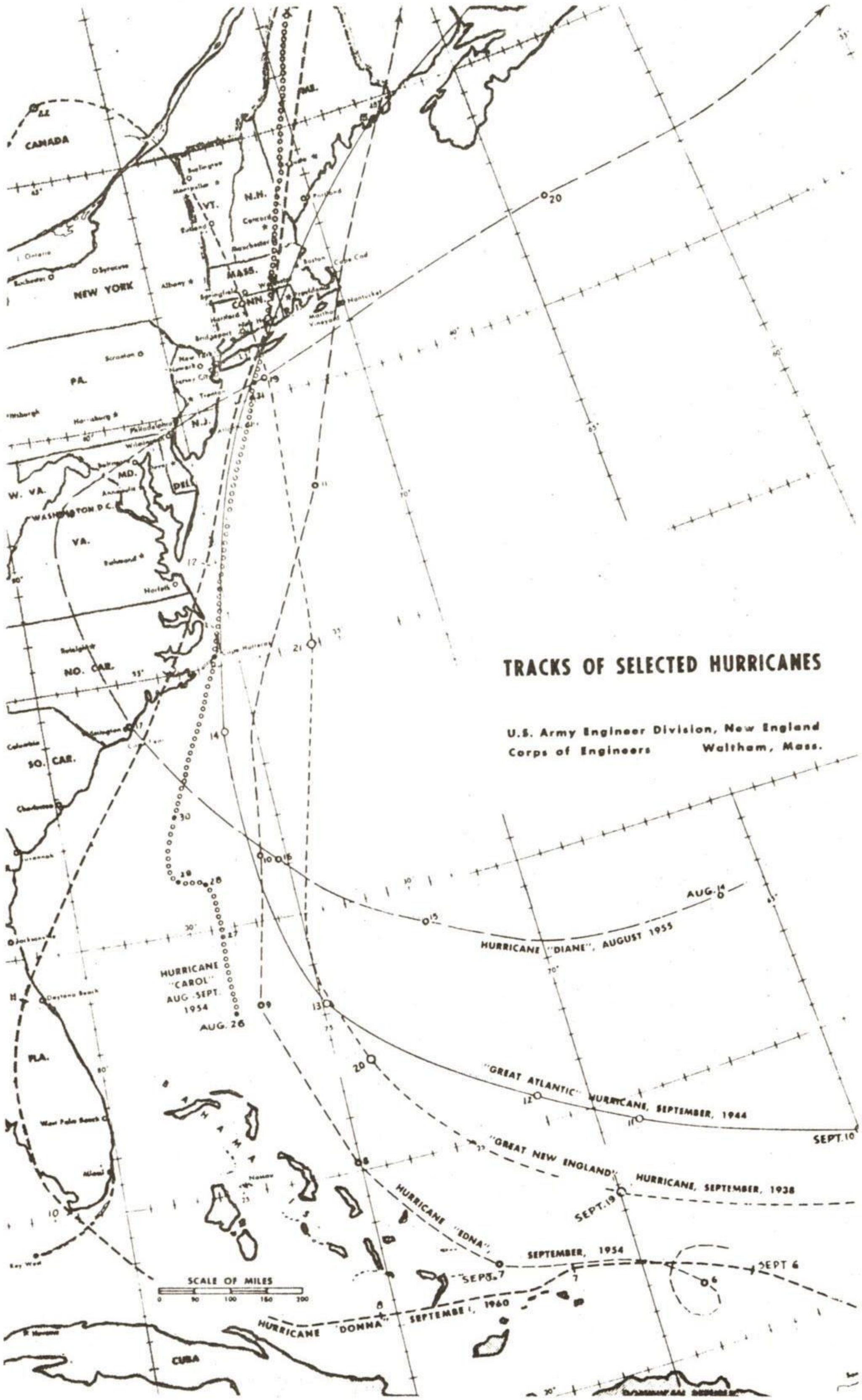
The structure of a low pressure storm system is such that the most intense winds are present near the central core. Wind velocity gradually decreases radially from the center. Wind intensity also varies around the storm center. Maximum velocities occur on the right side of the core (when viewed in the direction of travel) where wind velocity is augmented by the direction of movement of the storm system. Wind speeds in excess of 65 knots are possible although most storm winds peak at gale (34-40 knots) or whole gale force (48-55 knots).

Mather et al (1965) have determined from analysis of storm records for the period between 1921 and 1962 that the recurrence interval for damaging coastal storms (including hurricanes) in Connecticut is 1.14 years. Mather also states that the frequency of their occurrence has increased during the period between 1955 and 1964. On an annual basis tropical storms and northeasters are most frequent (in descending order) during the months of November, March, October, February, December, January and August.

Hurricanes are similar to low pressure systems in their wind circulation patterns, low pressure, and precipitation. The dissimilarities include greater wind intensity, tropical origin, smaller diameter, and seasonal distribution. Hurricanes form in the tropics during the months of August, September and October and travel west into the Caribbean or north towards the U.S. (Figure 9).

In order for a storm to rank as a hurricane, winds must exceed 64 knots and central barometric pressure must be less than 29 inches (U.S. Army Corps of Engineers, 1975).

FIGURE 9


TRACKS OF SELECTED HURRICANES
U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.
HURRICANE "DIANE", AUGUST 1955
HURRICANE "CAROL" AUG.-SEPT. 1954
AUG. 26
"GREAT ATLANTIC" HURRICANE, SEPTEMBER, 1944
SEPT.10
"GREAT NEW ENGLAND" HURRICANE, SEPTEMBER, 1938
SEPT.19
HURRICANE "EDNA", SEPTEMBER, 1954
SEPT 6
SEPT.7
HURRICANE "DONNA", SEPTEMBER, 1960
SCALE OF MILES
CANADA
NEW YORK
PA.
N.J.
MD.
DEL.
W. VA.
VA.
NO. CAR.
SO. CAR.
FLA.
CUBA
VT.
N.H.
MASS.
CONN.
AUG.14

Hurricanes have smaller diameters than low pressure systems, varying from 50 to 500 miles. The core is a well developed eye, or area of fair weather, with very low pressure. More intense winds surround the eye, and the most intense winds lie to the right of the storm center where the wind speed is augmented by the storm speed. Table 3 lists recorded hurricane events which have affected Connecticut.

Hayes and Boothroyd (1969) discussed coastal storms as geologic agents and listed variables affecting the impact of the storm upon the shoreline as:

1. Storm intensity (wind velocities).

2. Storm track (direction of storm movement).

3. Storm speed (velocity of the movement of the storm as a whole).

4. Tidal Phase (spring or neap).

5. Tidal level (high or low water).

6. Interval between storm occurrences.

The impacts of variations in storm intensity and speed are readily apparent. More intense storms generate higher and more sustained wind velocities. Storm speed contributes to the severity of wind speeds, as previously noted, by augmenting wind velocities on the right side of the storm. Increases in wind velocity attributed to the forward progression of a hurricane, for instance, can be significant. Hurricanes have been known to obtain forward speeds of as much as 50 knots.

Storm track is of critical importance since the movement of the storm determines which shoreline areas will be most affected. More specifically, since wind circulation is counter-clockwise around a storm center, if a storm passes to the right of a coastline, less damage will be experienced in that the coast will be exposed to offshore winds. If the storm passes to the left of a shoreline, onshore winds will prevail.

Tidal phase and tide level are also important in determining storm effects. Storms occurring during periods when tidal elevations are normally higher, such as spring high tides, generate waves which can approach more closely to shore as a result of increased water depths. In such instances a wider area of the coast is affected by the storm. Occurrence of storm related elevations of the coastal water surface in conjunction with high tide also lead to more extensive coastal flooding.

TABLE 3

HURRICANES AFFECTING NEW ENGLAND

Hurricanes causing considerable damage, listed in order of magnitude
(Source: U.S. Army Corps of Engineers, 1956)

Hurricane of September 21, 1938
Hurricane of August 24, 1893
Hurricane of August 31, 1954 (Carol)
Hurricane of September 15, 1815
Hurricane of September 14, 1944

Non-ranked hurricanes estimated to have been more intense than the hurric
of September 21, 1938

Hurricane of August 15, 1635
Hurricane of August 3, 1638

Other hurricanes affecting New England

Hurricane of September 11, 1954 (Edna)
Hurricane of August 12-19, 1955 (Connie and Diane)
Hurricane of August 27, 1971 (Doria)
Hurricane of August 10, 1976 (Belle)

Finally, the interval between storm occurrences affects the period over which damaged shoreline areas can recover. This is particularly true in the case of beaches when calmer weather conditions produce onshore transport of sediments which replenish them.

Effects of Storms and Hurricanes

Storms and hurricanes create extreme conditions in Long Island Sound. They form the largest waves, and produce *storm surges*.

One factor that increases the impact of storms and hurricanes is the east-west orientation of Connecticut's shoreline. Because storms and hurricanes approach from southerly direction, the east-west orientation increases the potential for direct onshore impacts of winds and hence, waves and storm surge.

Storm surge is defined as the "difference between observed water level and that which would have been expected at the same place in the absence of the storm" (Harris, 1963). Storm surge can be broken down into the following elements (Davies et al, 1973):

1. Low central air pressure in the storm center causes water level to rise at a rate of 1 inch for every 13 inch drop in barometric pressure (Hobbs, 1970). The ratio is probably lower on Long Island because of the small basin size.

2. Stress produced by onshore wind pushes water towards shore resulting in raised water surface level called wind set up (Figure 10).

3. Waves produced by onshore winds transport additional water into nearshore areas in the form of wave set up. Wave set up may account for as much as 3 to 7.0 feet additional increase in water surface elevation (Figure 10).

4. Wave run up resulting from the shoreward progression of water in the form of breaking waves extends the influence of water level further inland (Figure 10).

5. Heavy rainfall associated with the storm contributes to increased runoff which raises water levels in coastal streams particularly where they drain into Long Island Sound.

The effects of several major hurricanes on Connecticut's coast serve to illustrate the particular impacts of storms on the Sound's north shore. The following descriptions are taken from the Connecticut Coastline Study: Effects of Coastal Storms which was compiled for the Coastal Area Management Program by the U.S. Army Corps of Engineers, New England Division, in 1976. Storm surge levels which resulted from the 1938 and 1954 hurricanes in Long Island Sound are shown in Figure 11.

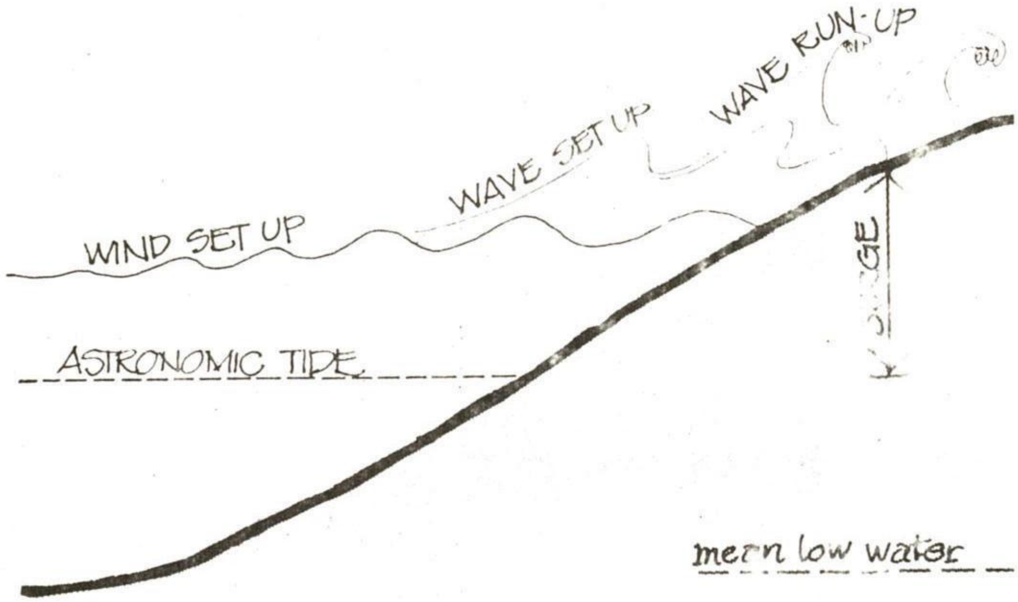
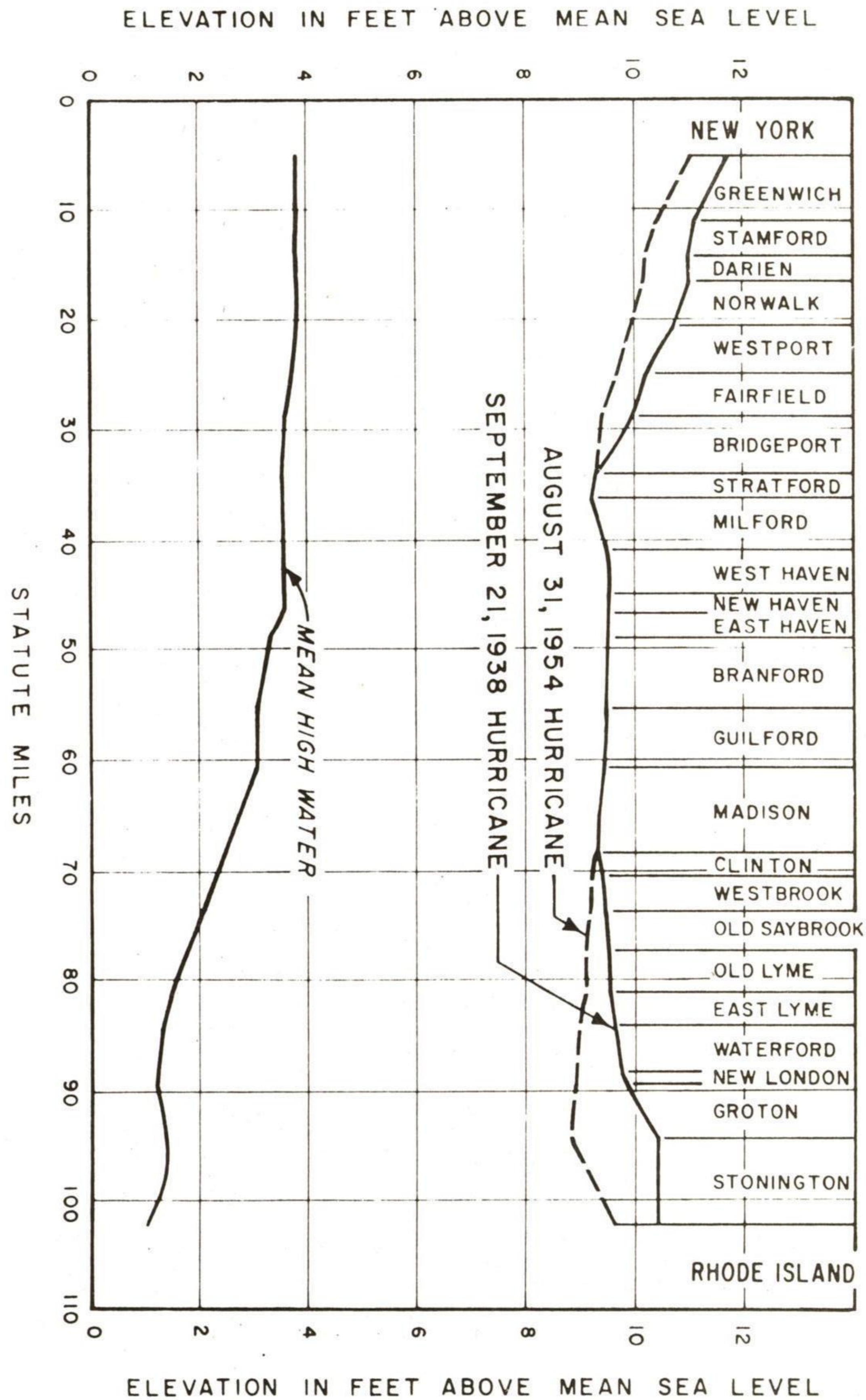


FIGURE 10

STORM SURGE

"Hurricane of September 21, 1938. - On September 21, 1938, the New England area was struck by a devastating hurricane which originated around the Cape Verde Islands. It traveled in a curved path in a northwesterly and then northerly direction, arriving in the New England area during mid-afternoon of the 21st of September. It entered Connecticut with its center just west of New Haven at 3:30 p.m. E.S.T., and continued northward at 50 to 60 miles per hour. Its eye was clearly observed at New Haven. Winds that were easterly since noon died down between 3:00 and 4:00 p.m., and were then followed by increasing southwesterly winds. The region of strongest wind lay in the dangerous semi-circle about 75 miles to the right of the storm center. Minimum barametric pressures were reported as follows: at Bridgeport 28.30 inches, at New Haven 28.11 inches at 3:50 p.m., at Hartford 28.04 inches at 4:17 p.m.. They dropped gradually until noon, and then dropped rapidly to their lowest pressures until about 4:00 p.m. Pressures then rose rapidly until 8:00 p.m., when the noon pressure was attained, then rose gradually. Maximum wind velocities in miles per hour for five minute periods and for gusts, respectively, were observed as follows: New Haven 38 and 46, Hartford 46 and 59 , over and area 80 miles wide from Saybrook, Connecticut, to Martha's Vineyard, Massachusetts 70 to 90 and probably

FIGURE 11



HURRICANE FLOOD LEVELS-CONNECTICUT

(SOURCE: U.S. Army Corps of Engineers, 1973) in excess of 100. The precipitation directly attributable to the hurricane is difficult to determine due to the fact that it rained for two days before it reached New England. The total precipitation ranged from 2 to 5 inches along the Connecticut shore, the major portion of which was probably directly due to the storm. Tides rose above their predicted heights. Tidal heights were increased more to the east of the hurricane center than to the west because of the counter-clockwise wind rotation. Reported high tide during the hurricane occurred 2 to 2 3/4 hours before the time of predicted tide. The effect of the hurricane was an addition of about 9 to 10 feet to the predicted high tide at the entrance to Long Island Sound, this addition decreasing to 7 feet at Bridgeport and increasing to 9 feet at the west end of the Sound. Wave action accompanying the storm produced a devastating effect upon the shoreline, pounding it mercilessly and resulting in widespread damage. Wave heights ranged from 10 feet at New London to 15 feet at New Haven and Bridgeport."

"Hurricane of September 14-15, 1944. - On September 14, 1944 the New England area was struck by a tropical hurricane which originated in the West Indies. This hurricane traveled in a northwesterly then northerly direction to Cape Hatteras, then swerved north-northeast across Long Island about 11:00 p.m., E.S.T. From there, it proceeded northeastward across Providence, Rhode Island, and then followed closely along the New England coast and passed over Newfoundland and out to sea. The greatest wind intensities occurred to the east of the storm center. The calm during the passage of the "eye" and the shift in the wind direction after its passage, were clearly noted at Westerly and Providence. The following minimum barometric pressures in inches were reported in the Connecticut area on September 14: New Haven 28.86 at 9:50 p.m.; Hartford 28.94 at 10:50 p.m.; Fisher Island 28.41 at 10:45 p.m.; Groton 28.40 at 11:00 p.m.; Westerly 28.30 at 11:00 p.m.; Block Island 28.34 at 11:09 p.m. Maximum wind velocities in miles per hour for five minute periods and for gusts, respectively, were reported as follows: New Haven - N 33 and NE 38, Hartford N 50 and N 62. Block Island - SE 82 and SE 88, gusts only in New London - 70 and Westerly - 75. Gusts were mostly estimated. Heavy rainfall was reported practically throughout the coastal portion of the Providence District, which extended from New York State to Cape Cod. In Providence, a total of 4.49 inches fell from 5:55 p.m. to midnight on 14 September. Tides rose above their predicted heights. The hurricane effect occurred on the ebb tide about 3 to 5 hours after predicted gravitational high water in the area from Watch Hill, Rhode Island, to Wood's Hole, Massachusetts."

Hurricane of August 31, 1954. - Hurricane Carol entered southern New England on August 31, 1954. It traveled in a north-northeastward direction from a central position about 100 miles off the Virginia Capes at midnight of August 30th and swept over the extreme eastern end of Long Island nine hours later. Its center moved on a northward course up the Connecticut-Rhode Island border into east central Massachusetts. Sustained winds and gusts, respectively, were recorded as follows: New Haven - 40 N and 65 N; Block Island - 100 SE and 135 SE; Providence - 90 ESE and 105, Nantucket - 72 SE and 77 ESE, Boston - 86 SE and 100 SE; Portland - 69 E and 78 E. Minimum barometric pressures and total precipitation, respectively, were recorded in inches as follows: New Haven - 28.77 (910 EST) and 2.75; Block Island - 28.40 (1000 EST) and 3.31; Providence - 28.69 (1045 EST) and 2.79; Nantucket 29.32 (1100 EST) and 1.89; Boston 28.83 (1148 EST) and 2.60; Portland 29.15 (1412 EST) and 2.26. The hurricane was most violent during the morning over the region extending eastward 100 miles from the center line of passage. Sustained hurricane winds ravaged extreme eastern Connecticut, Rhode Island and Massachusetts. Similar but lesser devastation occurred in the strip of Massachusetts and Connecticut west of the hurricane's center line to the Connecticut River. Damages from flooding occurred at low shore areas throughout Connecticut as a result of extremely high tides. Damages from wave attack were particularly severe only east of the Connecticut River, increasing in severity to the east with the greatest damages in the town of Stonington. Some damages due to wave attack occurred between New Haven and the Connecticut River at shore developments which were particularly vulnerable because of their locations at low beach areas. The greater part of all statewide losses resulted from water damage to industrial plants, business establishments and shorefront residences while east of the Connecticut River heavy losses resulted from damages to fishing and pleasure craft and harbor facilities and physical destruction of shorefront residences and bathing beach establishments."

Sea Level Rise

The accumulation of ice in the form of the Late Wisconsin Glacier resulted in a related loss of water volume available to the world's oceans. Accordingly, sea level began to retreat and continued to fall until the glacier reached its maximum areal extent approximately 18,000 years ago. At the point of maximum development, Curray (1965) has estimated that sea level had fallen at least 360 feet exposing most of the gently sloping continental shelf. As the continental ice sheet began to recede, in response to global warming, sea level began to rise. This marine transgression was rapid by geological standards, representing an average rate of approximately 2 feet per century over 18,000 years. During the initial period of glacial recession much variation in climate occurred resulting in local readvance and recession of the ice front (Curray, 1965).

The accumulation of glacial ice affected relative sea level in a way other than the alteration of the global water budget. The thickness of glacial ice, estimated at 1300 to 1600 feet in southern extremes, caused the underlying earth to subside as much as one-third of its thickness (Flint, 1971). Relative sea level change incurred by this movement is called *isostatic* sea level change.

At present, the crust has rebounded to its original position prior to glaciation (Flint, 1971). However, the completion of crustal rebound was delayed until well after the ice load had melted away. This caused an initial drowning of some areas as the sea level rose onto a depressed crust. As rebound reached completion, sea level rise continued at a slower pace.

Until approximately 8,000 years ago, sea level stood below minus 32 feet, the lowest elevation on the Mattituck Sill. As a result most of Long Island Sound was not influenced by the Atlantic Ocean. Between 7,000 and 8,000 years ago, sea level continued to rise finally gaining access to the Sound. During the initial 1,000 years of marine transgression in the Sound, sea level rise was too rapid for sediment accumulation to keep pace. As a result, tidal marshes did not begin to form until approximately 3,500 years ago (Bloom, 1967). The rate of sea level rise determined by Bloom for the period between 8,000 and 3,5000 years B.P. is 4.7 inches per century. From 3,500 to 75 years ago, the rate slowed further to 3.3 inches per century. The past 75 years have witnessed an apparent increase in sea level rise to 1 to 1.5 feet per century.

Recent periods of sea level rise have produced corresponding coastal submergence marked by a gradual migration of the shoreline landward. Tidal action has increased its influence on the Long Island

Sound estuary as the limit of saltwater intrusion gradually extended upstream. The configuration of the shoreline has also experienced change in response to marine transgression. Steep headlands and bluffs experience minor changes due to rising sea level. However, as a result of gradual increases in the depth of nearshore waters caused by rising sea level, erosive waves can approach closer to shore expending their energy on the bases of previously unexposed cliffs. Bedrock shoreline areas occupying low lying points on the shore have been drowned forming reefs and islands. Beaches have migrated landward under the influence of inundation, and associated erosion. Clearly the more rapid rates of submergence indicated for the last 75 years play a significant role in shoreline erosion.

SHORELINE CONFIGURATION COMPOSITION AND EROSION

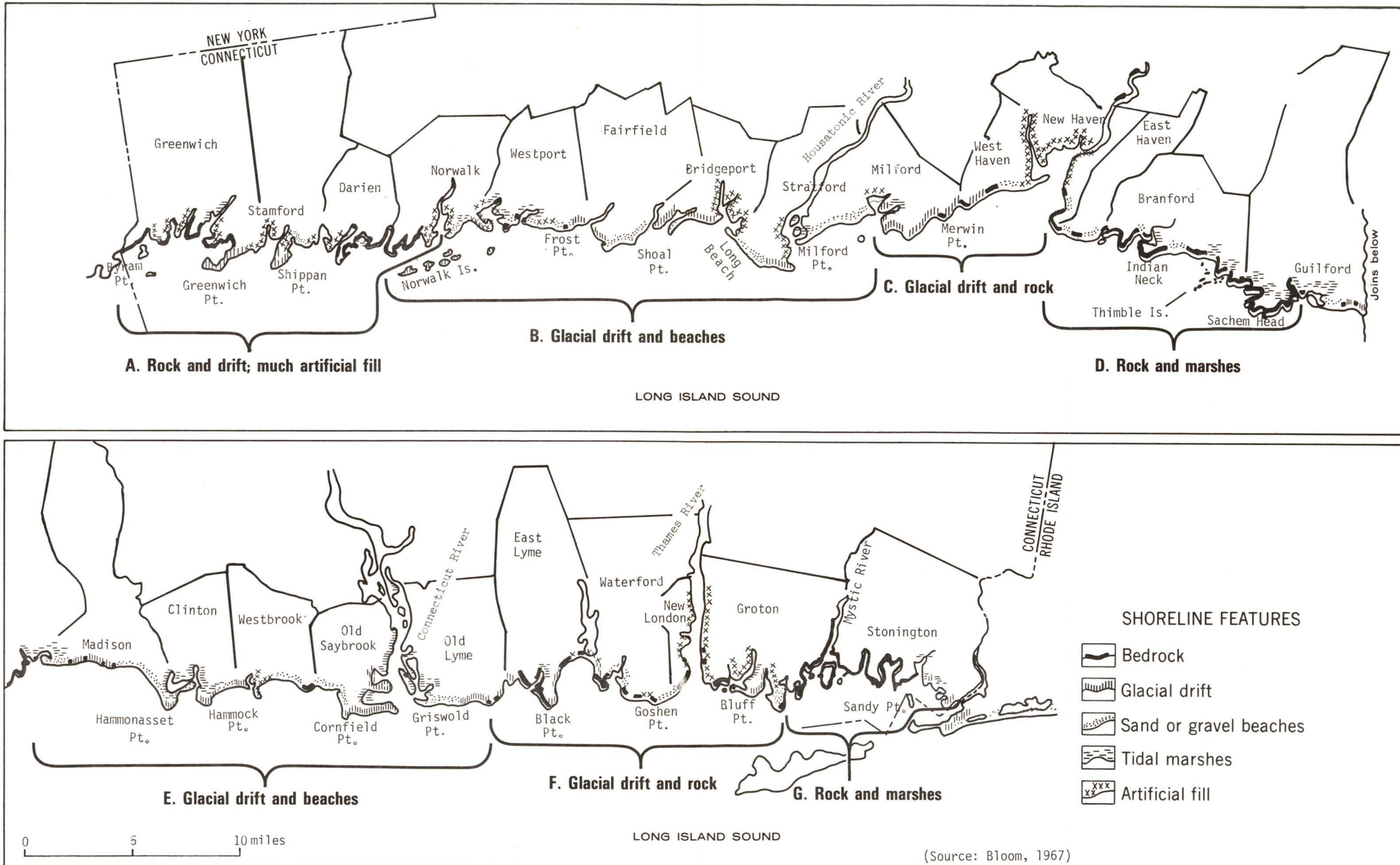
The geology and physical climate of Connecticut's coastal area shoreline and Long Island Sound have been briefly discussed in preceding sections. As previously noted, geologically speaking, the north shore of Long Island Sound is most aptly described as an embayed, primary coast, originally formed by glacial deposition and currently being submerged by rising sea level. These two processes, glacial deposition and submergence, are responsible for the overall configuration of Connecticut's shoreline. Coupled with the low energy environment of Long Island Sound, which is protected from the open ocean by Long Island, they have produced a shoreline which is variably irregular and curvilinear in configuration, and which is composed of bedrock, glacial drift, tidal marshes and beaches.

Review of all available pertinent literature and research dealing with the problems of shoreline erosion in the state indicates that only those portions of the coastal area fronting directly on Long Island Sound and the lower reaches of the state's three major tidal rivers are affected by erosion of any consequence. This direct Long Island Sound-fronting shoreline constitutes 278 miles of the total 458 miles of coastal area frontage. Examination of state and federal expenditures for erosion control over the past twenty-five years further verifies this conclusion. For these reasons the analysis and planning processes focus on the 278 mile portion of direct Sound-fronting shoreline.

H.S. Sharp (1929) presented the first discussion of the geology and physical history of Connecticut's shoreline. At that time he recognized several general districts, or shoreline divisions, based on geologic composition. Later in 1967, Sharp's classification was revised slightly by Arthur Bloom. Bloom's designation of shoreline districts is shown in Figure 12. Using shoreline composition as a basis for classification, seven shoreline districts may be recognized. Shoreline composition for each district has been tabulated from surficial geology and soils maps and is presented in Table 4. Information on shoreline composition has also been tabulated by town in Table 6. Statistical data on the occurrence of significant erosion (see definition 8, Table 12) have also been compiled on a town by town basis.

FIGURE 12

CONNECTICUT SHORELINE DISTRICTS



(Source: Bloom, 1967)

TABLE 4

Shoreline Statistics

DISTRICT	SANDY BEACH	GLACIAL DRIFT	BEDROCK	ARTIFICIAL FILL	TIDAL MARSH	TOTAL MILES	LINEAR MILES
A	17.7%	29.3%	22.4%	22.2%	5.8%	68.9	15
B	37.0%	20.0%	0.67%	28.3%	13.8%	60.0	20
C	50.0%	14.8%	3.9%	30.5%	0.8%	12.8	8
D	13.2%	10.2%	56.5%	9.0%	3.7%	33.3	12
E	54.4%	18.9%	1.8%	10.0%	14.3%	34.9	22
F	27.7%	36.4%	12.7%	13.0%	10.2%	39.3	13
G	16.0%	41.0%	16.5%	10.0	16.5%	18.2	8

Erosion statistics are based on information from the following sources:

1. Data gathered by coastal area Regional Planning Agencies.

2. Comparison of aerial photographs.

3. Comparison of historical shoreline configurations shown on National Ocean Survey Coastal Charts, for the years of 1835-38, 1884-86, 1933 and 1949-53.

4. Examination of state and federal expenditures for erosion control.

5. Review of all pertinent available literature including government documents, academic papers (theses, dissertations) and technical papers contained in various professional publications such as:

   The National Shoreline Study (U.S. Army Corps of Engineers, 1973)

   The Long Island Sound Regional Study. (New England River Basins Commission, 1975)

   Beach Erosion Control Cooperative Study of Connecticut. (U.S. Army Corps of Engineers, 1949-1958)

6. Limited information obtained from municipal flood and erosion control boards in response to CAM Program inquires regarding shoreline erosion in municipalities with Long Island Sound-fronting shoreline.

Appendix C contains more site specific information on those shoreline areas considered to be significantly affected by erosion. The listing is intended to be inclusive. As such, it contains data tabulated for all locations known to be of concern with respect to erosion. Undoubtedly, as additional information is obtained from future investigations the listing will change. However, for the purposes of establishing the nature and extent of erosion and to provide the basis for developing a planning process, as required by the Coastal Zone Management Act, the listing is considered to be adequate.

The following is a general description of shoreline composition, configuration and erosion in the districts shown in Figure 12. Names and locations referred to are those indicated on U.S. Geological Survey topographic maps. Due to their volume these maps are not included in the text. Rather, the interested reader is directed to them for further reference.

BYRAM RIVER, GREENWICH TO NORWALK HARBOR (District A)

General Character

The shoreline between the Byram River on the New York border in Greenwich and Norwalk Harbor is the most irregular segment of Connecticut's coast. A general measure of this irregularity is given by a comparision of irregular shoreline length, shown as total miles in Table 4, with the shoreline length measured linearly between the Byram River and Norwalk Harbor (linear miles). The geologic composition of the district is controlled by bedrock which is covered by a mantle of glacial till. Man's presence and use of shoreline areas strongly influence the natural shoreline and processes. Artificial fill and shore protection works occur along 50 percent of the shorefront and have so altered the system that any analysis of the physical environment is difficult, particularly in the absence of recent field study. Sediment sources, littoral transport and wave energy dissipation are all significantly affected by the occurrence of fill and coastal structures. Thus, the response of the shoreline to natural phenomena is much less predictable than along relatively less altered shorefronts.

More than 200,000 people inhabit the municipalities which comprise the district (Table 5) and a preponderance of development occurs near the coast. Shoreline ownership is predominantly private with some municipal park and beach areas interspersed. Estimated property values range well above an average of 200,000 dollars per acre.

Physical Climate

The physical environment of this shore district is dominated by two primary variables. First, the fetch is extremely limited to the south and west, thus reducing the influence of the dominant summer southwest winds and waves generated thereby. The maximum fetch lies to the east: a quadrant which usually produces storm waves. Therefore, the area is exposed

TABLE 5

CONNECTICUT TOWNS FRONTING ON LONG ISLAND SOUND.
with estimated square mileage and population
from Connecticut State Register and Manual 1978

	Town	Sq.Mi.	Pop.		Town	Sq.Mi.	Pop.
1.	Branford	27.9	21,800	15.	Norwalk	27.7	80,300
2.	Bridgeport	17.5	148,000	16.	Old Lyme	27.1	5,600
3.	Clinton	17.2	11,200	17.	Old Saybrook	18.3	9,300
4.	Darien	14.9	22,800	18.	Stamford	38.5	107,000
5.	East Haven	12.6	24,100	19.	Stratford	18.7	50,600
6.	East Lyme	34.8	13,400	20.	Stonington	42.7	17,000
7.	Fairfield	30.6	59,000	21.	Waterford	36.7	18,500
8.	Greenwich	50.6	63,800	22.	West Haven	10.6	54,100
9.	Groton	38.3	37,200	23.	Westbrook	16.2	4,800
10.	Guilford	47.6	14,900	24.	Westport	22.4	29,500
11.	Madison	36.3	12,700		TOTAL	639.1	1,018,900
12.	Milford	23.5	51,600				
13.	New Haven	21.1	131,000				
14.	New London	7.3	30,700				

to less frequent storm waves while being sheltered from more docile southwest, summer waves and winds. The second dominating variable is the large tidal range which varies from 7.3 feet (mean) in Greenwich to 7.1 feet in Norwalk. The large tidal range produces tidal currents with larger onshore and offshore directional components. Coupled with a steep offshore slope the currents can facilitate a net offshore transport of sediments. The generally smaller (less than 0.6 knots) magnitude of current velocities in the area appears to confine this movement to finer silt type sediments which can be carried by low velocity water flows. The large tidal range also affords some degree of storm protection. When storms occur in conjunction with low tide, wave breaking and energy release occur further offshore away from the heavily developed shoreline.

Composition and Morphology

The dominant role of bedrock is a major factor controlling the overall configuration of the district's shoreline. Inherent bedrock structures (hills and valleys) trend generally north-south producing a topographic "grain" which runs perpendicular to the shore. This bedrock relief has also controlled the deposition of glacial material as evidenced by the north-south orientation of the major *drumlinoid* (glacially sculpted hills) features which project seaward as headlands throughout the area. These features are most notable at Long Neck, Darien; Shippan Point, Stamford; and Greenwich Point. The slope of the bedrock surface here is markedly steeper than that to the east as indicated by the proximity of the 50 foot contour line to shore. The steep onshore slope is reflected by a steep slope of the Long Island Sound bottom in the nearshore which can enhance offshore sediment movement and reduce reciprocal onshore transport. The most extensive areas of bedrock are exposed along the shoreline in Greenwich, Darien and Norwalk.

Sediment transport in the district is small in magnitude and highly irregular in average, or net, direction. These local phenomena are a direct result of low shoreline sediment availability and irregular configuration attributable to bedrock control. Structural stabilization and naturally developed protection have further reduced the availability of the limited, naturally occurring sources of sediments along the shore. The latter is produced by the presence of large boulders contained in glacially deposited materials, which are removed by waves and deposited by gravity at the base of exposed cliffs and bluffs, forming natural *revetments* or sea walls. Deposits of boulders in areas offshore of most *headlands* indicate their former size and the extent of erosion.

Directions of alongshore transport usually diverge at headlands, flowing north into the bordering coves. Magnitude of sediment transport is limited by the small volume of material available at shorefront sites. The result is an extremely variable system of weak longshore transport which lacks any general directional continuity. The north south topographic trend of bedrock-cored headlands in the district limits the exposure of areas on their western flanks to storms generating waves from the east, while affording protection from southwesterly summer waves to areas on their eastern flanks.

Beaches in the district occur in pockets between headlands from which their sediments are derived. Where they are present their composition varies from *boulder lag* at the tips of exposed headlands to finer material which has been transported to and deposited in sheltered coves forming pocket beaches. Beach continuity is often broken by the presence of bedrock and stabilization structures common to the district. Most of the notable beach deposits occur between Greenwich Point and Holly Pond on the Stamford-Darien town line.

In the protected coves between the irregular headlands there are small exposures of saltmarsh. These exposures are more common in the eastern section of the district since most marsh exposures to the west have been artificially filled. Notable examples of artificial filling in wetland areas and small tidal coves are present at Holly Pond on the Stamford-Darien border and at Manresa Island on the west side of Norwalk Harbor. In many instances fringing marsh deposits have begun to develop in front of exposed headlands such as those at Greenwich Point, Greenwich, and Long Neck in Darien. This unusual phenomenon is indicative of the generally low energy nature of the shoreline in the district.

Numerous curvilinear beach features connecting islands and mainland (*tombolos*), which began to form naturally, have since been artificially stabilized for road bed construction. Examples include Hay Island and Pratt Island in Darien; Greenway Island in Stamford; and Elias Point, Saw and Horse Islands in Greenwich.

Nature and Occurrence of Erosion

The occurrence of recent erosion induced changes in this district are the least pronounced for any portion of the coast reflecting the area's bedrock composition, structural stabilization and the fetch-limiting protection afforded by Long Island. Significant natural changes in shoreline configuration are rare in the area (Bloom, 1967). On the other hand, more extensive changes arising from artificial filling of tidal areas are common. The effects of erosion are most focused on beach areas and unprotected glacial deposits which lie immediately behind them. Historically much time and effort have been expended in attempts to stabilize the beaches in the district. Two state and federally funded projects were initiated in the vicinity: one at Cummings Park in Stamford, and the other at Greenwich Point Park in Greenwich (Appendix C). The latter project, which was to consist of beach filling, was never completed. Attempts to locate submarine sand sources near the beach were unsuccessful.

Areas noted to have experienced significant erosion lie on the east and west sides of the large drumlinoid headland at Shippan Point in Stamford and between Flat Neck and Greenwich Points in Greenwich. Appendix C contains a more detailed description of the areas, their history of change. ownership and more precise extent. The primary response of the more erosion resistant shoreline in the district is submergence as a result of rising sea level.

NORWALK HARBOR TO MILFORD HARBOR (DISTRICT B)

General Character

Glacial drift, composed primarily of outwash and *ice-contact, stratified drift,* forms most of the shoreline in this district. Bedrock is virtually absent from the area, while the influence of filling and shoreline stabilization works are again in evidence along most of the segment. Artificial fill accounts for shoreline composition in nearly 30 percent of the district occurring primarily in harbor areas. The district also includes the Norwalk Islands a series of submerged end moraine segments (Flint and Gebert, 1976) south of Norwalk Harbor. The more homogenous and erodible nature of these glacial materials has led to a development of a semi-regular, curvilinear shoreline. In many instances erosion has affected and will continue to affect shoreline residents.

More than 400,000 persons live in the towns of Norwalk, Westport, Fairfield, Bridgeport, Stratford and Milford. The use of shoreline areas is very intense and average land values of 110,000 dollars per acre are characteristic, with higher values occurring in the more western municipalities. Shorefront ownership is predominantly private with some segments under public ownership. Two major state owned recreational facilities are present in the district: one at Sherwood Island in Westport, and the other, which is at present undeveloped, at Silver Sands Beach in Milford.

Physical Climate

The physical climate of this district is similar to that of District A, although it is exposed to larger fetches from the south and west, and correspondingly reduced fetch to the east, as a result of its more easterly location on Long Island Sound. Consequently, the area is somewhat less sheltered from gentle southwesterly summer waves, but it is still exposed to storm winds and waves from the eastern sector. Wave data, obtained by observation at Stratford Point and presented in the section on waves are representative for the area. Tidal range decreases from 7.1 feet in Norwalk to 6.6 feet at Milford Harbor. Maximum tidal current velocities are generally of the same order of magnitude as those in District A. However, in the vicinity of the mouth of the Housationic River, maximum tidal currents on the order of 1.5 knots occur during spring tides. The large tidal range gives rise to larger offshore and onshore components of tidal motion as was the case for the area previously discussed. However, the more gently sloping nearshore area produces a better balancing between on and offshore transport induced by tidal currents and waves.

Composition and Morphology

The dominant occurrence and erodibility of glacial outwash, composed mainly of sand and gravel, between Norwalk and Milford Harbors have produced two major effects. First, the onshore topography and the nearshore bathymetry both reflect the more gentle slope of their parent outwash plain. Secondly, the erodibility of the shoreline has resulted in a configuration which is comprised of relatively longer, more nearly east-west trending segments. The Housatonic River, one of the state's three larger tidal rivers, punctuates the district, at the Stratford-Milford boundary.

Beaches derived from eroded glacial deposits occur throughout the district and the nearshore area is characterized by extensive sandy shoals. Several of the state's larger barrier beaches, which are a mile or more in length, protect marshes at Sherwood Island State Park, Westport; Fairfield Beach, Fairfield; Long Beach, Stratford; and Myrtle through Silver Beaches in Milford. Other beaches in the area are fringing beaches which occur directly in front of deposits of glacial drift from which they are derived. The most highly developed areas of sandy shoals occur near shore at Compo Cove, Westport; Southport Harbor and Fairfield Point, Fairfield; near Bridgeport Harbor in Bridgeport; and continously from the Housationic River east to Milford Harbor. These shoal areas are unquestionably related to the behavior of beaches in the area. During storm events materials are removed from beach and adjacent nearshore areas and deposited on the shoal areas. Under calmer, normal conditions, waves can reverse the transport process resulting in a more balanced onshore-offshore system of sediment transport. The precise nature of the balance between the two types of transport is very complex. Storms may remove material from shore and deposit it at a depth at which more gentle waves are unable to effect transport onshore. The depth beyond which waves causing onshore transport of materials fail to induce such transport is termed the *depth of closure* (Dean, 1976). The depth of closure for Long Island Sound is unknown, however it may be on the order of 10 feet.

Owing to the more linear nature of shore in the district, longshore transport directionality is better developed. The dominant, or net, direction of longshore transport throughout the area is generally westerly, although in several localities the reverse is true, These reversals are most commonly due to shoreline orientation which precludes westerly movement. The net direction of alongshore transport is apparently a result of stronger southeastern storm waves. During a study of the Norwalk Islands, Ellis (1962) noted the reversal of longshore currents under storm conditions. During average conditions, longshore currents flowed in as easterly direction, with the exact path determined by the orientation of the shoreline. However, during storm conditions, a reversal of this general trend under the influence of strong, strom-generated southeast waves occured. Despite low frequency of occurrence, the resultant westerly, longshore currents transport more material than the weaker, more common, easterly currents, thus producing a net transport to the west.

Numerous groins, jetties and seawalls are present along all the beaches in the district and have significantly altered the natural movement of sediments along the shore. At Milford Point, Milford and at Pleasure Beach, Bridgeport the construction of major jetties at the distal ends of barrier beaches has resulted in larger scale accretion of as much as 600 feet. Two major groin fields occur at Long Beach in Stratford and Fairfield Beach in Fairfield. The former was constructed in response to storm induced breaching of the Long Beach barrier, possibly in 1938, although the exact date is unknown (U.S.A.C.E., 1952). The latter groin field at Fairfield Beach was erected to protect heavy residential development there and to prevent future breaching by storms, such as that which removed several hundred feet from the west end of the beach. Groin protection in both areas, except as it serves to widen the beach, is not likely to prevent future breaching. Groins are designed to inhibit longshore transport rather than storm overwash, which is a result of onshore-offshore transport perpendicular to shore.

Several large tidal marshes have developed in the area, most notably behind the westward trending barrier beaches at Fairfield Beach, Fairfield; Long Beach and Pleasure Beach in Bridgeport and Stratford;and Milford Point in Milford. The marshes obviously owe their existence to the protection afforded by the barriers. Artificial filling for residential development, harbor, industrial, and airport facilities and sanitary landfill purposes are evident in the marshes at Fairfield Beach, Fairfield; Long Beach, Stratford and Myrtle to Silver Beaches, Milford.

The few less pronounced headlands which occur in the area are composed of coarser glacial materials, which have developed natural protection through the deposition of boulders at their bases which form natural revetments. Coupled with numerous private seawalls, and the presence of natural protection they seriously limit sediment available to the system in headland areas.

Boulder lag deposits offshore of Cedar Point, Sherwood Point, Frost Point and Kensie Point indicate three things. First, these headlands once extended farther south than at present. Second, their erosion has provided material for near by barrier beaches such as Compo, Alvord, and Burial Hill Beaches, in Westport. Third, the high percentage of boulders offshore indicate that they are composed of till. This factor in part explains the greater irregularity of the western section of the district as compared to those sections to the east which are dominated by outwash. Similar lag deposits offshore of Grover Hill, Fayerweather Island, and the headland at the east end of Seaside Park in Bridgeport indicate similar conditions.

The Norwalk Islands which occur at the western end of the district in Norwalk, and Charles Island located offshore of Silver Sands State Park in Milford, are evidence of *relict* upland features which are being inundated by rising sea level. Both are glacial in origin. The Norwalk Islands, as previously noted, are end moraine features, while Charles Island is most probably a remnant hill composed of glacial till and isolated by encroaching sea level and erosion.

Nature and Occurrence of Erosion

The shoreline between Norwalk and Milford is more significantly impacted by the effects of shore erosion than any other district of Connecticut's coast. The intensity of development located in immediate proximity to the water, and the highly erodible nature of beaches and their source glacial deposits are the primary elements contributing to the problem. The most evident recent changes in the shoreline have taken place along the major barrier beach features of the district. They are a result of shoreward migration in response to rising sea level, lateral growth induced by longshore transport, and breaching by storm activity. Nineteen erosion control projects have been initiated and completed in the district utilizing state and federal funds. Together they account for more than half the total monies expended on state, or partially state, funded projects (See Appendix D). In spite of these expenditures erosion continues to impact the shoreline. State funded studies of erosion at Compo Beach and Sherwood Island State Park in Westport and for the entire Milford shoreline have been initiated recently.

Evaluation of shoreline changes in the area indicate that significant erosion is affecting more than twelve miles of the shoreline between Norwalk and Milford Harbors at the following locations:

Calf Pasture Beach, Norwalk
Compo Beach, Westport
Sherwood Island, Westport
Sasco and Southport Beaches, Fairfield
Fairfield and Jennings Beaches, Fairfield
Seaside Park, Bridgeport
Long Beach, Stratford
Short Beach, Stratford
Milford Point to Silver Sands Beach, Milford

More detailed information on the history and extent of erosion at these locations and their management is contained in Appendix C.

MILFORD HARBOR TO LIGHTHOUSE POINT, NEW HAVEN (DISTRICT C)

General Character

The shoreline of district C lies east of Milford Harbor. The general trend of the coast here is more northeasterly than that of the preceding districts. Glacial drift, which is high in clay content, dominates shoreline composition. Several exposed bedrock points and till headlands punctuate the district, and large amounts of artificial fill are present, with concentrations in New Haven Harbor. As was the case for previous westerly districts, the incidence of development is extremely high and in close proximity to shore. Seawalls and groins occur almost continuously between Milford Harbor and Lighthouse Point, limiting sediment availabilities and movement. The district's three towns are inhabited by more than 230,000 residents half of whom reside in New Haven (Table 6). Private ownership of shorefront is most common but a significant portion (more than 7 miles) is in public use. Average land values range as high as 140,000 dollars per acre.

Physical Climate

The more northeasterly trend of the shoreline all but eliminates the effects of winds and waves from due west. Consequently, the district is most influenced by southerly or southeasterly wind and wave patterns. At New Haven Harbor the Sound reaches its widest point, appreciably increasing the fetch to the south and, hence, the potential influence of southerly waves. The major embayment at New Haven Habor further limits shoreline exposure to waves traveling over large fetch areas between Bradley Point, West Haven and Lighthouse Point, New Haven. The shoreline between Milford Harbor and Oyster River Point in West Haven is most exposed to easterly and southeasterly storms. North of Oyster River Point three large breakwaters, located south of New Haven Harbor, function to significantly reduce the influence of east and southeast winds and waves. As a result the area north of the Point is most exposed to southerly and southwesterly influence.

Tidal range in the district decreases from a mean of 6.6 feet at Milford Harbor to 6.3 feet in New Haven Harbor. The difference of almost one foot in average tidal range between the area and District A reduces the significance of the onshore-offshore component of tidal flow.

Tidal currents are normally weak throughout the area and probably do not contribute appreciably to shoreline sediment motion. However, they are responsible for the erosion and redeposition of a small thickness of bottom sediments in the Sound's central basin on a daily basis (Gordon et al 1972).

Composition and Morphology

Intermixed deposits of glacial outwash and till characterize the composition of the district west of Bradley Point, West Haven. The more resistant till, which occurs as several north south trending hills, forms points which punctuate the outwash deposits at Welches Point in Milford and Oyster River Point in West Haven. Two other more pronounced points are occupied by exposed bedrock at Merwin Point in Milford and Bradley Point in West Haven. A fifth projecting headland is backed by glacial outwash at Pond Point in Milford. Normally, outwash would not be expected to occupy a point area since it is more easily eroded than bedrock or till. However, Pond Point is protected by an extensive stone revetment.

East of Bradley Point, deposits of sandy outwash form the shoreline between the point and the West River on the New Haven-West Haven border. In New Haven Harbor, which occupies the embayment created by the occurrence of Connecticut's Central Lowland Valley at the coast, extensive artificial filling has covered most of the naturally occurring outwash deposits. On the east side of the harbor at Lighthouse Point another till hill fronted by areas of exposed bedrock forms the shore.

Bedrock lies very near the surface throughout the district and is not uncommonly exposed in intertidal and nearshore areas.

The intermixed, somewhat transitional, nature of the district has resulted in a mixed shoreline morphology. West of Bradley Point coastal and nearshore areas are relatively steep as a result of the presence of the north-south trending till hills. East of Bradley Point, the reverse is true. The presence of outwash in New Haven Harbor has led to the development of a more gently sloping shoreline and nearshore.

Beaches which have developed in the area are primarily of the fringing variety and were initially derived from erosion of outwash and till deposits. Between Milford Harbor and Bradley Point most of the beaches are extremely narrow and composed of coarser material derived from erosion of till. Two small barrier beaches occur at the western end of Gulf Beach in Milford and in a pocket area between Welches Point and Pond Point. Substantial deposits of sandy outwash at Pond Point which could provide sediment for the natural development of beaches have been stabilized by shore protection works and are occupied by residential development.

Littoral sediment transport in the westerly segment of the district is probably dominated by offshore movement because of the steeper slopes in nearshore bathymetry. The area south of Bayview and Point Beaches is an exception. A gentler slope has developed here as a result of the outwash composition of shoreline materials.

East of Bradley Point extensive sandy beaches occur on the more east-west oriented shore of West Haven. The gently sloping nearshore area here leads to a more balanced relationship between on and offshore sediment movement. Pronounced, sandy tidal flats which lie in front of these beaches bear a similar resemblance, both in form and in function, to the tidal flats mentioned in the discussion of District B. That is, storm activity removes material from the beach and deposits it offshore. During calmer conditions the material stored offshore can be returned to the beach. As was the case in District B the so called depth of closure is important in this process.

On the east side of the harbor, the area near shore is somewhat less gently sloping and the intertidal flat is generally less developed. At Lighthouse Point, a glacially-sculpted, till hill and bedrock occupy the shore and nearshore bathymetry, which becomes relatively steep, generating conditions favorable to dominant offshore movement of materials.

Longshore sediment transport in the district is variable in direction and magnitude. The effects of numerous groins and jetties further complicate the evaluation of this type of sediment movement. West of Bradley Point transport is generally to the west in east-west trending areas and to the north on more north-south oriented shorelines. Because steep shoreline relief is more conducive to offshore transport, alongshore movement of material is less developed and hence smaller in magnitude. Vesper (1961) concluded, after a five year study of behaivor of beach fill at Prospect Beach, West Haven, that the movement of fill material lost from the area between mean high and mean low waters could be accounted for by deposition of material above mean high water and below mean low water.

Along the east-west trending shoreline of West Haven, longshore transport is apparently much better developed, as indicated by the presence of two small scale barrier beaches extending eastward into New Haven Harbor at Sandy Point and Morse Park. Both features indicate net easterly longshore transport. Their lateral growth has undoubtedly been influenced and augmented by the placement of 1,000,000 cubic yards of sand on beaches to their immediate west in 1949, and by the protected environment afforded by the construction of the three New Haven Harbor breakwaters in 1915. On the eastern side of the harbor longshore transport is again less apparent, probably due to the extreme wave sheltering conditions provided by its location on the Harbor which eliminates the possibility of storm wave attack from the east and southeast. However, the shoreline here is exposed to short, steep, choppy waves generated by predominantly northwesterly winter winds.

Virtually no tidal wetlands occupy shorefront areas in the district. The few small marshes that are evident have developed behind protective beaches, and in the lower reaches of two or three small tidal streams which dissect the area. The absence of marsh in the New Haven embayment is a result of filling for roadways and port facilities.

Nature and Occurrence of Erosion

Shore erosion in beach areas along the north-south trending shorelines of the district has been a long standing concern. The situation has been aggravated by extensive stabilization of major sources of sediment along eroding headland areas particularly at Pond Point.

Over the past 3 decades well over one million dollars in public funds have been expended for beach fill and construction of groins and revetments in the areas of Gulf Beach, Morningside and Woodmont in Milford; Prospect Beach and Oyster River (Aimes) Point in West Haven; and Lighthouse Point Park in New Haven (Appendix D). Even so, erosion has continued to affect these till dominated areas and is considered to be of significant magnitude along over seven miles of shorefront between Milford Harbor and Lighthouse Point. Approximately half of the affected shorefront is in public ownership while the other half is privately controlled (see Appendix C). Average erosion rates are on the order of 1.5 feet per year but have apparently exceeded the average in a few scattered locations. Gulf, Point and Bayview Beaches, Woodmont Shore, Prospect and Savin Rock Beaches, and the shorelines at Lighthouse Point Park and Morris Cove are all considered to be significantly affected by erosion.

LIGHTHOUSE POINT, NEW HAVEN TO GUILFORD POINT, GUILFORD (DISTRICT D)

General Character

This district, which consists of the shorelines of Guilford, Branford, and East Haven, exhibits radical differences from the districts to its east and west. The highly irregular configuration of the shoreline is produced by the presence of bedrock. Strikingly few deposits of glacial drift are present in the district. As a result, beaches are coarse in composition and infrequent in their occurrence. Numerous small rocky islands are present, particularly in the Guilford-Branford areas where the Thimble Islands form a northeast-southwest chain.

Development in shoreline areas is lower in intensity than that in towns to the west of New Haven. Slightly more than 60,000 persons live in the area and population decreases markedly to the east in Guilford (Table 6). Most of the offshore islands are inhabited and a preponderance of development occurs in the shoreline areas. On the average, shorefront property is similar in economic value to that in the preceding district. However, the cost of acreage in Branford and Guilford can range well above those for the more urban East Haven area.

Shoreline ownership is almost exclusively private. Minor segments are in public ownership consisting primarily of municipal beaches. One state owned facility occurs in the area at Cockaponset State Park, but Park shore frontage is extremely small.

Physical Climate

The district is nearly centrally located on the north shore of Long Island Sound and is exposed to approximately equal fetches to the south east and southwest. Directly to the south, an available expanse of twenty miles of open water between Connecticut and Long Island is the most limited fetch for the district. High velocity, northwest winter wind patterns, and waves which they generate, have little influence on the coast, except on the north sides of rocky headlands and islands which extend to the southwest at Indian Neck in Branford, Sachems Head in Guilford and in the Thimble Islands chain on the Branford-Guilford border. Other south-facing shorefronts are equally exposed to more gentle, southwest summer winds and waves, and more severe southeast storms. On east-facing shorefronts the effects of summer winds and waves are reduced, while the impacts of storms are increased by shoreline orientation.

Tidal ranges in the district decrease from 6.2 feet in New Haven to 5.4 feet at Sachems Head in Guilford. Tidally induced currents on the other hand are appreciably greater in magnitude, reaching maximum flood and ebb current velocities of nearly 1.2 knots near Sachems Head. Consequently, tidal currents in the Sound begin to play an important role in the movement of shoreline sediments of the district particularly on more seaward projecting promentories.

Composition and Morphology

With the exception of segments of the shoreline in East Haven and Indian Neck in Branford, bedrock is the primary variable controlling the configuration of the district's coastline. In East Haven and at Indian Neck substantial deposits of glacial drift, primarily till, are present at the shore. The bedrock is part of a large body of granite called the East Haven Granite which extends from Lighthouse Point to Sachems Head (Rogers et al, 1956). The structure and relief of this unit have created a topographic grain, similar to that observed in the Greenwich, Darien and Stamford areas. The northeast-southwest trend of the grain has also controlled glacial deposition and erosion. As a result, the configuration of the shoreline is a system of irregular coves and headlands which trend northeast almost perpendicular to the general east-west orientation of the coast. Post-glacial, sea level rise has submerged major portions of the bedrock ridges which extend into Long Island Sound, forming the Thimble Islands which occupy the ridges' high points.

Beaches in the Branford and Guilford areas are very narrow and extremely coarse in composition as a consequence of the paucity of parent glacial material. They form in small coves between rocky headlands as pocket beaches. In contrast beaches in East Haven and at Indian Neck in Branford are better developed due to their proximity to the deposits of glacial till which occur in these locations. Most of these beach features lie directly in front of the deposits of till and are termed fringing beaches. At one location at West Silver Sands Beach, East Haven a small barrier beach has developed fronting tidal marsh between bedrock features at Morgan Point and South End Point.

Littoral transport in the district is extremely variable in direction and magnitude. The irregular configuration and dominant bedrock composition complicate any general assessment of shoreline sediment movement. Along the east-west oriented shoreline of East Haven net longshore transport is predominantly to the east, most probably as a result of exposure to storm waves from the southerly quadrant. The eastward growth of the barrier beach between Morgan and South End Points is indicative of this situation. Along the Guilford and Branford shores longshore transport is north into numerous small coves and embayments on north-south trending shorelines, and dominantly east (as in East Haven) on east-west trending shorefront. The paucity of materials available for transport significantly reduces the influence of this mode of littoral transport in the Guilford-Branford areas. It is, therefore, less developed here than in East Haven.

Onshore-offshore movement of material in the district is also complex. Normally the occurrence of bedrock would produce a relatively steeper offshore than is evidenced. Bloom and Ellis(1965) have suggested that the lower offshore slope may be a result of outwash plain, which once extended over the area and which is now covered by estuarine mud. At any rate, the lower offshore slope in much of the area tends to reduce the effects of offshore transport which might normally be expected.

Tidal marsh occurs in many of the small coves and embayments in the districts, as well as behind the small barrier beaches in East Haven. Significant marsh areas are also present in the more seaward reaches of the Branford River in Branford, and the East and West River

Little artificial fill is evident at the shoreline in the area. However, significant deposits are noticeable in the *lee* of barrier beaches in East Haven and covering the fringes of marsh areas in Branford and Guilford. Most of the fill was placed to facilitate the construction of residences and the placement of roadway embankments which cross marsh areas.

Nature and Occurrence of Erosion

Because of its dominant bedrock composition, most of the districts' shoreline is remarkably stable. However, erosion has been a continual problem along beach shorefront in East Haven. The presence of many residential structures on the beach there have further aggravated the significance of the problem. The largest magnitude of shoreline change resulting from erosion is being experienced along the marshes of Chaffinch Island in Guilford Harbor, where the marsh edge is retreating at an annual rate of approximately 3 feet (Bloom and Ellis 1965).

Three public erosion control projects (Appendix D) have been developed in the area. One at West Silver Sands Beach, East Haven, and the others at Branford and Guilford Point Beaches. Each consisted of groin construction and/or sand fill, but the Guilford project also required dredging of silt prior to the placement of sand fill and could more properly be considered a beach building project. Funds have recently been appropriated for the mitigation of flooding and erosion occurring at Silver Sands Beach in the Momauguin area of East Haven. The Momaugin, Silver Sands Beach and Chaffinch Island areas are considered to be significantly affected by erosion (Appendix C).

GUILFORD POINT TO HATCHETT POINT, OLD LYME (DISTRICT E)

General Character

East of Guilford Point an abrupt change in the composition of Connecticut's coast produces a more gentle, semi-linear shoreline configuration.

The presence of large amounts of glacial drift, primarily outwash and end moraine, contribute to the development of low, wave-cut bluffs which lie behind laterally extensive beaches.

The shoreline of the district encompasses coastal frontage in the towns of Madison, Clinton, Westbrook, Old Saybrook and Old Lyme. The population density in these municipalities is the lowest of any coastal segment. The immediate shoreline area is characterized by the presence of many year-round residential structures, and summer homes which are rapidly being converted to year-round use. Less than 50,000 inhabitants live in the district and the average value of coastal property is more than 80,000 dollars an acre.

Heavy summer recreational use of beaches, and the proximity of homes to Long Island Sound, have generated much shoreline stabilization work. Many privately constructed groins, jetties, and seawalls occur throughout the district, dividing the natural shoreline into artificial segments. More than five miles of shorefront are in public ownership including a major state facility at Hammonasset State Park in Madison.

Physical Climate

The climate of the shoreline along the western end of this district is very similar to that presented for District D. However, the influence of winds and waves from the southwest is stronger, since the fetch to the southwest is significantly increased over that which exists to the southeast. In addition, the area of the Sound in which waves may be generated by winds from the south decreases toward the east from the maximum of twenty miles in Madison. At the extreme eastern end of the district in Old Lyme the shoreline is exposed in a southeasterly direction to the open Atlantic Ocean, through the Race at the Sound's eastern terminus. Logic would therefore dictate that this exposure would produce a shoreline characterized by the influence of open ocean swell (long low waves), and more severe storm waves approaching from the ocean through the Race. Unfortunately, information gathered to date neither proves nor disproves this theory, even though several shoreline features may indicate its validity.

Mean tidal range in the district decreases from 4.9 feet in Madison to slightly over 3 feet at Hatchett Point in Old Lyme. Tidally induced currents continue to increase from a spring tidal maximum of more than 1.0 knot offshore in Madison to nearly 1.7 knots at Hatchett Point, East Lyme. Recent investigations (Farrar, 1977) have demonstrated that stronger ebb tidal currents act to measurably augment the influence of southwest waves on shoreline sediment transport. Similarly, they serve to reduce the effects of waves approaching from the southeast by flowing in opposition (on the ebb) to longshore currents produced by these waves. Very little of the shoreline directly fronting on Long Island Sound in the district is protected from locally generated waves, although several small north-south oriented shoreline sections, notably at Hammonasset State Park in Clinton, and west of Cornfield Point in Old Saybrook, afford some sheltering from winds and waves originating in eastern quadrants.

Composition and Morphology

The curvilinear shoreline of this district is characterized by extensive exposures of glacial outwash in wave-cut bluffs which are fronted by wide, sandy fringing beaches. Also present in this district are moraine exposures and a few drumlinoid headlands composed of till. Several large barrier beaches have formed here protecting relatively large salt marsh deposits.

Outwash is present in the eastern section of the district, but it is most prevalent west of Hammonasset Point. There, it is the primary shoreline material, as far west as Chipman Point, Madis
result of the homogeneity of this exposure, the shoreline maintains a linear configuration. Any deviation from this configuration is a result of topographic influence. High points project further seaward than low points, creating small headlands. This is the case at Middle Beach, Madison where Tunxis Island represents a drowned continuation of the headland.

Sections of glacial moraine are exposed along the shoreline from Hammonasset Point east to Old Lyme, where they occur in the area immediately east of the Connecticut River. Their trend is generally parallel to shore, or on a line slightly north of east. The major impact of these morainal segments on the shoreline is their relative resistence to erosion. Cornfield Point, Old Kelsey Point, Kelsey Point, Hammonasset Point and Guardhouse Point all project into Long Island Sound as a result of their morainal composition. The ability of moraines to serve as sediment sources is limited by the large fraction of boulders which have been deposited at their bases providing natural protection.

East of the Connecticut River in Old Lyme, two north-south oriented drumlinoid hills form more resistant points on the shoreline at Hatchett Point, and at an unnamed point approximately two miles east of Griswold Point.

They are composed of glacial till, and their occurrence marks the beginning of a transition in shoreline composition from the predominantly outwash and moraine character of District E, to the till and bedrock character of the shoreline to the east. The till which forms these features has a larger boulder content, which has produced natural protection similar to that mentioned for the moraine deposits.

Bedrock does not outcrop extensively anywhere in this shoreline district. There are substantial exposures both inland and offshore as islands, but no major exposures at the shoreline. As a result, bedrock has minimal influence, either directly or indirectly, on shoreline configuration in this district.

Several moderatley sized barrier beaches occur in the district at Plum Bank Beach and Great Hammock Beach in Old Saybrook, West and Grove Beaches in Clinton, along part of Hammonasset Beach in Madison, and at Griswold Point in Old Lyme. These features are associated primarily with the glacial, moraine deposits although the source of sediment for the development of the barrier beach at Hammonasset State Park is an outwash deposit. Other beaches in the district are fringing beaches, lying immediately in front of deposits of glacial outwash, till and end moraine which provide a source for their sediments.

Tidal marshes are present throughout the district and have generally developed in protected areas behind the noted barrier beaches, and in the southern reaches of the district's tidal streams. Particularly well developed marshes are present in the Hammonasset River which flows into Clinton Harbor; east of Plum Bank in Old Saybrook; and in the Connecticut River behind the barrier beach at Griswold Point. Artificial fill for residential development, roadway construction, and marina development is common in most marsh fringe areas. Large deposits of artificial fill, apparently derived from historic dredging of the navigation channel in the Connecticut River, are present on the Great Island Marsh. However, most of the fill has been recolonized by marsh vegetation.

The offshore slope in the district between Hatchett Point and Hammonasset Point is relatively gentle. However, west of Hammonasset Point, where the shore is backed primarily by outwash, the slope of the nearshore bottom is steeper than that observed in other outwash areas. Several hundred feet offshore in this area, the slope lessens to form an extensive shelf.

Littoral transport of material longshore is well developed in the district, due to both the linearity of the shoreline and its composition, which is almost totally comprised of erodible glacial materials. The direction and magnitude of longshore transport are variable.

West of the Patchogue River in Westbrook, on east-west trending shorelines, net transport is largely eastward with several minor exceptions. East of the river the general movement varies from dominantly east to primarily west depending on precise shoreline alignment. East of the Connecticut River, longshore transport is dominantly west as evidence by the lateral growth of the barrier beach at Griswold Point.

Movement of materials onshore and offshore in the district has shown some evidence of being cyclic. Recent investigations at Hammonasset Beach (Farrar, 1977) have indicated that material removed from the beach by storm waves is restored during periods of calmer weather. Farrar makes two observations concerning the process. First, the cycle is a function of wave steepness which depends on storm frequency, not season. Second, although there is cyclic behavior of the beach, there is also a net loss of material. It is likely that these phenomena occur on other beaches in the area but such a conclusion is not fully documented.

Nature and Occurrence of Erosion

The erosion of beaches and low bluffs of glacial materials, with which they are associated, is common in the district. More than ten miles of shoreline here are significantly influenced be erosion (Appendix C), and numerous private attempts at controlling erosion are evidenced by the consistent presence of groins and seawalls in the area. Slightly less than one million dollars in public funds has been expended for erosion control with a majority of that being used for protection at Hammonasset State Park (Appendix D). The relatively low rate of public expenditure is most likely a result of private ownership of shoreline and the reluctance of private interests to share in construction costs. Structural erosion control efforts, particularly groins and seawalls, have succeeded in altering natural shoreline processes. In many areas they are responsible for aggravating the natural process of erosion by stabilizing sediment sources needed for natural beach replenishment, and artificially interrupting longshore drift.

Several large scale changes in shoreline configuration have occurred along the barrier beaches of the district. They are most notable at Menunketesuck Island in Westbrook and at Griswold Point in Old Lyme. Analysis of old shoreline charts shows that the former was connected to shore at Grove Beach west of the Patchoque River, prior to 1929, by a small sandy strip of barrier beach. Subsequently, the beach was breached, probably by storm activity, creating an island. Griswold Point is probably the most dynamic barrier beach in the state. It has developed from the lateral, westward growth of two small barrier *spits* which joined to form the present day barrier. Erosion rates as high as 3 feet per year (Demico, 1977) are experienced along the beach and in the area to the east at White Sands Beach. These rates are well in excess of the average for Connecticut's coast.

Other areas affected by significant erosion are (Appendix C):

Circle Beach, Madison
West Wharf, Madison
Hammonasset Beach, Madison
Middle Beach, Madison
Seaview Beach, Madison
Grove Beach, Clinton
West Beach, Westbrook
Chalker Beach, Old Saybrook
Chapman Beach, Old Saybrook
Plum Beach, Old Saybrook
Great Hammock Beach, Old Saybrook

HATCHETT POINT, OLD LYME TO GROTON LONG POINT (DISTRICT F)

General Character

Glacial till, in the form of large drumlins, is the principal shoreline material in this district. Bedrock is present in several locations, but its appearance is markedly secondary to the massive exposures of till. The large drumlins project Soundward dividing the district into several cuspate sections, and affording protection for moderately extensive barrier beaches which have formed near the mouths of the smaller rivers entering the Sound in the area. The Thames River, which dissects the district between New London and Groton, is one of the three largest tributaries to Long Island Sound.

For the most part, development in immediate shorefronting areas is less intense than that evident in preceding districts. The effect of lower intensity development is reflected in the less frequent occurrence of shoreline stabilization structures.

The towns of East Lyme, Waterford, New London and Groton, which comprise the district, have a combined population of more than 100,000 people and the average value of shorefront land is estimated to be 150,000 dollars per acre. A majority of the shoreline in the district is in private ownership. However, more than 5 miles of shoreline are in public use, including two state parks: Rocky Neck in East Lyme and Harkness Memorial in Waterford. Bluff Point in Groton is the largest single tract of undeveloped land in the coastal area. The Point has been acquired by the state and is a designated coastal preserve.

Physical Climate

The shoreline of District F occupies a position very near the extreme eastern terminus of Long Island Sound. It is therefore exposed to a relatively large fetch (nearly 100 miles) from the southwest. Most of the shoreline is also exposed to southerly waves entering Long Island Sound from the open Atlantic ocean through the "Race." Exposure to open ocean waves is limited, however, by strong ebb tidal currents which flow in a direction opposite to wave propogation and can cause wave steepening and breaking in the "Race." This process may prevent larger waves from reaching shore during ebb tidal cycles.

The eastern segment of the district between New London and Groton is afforded protection from southeast winds and waves by Fishers Island which limits the maximum fetch in this direction to approximately four miles.

On a regional basis the area is most exposed to the southwest quadrant which is dominated by lower energy summer wind and wave activity. It is least exposed to the east and southeast directions from which less frequent storm winds and waves approach. The north-south orientation of drumlinoid hills offers additional protection to shoreline areas on their east and west flanks. Shorelines on the western sides of the hills are protected from waves generated in eastern quadrants. Similarly, shorelines on the eastern sides of the hills are protected from waves approaching from western quadrants.

Northwest winter winds and waves generally have a very limited influence on the shoreline, except on the western flanks of the drumlinoid hills. For the most part northwest winds and waves propogate offshore.

Tidal ranges in the district decrease from a mean of slightly over 3 feet at Hatchett Point in Old Lyme to 2.6 feet at Groton Long Point. Tidal currents continue to increase from west to east as in preceding districts. Maximum flood tidal currents of greater than 1.5 knots are observed at Hatchett Point in Old Lyme and Black Point in East Lyme. Ebb tidal currents reach a maximum of 1.7 knots near Goshen Point in Waterford. Current velocities of these magnitudes are certainly capable of contributing to the movement of shoreline materials.

Composition and Morphology

Large, elongate drumlinoid hills, composed of glacial till are the dominant feature of the shoreline area between Hatchett Point and Groton Long Point. The long axes of these hills trend generally north-south, forming a topographic grain which is similar to that of District A.

The hills are more resistant to erosion and project Sound-ward producing well developed points or headlands at Black Point in East Lyme, Goshen Point in Waterford and at Avery, Bluff and Groton Long Points in Groton.

Except in areas occupied by drumlins the covering of glacial materials is thin, and bedrock is exposed at several locations in the form of islands, such as Griswold and Huntley Islands in East Lyme, and as more resistant and pronounced points at Land's End and Grant's Neck in East Lyme, and at Millstone Point in Waterford. Bedrock is also evident along the more southern perimeters of the drumlinoid features where it has been exposed by marine erosion at McCook Point in East Lyme; Magonk and Seaside Points in Waterford; Long Rock and Quinnipeag Rocks in New London; and at Eastern Avery and Bluff Points in Groton.

A number of variably sized tidal streams which range in magnitude from the Thames River to Brides Brook, a small meandering tidal creek, dissect the district and flow into small bays and coves which are separated by drumlins. The most notable embayments occur at the mouth of the Niantic River on the Waterford-East Lyme border (Niantic Bay), and at the mouth of the Thames River. Other small coves occur at the mouth of Jordan Brook (Jordan Cove) in Waterford, and at the mouths of the Patagaunsett and Pocquonock Rivers in East Lyme and Groton respectively. Mumford Cove in Groton occupies the embayment between Bluff Point and Groton Long Point.

The numerous exposures of till in the district have provided substantial sources of beach material for the development of several small to moderatley large scale barrier beaches on the east and west flanks of exposed headlands throughout the area. A number of these barrier beaches can be more precisely termed *baymouth barriers* since they formed across the mouths of rivers and streams forming more protected coves and embayments. Examples of such features are The Bar in Niantic Bay, the small beach at the mouth of Jordon Cove in Waterford and Bushy Point Beach at the mouth of the Poquonock River in Groton. Other barrier beaches occur in the district at Groton Long Point in Groton; Ocean Beach in New London; south of Goshen Cove in Waterford;and extending immediately to the west of Black Point in East Lyme.

Salt marsh deposits in the district are limited in their occurrence. They are present in minor expanses in the lower reaches of the smaller rivers and streams in the area. No significant marshes are present in the lower Thames River. The lack of saltmarsh in this estuary is probably a result of its naturally steep stream banks and the heavy commercial, industrial and residential development which occurs there.

Artificial fill is relatively scarce as a shoreline material in the area except for a moderate concentration which has been placed in the Thames River in conjunction with waterfront development. The placement of fill for railway embankments on The Bar in Waterford has rendered this barrier beach essentially stable.

The topographic relief of the shoreline in the area is relatively steep as indicated by the proximity of the 20 foot contour elevation to shoreline. Steep onshore relief is reflected by a steep offshore bathymetry particularly at the southerly ends of the major headlands in the district. Within the confines of several bays and coves at Niantic Bay, Jordon Cove and Mumford Cove, and between Giants Neck and Land's End in East Lyme, offshore slope is considerably gentler forming exceptions to the general rule.

Littoral transport of sediments is again variable in magnitude and direction as is the case for all of Connecticut's coast. The steep offshore slope which exists in most areas is conducive to the development of strong offshore movement of sediments. Longshore transport, as a general rule, diverges at headlands flowing on the average, to the north and west on their westerly sides and to the north and east on their eastern flanks. However, local and seasonal reversals in the direction of longshore transport are not uncommon. As previously noted, a number of barrier beach features have developed in bays and coves to the east and west of headlands as a result of historic patterns and volumes of longshore transport. At present the volumes of material available to the system is thought to be generally small due to the natural protection of headlands which is afforded by exposed bedrock and the concentration of boulder lag in point areas. As a result of this natural limitation of sediment supply and the sporadic presence of stabilization works, beaches in the district are commonly narrow, and little large scale change in the configuration of most barrier beaches has occurred in recent years.

The development of scattered small offshore islands and rocky shoals in the district are evidence of the influence of rising sea level on coastal configuration, as are the locations of embayments which occur in areas of low relief.

Nature and Occurrence of Erosion

The relative resistance of glacial till to erosion coupled with the protection from southeast storm waves afforded by Fishers Island have reduced the impact of shoreline erosion in the district. No major large-scale changes have been evidenced in the district although marine erosion has resulted in the development of steep bluffs at the southern ends of several of the major headlands in the area. These bluffs are commonly associated with bedrock exposures and large deposits of boulder lag indicating the extent of recent erosion. The principle result of erosion at headlands has been a depletion of source materials available to beaches, due to the exposure of bedrock and the deposition of boulder lag which now protect their shorelines under normal conditions. Currently most significant erosion is being experienced at beach locations.

More than 609,000 dollars in state and municipal funds have been expended to construct protection works at six locations in the district: Giants Neck and McCook Point in East Lyme; Esker and Avery Points in Groton; Neptune Beach in New London;and Seaside Regional Center in Waterford.

Recent analysis indicates that significant erosion is being experienced along approximately five miles of coast between Hatchett Point and Groton Long Point. Nearly three miles of the significantly eroding shorefront are encompassed by barrier beaches at Goshen Point and Jordan Cove in Waterford; Ocean Beach in New London; and Bushy Point Beach in Groton.

Other shoreline areas which are significantly affected by erosion include:

Oak Grove Beach, East Lyme
Pond Point, East Lyme

GROTON LONG POINT TO THE PAWCATUCK RIVER, STONINGTON (DISTRICT G)

General Character

The geologic composition and configuration of the shoreline east of Groton Long Point is dominated by bedrock. The irregularity of the coast is very similar to that evidenced in the Greenwich, Stamford and Darien areas at the western end of the Sound. Scattered salt marsh deposits occur in the district and beaches are notably limited in their appearance as shoreline landforms.

Development of the immediate shoreline area is perhaps the least intense of any of the seven shoreline districts. However, concentrated residential use occurs at Morgan Point in Groton, Stonington Point in Stonington and in the Mystic River estuary on the Stonington-Groton border. Development of shorefront for marine purposes (marina and fisheries uses) is most common in the Mystic River and on the west side of Stonington Point. In these locations artificial fill and shoreline structures such as piers, seawalls and bulkheads are most noticeable.

More than 20,000 residents, most of whom live in Stonington, inhabit the district. Shorefront ownership is predominantly private, with several interspersed municipal beach facilities and one major state hunting area. The latter is comprised primarily of salt marsh acreage at Barn Island in Stonington. Estimated values of shorefront property may exceed 170,000 dollars per acre depending on location.

Physical Climate

The coastline between Groton Long Point and the Pawcatuck River is the most protected area on the Connecticut shore of Long Island Sound. The presence of Fishers Island, which occupies the eastern end of the Harbor Hill Moraine, approximately two to three miles south of the coasts of Groton and Stonington provides effective sheltering for the shoreline in the area. As a result of this sheltering and protection afforded by Napatree Beach, the east-west trending barrier beach between Napatree and Watch Hill Points in Rhode Island, the influence of south and southeasterly winds and waves is substantially reduced.

To the west and southwest the shore is exposed to a much larger fetch (approximately 100 miles). However winds and waves approaching from these directions are generally less severe since they are produced by calmer summer weather conditions. The north-south orientation of several major hills which occur at shore throughout the district serves to further alter the influence of waves on the shoreline. The hills' eastern flanks are protected from westerly winds and waves while their western sides are similarly protected from easterly wave and wind phenomena.

Northwest winds and waves which dominate the winter months on Long Island Sound have little influence on most of the shoreline, except on the western sides of the seaward projecting hills and islands. For the most part winds and wind generated waves from this direction propogate offshore towards Fishers Island where their influence on the island's north shore is more pronounced.

Tidal range in the district varies slightly from a mean of 2.3 feet at the entrance to the Mystic River to 2.7 feet at the mouth of the Pawcatuck River on the Connecticut Rhode Island boundary. Associated tidal currents are, on the average, relatively strong within Fishers Island Sound. Maximum ebb and flood tidal velocities of greater than 1.5 knots are observed in mid-sound areas while velocities of approximately 0.5 knots or less occur nearer shore in Groton and Stonington. Ebb current velocities in excess of 2 knots, and flood current velocities slightly less than 2 knots, are commonly observed during spring tides at the eastern end of Fishers Island.

No field investigations have been conducted to determine the influence of these currents on shoreline erosion, but their magnitudes suggest they play an important role in the process.

Composition and Morphology

The presence of bedrock at shore and in upland areas near the coast typify the district. The bedrock is characteristically covered by a relatively thin layer of glacial till, but its resistance to erosion and control of shoreline configuration are evident. Elongate hills form projecting north-south oriented headlands at Morgan Point in Groton and Wamphassuck Neck, Stonington and Pawcatuck Points in Stonington. At the southern extremes of most headlands, bedrock has been exposed by primarily wave induced marine erosion. Exposed bedrock is also common along the perimeters of most of the islands in the area.

Between headlands a series of small to moderately sized coves and harbors occupy low lying areas whose shores are comprised of glacial outwash and salt marsh. These coves and harbors occupy the most southerly terminus of the Mystic River and several other smaller tidal streams which enter Fishers Island Sound in the district. They are best developed at Mystic Harbor on the Groton-Stonington border and at Stonington Harbor and Quiambog and Wequetequock Coves in Stonington.

A number of islands are present near the shore principally in Stonington. They occupy the higher points of former hills which have been submerged as a result of rising sea level. The islands are similar in composition (bedrock and till) and orientation (north-south) to the previously noted headland features. Mason Island, located near the mouth of the Mystic River, is the state's largest island. Other smaller but noteworthy islands occur immediately to the south and east of Mason Island (Ram, Baker, Dodges and Andrew Islands) and on the west side of Wequetequock Cove (Elihu Island).

Few beaches occur along the shoreline reflecting the limited availability of natural sediments necessary for their formation. The beaches that have developed in the area are most consistently found in small protected coves and harbors between the major headland features. Their composition is commonly very coarse consisting of cobbles or pebbles. Most of the beaches are of the fringing variety located immediately in contact with deposits of glacial till or outwash, although several minor barrier beaches protect salt marshes on the east side of Mason Island and approximately one quarter of a mile west of Quiambog Cove.

Sandy Point, a barrier island, formerly connected to Napatree Point, extends slightly across the Connecticut-Rhode Island boundary just east of Stonington Point. The island was created in 1938 as a result of breaching by the hurricane which occurred in September of that year. Technically, Sandy Point is not a part of District G. Rather, it marks a distinct transition from the rocky irregular shorelines of Groton and Stonington to the nearly continuous sandy barrier beach shoreline of western Rhode Island.

Saltmarshes in the district are generally small in areal extent. They consist chiefly of thin veneers of sandy peat material punctuated by projecting boulders and bedrock. Most marsh deposits are confined to protected locations between headlands in or in the lee of islands.

Structural alteration of shorefront is minor as evidenced by the small amount of artificial fill present in the district (Table 4). Most filling for development and alteration of the coastline has occurred in the estuary of the Mystic River, in Stonington Harbor and on the east side of Stonington Point. The only other extensive deposits of artificial fill are those which were placed during the construction of the New York, New Haven and Hartford rail line, which dissects the district and crosses nearly every salt marsh near the shore.

Patterns of littoral transport in the district are exceedingly difficult to discern. The offshore slope varies greatly throughout the district, corresponding roughly with shoreline configuration. Coves and harbors exhibit gentle slopes resulting from increased sedimentation in their protected low energy environments. The combined effects of greater topographic relief and the focusing of wave energy at points have produced steeper bottom topography in offshore areas south of headlands. Because of the variation in offshore slopes and their influence on littoral transport perpendicular to shore, it appears that onshore transport dominates in cove and harbor areas, and offshore movement is more prominent in headland areas.

Movement of shoreline materials by wave and tide caused longshore currents is very small in magnitude. The reduced role of longshore transport is due to a number of factors. First, the composition of the shoreline renders it highly resistant to erosion. Bedrock protects the coast in a number of areas, and substantial deposits of accumulated boulders provide natural protection in others. Hence, the availability of sediment to the longshore transport system is small. Second, waves, the primary agent of longshore transport, are normally small and of lower energy in nature. These characteristics result because of the sheltering afforded by Fishers Island and Napatree Beach. Waves therefore are less capable of transporting the coarser shoreline materials of the district along shore. Finally, the irregular configuration of the shore prohibits the development of any continuous system of longshore transport.

Net directions of longshore movement of materials are extremely variable. However, sediment is generally transported to the north on north-south oriented shoreline segments, and to the west on east-west trending seqments. The dominance of westerly transport on east-west trending coastlines suggests that waves entering Fishers Island Sound from the south-east through the straight between the eastern end of Fishers Island and Napatree Point have a strong influence on longshore transport.

Nature and Occurrence of Erosion

Because of the protected nature of the eastern Groton and Stonington shore, and as a result of the rocky composition, erosion has had limited influence on the area. No recent significant changes in shoreline configuration have been noted.

Over the past thirty years only one state-funded, public erosion control project has been initiated in the area. The project consisted of the placement of 7,400 cubic yards of sand along the shore at Esker Point Park in Groton for the purposes of creating a public beach. Prior to the placement of the sand fill more than 14,000 cubic yards of silt were removed from the area. Hence, the action could more properly be considered a beach construction rather than an erosion control project.

Only one portion of the shoreline of Stonington is considered to be significantly affected by erosion. It consists of the most northerly tip of the north-south trending barrier island, Sandy Point.

EROSION PROBLEM

Shoreline erosion in Connecticut has expressed itself most significantly in the form of erosion affecting beaches and related bluffs which are sources of beach sediment. Statistics compiled for the Long Island Sound Regional Study (LISRS) by the U.S. Army Corps of Engineers in 1975 indicated that approximately 26 miles, or 10 percent of our shoreline, could be classified as subject to "critical erosion." The LISRS further states:

> "The erosion is mainly confined to beaches that are receeding at an estimated rate of one to one and one-half feet per year."

A more recent inventory conducted by the Coastal Area Management Program has concluded the following. Connecticut has a total 278 miles of shoreline which front on Long Island Sound. Of that total approximately 85 miles are beach, 69 miles are composed of glacial drift, 30 miles are salt marsh, 44 miles consist of bedrock and the remaining 50 miles are dominated by artificial fill. Potentially, the beach, salt marsh, glacial drift and artificial fill portions of the shoreline are erodible, while bedrock can be considered non-erodible. Based on a comparative analysis of historical shoreline data, aerial photographs and information obtained from other sources listed in the preceding section, 48 miles, or approximately 17 percent, of our shoreline are significantly affected by erosion. Table 6 gives further details on measurement techniques and definitions and statistical breakdowns by town. Examination of the figures contained in the table indicates the following towns encompass a majority of the state's significantly eroding shoreline.

Milford	6.5 miles
West Haven	4.6 miles
Fairfield	4.6 miles
Madison	4.0 miles
Old Lyme	3.5 miles
Stratford	3.2 miles
Westport	2.7 miles
Stamford	2.7 miles

It is also worthy of note that 30 percent of the total shoreline miles classified as significantly eroding is attributable to erosion being experienced along the state's larger barrier beaches. A complete listing of those sites considered to be significantly eroding is contained in Appendix C.

Relatively speaking, shore erosion on the north side of Long Island Sound is not as critical, in terms of magnitude, as that encountered along shorelines exposed to the open ocean. For instance, the outer shore of Cape Cod is subject to average erosion rates on the order of three feet or more per year -- these rates are three times that experienced along Connecticut's coast. The difference is primarily a result of fetch limiting by Long Island. That is, Long Island functions as a wind break

TABLE 6

SHORELINE COMPOSITION AND EROSION STATISTICS

TOWN	DOMINANT SHORELINE COMPOSITION[1] BEACH mi. (km)	GLACIAL DRIFT[2] mi. (km)	SALT MARSH[5] mi. (km)	ARTIFICIAL FILL mi. (km)	POTENTIALLY ERODIBLE SHORELINE[3] mi. (km)	SHORELINE SIGNIFICANTLY AFFECTED BY EROSION[8] mi. (km) %	BEDROCK[4] mi. (km)	SHORELINE TOTAL[7] mi. (km)
Greenwich	1.7 (2.7)	7.3(11.8)	2.7 (4.4)	7.0(11.3)	18.7 (30.3)	0.8 (1.3) 3.5	3.8 (6.1)	22.5 (36.5)
Stamford	3.2 (5.2)	1.1 (1.8)	0.3 (0.5)	3.8 (6.1)	8.4 (13.6)	2.7 (4.3) 26.2	1.9 (3.1)	10.3 (16.7)
Darien	0.6 (1.0)	4.9 (7.9)	1.1 (1.8)	1.1 (1.8)	7.7 (12.5)	-----	5.9 (9.5)	13.6 (22.0)
Norwalk	15.0(24.3)	9.7(15.7)	1.6 (2.6)	3.4 (5.5)	29.8 (48.4)	0.4 (0.6) 1.1	3.8 (6.1)	33.6 (54.4)
Westport	5.0 (8.2)	4.3 (6.9)	2.1 (3.4)	2.6 (4.2)	14.1 (22.9)	2.7 (4.3) 19.1	----	14.1 (22.8)
Fairfield	4.2 (6.8)	1.6 (2.6)	0.7 (1.1)	1.3 (2.1)	7.8 (12.6)	4.6 (7.4) 58.9	----	7.8 (12.6)
Bridgeport	3.0 (4.8)	2.1 (3.4)	0.3 (0.5)	8.7(14.0)	14.1 (22.8)	2.4 (3.8) 17.0	----	14.1 (22.9)
Stratford	4.0 (6.5)	0.7 (1.1)	3.2 (5.2)	3.6 (5.8)	11.5 (18.6)	3.2 (5.1) 27.8	----	11.5 (18.6)
Milford	5.9 (9.6)	3.3 (5.4)	1.9 (3.1)	0.8 (1.3)	12.0 (19.4)	6.5(10.4) 52.4	0.4 (0.7)	12.4 (20.1)
West Haven	4.5 (7.4)	1.1 (1.8)	0.1 (0.2)	0.4 (0.7)	6.3 (10.2)	4.5 (7.4) 71.8	0.2 (0.3)	6.4 (10.4)
New Haven	1.8 (2.9)	0.8 (1.3)	---	3.4 (5.5)	6.0 (9.7)	1.0 (1.6) 15.8	0.3 (0.5)	6.3 (10.2)
East Haven	1.0 (1.6)	0.2 (0.3)	0.2 (0.3)	---	1.4 (2.3)	0.9 (1.5) 39.1	0.9 (1.5)	2.3 (3.7)
Branford	2.6 (4.2)	2.3 (3.7)	2.0 (3.2)	1.1 (1.8)	8.0 (13.0)	----	12.9(20.9)	20.9 (33.9)
Guilford	0.8 (1.3)	0.9 (1.5)	1.5 (2.4)	1.9 (3.1)	5.1 (8.3)	1.3 (2.1) 13.0	4.9 (7.9)	10.0 (16.2)
Madison	4.9 (7.9)	1.1 (1.8)	.2 (0.3)	0.8 (1.3)	7.0 (11.3)	4.0 (6.4) 52.6	0.6 (1.0)	7.6 (12.3)
Clinton	2.7 (4.4)	0.8 (1.3)	1.3 (2.1)	1.2 (1.9)	6.0 (9.7)	1.2 (1.9) 20.0	----	6.0 (9.7)
Westbrook	3.8 (6.2)	1.7 (2.8)	---	---	5.6 (9.1)	1.4 (2.2) 25.0	----	5.6 (9.1)
Old Saybrook	3.8 (6.2)	1.5 (2.4)	1.4 (2.3)	1.4 (2.3)	8.1 (13.1)	2.0 (3.2) 24.6	----	8.1 (13.1)
Old Lyme	3.8 (6.2)	1.4 (2.3)	2.1 (3.4)	0.1 (0.2)	7.4 (12.0)	3.5 (5.7) 47.3	---	7.4 (12.0)
East Lyme	3.0 (4.7)	2.7 (4.4)	1.3 (2.1)	0.2 (0.3)	7.1 (11.5)	0.5 (0.8) 5.4	2.0 (3.2)	9.1 (14.7)
Waterford	2.5 (4.0)	2.7 (4.4)	0.2 (0.3)	0.6 (1.0)	6.0 (9.7)	1.2 (1.9) 17.6	0.8 (1.3)	6.8 (11.0)
New London	1.7 (2.7)	1.2 (1.9)	----	1.7 (2.7)	4.5 (7.3)	0.5 (0.7) 10.0	0.4 (0.7)	5.0 (8.1)
Groton	3.8 (6.1)	7.6(12.3)	2.5 (4.0)	2.6 (4.2)	16.5 (26.8)	1.2 (1.9) 6.6	1.8 (2.9)	18.3 (29.6)
Stonington	2.9 (4.7)	7.4(12.0)	3.0 (4.9)	1.8 (3.0)	15.2 (24.6)	0.3 (0.5) 1.6	3.0 (4.9)	18.2 (29.5)
TOTALS	36.2 (139.6)	68.4 (110.8)	29.7(48.1)	49.5(80.1)	234.3(379.4)	46.9(75.0) 16.8	43.6(70.6)	277.9 (450.1)

1. Shoreline composition categories indicate dominant shoreline types (i.e. minute, narrow.beach shorefront, backed immediately by glacial till, is considered to be dominantly glacial drift). Measurements were compiled from Surficial Geology and Soils maps of a scale of 1:24,000.

2. Glacial drift includes all types of glacial material: outwash, till, end moraine, etc.

3. Beach, glacial drift, salt marsh and artificial fill are all considered to be potentially erodible.

4. Bedrock is considered to be non-erodible or to have limited potential for erosion.

5. Salt marsh measurements are generalized and do not include frontages on minor streams and ditches.

6. Only large islands, such as Masons Island (Stonington), and large island groups, such as the Norwalk and Thimble Islands, are included in the shoreline measurement.

7. Shoreline measurements include river frontage up to the first bridge, usually I-95.

8. Significant erosion occurs where erosion presents significant problem because the rate of erosion, considered in conjunction with economic, industrial, recreational, demographic, environmental, and other relevant factors indicates that action to mitigate such erosion may be justified.

which effectively controls the generation of surface waves in the Sound. Consequently, smaller shorter waves predominate in the Sound and littoral transport along the shoreline is generally very weak. However, the persistent occurrence of these shorter steeper waves can, and does, contribute appreciably to long term erosion trends. As a secondary characteristic, fetch limiting confines major erosion to those periods when storms and hurricanes occur. It also markedly reduces the generation of swell (long, low waves) which can act to move materials onshore to replenish eroded areas. Near the mouths of the three major coastal rivers, the Connecticut, Thames and Housatonic and at several of the large seaward projecting headlands, strong tidal currents act to supplement weak, wave-induced littoral transport and may, at times, play a dominant role in the erosion process.

In conjunction with the erosion process, rising sea level is also affecting the shoreline. Recently (within the last 100 years), sea level in Long Island Sound has been rising at the rate of one to one and one-half feet per century. On initial consideration an annual increase in sea level of .08 to .16 inches seems insignificant. However the impact of such a fluctuation is more evident when its effect on a sloping land surface is considered. For example, an increase in sea level of one to one and one-half feet over a century would "drown" 20 to 30 feet of shorefront with a slope of 1:20 (one foot increase in elevation for every 20 horizontal feet).

Although Connecticut's shoreline experiences lower erosion rates as a result of sheltering by Long Island, the intense use and development of the coast offset these lower rates and focus the impact of smaller scale changes. This phenomenon is particularly evident along the more intensely developed coastal segments west of New Haven.

Historically, structural stabilization (groins, seawalls, breakwaters, etc.) has accompanied recreational, residential, commercial and industrial uses of the shoreline, almost as a corollary. As a result, structural stabilization plays a major role in the erosion-sedimentation process affecting our shore. Revetments (sloping seawalls) and seawalls have been used to stabilize many of the sediment sources which naturally supplied materials to beaches and dunes through wave and tidal current-induced erosion and transport. Groins and jetties which are utilized to protect beaches and retard longshore transport of material have worked, but often at the expense of originating erosion on adjoining parcels. In addition, figures compiled as part of the LISRS (Table 7) indicate that total erosion damages (estimated in 1970 dollars) of $1.8 million are experienced along our coast annually. Of that total approximately 20 percent is attributable to the cost of reparing existing erosion control structures. Allowing for inflation and variations in annual climatic conditions, the cost of annual damages in 1979 dollars could easily be three times as great.

In short, structural methods used to prevent erosion are not only costly but have commonly been utilized without adequate attention to natural processes, or without the benefit of a clearer understanding of coastal processes which exist today. Further, lack of necessary annual maintenance or erosion control structures has resulted in structural failure and in near critical structural conditions at many locations.

ESTIMATED ANNUAL COASTAL EROSION DAMAGES
(in 1,000's of 1970 dollars)

Sub-Coastline [1] region length (see map below)	1970 damages: Land loss Acres/yr.	Ave. value	Total	To erosion structures and grounds	Damage to facilities	Total 1970	Projected future damages: 1990	2020
1	1.0	100	100	80	40	220	330	900
2	3.0	60	180	120	50	350	530	2250
3	2.0	100	200	130	70	400	600	1140
4	3.5	70	230	150	80	460	690	450
5	2.5	90	230	150	80	460	690	450
Total	12.0	420	1140	630	320	1890	2840	5190

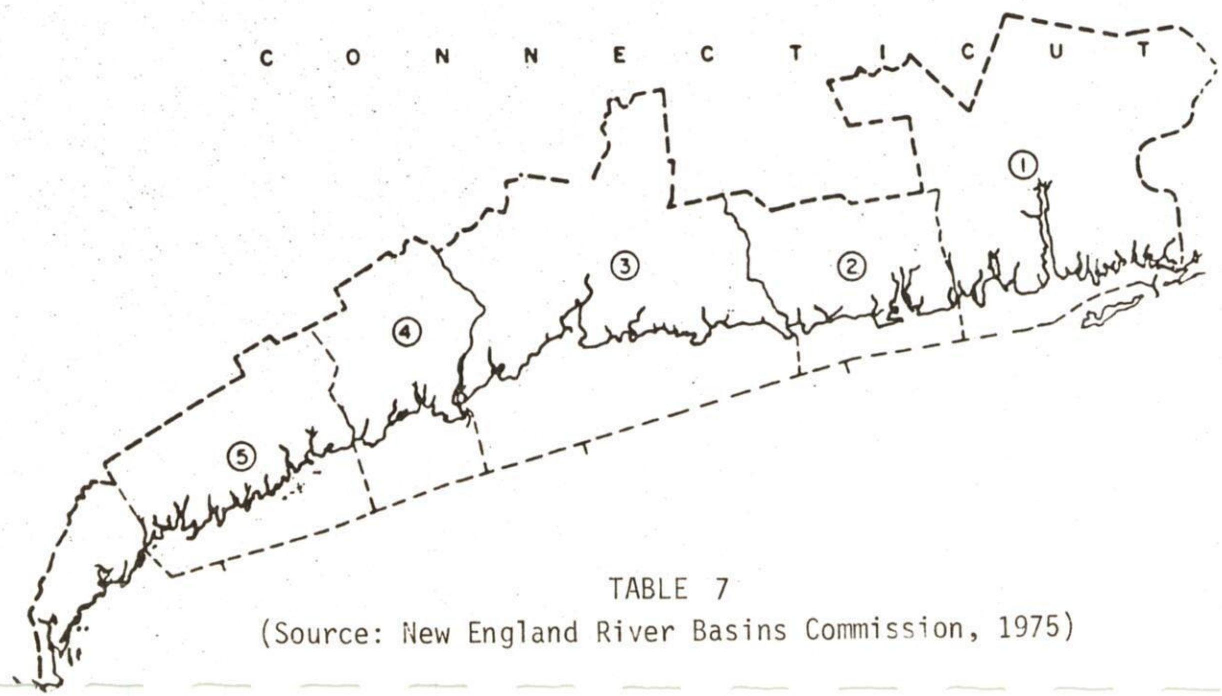


TABLE 7
(Source: New England River Basins Commission, 1975)

Clearly the erosion "problem" is a manifestation of the interaction of a number of variables. However, it may be briefly characterized as a storm-induced beach erosion problem which has been intensified by the high use demands for recreational beach in the state, by the intense use of all shorefront areas for recreational, commercial, residential and industrial purposes, and by the high degree of structural shoreline stabilization.

In terms of its spatial occurrence most significant erosion is limited to two general segments of the shoreline. The first segment lies west of New Haven and includes shorefront in the towns of Westport, Fairfield, Bridgeport, Stratford, Milford and West Haven. The second segment encompasses the shoreline area between Guilford and Old Lyme. Geographically these two segments correspond with shoreline districts B,C and E which were discussed in the preceding section. Their composition is largely glacial drift (primarily outwash) and beaches. Damages arising from erosion in these areas account for nearly 65 percent of the total annual damages experienced as a result of erosion.

EROSION CONTROL TECHNIQUES

Many techniques may be applied to shorelines in an attempt to control or mitigate the effects of erosion. In general, they fall into two categories. *Structural alternatives* are those involving the construction of a concrete, timber, sheet steel or rock structure which diverts erosive forces or contains the shoreline which is eroding. *Non-structural alternatives* are those which involve no structures at all, such as placement of sand fill, dune building or restoration, and control of land use in such a manner as to allow erosion to continue without affecting buildings or facilities.

Over the long term neither structural nor non-structural techniques will halt shoreline recession. Rising sea level in conjunction with storms, winds, waves and tidal currents will continue, on a geologic time scale, to rearrange and submerge Connecticut's shoreline. With this in mind, the approach to be used in dealing with eroding shoreline will depend on the economic value and use of the shoreline for which protection is considered, and the monies available for implementation of protection. Appendix D contains a listing of shoreline protection works constructed with state and federal funds, their costs, locations and descriptions.

Structural Techniques

Seawalls, Revetments, Bulkheads

As a group, these erosion control structures are wall-type retaining works built immediately adjacent and parallel to shore. Seawalls are the largest and most massive of the three. They are normally constructed of steel-reinforced cement and are designed to physically withstand the direct force of storm surge and waves. As a rule their configuration is that of a vertical wall although some sloping and curved-face seawall types are used. Because of their size and design purpose seawalls are the most expensive wall-type structures.

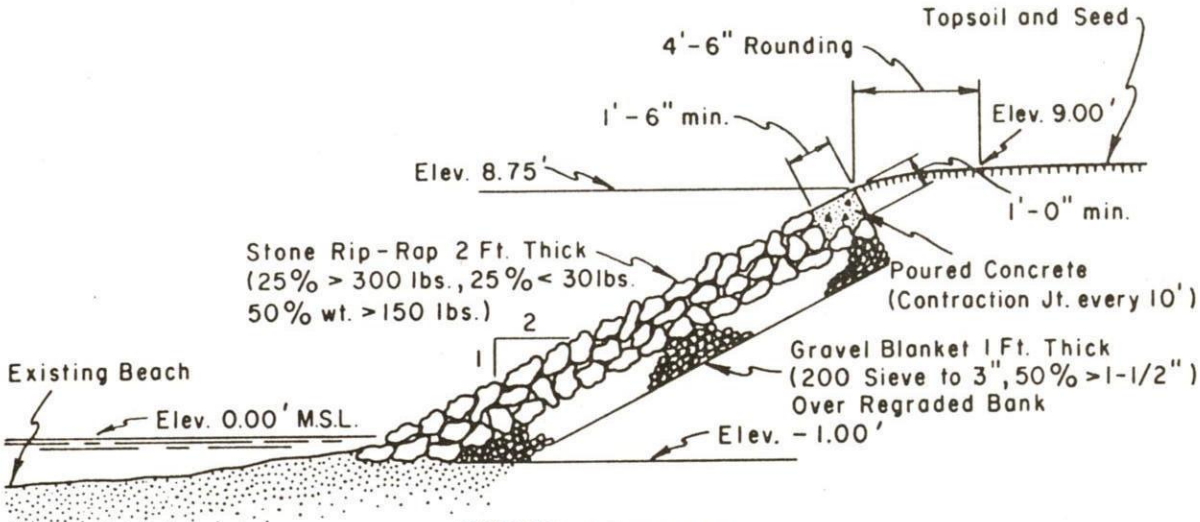
Bulkheads (Figure 14) are similar in appearance to seawalls. They may be constructed of piles and timber, sheet steel and masonary or cement. Their purpose, however, is decidedly different from seawalls. They are erected to perform tow functions. First, to contain material which is placed in the filling and grading of a shorefront parcel and, second, to protect the shoreline and fill material from erosion. Bulkheads are somewhat less substantial and massive than seawalls and, hence, are used to protect and stabilize areas which are not exposed to larger, more powerful waves. Since Long Island Sound, as a whole, is sheltered from the open ocean, bulkheads are used to protect shorefront throughout the area and are perhaps the most common type of shore protection. They are less expensive than seawalls to construct and thus are more economically attractive to shoreline land owners.

A third type of wall-like protection is the revetment. Several types of revetments are in common use along Connecticut's coast. Most prevalent are the *dumped rubble mound* (Figure 13), and *keyed and placed* types. Both are constructed of large blocks of granite or other durable quarried stone. The keyed and placed type is, as the name implies, constructed of stone which is cut in such a way as to form an interlocking, sloping surface. The dumped rubble mound revetment consists of stone which is dumped to form a sloping mound in front of the shore to be protected. Both types of revetments are constructed on a gravel base which prevents soil from being washed out from behind the structure. The sloping configuration of revetments is most ideal for absorbing wave energy since it allows waves to run up on the structure and, hence, absorbs their energy rather than reflecting it as do bulkheads and seawalls. Revetments are less commonly used as shore protection than bulkheads, but they have been used most effectively to protect several major exposed headlands such as Pond Point in Milford and Oyster River Point in West Haven. The costs of revetments vary depending on their height and linear extent, but generally material for their construction costs from 20 to 30 dollars per cubic yard.

All three wall-type structures can and have provided effective control of erosion along Connecticut's coast provided that they are properly constructed and maintained. Annual and post storm maintenance is critical to the effectiveness of all erosion protection works. In many instances lack of maintenance results in reversion to conditions which existed before the installation of protective works. In some cases, loans incurred for construction of public protection works of this type have not been completely paid off before a structure needs additional and substantial maintenance.

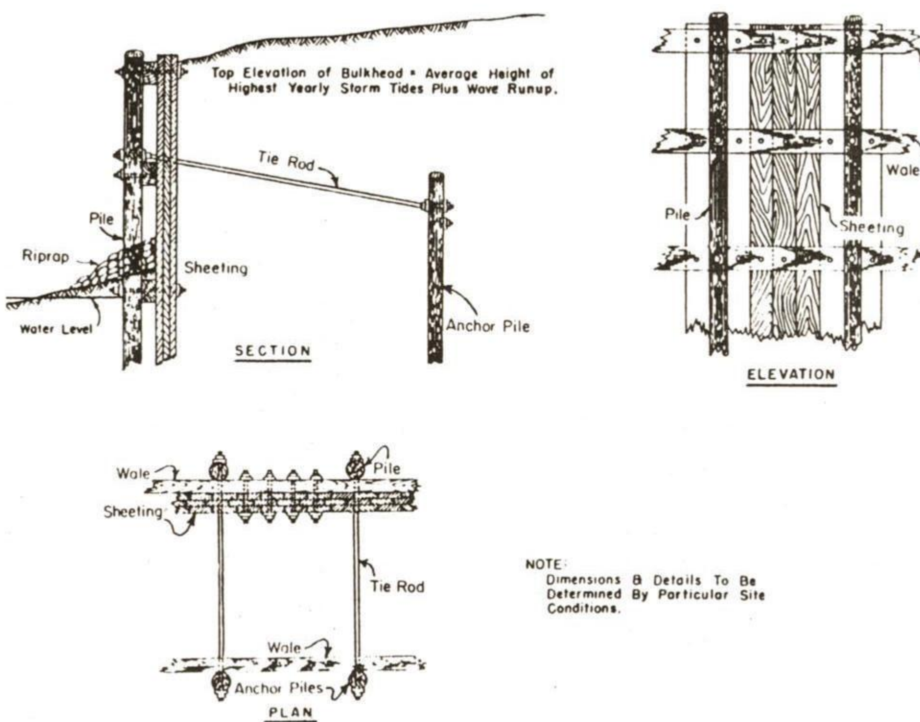
None of the structures noted provide effective protection for beaches in and of themselves. They are not designed to contain and hold beach materials but are best used to protect structures such as houses, roads and parking lots which are in close proximity to shore. Seawalls and bulkheads may actually induce erosion at their bases because of scouring by waves which are reflected from their vertical faces. Often this induced scouring exposes the wall or bulkhead foundation and results in structural failure. Revetments, on the other hand, are less subject to this phenomenon since they are sloping surfaces. As such, they can provide excellent protection

FIGURE 13



TYPICAL REVETMENT

FIGURE 14



TYPICAL BULKHEAD
(Source: U.S. Army Corps of Engineers, 1975)

for the bases of seawalls and bulkheads and are perhaps the most effective alternative for direct shoreline protection Sound-wide. The primary drawback to the use of seawalls, bulkheads and revetments is that they are often used to stabilize erodible deposits which form important sources of material for adjoining beaches, thereby aggravating erosion.

Typical designs of a rip-rap revetment and pile and timber bulkhead are shown in Figures 13 and 14. Depending on availability of materials and site conditions, such as topography, depth of water in the shoreline area to be protected, and the degree of exposure to waves and storm surge, costs of these alternatives are:

	Estimated cost per linear foot of protection[2]
Steel Bulkhead	$350-500
Timber Bulkhead	$250 (average)
Stone Revetment	$150-400

Groins, Jetties

Groins are constructed perpendicular to shore and usually consist of stone, piles and timber or sheet steel pilings. They are used to divert materials which are transported along shore by waves and tidal currents or to hold beach material which is placed between them. Jetties may also be used to perform the same function as groins. The difference between the two is that jetties are used to stabilize navigation channels and inlets. Both types of structures are very common along all of the shoreline but they are particularly abundant where beaches occur naturally.
Since the availability of materials which may be eroded to form beaches is low along the coast, due to the presence of stabilization works and the occurrence of bedrock, groins constructed without sand fill provide little additional protection and are normally ineffective in trapping and holding beach material. When used with sand fill, groins temporarily provide protection but inevitably additional fill must be placed to replenish lost material. Groins are completely ineffective in the prevention of onshore and offshore transport which move material perpendicular to shore. As a result, they cannot mitigate storm overwash and erosion and transportation of material from the beach and nearshore to the offshore. In addition, short term beach realignment is invariably associated with the construction of groins. This realignment is caused by groin-initiated erosion of the beach on the *downdrift* side and accretion on the *updrift* side.

Groins are undoubtedly the most prevalent form of erosion protection in Connecticut. Their profuse occurrence has divided the shoreline into a number of artificial segments which have largely altered the natural process of erosion and sedimentation.

[2]Based on discussions with local marine contractors

Figures 15, 16 and 17 show typical section and elevation views of stone, timber and steel, and timber groins. Cost of construction are highly site dependent.

	Estimated cost per linear foot of protection [2]
Sheet Steel groin	\$300-350
Pile and Timber groin	\$250-300
Stone groin	\$250-500

Breakwaters

Breakwaters are structures erected for the purposes of protecting harbors, anchorages and port facilities from wave forces by providing a surface against which waves break. Breakwaters may be constructed of stone, piles and timber or concrete. Two types of breakwaters are common, those which are connected to shore and those which are not connected to shore. Offshore breakwaters are generally of the rubble mound (stone) type construction while breakwaters which are not exposed to open waters may be constructed of less durable pile and timber. Floating breakwaters have been used for protection in areas outside Long Island Sound, but they require intensive maintenance since they are more easily pulled apart by wave forces. Breakwaters are the most expensive type of shore protection. Primarily because they must be placed in deeper water and must be able to absorb larger wave forces. Breakwaters provide shore erosion protection in two ways: by providing wave sheltered areas where littoral materials may be deposited, and by interupting longshore transport and trapping littoral materials when they are connected to shore. The latter effect is similar to that of groins and jetties. The former effect is more difficult to qualify but erosion protection in this case arises from reduction of wave energies experienced in the sheltered area. This reduction of wave energies limits the ability of waves to transport materials which occur within, or are naturally or artificially supplied to, the protected area.

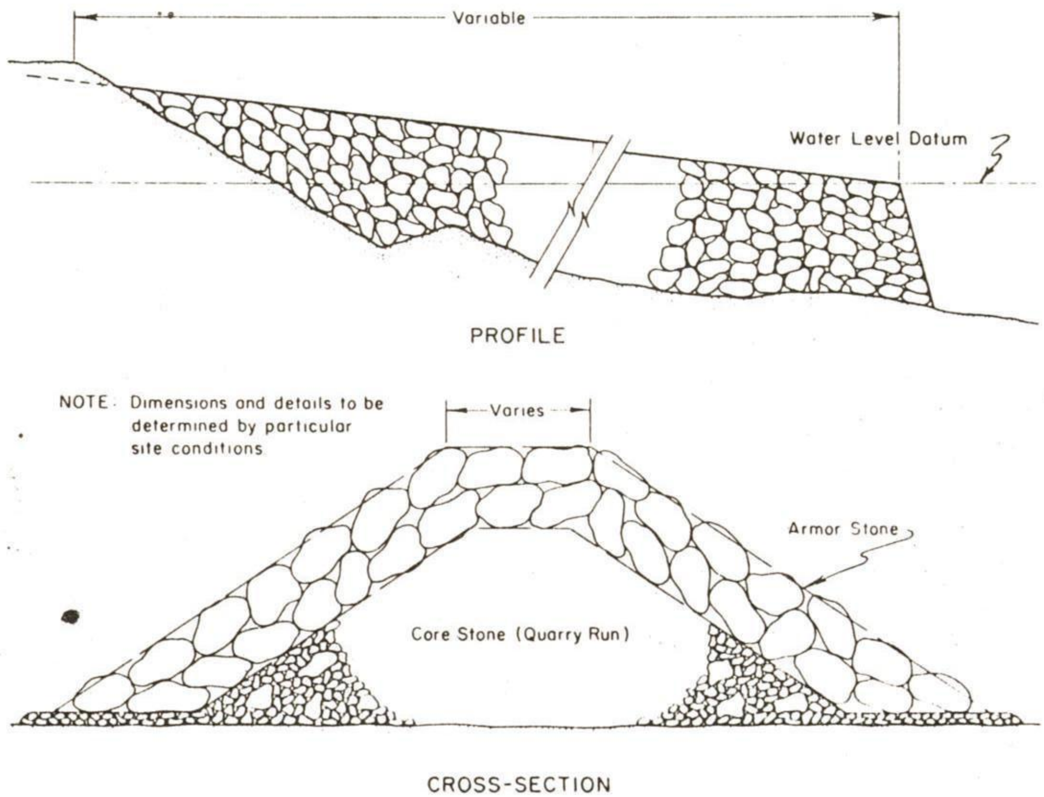
Breakwaters occur along numerous portions of the coast, but the larger, more notable structures are found in the state's urban harbors such as Bridgeport, New Haven and Stamford. The development of Sandy Point and the wider beaches occurring along the eastern portion of the shore in West Haven may be attributable to the large offshore breakwaters which protect New Haven Harbor.

Breakwaters can provide one of the most effective forms of erosion protection but they are extremely expensive and their design and orientation require detailed study of local conditions.

Typical construction of a rubble mound breakwater such as those protecting New Haven Harbor is shown in Figure 18.

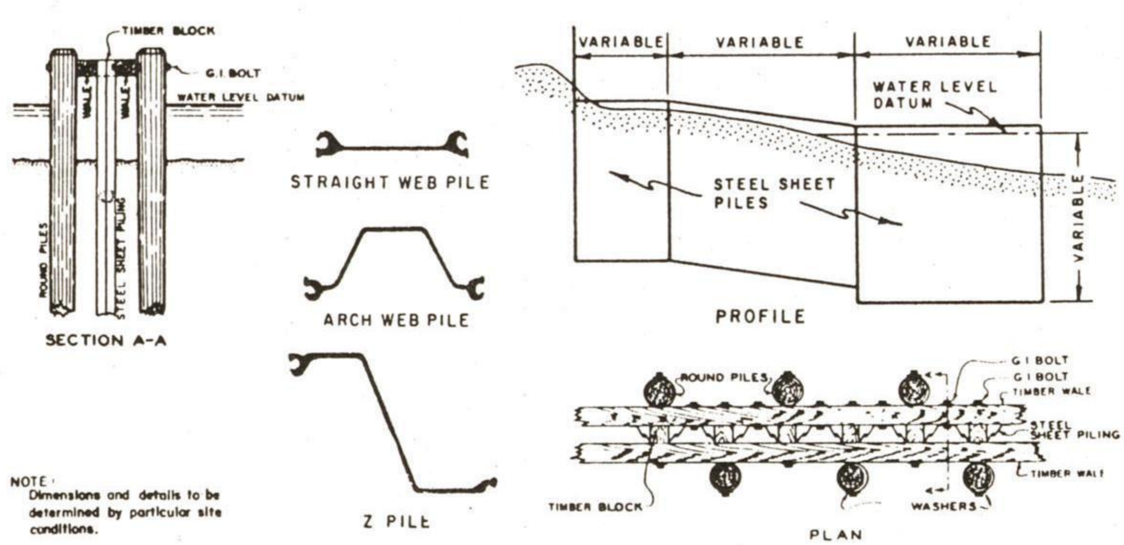
[2] Based on discussions with local marine contracters

FIGURE 15



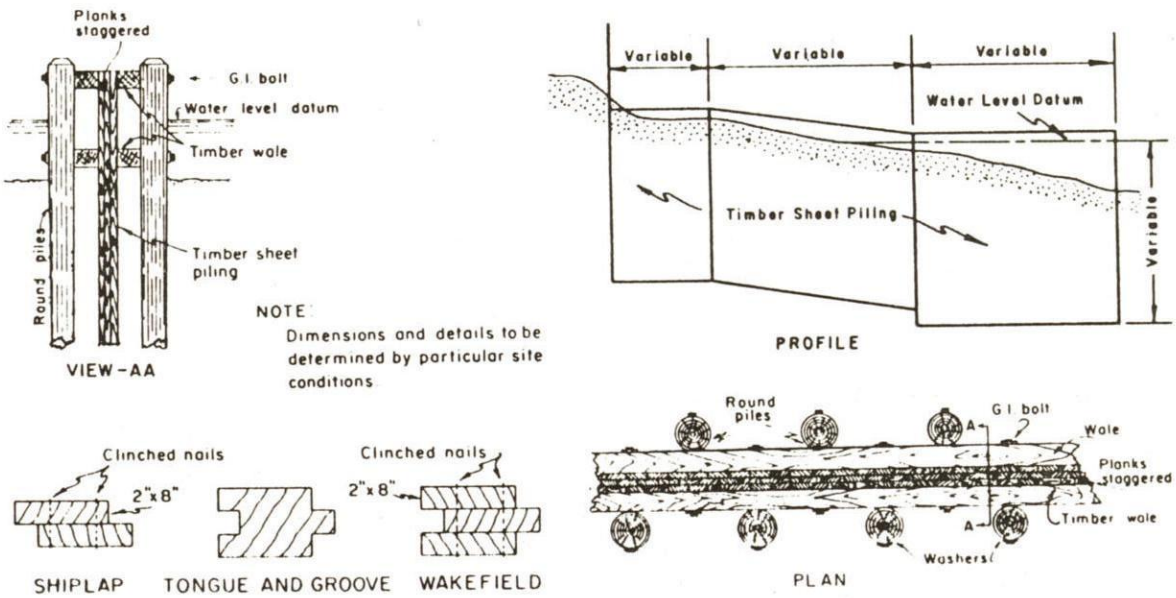
TYPICAL STONE GROIN

FIGURE 16



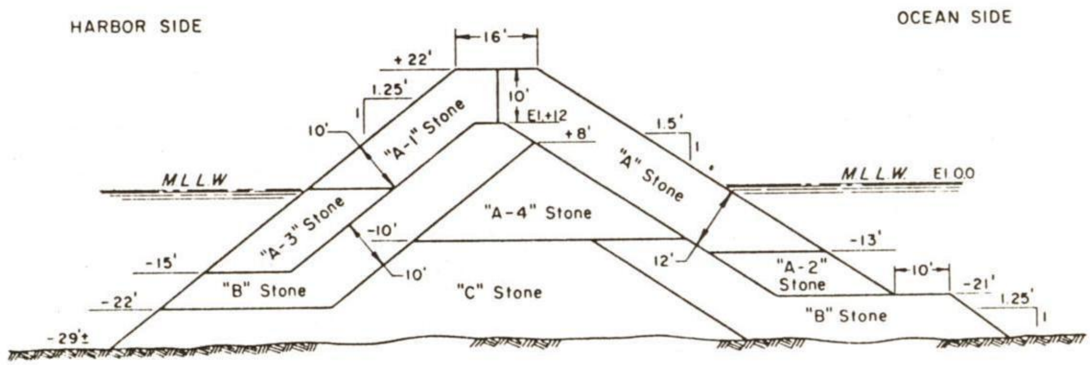
TYPICAL SHEET STEEL GROIN
(Source: U.S. Army Corps of Engineers, 1975)

FIGURE 17



TYPICAL PILE AND TIMBER GROIN

FIGURE 18



"A" Stone — 16 tons or greater
"A-1" Stone — 13 tons or greater
"A-2" Stone — 8 tons or greater.
"A-3" Stone — 6 tons or greater
"A-4" Stone — 500 lbs to 8 tons
"B" Stone — Core stone varies from quarry-run stone to pieces of 1 ton to 4 tons
"C" Stone — Core stone varies from quarry-waste to pieces of 1,500 lbs to 4 tons.

TYPICAL STONE BREAKWATER
(Source: U.S. Army Corps of Engineers, 1975)

Non-Structural Techniques

Sand Fill

The placement of sand fill along a portion of shorefront is a non-structural erosion control technique which is utilized for the protection of beach areas or for the creation of protective beaches in areas where none occur. Sand fill may be used in two ways. It may be placed directly onto the shore to be protected or developed as beach, or it may be placed in an area adjacent to and updrift of the area to be protected. That is, it may be directly placed or placed to form a feeder beach which is designed to be eroded by waves and tidal currents and transported via longshore transport to the area to be protected. In Connecticut sand fill has been used nearly exclusively in conjunction with groins and jetties. In this case sand is placed between the groins or groins and jetties filling them to capacity. When the groins are filled to capacity they are less likely to impact or trap littoral materials since theoretically no additional storage capacity is available. Sand fill may also be utilized in conjunction with the development of dunes and dune management (see following section). McCabe (1970) has presented a complete basic analysis of the behavior of beach fill placed in conjunction with 39 erosion control projects at various locations along Connecticut's coast. Some of his conclusions are:

1. Under wave conditions of the north shore of Long Island Sound beaches generally assume a natural face slope of one in ten (one foot increase in evelation over a distance of 10 horizontal feet) between mean low water and a point 5 feet above mean high water.

2. Beach profiles in the area apparently stabilize when waves are broken by bars or benches located about 200 feet from the beach toe at depths near mean low water. Sometimes extra sand needs to be placed to establish such bars or benches.

3. Alongshore sand movement is minimized when the beach is facing the predominant direction from which waves approach. Beaches at a skew to this position are unstable and in the absence of an unlimited sand supply the beach will erode unless there is an artificial or natural barrier at its downdrift end. (Note: An adequate barrier at the downdrift location can accumulate sand causing the beach to reorient to a more stable alignment.)

4. Groin construction does not cause recession on adjacent beaches <u>if</u> the beach was already in a stable orientation with respect to dominant direction of wave approach.

In order for sand fill to provide effective mitigation to erosion a source of sand must be readily and economically available to provide initial fill material and to facilitate annual replacement of eroded fill. The fill must also have grain size and distribution characteristics that are compatible with the area into which it is to be placed. Fill may be obtained from two sources. Either from a land based sand and gravel mining facility or from dredging of offshore sand deposits. Depending on the location and transportation required, sand fill may cost from four to eight dollars per cubic yard. In Connecticut sand fill has generally been obtained by hydraulic dredging of offshore sand deposits. Offshore sources have proven more economical because of the low availability of land sources in proximity to shore areas, the high degree of development in proximity to the shoreline,which makes land transport difficult, and the costs of upland excavation and transportation.

Removal of sand from offshore areas and its use as beach fill involve several problems. First, excavation of offshore sand deposits in too close proximity to shore may change the way in which waves normally approach the shore and break. This change in wave patterns can result from refraction, or bending, of waves induced by creation of deeper water areas through excavation (see section on waves). Such alteration may result in the occurrence of more erosive waves along a portion of shorefront than were previously experienced. Secondly, sand fill must be constantly replenished. Fill material placed along any shoreline to create beach is, at best, temporary. Waves generated by storms and hurricanes,and higher velocity tidal currents continuously remove and rearrange the fill material. As a result, the need for a dependable and economic source of material for maintenance is critical to beach fill techniques. Finally, dredging of offshore sand sources which are not relatively free of silt, decaying vegetable matter and pollutants which may be associated with the silt and clay can produce temporary, local water quality and biological impacts. It may also induce changes in the nature of naturally occuring bottom sediments and habitats depending on the depth of the dredged area. The latter impacts on bottom character may be reduced by limiting the depths of dredged areas such that they do not create pronounced isolated holes. The optimum method for obtaining material to be used as beach fill is to utilize sand dredged from navigation channels, provided the sand is relatively free of organic matter, silt and pollutants and that grain sizes are compatible with existing beach sands in the location to be filled. This technique is not always practical but it does provide a solution to two problems: the disposal of dredged sand from the navigation project and location of a beach borrow area. In addition, it is most cost effective since the dredged sand may be obtained at no or a very low cost.

The major advantage of using sand fill alone as erosion protection is that it precludes the use of structures which can induce erosion such as groins and jetties. However, in many instances, sand fill may be removed so rapidly that stabilization works must be constructed to retain the fill or substantial volumes of sand must be replaced at a considerable cost.

Dune Management

The construction of dunes and the stabilization of existing or artificial dunes with vegetation, particularly American Beach Grass *(Ammophila breviligulata)*, is a second type of non-structural erosion mitigation. Under this technique dunes are constructed or enhanced by the placement of sand fill and by the planting of stabilizing vegetation. Snow fences may also be used to physically retain initial sand fill until vegetative cover is adequate or to control access points so as to prevent the destruction of dune grasses. Dunes are constructed parallel to and behind the beach proper and serve to trap and absorb sand which is transported onshore by wind and storm overwash. Care must be taken in the development of dunes to insure that maximum dune elevations do not prevent natural storm overwash. The process of overwash provides sand to sand flats behind dune areas and is important to dune stability and function.

Basic unit costs and construction methods are the same as those for beach fill (see preceding section) with the exception of the additional expense of obtaining and planting beach grasses. Dune maintenance and/or construction can provide a most effective means of alleviating shoreline erosion. Since dunes act as a dynamic sand reservior and flood barrier they are able to adjust to varying wave and wind conditions and rising sea level in contrast to static structures such as seawalls and groins.

Dune management has been limited in use as an approach to shoreline erosion in Connecticut. Only one such management effort has been undertaken at Hammonasset State Park in Madison. The effort was initiated in 1973.

Utilization of dune management and construction does have several drawbacks. Existing uninterrupted dunes are not common along the shoreline and in many areas construction has taken place in such close proximity to the beach proper that creation of a dune line would also require massive beach fill. Even so, dune management is probably the most viable approach to managing barrier beaches where necessary.

Use Controls

Controlling the use of shoreline areas in order to avoid the creation of erosion hazards and to prevent endangerment of development is another method of non-structural mitigation. Under this approach shoreline areas may be designated as no construction areas, or special structural design may be required within them. Alternatively, setbacks for building may also be established. These setbacks should be based on a thorough consideration and analysis of the following factors:

1. Elevation of historical storm and hurricane tides
2. Maximum wave run up.
3. Beach or shoreline contours and the bathymetry of the nearshore bottom.
4. Erosion trends.
5. Existing dune or shoreline vegetation.
6. Configuration of dune or bluff lines.
7. Existing coastal development.

However, if an average erosion rate is available application of a setback line, based on the rate and the expected life of structures, is a prudent alternative.

Both methods require the identification of some justifiable and equitable parameter for delineation of boundaries or setbacks and entail complex engineering and geologic evaluation.

An example of the former approach, which is being applied in Connecticut, is the Department of Housing and Urban Development's (HUD) Flood Insurance

Program (FIP). HUD-FIP has identified several zones within the coastal area on the basis of the 500 year (B zone) and 100 year (A zone) coastal floods and the occurrence of areas exposed to storm waves (V zones). These zones have been designated primarily for flood management purposes. However, they are also effective for use in erosion management since most erosion is storm induced. Within each established zone new residential structures must meet certain storm proofing requirements and residences which are destroyed must also conform to the criteria when, and if, they are rebuilt. The sanctions are applied at the municipal level. In return, communities are eligible for federally (HUD) subsidized flood insurance.

The setback method of management is somewhat different. This technique requires that annual erosion trends and other conditions, listed above, be determined in hazard areas. After these conditions have been established a fixed linear distance setback from a reference point such as mean high water or a bluff line may be delineated. Construction of dwellings seaward of the setback line would then be allowed only by special permit.

Both methods are best applied to property which is undeveloped. Establishment of a setback line after an area is developed provides no protection for development nor does it preclude the need to construct protective works. In addition, the setback method requires an accurate and enforceable determination of erosion trends and lines. Unfortunately, annual erosion rates which are accurate and area specific are not presently available for Connecticut's coast. In addition, the intensity of existing development on Connecticut's coast limits the value of applying setback lines.

Final establishment of HUD-FIP hazard zones has not been completed in all coastal municipalities but preliminary boudaries and associated criteria have been implemented coast-wide.

Alternatives

Each structural and non-structural alternative has unique characteristics which make it the most desirable approach to erosion mitigation in a particular situation. For example, non-structural protection of a developed bluff area is more difficult to achieve than structural protection simply because of topographic and use considerations. Setbacks and building restrictions would prove useless to protect existing development and the placement of beach fill or dunes is not always compatible with the shoreline characteristics. Hence, structural controls, such as a revetment, would need to be implemented in order to provide protection. In addition to site and development considerations, costs of construction and maintenance needs play a significant role in the selection of erosion control alternatives. In the case of Connecticut's shoreline these considerations take on an added complexity. The varied use and development of the shoreline coupled with its extremely variable and diverse composition and configuration preclude the application of one type of alternative (structural or non-structural) coast-wide.

Several observations serve to provide a basis for the establishment of priorities for the use of control techniques. General evaluation of structural alternatives implemented in the state indicate that:

1. Repayment periods on state loans which have been incurred by local interests (towns and private associations) to implement erosion control works have often exceeded the effective life of protection projects.

2. The cost of annual maintenance of structures and sand fill have resulted in neglect of maintenance, and reduced project lives. Further, lack of regular maintenance can lead to catastrophic structural failure.

3. Structural means of erosion control such as seawalls and groins have often aggravated erosion in adjacent areas, or in the case of vertical seawalls, induced erosion on site.

4. Structural stabilization which has historically occurred along the coast has depleted or limited sediment sources necessary for the natural development of protective beaches, and has significantly altered shoreline behavior and the way in which the shore naturally copes with erosion.

In contrast to wholly structural measures, non-structural alternatives provide several distinct advantages. Sand fill, beach development and dune construction serve to enhance and expand recreational resources and, therefore, provide recreational benefits in addition to mitigating shore erosion. These types of erosion protection also function more effectively <u>with</u> the natural system as opposed to structural measures which seek to <u>limit</u> or alter completely erosional processes. Because they augment natural erosion and flood control mechanisms, non-structural managerial techniques are often more easily maintained.

In recognition of the advantages and drawbacks of both structural and non-structural erosion control techniques, Connecticut's approach to determining the most effective means of mitigating erosion should be predicated on site specific conditions. In general, however, it should be the state's policy to implement controls on the following priority basis:

First priority: non-structural control
Second priority: combination structural and non-structural control
Third priority: structural control
Fourth priority: no control

R E C O M M E N D E D

M A N A G E M E N T   A P P R O A C H

In order to provide continued planning for and management of the effects of shoreline erosion the state should implement a three phased approach to the problem. Under this approach three inter-related aspects of shoreline erosion management should be addressed utilizing existing state municipal and federal authorities. The basic elements of the management approach are:

1. Funding for design, construction and management of structural and nonstructural control techniques through existing Flood Control and Beach Erosion Authorities.
2. Provision of technical assistance to individuals and municipalities in the planning and implementation of non-state and non-federally funded erosion control techniques under the provisions of the Connecticut Coastal Area Management Act and through the existing State Flood control and Beach Erosion Program.
3. Regulation of activities affecting and affected by shoreline erosion under:
    a. Municipal authorities for Coastal Site Plan Review as provided for by the Connecticut Coastal Area Management Act.
    b. Municipal authorities for the implementation of the Department of Housing and Urban Development-Flood Insurance Program.
    c. State authorities governing the erection of structures in tidal, coastal or navigable waters.
    d. State authorities governing the removal of materials from coastal or navigable waters.

Utilizing these authorities state and municipal officials entrusted with the management of coastal resources will be able to develop plans for the protection of existing facilities which are endangered by erosion, and to guide new coastal development in such a way as to minimize the impacts of shoreline erosion on future land use.

A majority of the listed authorities are currently in place and operational. Implementation of municipal efforts under Coastal Site Plan Review are pending passage of the Coastal Area Management Act.

Authorities

Flood Control and Beach Erosion Program

Authority for cooperative funding, design and construction of erosion control works is derived from sections 25-69 through 25-98 of the Connecticut General Statutes. These sections provide for the organization of municipal flood and erosion control boards. They empower the Department of Environmental Protection (DEP) to cooperate with such boards and the federal government in the construction of and payment for flood and erosion control systems. An initial sum of four million dollars was allocated to pay for the costs of state participation in the development of beach erosion control systems under the following cost sharing formulae:

	PERCENT CONTRIBUTION	
Property Ownership	State	Municipal
public (municipal)	66.6	33.3
public (state)	100%	----
private	33.3%	66.6%

State funded loans are also available to local authorities for the initial payment of the local contribution on projects. In the event that protection works are constructed for the benefit of private owners, the municipal Flood and Erosion Control Board is authorized to levy assessments or taxes on the protected property for the purpose of paying costs incurred by local interests.

As a rule, when public property is considered for the purposes of erosion protection the participation of the federal government in the project can be justified pursuant to section 103 of the Rivers and Harbors Act (33 U.S.C., 426 et seq.). In such cases 50 percent of the cost of construction of economically-feasible beach erosion control projects involving public shorefront can be paid by the federal government. In certain special cases involving park or conservation areas up to 70 percent of the cost of protection may be paid. The maximum amount of federal contributions cannot exceed 1,000,000 dollars without additional congressional authorization.

During the period between 1955 and 1971 a total of fifty erosion control projects were completed at a cost of 7.5 million dollars (Appendix D). Nineteen of the projects involved the participation of the federal government through the U.S. Army Corps of Engineers under Section 103 of the Rivers and Harbors Act of 1899 (33 U.S.C. Sections 426e to 426i). The Corps' involvement consisted of contribution of 50 percent of the cost of the construction of protection works which benefited public property.

More recently, in 1978, the State Legislature allocated an additional 3 million dollars for the continuation of the beach erosion control program. Utilizing these and other specially allocated funds, studies have been initiated for the protection of shoreline areas in Milford, East Haven and Westport. It is fully anticipated that erosion management under existing programs will continue to improve contingent upon funding availabilities at municipal and federal levels.

In order to provide for a fair and equitable allocation of public funds for the mitigation of shoreline erosion and to provide for the greatest public benefit from expenditures, it should be the state's policy to provide erosion control funds on the following basis:

1. State owned public shorefront
2. Municipally owned public shorefront.
3. Quasi-public recreational shorefront where public access is provided.
4. Privately owned recreational shorefront where public access is provided.

5. Privately owned recreational shorefront.

This policy is not intended to exclude privately owned shorefront from receiving the financial benefit of state-funded protection when such protection is justified and economically feasible. Rather it is designed to prioritize expenditures when projects involving several different types of shorefront are competing for limited state and federal funds.

In order to most effectively utilize the monies allocated for erosion control projects the state should develop, in conjunction with municipal Flood and Erosion Control Boards, a listing of priority areas for erosion protection. This listing should be developed from the inventory of "areas of significant erosion" listed in Appendix C.

Coastal Site Plan Review

Connecticut's proposed Coastal Area Management Act (Raised Committee Bill 7878) requires municipalities to initiate a site plan review for the following activities when they occur within the coastal boundary:

1. Buildings, uses or structures subject to zoning regulations (Section 8-3 of the Connecticut General Statutes (C.G.S)).
2. Subdivisions of land (C.G.S. Section 8-25).
3. Planned unit developments (C.G.S. Section 8-13f).
4. Variances (C.G.S. Section 8-7).
5. Requests for special exceptions or special zoning permits (C.G.S. Section 8-2).
6. Municipal improvements (C.G.S. Section 8-24).

Under the provisions of the site review procedure any person or municipal board undertaking an activity which is regulated under the sections of the general statutes listed above must submit a coastal site plan to the municipal planning or zoning commissions for review. As part of the review process, and in addition to the criteria provided for by municipal regulations, the board or commission responsible for coastal site plan review must consider three criteria in the evaluation of a coastal site plan:

1. The characteristics of the site, including the location and condition of any coastal resources defined by the Coastal Area Management Act.

2. The potential adverse and/or beneficial effects of the proposed activity on coastal resources and future water dependent development opportunities.

3. The goals and policies contained in the Coastal Area Management Act.

Based on consideration of these three criteria the municipal board or commission responsible for coastal site plan review may approve, deny or modify permits issued for development within the coastal area. Certain minor activities may be exempted from the review process by local regulation.

To aid municipal decision makers in the evaluation of erosion hazards, resource factor maps depicting shoreline composition, areas of significant erosion (listed in Appendix C) and historic shoreline changes are being developed by the Coastal Area Management Program. Sample maps are contained in Appendix B.

National Flood Insurance Program

The National Flood Insurance Act (42 U.S.C. 4001-4128) provides low cost insurance against flood damages in designated hazard areas (see section on use controls). In return, communities must apply a set of established regulations to the evaluation of any development involving hazard areas. Part of the regulations which are applied involve the evaluation of erosion hazards. Sections 1910.5 (a) (1), (2) and (3) of Title 24 of the Code of Federal Regulations apply in all of Connecticut's coastal communities. Under these authorities a permit is required for development in flood hazard areas including areas of flood-related erosion as they are known to the community. In the evaluation of permit applications a determination is made regarding the safety of site improvements from flood-related erosion and the likelihood that the proposed improvements will induce erosion. In the event a proposed improvement is found to be in the path of flood-related erosion, or likely to induce flood-related erosion, protective measures may be required. Factor maps depicting areas of significant erosion are being developed by the CAM Program for use in the identification of hazard areas (Appendix B).

Coastal Structures Regulatory Program

Sections 25-7b through 25-7f of the Connecticut General Statutes authorize the Commissioner of Environmental Protection to regulate the erection of structures and the placement of fill in the tidal, coastal, and navigable waters of the state. Under this regulatory program, all construction and filling waterward of the mean high water line in the state's tidally-influenced waters must be conducted in accordance with a permit issued by the Department of Environmental Protection (DEP). All permits issued under these authorities are, by law, evaluated with respect to "the prevention or alleviation of shore erosion" (Section 25-7b). Provision is also made under these sections for the removal of nuisance structures and the levying of fines for violations.

Coastal Dredging Regulatory Program

The authority to regulate the removal of sand, gravel, or other material from beyond the mean high water mark is vested in the Department of Environmental Protection by Sections 25-10 through 25-18 of the Connecticut General Statutes. Prior to the initiation of any dredging or excavation within the state's coastal waters a permit must be obtained from the Commissioner of Environmental Protection. Only previously permitted maintenance dredging of navigation channels, berths, basins, moorings and waterfront facilities are exempt from regulation. As part of its review of dredging and excavation applications, the Department of Environmental Protection must evaluate the impact of the activity on shore erosion. Section 25-18 provides penalties for violations.

Recommended Policies

In order to provide overall guidance for the administration of federal, state and municipal authorities involving shoreline erosion the following general and specific policies are recommended to guide the operation of the regulatory and managerial efforts noted above. The recommended policies should apply to state and municipal regulatory review of shoreline activities, and to the institution of cooperative state-federal-municipal erosion control projects. Particular emphasis should be given to the policies listed below:

1. Erosion and Sedimentation
   Definition: The removal of sediments from a particular location (erosion) and their transportation to and deposition (sedimentation) at another location as caused by natural forces whether naturally occurring or man induced.

   a. General Policy: To minimize the adverse impacts of coastal erosion and sedimentation through the use of non-structural methods where practicable.

   b. Specific Policy: To maintain the natural relationship between eroding and depositional coastal landforms and to minimize the adverse impacts of erosion and sedimentation on coastal land uses through the promotion of non-structural mitigation measures. Structural solutions are permissible when necessary and unavoidable for the protection of infrastructural facilities, water dependent uses, or existing inhabited structures, and where there is no feasible, less environmentally damaging alternative and where all possible mitigation measures and techniques have been provided to minimize adverse environmental impacts.

   c. Specific Policy: To implement erosion control projects on the following general priority basis in accordance with policy *b* above, and as appropriate to the specific site conditions:
      First Priority: Non-structural control
      Second Priority: Combination structural and non-structural control
      Third Priority: Structural control
      Fourth Priority: No control

   IMPLEMENTATION--Policies *a, b* and *c* should be implemented at the state level by the Department of Environmental Protection under the regulatory authority for the coastal structures and dredging programs and under the funding authority for flood and erosion control projects. At the local level, these policies should be implemented by municipalities under planning and development authorities for flood and erosion control projects and under the authorities contained in the proposed amendments to the Coastal Management Act which enable municipalities to review coastal site plans.

2. Coastal Structures (tidal, intertidal and navigable waters)

   a. General Policy: To discourage the filling of intertidal lands and to require that coastal structures be built so as to minimize interference with neighboring properties and to minimize adverse impacts on coastal resources.

b. Specific Policy: To require that structures in tidal wetlands and coastal waters be designed, constructed and maintained so that they minimize impacts on coastal resources, circulation and sedimentation patterns, water quality, and flooding and erosion, and so that they reduce to the maximum extent practicable the use of fill and reduce conflicts with the riparian rights of adjoining and adjacent landowners.

c. Specific Policy: To disallow any filling of tidal wetlands and nearshore, offshore and intertidal waters for the purpose of creating new land from existing wetlands and coastal waters which would otherwise be undevelopable, unless it is found that there is no feasible alternative and the adverse impacts on coastal resources are minimal.

IMPLEMENTATION--Policies *a, b,*and *c,* should be implemented by the Department of Environemtnal Protection under the coastal structures regulatory program.

3. Coastal Hazard Areas

Definition: Those land areas inundated during normal or extreme coastal storm events or subject to erosion induced by such events (all flood and erosion hazard areas identified by HUD-FIP mapping under the emergency and regular program phases).

a. General Policy: To prevent development on coastal hazard areas that endangers public health, safety and welfare through the implementation of the HUD Flood Insurance Program.

b. Specific Policy: To manage coastal hazard areas so as to insure that development proceeds in such a manner that hazards to life and property are minimized; and to promote non-structural solutions to flood and erosion problems except in those instances where structural alternatives prove unavoidable and necessary to protect existing inhabited structures, infrastructural facilities, or water-dependent uses.

IMPLEMENTATION--Policies *a,* and *b,* should be implemented by municipalities under the authorities contained in the proposed amendments to the Coastal Management Act which enable municipalities to undertake coastal site plan reviews. At the state level, these policies should be implemented by the Department of Environmental Protection through the regulatory authority for the coastal structures and dredging programs.

4. Coastal Bluffs and Escarpments

Definition: Naturally eroding shorelands marked by dynamic escarpments or sea cliffs with slope angles which constitute an intricate adjustment between erosion, substrate composition, drainage and degree of plant cover.

a. General Policy: To maintain, where feasible, the function of coastal bluffs and escarpments as natural sources of sediment supply for adjacent shoreline features.

b. Specific Policy: To manage coastal bluffs and escarpments so as to preserve their slope and toe; to discourage uses which do not permit continued natural rates of erosion; and to disapprove uses that accelerate slope erosion and alter essential patterns and supply of sediments to the littoral transport system.

IMPLEMENTATION--Policies *a* and *b* should be implemented at the local level by municipalities under the authorities contained in the proposed amendments to the Coastal Management Act which enable coastal municipalities to undertake coastal site plan reviews and to prepare municipal coastal programs. At the state level, these policies should be implemented by the Department of Environmental Protection under the regulatory authority for the coastal structures program.

5. Beaches and Dunes
Definition: Beach systems including barrier beach spits and tombolos, barrier beaches, pocket beaches, land contact (fringing) beaches, and related dunes and sandflats.

a. General Policy: To preserve the form and function of natural beaches and dunes and to encourage the restoration or enhancement of disturbed or modified beaches and dunes.

b. Specific Policy: To preserve the dynamic form and integrity of natural beach systems in order to provide critical wildlife habitats, a reservoir for sand supply, a buffer for coastal flooding and erosion, and valuable recreational opportunities; to insure that coastal uses are compatible with the capabilities of the system and do not unduly interfere with natural processes of erosion and sedimentation; and to encourage the restoration and enhancement of disturbed or modified beach systems.

IMPLEMENTATION--Policies *a* and *b* should be implemented at the local level by municipalities under the authorities contained in proposed amendments to the Coastal Management Act which enable municipalities to undertake coastal site plan reviews and to prepare municipal coastal programs. At the state level, these policies should be implemented by the Department of Environmental Protection under the regulatory authorities for the coastal structures and dredging programs and under DEP funding authority for flood and erosion control projects.

6. Intertidal Flats
Definition: Very gently sloping or flat areas located between high and low tides composed of muddy, silty and fine sandy sediments and generally devoid of vegetation.

a. General Policy: To encourage the preservation of intertidal flats as shellfish and finfish habitats and wildlife feeding areas.

b. Specific Policy: To manage intertidal flats so as to preserve their value as a nutrient source and reservoir, a healthy shellfish habitat, valuable feeding areas for invertebrates, fish and shorebirds; to encourage the restoration and enhancement of degraded intertidal flats; to allow coastal uses that minimize change in the natural current flows, depth, slope, sedimentation, and nutrient storage functions; and to disallow uses that substantially accelerate erosion or lead to significant despoilation of tidal flats.

IMPLEMENTATION--Policies *a* and *b* should be implemented by the Department of Environmental Protection under the regulatory authority for the coastal structures and dredging programs.

Funding for Acquisition of Erosion Prone Areas

Perhaps the most effective means of dealing with shoreline erosion is direct acquisition of affected shoreline areas. However, due to the intense development of the Connecticut shoreline and the rapidly increasing value of already extremely expensive shoreline parcels, this erosion mitigation alternative is somewhat impractical. In addition, the availability of funds provided through various state and federal programs has not been sufficient in the past to facilitate acquisition of erosion prone areas. Future improvement insuch funding availabilities is not foreseen. None the less several federal and state programs have made provisions for the possibility of acquiring shorefront areas for the purposes for flood and erosion protection and recreation. Acquisition of property for recreational purposes provides erosion and flood protection when such parcels are flood or erosion prone and attractive recreational resources. Beach areas are an excellent example of this situation. If fund levels were sufficient the following programs may prove useful means of acquiring erosion prone areas:

Federal Programs

The Department of Interior's Heritage Conservation and Recreation Service (HCRS) is responsible for administering the Land and Water Conservation Fund. The fund can provide financial assistance to states for the planning, acquisition and development of recreation facilities and lands. Funding is allocated on a 60 percent cost sharing basis to both states and municipalities. These funds could be used to acquire beach areas which are susceptible to erosion. However, at this juncture the state has no plans to acquire new beach areas.

A second federal program which could provide funding for acquisition of erosion prone areas is the Department of Housing and Urban Development's Flood Insurance Program. Section 1362 of the National Flood Insurance Act of 1968, as amended, empowers the Secretary of Housing and Urban Development to purchase property which:

1. was located in any flood-risk area as determined by the secretary

2. was covered by flood insurance under the flood insurance program and

3. was damaged substantially beyond repair by flood while covered by flood insurance.

Prior to purchase, the Secretary of Housing and Urban Development must find that the public interest is served by such acquisition. Property purchased under these authorities may be sold, donated or leased to State or local agencies for uses consistent with sound land use management in flood hazard areas. Although the intent of section 1362 is to provide for the alleviation of flood or erosion hazards through purchase, no funding has been provided for such action to date.

State Programs

The Commissioner of Environmental Protection is empowered by the Connecticut General Statutes to acquire lands for natural area preserves (C.G.S. 23-5h) and for open space recreation (C.G.S. 23-8). Historically these authorities have been used to acquire some shorefront parcels such as the state park facilities at Sherwood Island, Westport; Silver Sands Beach, Milford; Hammonasset Beach, Madison; and the natural area preserve at Bluff Point in Groton. Each of these areas is an example of shorefront having high recreational, natural and aesthetic values. They are also subject to significant shoreline erosion. Their acquisition has reduced the potential of damage to dwellings and other private facilities which might have occurred if they were left open to private development.

More recently as part of the State's Comprehensive Outdoor Recreation Plan (SCORP) two key recommendations were made. The first was to:

> "Acquire new coastal beaches through State action when large, privately-owned beaches, providing ample space for parking and ancillary facilities, are available for purchase. Areas frequently flooded or storm damaged should be considered for condemnation and/or acquisition."

The second recommendation was to:

> Establish a special project acquisition fund to acquire special, large-scale projects, which are beyond the fiscal capability of the regular state action program and whose preservation may require prompt action by the state. Such major emergency acquisitions may include storm-damaged shoreline areas, key sites with significant recreation potential, and large, unique tracts of land with conservation district potential.

While both these recommendations would favorably affect the acquisition of shorefront recreational parcels also subject to erosion damages, a study of coastal recreation conducted by the Coastal Area Management Program concluded:

> "little progress has been made towards realizing the goals and recommendations of SCORP, particularly those involving shorefront access, due to the current financial and administrative contraints. New acquisitions, while not being ruled out, are not being encouraged due to state budgetary constraints. Increasing emphasis is being placed on the management efficiency of acquisitions or gifts. The number of land parcels which constitute "manageable units" along the coast are very limited due to ownership and development patterns."

It is therefore likely that neither state nor federally funded programs will provide sufficient impetus for the acquisition of parcels for recreation and erosion mitigation. However, this alternative should not be completely ruled out when, and if, sufficient funds become available.

Recommended Additional Investigations

Establishment of a firm and adequate geophysical baseline is of paramount importance to the solution of shoreline erosion problems in Connecticut. It is as vital to the regulation of coastal structures and dredging as it is to the design and implementation of erosion mitigation projects and the planning and construction of recreational, residential, industrial and commercial facilities along the coast.

In order to provide the necessary scientific basis for long term management of shoreline erosion in Connecticut a more complete and current evaluation of the dynamics of the erosion process is needed. Much of the information on erosion rates and processes presented in this report is generalized from various studies which are outdated. In a larger sense, problem areas can be easily identified along the shoreline, and factors contributing to the problems may also be generally quantified. However, prior to the initiation of structural and non-structural solutions, and for the purposes of effective land use planning, more detailed information on the mechanics and effects of erosion must be developed.

Two approaches may be taken to the development of detailed information on erosion. Managers may either wait until the problem becomes of sufficient magnitude to warrant the development of specific plans of action for each individual problem area, or a system of long term monitoring may be instituted in order to aid in the avoidance of, or reduce the need for, remedial action. Although economics may dictate the former alternative, wise planning is predicated on the latter.

At present no comprehensive system of shoreline erosion monitoring is in effect in Connecticut. Recent monitoring and investigation of processes and patterns of shoreline erosion have been few and far between. The last comprehensive, site-specific evaluation of the nature and occurrence of shore erosion in the state was conducted in cooperation with the U.S. Army Corps of Engineers during the period between 1949 and 1958. Even the most recent of these reports is more than 20 years old. In addition, although the reports arising from the study were quite detailed, the state elected not to collect wave data as part of the study, and only one series of shoreline profiles were established by survey. These two shortcomings are critical to an analysis of present and future erosion trends.

Waves are the prime cause of erosion on Long Island Sound's shoreline. Incomplete information on the observed characteristics (height, length, etc.) of waves at various locations in the Sound has resulted in a limited knowledge of their short and long term influences on the shoreline. Little is known about the volumetrics of wave induced littoral transport along most of the coast. Almost no information is available concerning the absence or presence of cycles of erosion and accretion on beaches. The irregular configuration of the shoreline has further complicated the evaluation of wave induced erosion. Data available for one location, such as that presented for Stratford Point, may not necessarily be applied to another location because of differences in shoreline orientation. In addition, mathematical modeling and determination of wave characteristics often yield incorrect data because of the depth and fetch limited nature of Long Island Sound.

The absence of field data obtained from surveyed measurements along Connecticut's beaches and bluffs is disturbing. Lack of continued annual or semi-annual measurements of the position of mean high water and erosion rates which can be determined therefrom make shoreline erosion planning difficult. Because the geologic composition of the coast varies, both along and perpendicular to shore, the behavior of the shoreline in response to erosion-inducing waves and tidal currents also varies. Utilization of annual aerial photography or other forms of remote sensing are of limited value in detecting changes other than those of relatively large magnitude. Average erosion rates such as those estimated for Connecticut's coast (1-1.5 feet per year) may well be obscured by the accuracy of such measurement. Further, past aerial photographic records are inconsistent in scale, incomplete, in terms of their coverage of the coast, and contain gaps for which no photographs are available. In addition, it is not possible to accurately locate the mean high water line or photographs taken during unknown tidal conditions. Consequently, the need for field observation is apparent.

Data collected as part of a monitoring program can provide an effective analytical tool for the following day-to-day functions and responsibilities of various municipal, state, and federal agencies in the following areas:

1. Planning of shoreline development and land use.

2. Design and implementation of erosion control measures.

3. Regulation of the erection of coastal structures and dredging.

4. Provision of technical assistance to local boards and shorefront property owners in regard to shore erosion problems.

5. Collection and dissemination of scientific and technical data.

6. Designation of flood-related erosion hazard areas.

7. Planning and development of shoreline recreation facilities.

Important agencies having one or more of the noted responsibilities include (numbers in parentheses refer to the above noted responsibilities):

1. Municipal Flood and Erosion Control Borads (2,3)

2. Municipal Planning and Zoning Commissions (1)

2. Water Resources Unit of the Department of Environmental Protection D.E.P. (2,3,4)

3. Natural Resources Unit, D.E.P. (5)

4. Parks and Recreation Unit, D.E.P. (7)

5. Department of Housing and Urban Development-Flood Insurance Administration (6)

6. U.S. Army Corps of Engineers New England Division. (2,3,4)

7. Coastal Area Management Program, D.E.P. (4,5,6)

With these planning, technical assistance, and regulatory needs in mind, it is recommended that the state institute, in cooperation with interested federal and municipal agencies, a continued shoreline monitoring program. The program should be implemented through the University of Connecticut's Marine Science Institute in order to achieve the most effective use of funding. Several sources of monies are feasible, including:

1. Specially allocated state funds

2. Funding, on a cost sharing basis provided through the National Oceanographic and Atmospheric Administration's Sea Grant Program

3. Funding provided on a cooperative basis through interested and affected state, federal and municipal agencies.

The monitoring program should include the following basic elements and should be tailored to meet the specific needs of those agencies listed above:

1. Establishment of a system of permanent benchmarks and transects, utilizing where possible historical benchmarks and transects established by the Corps of Engineers in preparing the Beach Erosion Control Reports, and those established during the construction and monitoring of state beach erosion control projects. All sites should be resurveyed semi-annually.

2. Collection of measured wave data including wave height, length, period and direction of approach for at least three locations in Long Island Sound's eastern, central and western segments.

3. Collection of appropriate information on the contributions of winds and tidal currents and sea level fluctuations as they are important to the erosion process.

4. Based on analysis of the information outlined in items 1 through 3 above, compilation of site specific information on:

    a. The relative contributions of winds, waves and tidal currents to erosion.

    b. The character, direction and volume of littoral transport of material both along, on and offshore.

c. The annual rate of erosion being experienced at transect locations.

d. Important local sources of shoreline material naturally available to the littoral system.

e. Documentation of shoreline behavior in response to littoral forces (winds, waves, tidal currents) and sea level rise at established monitoring locations.

Should the economic feasibility of such an effort prove undesirable, contingency planning for more limited field monitoring or use of aerial photography should be considered. Failure to initiate either form of investigation will severely handicap the management effort.

GLOSSARY OF TERMS USED

AEOLIAN -	Wind-blown; used in reference to wind-blown sand deposits, or dunes.
BARRIER BEACH -	A strip of beach running parallel to the shore but separated from it (at least for the most part) by a body of water or marsh. The term includes features such as spit , baymouth barrier, and tombolo.
BAYMOUTH BARRIER -	A barrier beach feature extending partly across the mouth of a bay or riverine embayment.
BEDROCK -	Solid rock which underlies surface sediments or which is exposed at the surface as an outcrop.
BOULDER LAG -	A deposit of rocks greater than ten inches in diameter created by the removal (erosion) of surrounding finer sediments which leaves the larger rocks behind.
DEPTH OF CLOSURE -	The depth beyond which waves causing onshore transport of materials fail to induce transport.
DOWNDRIFT -	In the direction of predominant movement of littoral materials.
DRUMLIN -	Glacially sculpted, elongate, streamlined hills.
DRUMLINOID -	Drumlin-like; used interchangeably with the term drumlin.
DURATION -	The period of time for which an event lasts; used in reference to the length of time for which the wind blows from a particular direction.
EBB -	To recede from the flood stage; used in reference to a falling or out-going tide or tidal current.
FETCH -	The horizontal distance over which a wind generates waves on the surface of a water body.
FLOOD -	To rise from the ebb stage used in reference to a rising or incoming tide or tidal current.
GEOLOGIC -	Of or relating to the composition of the earth and its materials and the study there of.
GEOPHYSICAL -	Of or relating to the physics of the earth; used in reference to the interaction of the earth, its geologic materials and winds, waves, tides or weather.

GEOMORPHOLOGY - Literally earth form; used in reference to the description of the relief and configuration of land masses or geographic areas.

GLACIAL DRIFT - All glacially deposited materials including: till, moraines, outwash, etc.

GNEISS - A coarse-grained metamorphic rock consisting of alternating layers of different minerals and having a banded appearance.

HEADLAND - A high, steep-faced promontory extending seaward.

ICE CONTACT STRATIFIED DRIFT - Deposits of sand, gravel, silt and clay deposited in streams and lakes which occurred in close relation to melting glacial ice.

IGNEOUS - Having a fiery origin; used in reference to rocks formed by volcanic action or intense heat, at or below the earth's surface.

ISOSTATIC SEA LEVEL RISE - A relative change in the elevation of sea level, with respect to land mass, which results from the rising of the land mass in response to the removal of glacial ice which originally depressed it.

KNOT - A rate of speed equal to one nautical mile per hour. One knot is approximately equal to 1.15 statute miles per hour. One nautical mile is approximately equal to 6076 feet.

LEE - A sheltered area occurring on the side of an object or land form which is away from the wind or waves.

LITTORAL - Of or pertaining to a shore or shoreline especially of the ocean.

LITTORAL TRANSPORT - The movement of littoral materials by waves and currents. The term includes movement parallel to shore and perpendicular to shore.

LONGSHORE TRANSPORT - The movement of littoral materials by waves and currents parallel to shore.

METAMORPHIC - Characterized by a change in composition; used in reference to rocks whose composition, structure or texture have changed in response to pressure, heat or chemical activity.

MORAINE - A mass of rocks, gravel, sand, clay, etc. carried and deposited by a glacier along its side (lateral moraine), lower end (end moraine), or beneath the ice (ground moraine).

MORPHOLOGY - The form and structure of a region or land area; used in reference to shoreline form.

NEARSHORE - An indefinite zone extending seaward from the shoreline well beyond the area of active wave breaking to a depth of 30 feet.

OFFSHORE - The zone extending from a depth of approximately 30 feet (the seaward end of the nearshore zone) seaward. Also used to indicate a direction of movement off, or seaward from, the shoreline.

ONSHORE - A direction landward from the sea; used in reference to the movement of littoral materials.

ORTHOGONALS - A line drawn perpendicular to wave crests on a wave refraction diagram (see Figure 6 in the text).

OUTWASH - Sediments deposited by streams formed from melting glacial ice.

REFRACTION - The process by which the direction of travel of a wave moving in shallow water is changed. The part of the wave crest in shallower water travels more slowly than the portion in deeper water causing a bending of the wave crest.

RELICT - A geologic or physical feature or structure remaining after other components have been altered, eroded or wasted away.

SEDIMENTARY - Containing material deposited by wind or water; used in reference to rocks formed from materials deposited by wind or water.

SPIT - A narrow strip of beach projecting into a body of water from the shoreline.

TIDAL CO-OSCILLATION - A tidal oscillation produced when the ocean tide serves as a forcing agent inducing a tidal oscillation within a basin such as Long Island Sound.

TIDAL RANGE - The difference in height between consecutive high and low water levels.

TILL - Unstratified, unsorted,glacial material consisting of clay, sand, silt, boulders and gravel.

TOMBOLO - A narrow strip of beach connecting two islands or an island and the mainland.

UPDRIFT - The direction opposite to predominant movement of littoral materials; normally used in reference to longshore transport.

WAVE PERIOD - The time required for two successive wave crests to pass a fixed point.

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APPENDIX A

Requirements of the Coastal Zone Management Act and Regulations

Section 923.25 Shoreline erosion/mitigation planning.

(a) Statutory Citation, Section 305(b)(9):

The management program for each coastal state shall include * * * A planning process for (A) assessing the effects of shoreline erosion (however caused), and (B) studying and evaluating ways to control, or lessen the impact of, such erosion, and to restore areas adversely affected by such erosion.

(b) The basic purpose in developing this planning process is to give special attention to erosion issues. This special management attention may be achieved by designating erosion areas as areas of particular concern pursuant to Section 923.21 or as areas for preservation or restoration pursuant to Section 923.22.

(c) Requirements. (1) The management program must include a method for assessing the effects of shoreline erosion and evaluating techniques for mitigating, controlling or restoring areas adversely affected by erosion.

/Comment. In developing assessment and evaluation techniques, states should consider:

(i) loss of land along the shoreline of estuarine banks;

(ii) whether the loss resulted from natural or man induced forces;

(iii) whether the erosion is regularly occurring, cyclical, or a one time event;

(iv) impacts of the erosion on adjacent shorelines, and land and water uses;

(v) probable impacts of mitigation on adjacent shorelines, land and water uses, littoral drift and other natural processes such as accretion; and

(vi) probable impacts of re-establishment of pre-erosion shoreline or rebuilding on wetlands and natural habitat, particularly as the re-establishment or rebuilding might relate to the Executive Orders on Wetlands and Floodplains (see Section 923.3(b)(2)(ii))./

(2) There must be an identification and description of enforceable policies, legal authorities, funding techniques and other techniques that will be used to manage the effects of erosion as the State's planning process indicates is necessary.

/Comment. In developing a process to manage the effects of erosion, States should consider:

(i) the extent and location of erosion problems;

(ii) the necessity for control versus non-control of erosion;

(iii) whether structural (e.g., groins) or nonstructural controls (e.g., land use setbacks) are appropriate;

(iv) costs of alternative solutions (including operation and maintenance costs); and

(v) the National Flood Insurance Program (24 CFR 1909 et seq.) and regulations of the Federal Insurance Administration on flood-related erosion-prone areas (24 CFR 910.5)/

/Comment. Due to restrictions on the use of section 306 funds (see Section 923.94), not all means of restoration proposed by States may be eligible for funding under section 306 or other sections of the Act. Accordingly, particular attention should be given to coordination of shoreline erosion management objectives with funding programs pursuant to the U.S. Army Corps of Engineers Beach Erosion Control Program (33 U.S.C. 426 et seq.), the Hurricane Protection Program (33 U.S.C. 701 et seq.) and other programs as may be appropriate./

APPENDIX B

SAMPLE RESOURCE FACTOR MAPS

SHORELINE CHANGE MAP

LEGEND

The pupose of this map is to depict historical changes in the configuration of the state's 278 miles of Long Island Sound fronting coast. The map is presented at a scale of approximately 1:24,000 so that it may be compared to current shorelines shown on U.S. Geological Survey topographic maps.

SHORELINE AND 12 FOOT DEPTH

LEGEND

DATE	SHORELINE	12 FOOT DEPTH
1949	————————	
1937	....	••———••———••
1883	- - - - - - - - - - - -	XX———XX———XX
1851	o—o—o—o—o—o—o—o—	oo———oo———oo
1838	•—•—•—•—•—•—•—•—	..———..———..

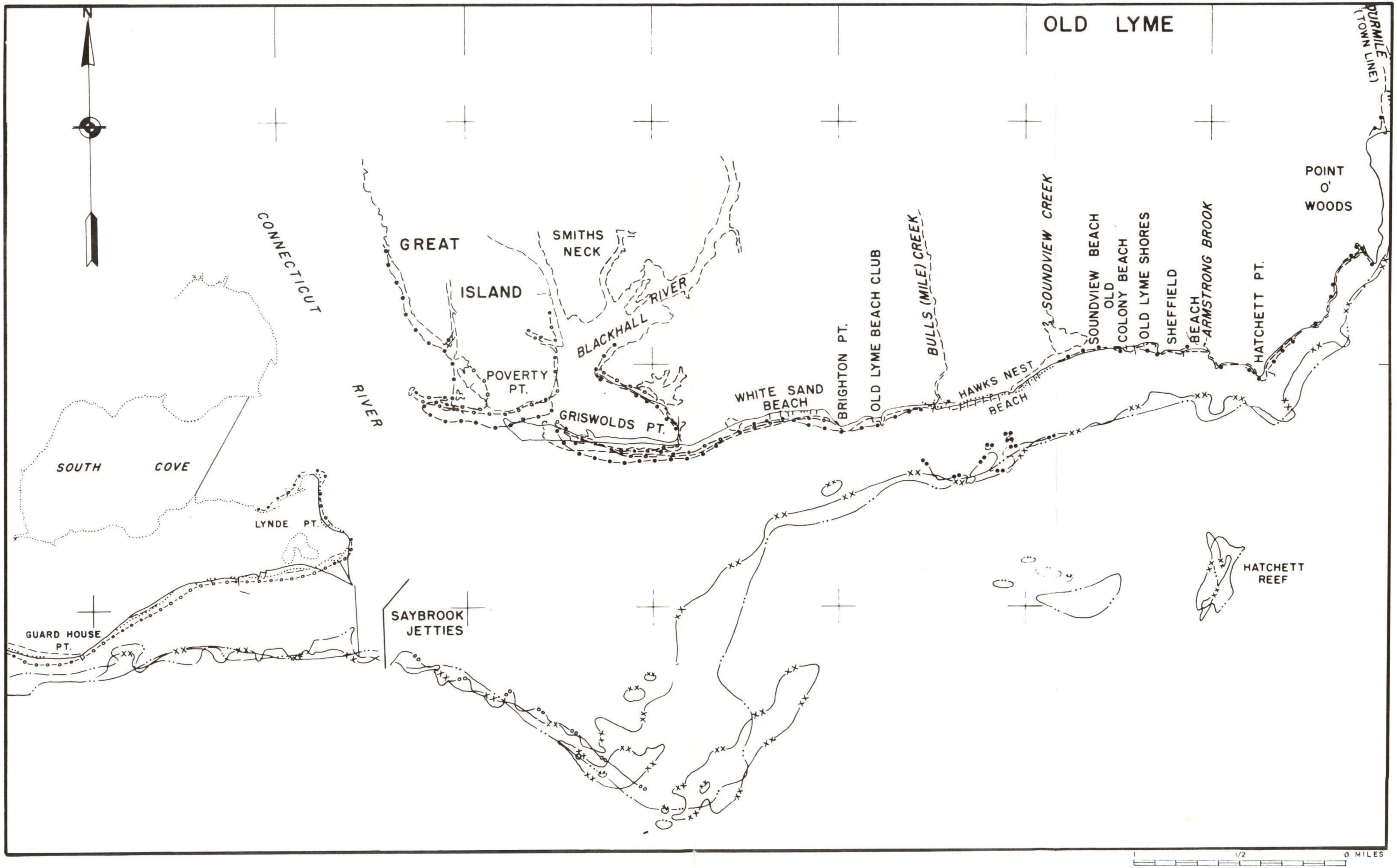
NOTES

Shorelines prior to 1949 and offshore contours traced from drawings prepared by the Beach Erosion Board, Washington, D.C., from U.S.C. & G.S. Data.

Depths are referred to the plane of Mean Low Water.

The 1949 shoreline is the Mean High Water line located for this study.

Source: Beach Erosion Control Report— Cooperative Study of Connecticut, U. S. Army Corps of Engineers, 1952


OLD LYME
N
FOURMILE (TOWN LINE)
POINT O' WOODS
CONNECTICUT RIVER
GREAT ISLAND
SMITHS NECK
BLACKHALL RIVER
POVERTY PT.
GRISWOLDS PT.
WHITE SAND BEACH
BRIGHTON PT.
OLD LYME BEACH CLUB
BULLS (MILE) CREEK
HAWKS NEST BEACH
SOUNDVIEW CREEK
SOUNDVIEW BEACH
OLD COLONY BEACH
OLD LYME SHORES
SHEFFIELD BEACH
ARMSTRONG BROOK
HATCHETT PT.
SOUTH COVE
LYNDE PT.
GUARD HOUSE PT.
SAYBROOK JETTIES
HATCHETT REEF
1
1/2
0 MILES

LITTORAL SEDIMENT SYSTEMS AND SURFICAL GEOLOGY

LEGEND

Postglacial

af

Artificial fill

s

Swamp sediments

Silt, sand, and clay mixed with organic matter in poorly drained areas, both fresh-water and tidal.

ws

Wind-blown sand

Narrow, thin patches of sand adjacent to beaches.

bs

Beach sand and gravel

Includes some wind-blown sand.

al

Alluvium

Sand, silt, and gravel occurring as thin covers on some valley floors. Locally includes colluvium and bodies of clay.

Glacial

ow

Outwash sediments

Sand and gravel, mainly with cut-and-fill stratification, grading up-valley into ice-contact stratified drift.

ic

Ice-contact stratified drift

Sand, gravel, silt, and clay, in many places poorly sorted, with abrupt changes in grain size, and deformed. Deposited in streams and local ephemeral lakes in close relation to melting glacier ice. Many bodies grade into outwash sediments.

em

End moraine

Ridges and mounds of till and stratified drift, elongate NE-SW. Concentrations of boulders locally conspicuous.

t

Till

Compact, nonsorted sediment deposited by glacier ice. Includes small bodies of stratified sediment.

Bedrock

Individual exposures in dark color; light color denotes areas with complex patterns of bare rock and rock thinly covered with residuum, small patches of till, and scattered sliderock.

Geologic contact

Dashed where located only approximately.

Gr

Erratic boulder 10 feet or more in greatest diameter.

Letters denote lithology:

Gr: granitic rock. Gn: gneissic rock.

pgm: pegmatite;

No letter: not identified.

Glacial striations and/or grooves.

Pit (operating) in sand and gravel or till. Hachures denote pit faces.

Pit (abandoned) in sand and gravel or till. Hachures denote pit faces.

p

Artificial pond not shown on topographic base map.

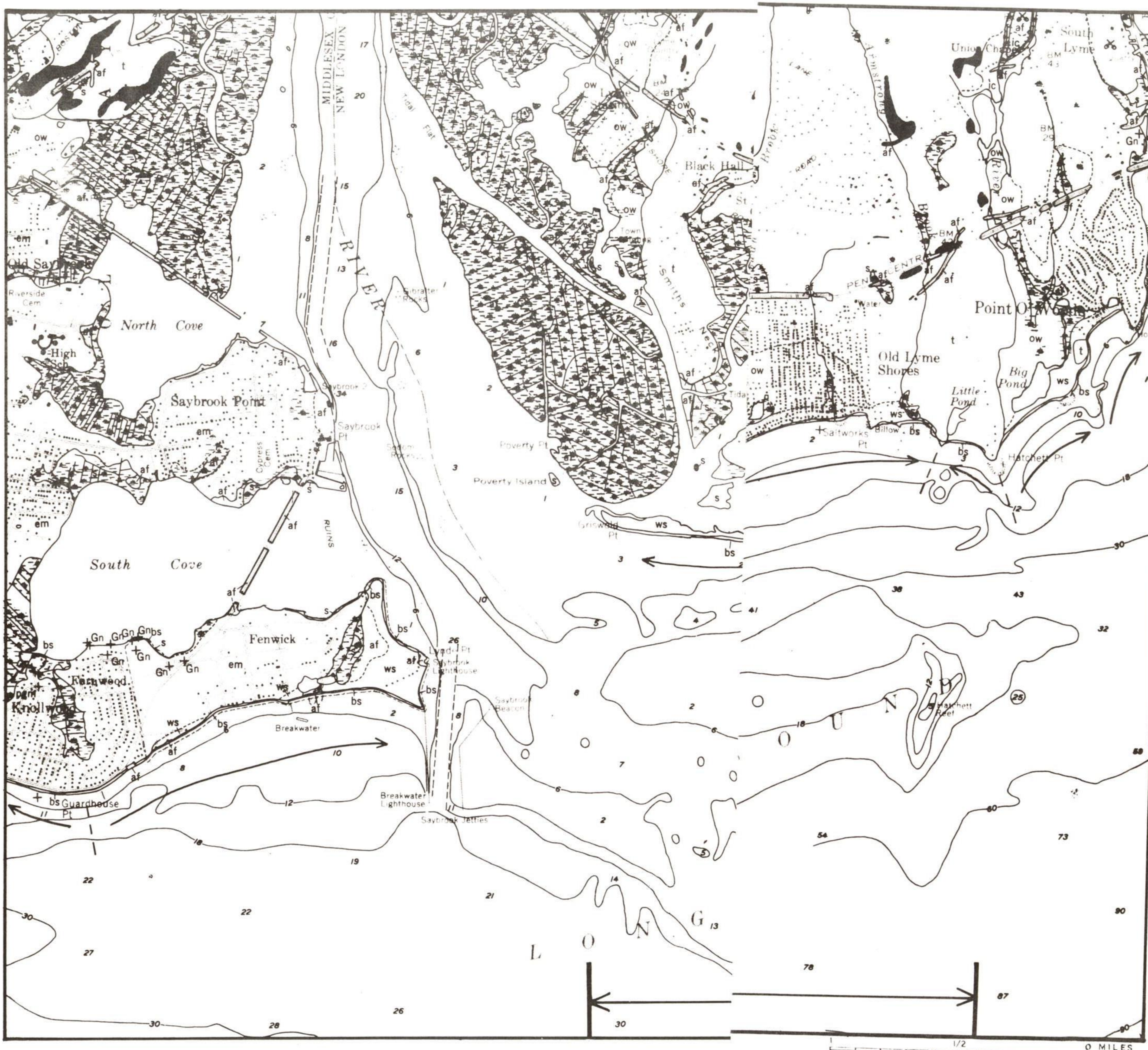
Dominant direction of alongshore sediment transport which is induced by waves and tidal currents.

Approximate sediment cell boundaries (areas where directions of alongshore transport converge and diverge).

area of significant erosion

Denotes an area where erosion presents a significant problem because the rate of erosion, considered in conjunction with economic, industrial, recreational, agricultural, navigational, demographic, environmental, and other relevant factors indicate that action to mitigate such erosion may be justified.

Sources: Surficial geology reproduced from U.S.G.S. and Connecticut Geology and Natural History Survey maps.



Old Saybrook
North Cove
High Sch
Riverside Cem
Saybrook Point
Saybrook Pt
Cypress Cem
South Cove
Fenwick
Fenwood
Knollwood
Guardhouse Pt
Breakwater
Breakwater Lighthouse
Saybrook Jetties
Lynde Pt
Saybrook Lighthouse
Saybrook Beacon
MIDDLESEX
NEW LONDON
RIVER
Tidal Flat
Gibraltar Rocks
Poverty Pt
Poverty Island
Griswold Pt
Black Hall
Smiths Neck
Old Lyme Shores
Saltworks Pt
Billow
Little Pond
Big Pond
Point O' Woods
Hatchett Pt
Hatchett Reef
Union Chapel
South Lyme
L O N G
S O U N D
1/2
0 MILES

APPENDIX C

Areas of Significant Erosion

NAME OF SITE: Greenwich Point

TOWN: Greenwich

COUNTY: Fairfield

QUADRANGLE: Stamford

APPROXIMATE LIMITS: Flat Neck Point to Greenwich

LENGTH: 0.8 miles (1.3 km)

OWNERSHIP: Municipal

LAND USE: Municipal park and beach

TYPE OF FEATURE: Low lying bluff composed of glacial outwash with narrow fringing beaches comprised of coarser materials (cobbles and pebbles).

HISTORY OF CHANGE: 1885-1933 erosion up to 150 feet, averaging approx. 100 feet
1933-1953 small, variable accretion

HISTORY OF MANAGEMENT: Sections of revetment constructed by municipality at Greenwich Point and along road east of Flat Neck Point.

JUSTIFICATION FOR DESIGNATION: Important municipal recreational facility with roadways and beaches subject to potential damage by storm induced erosion.

NAME OF SITE: Shippan Point

TOWN: Stamford

COUNTY: Fairfield

QUADRANGLE: Stamford

APPROXIMATE LIMITS: Shore Point opposite Rhode Island Rocks to entrance Channel to Cummings Park boat basin.

LENGTH: 2.7 miles (4.3 km)

OWNERSHIP: Predominantly private with some municipal public beach (West Beach).

LAND USE: Primarily urban low-density residential, public recreational beach.

TYPE OF FEATURE: Fringing beaches fronting deposits of glacial till.

HISTORY OF CHANGE: 1835-1885: recession along west shore of up to 100 feet
1885-1933: little notable change
1933-1953: recession of up to 100 feet in area immediately to the west of Cummings Park channel.

HISTORY OF MANAGEMENT: Major groin field at southern end of segment. Many private seawalls and groins also present.

JUSTIFICATION FOR DESIGNATION: Shoreline area is heavily stabilized, fringing beaches, in area are subject to continual loss of material which cannot be naturally replenished. Many residences occur in close proximity to shoreline and are subject to potential catastrophic damage from storm erosion.

NAME OF SITE: Calf Pasture Beach

TOWN: Norwalk

COUNTY: Fairfield

QUADRANGLE: Norwalk South

APPROXIMATE LIMITS: Calf Pasture Point to Canfield Island

LENGTH: 0.4 miles (0.6 km)

OWNERSHIP: Municipal

LAND USE: Municipal park and beach

TYPE OF FEATURE: Fringing beach fronting glacial outwash deposit.

HISTORY OF CHANGE: 1835-1933: variable, accretion of up to 100 feet
1933-1953: erosion 50-75 feet

HISTORY OF MANAGEMENT: Two groins constructed by the municipality prior to 1958. Existing groins lengthened and 94,000 cubic yards of sand fill placed on beach in 1958.

JUSTIFICATION FOR DESIGNATION: Important municipal recreation facility requiring periodic maintenance and replacement of eroded beach material.

NAME OF SITE: Compo Beach to Old Mill Beach

TOWN: Westport

COUNTY: Fairfield

QUADRANGLE: Sherwood Point

APPROXIMATE LIMITS: Compo Yacht Basin to Sherwood Mill Pond

LENGTH: 1.3 miles (2.1 km)

OWNERSHIP: Municipal

LAND USE: Municipal park and beach.

TYPE OF FEATURE: Fringing beach fronting deposits of artificial fill glacial outwash and till.

HISTORY OF CHANGE: Variable erosion throughout the site ranging from 0 to 50 feet.

HISTORY OF MANAGEMENT: 1957: Two stone groins constructed at Compo Beach and 260,000 cubic yards of sand placed between groins. Other protective works consist of municipally constructed revetment at Hills Point and a groin west of the entrance to Sherwood Mill Pond (construction dates unknown).

JUSTIFICATION FOR DESIGNATION: Important recreational facilities requiring periodic and repeated maintenance and replenishment of eroded beach materials.

NAME OF SITE: Sherwood Island State Park, Compo Mill Beach

TOWN: Westport

COUNTY: Fairfield

QUADRANGLE: Sherwood Point

APPROXIMATE LIMITS: Sherwood Mill Pond to Greens Farms Brook

LENGTH: 1.4 miles (2.2 km)

OWNERSHIP: State, private residental

LAND USE: Public recreational beach, residential low-density (estate)

TYPE OF FEATURE: Fringing beach at Sherwood Point. Barrier beaches extending east and west from point. Central portion of "island" is outwash with till hill on western flank.

HISTORY OF CHANGE:

Sherwood Point:	erosion (hightide shoreline) 250ft. , 1957-1971	
	erosion (lowtide shoreline) 125ft. 1957-1971	
East Beach:	erosion (hightide shoreline) 25ft. 1957-1971	
	(low tide shoreline) 200ft., 1957-1971	
West Beach:	(high tide shoreline) 15ft., 1957-1971	
	(low tide shoreline) variable changes)	

HISTORY OF MANAGEMENT: 1957 - Sherwood Island State Park, Burial Hill Creek Stabilized with training walls, 1,070,000 $yd.^3$ of sand fill placed, groin constructed at west-end of western beach.

JUSTIFICATION FOR DESIGNATION: Recent history of significant erosion. Large important recreational resource maintained only by artificial beach fill.

NAME OF SITE: Southport and Sasco Hill Beaches

TOWN: Fairfield

COUNTY: Fairfield

QUADRANGLE: Westport/Sherwood Point

APPROXIMATE LIMITS: Sasco Brook to Kensie Point

LENGTH: 1.6 miles (2.6 km)

OWNERSHIP: Municipal and private

LAND USE: Municipal beach (Southport and Sasco Hill), residential estates (very low density).

TYPE OF FEATURE: Fringing beaches at Sasco Hill and Southport lying in front of outwash deposits. Low lying bluff composed of glacial till at Kensie Point.

HISTORY OF CHANGE: 1885-1943: minor accretion

Present observation indicates beach realignment induced by groins has caused localized erosion particularly at Sasco Hill Beach.

HISTORY OF MANAGEMENT: 1957: Groin constructed at Southport Beach east of Sasco Brook, 22,000 cubic yards of sand fill placed on Southport Beach.

1958: Jetty constructed at Sasco Hill Beach east of Mill River, 20,000 cubic yards of sand fill placed on Sasco Hill Beach.

Other protection works consist of municipally constructed revetments and private seawalls.

JUSTIFICATION FOR DESIGNATION: Important recreational facilities at Sasco Hill and Southport Beaches require annual maintenance and replenishment of eroded beach material. Erosion at Sasco Hill Beach is encroaching onto golf course behind the beach. Some recent failures of private seawalls noted on west side of Kensie Point.

NAME OF SITE: Kensie Point to Ash Creek

TOWN: Fairfield

COUNTY: Fairfield

QUADRANGLE: Bridgeport/Westport/Sherwood Point

APPROXIMATE LIMITS: Kensie Point to Ash Creek

LENGTH: 3.0 miles (4.8 km.)

OWNERSHIP: Predominantly private; Municipal ownership with public access at Jennings Beach.

LAND USE: Private recreational beach, urban low-density residential use and municipal recreational beach.

TYPE OF FEATURE: Land contact beach (east end of site).
Barrier beach between Pine Creek and Shoal Point.
Bluff and escarpement Kensie Point and Pine Creek.

HISTORY OF CHANGE:
Fairfield Beach: Minor changes
Shoal Point: accretion, 50 ft., 1933-1933
accretion, 50 ft., 1933-1948
erosion, 200 ft., 1943-1970
West Fairfield Beach: 1300 ft. truncated from end of barrier beach 1948-1960
East of Kensie Point: erosion 100 ft. 1835-1909
minor erosion 1909-1948

HISTORY OF MANAGEMENT: 1959-Fairfield Beach, 140,000 yd^3. of sand fill placed, two groins constructed.
1964-West Fairfield Beach, 165,000 yds. of fill placed, 7 groins constructed.
1951-800 foot long jetty constructed at east end of Jennings Beach.
Other protective works consist of private seawalls and groins and a municipally constructed revetment at Kensie Point.

JUSTIFICATION FOR DESIGNATION: Erosion poses serious threat to urban high-density residential area. Pine Creek Spit is a migratory barrier beach. High intensity development and stabilization renders barrier beach unable to adjust to rising sea level.

NAME OF SITE: Seaside Park

TOWN: Bridgeport

COUNTY: Fairfield

QUADRANGLE: Bridgeport

APPROXIMATE LIMITS: Fayerweather Island to west harbor breakwater.

LENGTH: 2.0 miles (3.2 km).

OWNERSHIP: Municipal

LAND USE: Park and recreational beach

TYPE OF FEATURE: fringing beach fronting artificial fill

HISTORY OF CHANGE: 1837-1950 minor erosional changes in shoreline. Major changes resulted from artificial filling and construction. 1959-1962 variable erosion 0 to 50 ft.

HISTORY OF MANAGEMENT: 1914-1918-1200 feet of seawall constructed between Breezy Point and Fayerweather Island
1957-550,000 cubic yards of sand fill placed on beach between Breezy Point and Fayerweather Island.

JUSTIFICATION FOR DESIGNATION: Important municipal recreation facility requiring periodic maintenence and replenishment of eroded beach sands and repair of storm damages to seawall.

NAME OF SITE: Point No Point/Long Beach/Pleasure Beach

TOWN: Stratford/Bridgeport

COUNTY: Fairfield

QUADRANGLE: Bridgeport

APPROXIMATE LIMITS: Bridgeport Harbor to a position 0.5 miles east of Point No Point

LENGTH: 2.8 miles (4.5 Km); Bridgeport - .4 miles (.6 Km)
Stratford - 2.4 miles (3.9 Km)

OWNERSHIP: Predominantly municipal, some private residential

LAND USE: Public receational beach, residential urban high and low-density.

TYPE OF FEATURE: Point No Point - land contact beach
Long Beach/Pleasure Beach - barrier beach

HISTORY OF CHANGE:
Point No Point: minor changes - erosion on east end accretion on west end.
Long Beach: migration, 200 - 300 ft., 1883 - 1933
migration, 150 ft., 1933 - 1950
breached by storm, 700 ft. wide, 1950
breach artificially closed 1960
Pleasure Beach: accretion up to 400 ft., 1883 - 1933
accretion up to 250 ft., 1933 - 1950
little change, 1960 - 1970

HISTORY OF MANAGEMENT:
1966 - Long Beach: 600,000 yds.^{3} of sand fill placed, 7 groins constructed.

JUSTIFICATION FOR DESIGNATION: Proximity of residential structures to shoreline at Point No Point. Long Beach/Pleasure Beach is a barrier beach subject to breaching and landward migration.

NAME OF SITE: Short Beach

TOWN: Stratford

COUNTY: New Haven

QUADRANGLE: Milford

APPROXIMATE LIMITS: Stratford Point north to marine basin

LENGTH: 0.75 miles (1.2 km).

OWNERSHIP: Municipal

LAND USE: Public Beach

TYPE OF FEATURE: Fringing beach fronting glacial outwash and artificial fill deposits.

HISTORY OF CHANGE: 1837-1933 - accretion of 200 ft. along northerly shore
erosion of 0-600 ft. along southerly shore
1933-1950-erosion varying between 0 and 75 feet.

HISTORY OF MANAGEMENT: 1955 - beach fill placed along beach during dredging of navigation chanel in Housationic River.

JUSTIFICATION FOR DESIGNATION: Important municipal recreational facility requiring periodic maintenance and replenishment of eroded beach sand.

NAME OF SITE: Silver Sands Beach to Milford Point

TOWN: Milford

COUNTY: New Haven

QUADRANGLE: Milford

APPROXIMATE LIMITS: Milford Point to Silver Beach

LENGTH: 4.0 miles (6.4 km).

OWNERSHIP: State (Silver Sands Beach), remainder privately owned by individuals or beach associations. Some public access points occur within private sectors.

LAND USE: Public Recreational Beach, urban low-density residential and urban high-density residential uses.

TYPE OF FEATURE: Silver, Myrtle and Cedar Beaches and Milford Point are barrier beaches backed by marsh and much artificial fill. Walnut, Wildermere and Laurel Beaches are fringing beaches fronting glacial outwash deposits.

HISTORY OF CHANGE: Myrtle to Cedar Beaches - erosion, 50-100 ft., 1933-1949
Cedar Beach - accretion, 50 ft., 1933-1949
Milford Point - minor migration northward
lateral growth, 100 ft., 1910-1933
lateral growth, 100 ft, 1933 - 1949

HISTORY OF MANAGEMENT: 1960 - Silver, Meadows End and Myrtle Beaches 223,000 yds.^{3} of sand fill placed.
1965 - Laurel Beach 70,000 yds of sand fill placed, 2 groins constructed.
many other private seawalls, groins and revetments constructed on indeterminant dates.

JUSTIFICATION FOR DESIGNATION: Public and private beaches maintained solely by filling. Residential structures in eminent danger. Milford Point is a migratory barrier beach.

NAME OF SITE: Gulf Beach

TOWN: Milford

COUNTY: New Haven

QUADRANGLE: Milford

APPROXIMATE LIMITS: Milford Harbor entrance to Welches Point

LENGTH: 0.5 miles (0.8 Km)

OWNERSHIP: Public (Town of Milford), private residental (approximately equal portions)

LAND USE: Public recreational beach, residential

TYPE OF FEATURE: Land contact beach fronting till.

HISTORY OF CHANGE: Erosion, southerly section, 50 ft. 1933 - 1949
accretion, at jetty on northerly end, 150 ft. 1933 - 1949

HISTORY OF MANAGEMENT: 1957- 55,000 yds.^{3} of sand fill placed
1966- 15,000 yds.^{3} of sand fill placed
1967- jetty extended and raised

JUSTIFICATION FOR DESIGNATION: Public recreational beach maintained only through regular nourishment.

NAME OF SITE: Point Beach to Bayview Beach

TOWN: Milford

COUNTY: New Haven

QUADRANGLE: Milford

APPROXIMATE LIMITS: Welches Point to Pond Point

LENGTH: 1.2 miles (2.0 Km.)

OWNERSHIP: Private with some public access points

LAND USE: Private recreational beaches fronting urban low-density residential areas.

TYPE OF FEATURE: Land contact beach with small barrier beach between two outwash headlands

HISTORY OF CHANGE: Point Beach - minor erosion 1933-1939
Bayview Beach - relatively stable

HISTORY OF MANAGEMENT: Private stabilization in the form of revetments, seawalls and groins

JUSTIFICATION FOR DESIGNATION: Residential structures in eminent danger of damage from erosion of any magnitude.

NAME OF SITE: Woodmont

TOWN: Milford

COUNTY: New Haven

QUADRANGLE: Woodmont

APPROXIMATE LIMITS: Merwin Point to Oyster River

LENGTH: 0.8 miles (1.3 Km)

OWNERSHIP: Public, private (approximately equal portions)

LAND USE: Private recreational beach with some public access points, public recreational beach, both backed by residential suburban high and low density.

TYPE OF FEATURE: Fringing beach fronting glacial till deposits

HISTORY OF CHANGE: Minor changes erosion ~ 50 ft., 1838-1949

HISTORY OF MANAGEMENT: 1959 - 5 groins constructed, 170,000 $yds.^3$ of sand fill placed between Oyster River and Merwin Point
1964 - 5 groins repaired, 63,000 $yds.^3$ of sand fill placed.

JUSTIFICATION FOR DESIGNATION: Recreational beach experiencing continual erosion. Beach facility maintained only through repeated nourishment.

NAME OF SITE: Prospect and Savin Rock Beaches

TOWN: West Haven

COUNTY: New Haven

QUADRANGLE: New Haven/Woodmont

APPROXIMATE LIMITS: Oyster River to Sandy Point

LENGTH: 4.6 miles (7.4 Km.)

OWNERSHIP: Principally public (town of West Haven) some private residential and beach associations.

LAND USE: Public recreational beach with some public access points.

TYPE OF FEATURE: Fringing beach, fronting deposits of glacial outwash, between Oyster River and Morse Point. Sandy Point and Morse Point spits are barrier beaches.

HISTORY OF CHANGE: Sandy Point - migration (north) 800 ft., 1884-1971
lateral growth (east) 2300 ft., 1884-1971
Morse Point - lateralgrowth (east) 1300 ft., 1949-1971
Savin Rock Beach - accretion (along entire length)
50 - 100 ft., 1933 - 1949
Savin Rock Beach - erosion (along entire length) 50-100 ft., 1949-197
(Prospect Beach - accretion along entire length 50 - 100 ft., 1949-197

HISTORY OF MANAGEMENT: 1957 - 440,000 yds^3. of sand fill placed on Prospect Beach
1973 - 6 groins built 25,000 yds^3 of sand fill placed, 2 groins
built on Prospect Beach

JUSTIFICATION FOR DESIGNATION: Recreational beach with a history of large scale maintenance and filling. Sandy point, Morse Point are migratory barrier features.

NAME OF SITE: Morris Cove

TOWN: New Haven

COUNTY: New Haven

QUADRANGLE: New Haven

APPROXIMATE LIMITS: Lighthouse Point to Forbes Bluff

LENGTH: 0.7 miles (1.1 km).

OWNERSHIP: Approximately equal portions of private and municipal properties.

LAND USE: Municipal Park and surban high density residential.

TYPE OF FEATURE: Fringing beach fronting glacial till, outwash and artificial fill deposits.

HISTORY OF CHANGE: 1838-1933 variable erosion. Recession of 150 ft. near Fort Hale Park diminishing to 25 ft. of recession north of Lighthouse Point Park.

HISTORY OF MANAGEMENT: Area is protected predominantly by privately constructed bulkheads and seawalls which have deterioriated. Municipal park area is protected by municipally constructed seawall and groin.

JUSTIFICATION FOR DESIGNATION: Recent significant loss of beach material from in front of seawalls coupled with deteriorating condition of walls has produced a potentially dangerous situation along the resedentially developed portions of shore.

NAME OF SITE: Lighthouse Point

TOWN: New Haven

COUNTY: New Haven

QUADRANGLE: Woodmont

APPROXIMATE LIMITS: Lighthouse Point to Morris Creek

LENGTH: 0.25 miles (0.4 Km)

OWNERSHIP: Municipal

LAND USE: Public recreational beach

TYPE OF FEATURE: Land contact beach fronting artificial fill

HISTORY OF CHANGE: erosion - 50 ft., 1952 - 1955
accretion - 100 - 200 ft., 1960-1970
(possible fill)

HISTORY OF MANAGEMENT: 1958 - groin constructed at west end of beach
1949 - 168,000 yds^3 of fill placed on beach

JUSTIFICATION FOR DESIGNATION: Public recreational beach requiring significant beach nourishment for maintenance. Erosion constitutes large impact on public use.

NAME OF SITE: Momauguin and Silver Sands Beaches

TOWN: East Haven

COUNTY: New Haven

QUADRANGLE: Branford/Woodmont

APPROXIMATE LIMITS: Caroline Creek to Mansfield Point

LENGTH: .95 miles (1.5 Km)

OWNERSHIP: Private with one small section of public beach

LAND USE: Residential (suburban high - density), recreational beach.

TYPE OF FEATURE: Eastern end, fringing beach fronting artificial fill. West end, barrier beach.

HISTORY OF CHANGE: Momauguin - erosion 100 ft., 1885-1952
Silver Sands - erosion (west end) 100 ft., 1933-1952

HISTORY OF MANAGEMENT: Caroline Creek structurally relocated and channelized. Channelization has failed private seawalls and groins along beaches.

JUSTIFICATION FOR DESIGNATION: Residential structures presently standing in water during normal tide conditions as a result of erosion of beach area.

NAME OF SITE: Chaffinch Island

TOWN: Guilford

COUNTY: New Haven

QUADRANGLE: Guilford

APPROXIMATE LIMITS: Tuttles Point to West River

LENGTH: 0.46 miles (0.75 Km)

OWNERSHIP: Public, private residential

LAND USE: Open space - vacant land public portions utilized for recreational purposes.

TYPE OF FEATURE: Two arcuate marsh coves punctuated by three bedrock headlands. Minor deposits of beach material present in coves

HISTORY OF CHANGE:
erosion - (entire segment) 200 - 300 ft., 1885 - 1933
erosion - (entire segment) 150 - 200 ft., 1933 - 1948
erosion - (west cove) 100 ft., 1948 - 1970

HISTORY OF MANAGEMENT: No structures, undeveloped

JUSTIFICATION FOR DESIGNATION: Largest magnitude of recent change on Connecticut coast.

NAME OF SITE: Circle Beach - Grass Island

TOWN: Madison/Guilford

COUNTY: New Haven

QUADRANGLE: Guilford

APPROXIMATE LIMITS: West end of Grass Island to Hogshead Point

LENGTH: 0.9 miles (1.5 Km) Guilford - 0.8 miles (1.3 Km)
Madison - 0.1 miles (0.2 Km)

OWNERSHIP: Circle Beach - Predominantly private
Grass Island - municipal

LAND USE: Public recreational beach, private recreational beach fronting open space and residental suburban low - density.

TYPE OF FEATURE: Minor barrier feature backed by tidal marsh.

HISTORY OF CHANGE: Circle Beach - erosion 50 ft., 1883 - 1948
Grass Island - erosion(south shore) 200 ft., 1838 - 1933
Grass Island - erosion(west shore) 100 ft., 1838 - 1933

HISTORY OF MANAGEMENT: Private groins and seawalls

JUSTIFICATION FOR DESIGNATION: Circle Beach - proximity of houses to water. Houses directly on beach. Grass Island - large magnitude of change combined with presence of residences in immediate proximity to shoreline.

NAME OF SITE: West Wharf, Middle and Seaview Beaches

TOWN: Madison

COUNTY: New Haven

QUADRANGLE: Clinton

APPROXIMATE LIMITS: West Wharf to Webster Point

LENGTH: 2.0 miles (3.2 km).

OWNERSHIP: Predominantly private with small segments of municipal ownership at East Wharf, West Wharf and along Middle Beach.

LAND USE: Private recreational beach, with two small municipally owned public beaches (East Wharf, West Wharf) and areas of low density residential use.

TYPE OF FEATURE: Fringing beach fronting deposits of glacial outwash at East and West Wharves and Seaview Beach. Low bluff composed of glacial outwash and protected by revetment at Middle Beach.

HISTORY OF CHANGE: 1838-1933 variable erosion 50-100 feet throughout the area. Erosion in excess of 100 feet noted at Middle Beach.

HISTORY OF MANAGEMENT: 1957-stone revetment constructed at Middle Beach. Other protective works consist of private and municipally constructed seawalls and groins.

JUSTIFICATION FOR DESIGNATION: Important municipal recreational facilities affected by loss of beach material. Residential development in close proximity to shore and roadway located at shoreline.

NAME OF SITE: Hammonasset Beach

TOWN: Madison

COUNTY: New Haven

QUADRANGLE: Clinton

APPROXIMATE LIMITS: Webster Point to Hammonasset Point

LENGTH: 1.9 miles (3.0 Km)

OWNERSHIP: State

LAND USE: Public Recreational beach

TYPE OF FEATURE: Fringing beach with small barrier feature at eastern end connecting the central outwash deposit with eastern till deposits.

HISTORY OF CHANGE: erosion - (west end) 150 ft., 1883 - 1949
accretion - (east end) 100 ft., 1883 - 1949
changes between 1883 and 1949 indicate rotation of shoreline clockwise about central point.
1976-1977, 14,000 cubic yards of material lost from beach area.

HISTORY OF MANAGEMENT: 1955 - Toms Creek inlet channelized by training walls, groin constructed at Hammonasset Point, 380,000 yds^3 of sand fill placed on beach.

JUSTIFICATION FOR DESIGNATION: Major state shoreline recreational facility subject to regular erosion.

NAME OF SITE: Grove Beach, Clinton Beach

TOWN: Westbrook/Clinton

COUNTY: Middlesex

QUADRANGLE: Essex/Clinton

APPROXIMATE LIMITS: Kelsey Point to Grove Beach Point

LENGTH: 2.3 miles (3.7 Km) Westbrook - 1.1 miles (1.8 Km)
Clinton - 1.2 miles (1.9 Km)

OWNERSHIP: Private

LAND USE: Private recreational beach fronting residential urban low-density.

TYPE OF FEATURE: Fringing beach fronting end moraine. Flanked on east and west by barrier beaches fronting salt marsh. Artificial fill present in marsh behind Grove Beach.

HISTORY OF CHANGE: Grove Beach - erosion, 300 - 500 ft., 1883-1970
(major changes at east end)
Clinton Beach - erosion, 50 - 150 ft., 1883 - 1970
(regular erosion between Kelsey Point and a position 1.7 miles east of Point)

HISTORY OF MANAGEMENT: Groin field at Clinton Beach privately constructed.

JUSTIFICATION FOR DESIGNATION: Proximity of residential structures to shoreline in shoreline in combination with historical erosional changes.

NAME OF SITE: West Beach

TOWN: Westbrook

COUNTY: Middlesex

QUADRANGLE: Essex

APPROXIMATE LIMITS: Groin at east end of beach to a point 0.25 miles (0.4 Km) west

LENGTH: 0.25 miles (0.4 Km)

OWNERSHIP: Private and municipal

LAND USE: Public recreational beach fronting urban low density residental

TYPE OF FEATURE: Barrier beach extending west from morainal deposits, fronting tidal marsh

HISTORY OF CHANGE: erosion ~ 100 ft., 1933 - 1949
erosion ~ 50 ft., 1949 - 1970

HISTORY OF MANAGEMENT: Large groin at east end of segment constructed on unknown date

JUSTIFICATION FOR DESIGNATION: Recent erosional changes adversely impacting land use at municipal beach.

NAME OF SITE: Chapman Beach, Chalker Beach

TOWN: Old Saybrook

COUNTY: Middlesex

QUADRANGLE: Essex

APPROXIMATE LIMITS: Old Kelsey Point east to Chapman Point

LENGTH: 0.9 miles (1.4 Km)

OWNERSHIP: Private

LAND USE: Private recreational beach fronting urban low-density residential

TYPE OF FEATURE: Fringing beach and barrier beach backed by substantial artificial fill on contiguous wetland.

HISTORY OF CHANGE: Minor changes over period of record, most resulting from erosion and accretion around groins.

HISTORY OF MANAGEMENT: 1961 - 9700 $yds.^3$ of sand fill placed on Chalker beach, private groins.

JUSTIFICATION FOR DESIGNATION: Any erosion will result in adverse impact on residential structures located on beach.

NAME OF SITE: Plum Bank, Great Hammock Beach

TOWN: Old Saybrook

COUNTY: Middlesex

QUADRANGLE: Essex

APPROXIMATE LIMITS: Indiantown Harbor to Cornfield Point

LENGTH: 1.1 miles (1.8 Km)

OWNERSHIP: Private, one small segment of municipal beach

LAND USE: Private recreational beach fronting urban low-density residential.

TYPE OF FEATURE: barrier beaches fronting substantial artificial fill projecting north from morainal deposit at Cornfield Point.

HISTORY OF CHANGE: No documented changes over the period of record.

HISTORY OF MANAGEMENT: Many private seawalls, revetments, groins.

JUSTIFICATION FOR DESIGNATION: Location of residential development on beach. Any erosion will produce serious effects on land use.

NAME OF SITE: Griswold Point

TOWN: Old Lyme

COUNTY: New London

QUADRANGLE: Old Lyme

APPROXIMATE LIMITS: Griswold Point to White Sands Beach

LENGTH: 0.9 miles (1.5 Km)

OWNERSHIP: non-profit private organization (Nature Conservancy) and private.

LAND USE: Undeveloped, open space; residential estate

TYPE OF FEATURE: Barrier spit extending from morainal deposits on east into Connecticut River.

HISTORY OF CHANGE: Northern migration 200 ft. 1883 - 1949
lateral westerly growth 1000 ft. 1883 - 1949
northern migration 100 - 200 ft. 1949 - 1970
lateral westerly growth 400 ft. 1949 - 1970
Recent investigation indicates erosion rates on the order of 3 feet per year.

HISTORY OF MANAGEMENT: no structural or non-structural management

JUSTIFICATION FOR DESIGNATION: Large scale migratory feature subject to major migration and lateral growth.

NAME OF SITE: White Sands Beach to Hatchett Point

TOWN: Old Lyme

COUNTY: New London

QUADRANGLE: Old Lyme

APPROXIMATE LIMITS: White Sands Beach to Hatchett Point

LENGTH: 2.6 miles (4.2 Km)

OWNERSHIP: Predominantly private, ~ 0.7 miles in public ownership.

LAND USE: Residential urban high and low-density with private recreational beach, some public beach, undeveloped wetland and open space.

TYPE OF FEATURE: Fringing beach fronting till, outwash and end moraine deposits with minor barrier beaches between.

HISTORY OF CHANGE: erosion - average ~ 50 - 100 ft., 1883 - 1949
White Sands Beach ~ erosion - 200 ft., 1883 - 1949
Recent investigations indicate erosion rates on the order of 3 feet per year in the vicinity of White Sands Beach.

HISTORY OF MANAGEMENT: 1957 - 2 groins constructed at White Sands Beach in addition to existing groin.
1966 - 37,000 $yds.^3$ of sand fill placed at White Sands Beach.
Large private groin field maintained at Hawks Nest Beach by beach association.

JUSTIFICATION FOR DESIGNATION: Residential structures in area constructed on beach in close proximity to water. Any erosion will result in major impact on use.

NAME OF SITE: Oak Grove Beach, Pond Point

TOWN: East Lyme

COUNTY: New London

QUADRANGLE: Niantic

APPROXIMATE LIMITS: 0.25 miles north and south of Pond Point

LENGTH: 0.5 miles (0.8 Km)

OWNERSHIP: Private

LAND USE: Residential, urban low-density with private recreational beach.

TYPE OF FEATURE: Small barrier and fringing beaches fronting Indian Pond. Bedrock exposed in foreshore.

HISTORY OF CHANGE:
erosion: (south of point) $\sim$ 150 ft., 1882 - 1949
erosion: (south of point) $\sim$ 200 ft., 1949 - 1970

HISTORY OF MANAGEMENT: No control structures in evidence

JUSTIFICATION FOR DESIGNATION: Large magnitude of change south of Pond Point. Proximity of residences to water north of Pond Point.

NAME OF SITE: Jordan Cove Spit

TOWN: Waterford

COUNTY: New London

QUADRANGLE: Niantic

APPROXIMATE LIMITS: North end of Jordan Cove Spit to north end of Pleasure Beach.

LENGTH: 0.5 miles (0.8 Km)

OWNERSHIP: Private

LAND USE: Open space (regulated tidal wetland)

TYPE OF FEATURE: Barrier spit fronting salt marsh

HISTORY OF CHANGE: Lateral growth (westerly) ~1300 ft. 1883 - 1949
Lateral growth (northerly) ~ 400 ft. 1949 - 1970
Landward migration ~ 50 - 100 ft. 1949 - 1970
erosion (southwest point) ~ 100 ft. 1949 - 1970

HISTORY OF MANAGEMENT: 2 bulkheads constructed privately on landward side of spit prior to 1949

JUSTIFICATION FOR DESIGNATION: Medium scale barrier feature subject to major historical migration and lateral growth.

NAME OF SITE: Goshen Point, Ocean Beach

TOWN: Waterford, New London

COUNTY: New London

QUADRANGLE: New London

APPROXIMATE LIMITS: Goshen Point to Long Rock

LENGTH: 1.2 0.75 miles (1.2 km) Waterford
0.45 miles (0.72 km) New London

OWNERSHIP: State and Municipal

LAND USE: State and municipal parks with recreational beach

TYPE OF FEATURE: Barrier beach fronting wetland

HISTORY OF CHANGE: General accretion, 50-100 ft., 1839-1883
General erosion, 25-50 ft., 1883-1955
Migration of Alewife Cove inlet 100 ft. southward, 1839-1955

HISTORY OF MANAGEMENT: Beach fill, unknown volume, 1940.

JUSTIFICATION FOR DESIGNATION: Important public recreational beach facility located on small scale migratory barrier beach.

NAME OF SITE: Bluff Point - Bushy Point Beach

TOWN: Groton

COUNTY: New London

QUADRANGLE: New London

APPROXIMATE LIMITS: West end of Bushy Point Beach to Mumford Point

LENGTH: 1.2 mile (1.9 Km)

OWNERSHIP: State

LAND USE: Coastal Reserve

TYPE OF FEATURE: Bedrock core drumlin (Bluff Point) with associated barrier spit (Bushy Point Beach)

HISTORY OF CHANGE: Bushy Point Beach originally formed as a tombolo through reworking and transport of till from Bluff Point, Bushy Point and the till platform on which it rests. Tombolo was breached in 1938, by hurricane, forming spit. Landward recession of ~ 150 ft., 1846 - 1949.

HISTORY OF MANAGEMENT: Undeveloped, no control structures

JUSTIFICATION FOR DESIGNATION: Large scale migratory feature exhibiting significant change, breaching.

NAME OF SITE: Sandy Point

TOWN: Stonington

COUNTY: New London

QUADRANGLE: Mystic

APPROXIMATE LIMITS: Distal end of Sandy Point to Connecticut/Rhode Island Border.

LENGTH: 0.3 miles (0.48 Km)

OWNERSHIP: Private

LAND USE: Private recreational beach

TYPE OF FEATURE: Barrier spit

HISTORY OF CHANGE: Lateral growth (northerly) from Napatree Point, breached in 1938 by hurricane. Recent migration to north occurring in conjunction with counter clockwise rotation of barrier island.

HISTORY OF MANAGEMENT: Undeveloped, no control structures

JUSTIFICATION FOR DESIGNATION: Large scale barrier island subject to major migratory change and breaching.

APPENDIX D

Erosion Control Projects

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		BRANFORD				
1	25	*Branford Point Park (1963) 11,000 yd³ of sand fill placed along 300' of beach widening it to 100'		18237.00	9119.00	27356.00
		BI-FC-50				
		Town Total				27356.00
		BRIDGEPORT				
2	12	Grover Hill (1968) 2320' of stone revetment Constructed parallel to Grover Ave.		133395.00	66697.00	200092.00
		BI-FC-63				
		*Seaside Park (1957) 550,000 yd³ of sand fill placed along 8800' of beach widening it to 125' between Breezy Point and Fayerwether Island.	150000.00	169947.00	159973.00	479920.00
		Town Total				680012.00
		CLINTON				
4	29	*Clinton Town Beach (1964) 21,000 yd³ of sand fill placed on beach		29885.00	14942.00	44827.00
		BI-FC-33				
		Town Total				44827.00
		EAST HAVEN				
5	24	West Silver Sands (1958) 1 200' groin constructed, 170,000 yd³ of sand fill placed along 2550' of beach widening it to 100'		78714.00	157428.00	237142.00
		BI-FC-11 A&B				
		Town Total				237142.00

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		EAST LYME				
6	33	Giants Neck (1975) 2 sections of Stone revetment constructed-300' and 550' long parallel to Giants Neck Road and Patagansett Road		23966.00 +20000.00	47933.00	91899.00
7	34	*McCook Point (1974) 300' of stone revetment constructed east side of Point. One groin, 150' long constructed east of point			86090.00	86090.00
		BI-FC-69				
		Town Total				177989.00
		FAIRFIELD				
8	11	*Jennings Beach (1951) 800' long jetty constructed west of mouth of Ash Creek	14401.00	14799.00	13941.00	43141.00
		BI-FC-14 BI-FC-5 A				
9	10	Fairfield Beach (1959) 140,000 yd^3 of sand fill placed along 4400' of beach, two 325' long groins constructed between Shoal Point and Jennings Beach.		80269.00	160538.00	240807.00
		BI-FC-18 A&B				
10	8	*Sasco Hill Beach (1958) 20,000 yd^3 of sand fill placed along 900' of beach widening it to 100', one 400' jetty constructed east of entrance to Southport Harbor	23759.00	23759.00	23758.00	71276.00
		BI-FC-5A BI-FC-14				

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		FAIRFIELD (Con't)				
11	7	*Southport Beach (1957-58) 22,000 yd ^{3} of sand fill placed along 700' of beach widening it 700' to 100', 400' long groin constructed east of moutn of Sasco Brook.	17631.00	17632.00	17631.00	52894.00
		BI-FC-5A BI-FC-14				
12	9	West Fairfield Beach (1964) 165,000 yd3 of fill placed along 5600' of beach, 7 groins constructed (2 by town) between Pine Creek Pt. and Shoal Point.		121792.00	243576.00	365368.00
		BI-FC-39 A&B				
		Town Total				773486.00
		GROTON				
13	38	*Esker Point Park (1969) 14,500 yd ^{3} of material excavated, 7,403 yd ^{3} of sand fill placed.		88569.00	44284.00	132853.00
		BI-FC-55				
14	37	*Avery Point, UConn (1971) 12,000 ft. ^{2} of seawall repaired east side of Avery Point		45793.00		45793.00
		BI-FC-74				
		Town Total				178646.00

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		GUILFORD				
15	26	*Guilford Point Beach (1957) 300' long groin constructed at east end of beach. BI-FC-8	15620.00	15920.00	15321.00	46861.00
16	26	*Guilford Point Beach (1959) 13,000 yd^3 of sand fill placed along 400' of shoreline west of groin, 14,585 yd^3 of mud removed. BI-FC-16		28186.00	14094.00	42280.00
		Town Total				89141.00
		MADISON				
17	28	*Hammonasset Park (1955) Two training (sheet steel) walls constructed at mouth of Tom's Creek-320' long and 400' long, one 800' long groin constructed at Meigs Point, 380,000 yd^3 of sand fill placed between Tom's Creek and Meigs Point. BI-T-23	163188.00	326366.00		489549.00
		*Hammonasset Park (1966) Stone groin repaired BI-FC-61		21062.00		21062.00
.9	27	*Middle Beach (1957) 700' of stone revetment constructed along Middle Beach Road. BI-FC-10	8810.00	8810.00	8810.00	26430.00
		Town Total				537041.00

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		MILFORD				
20	18	*Gulf Beach (1957) 55,000 yd^3 of sand fill placed along 1200' of beach widening it to 100'. BI-FC-4	21303.00	21303.00	21303.00	63909.00
21	18	*Gulf Beach (1966) 15,000 yd^3 of sand fill placed along 800' of beach. BI-FC-43		22650.00		22650.00
22	18	*Gulf Beach (1967) 350' of existing jetty raised and a spur groin added. BI-FC-56		27191.00	13595.00	40786.00
23	173	Laurel Beach (1965) 2 groins reconstucted, one new groin constructed, 70,000 yd^3 of sand placed along 2800' of shore between 1st and 7th Avenues. BI-FC-49 A&B		60698.00	121394.00	182092.00
24	19	Morningside Beach (1963) 1500' of stone revetment constructed along Morningside Drive between Crest Place and Beacher Road. BI-FC-47		52559.00	26280.00	78839.00

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		MILFORD (con't)				
24	19	Morningside Beach (1965) 1000' of stone revetment constructed adjacent to existing revetment (above)		47690.00	22346.00	70036.00
		BI-FC-57				
26	16	Silver To Cedar Beaches (1955) Fill placed along 8500' of shore	cost breakdown unavailable			333255.0(
27	16	Silver Meadows End and Myrtle Beaches (1960) 223,000 yd^3 of sand fill placed along 5300' of shorefront parallel to East Broadway between Cedar and Pearl Streets.	cost breakdown unavailable			301507.0(
		BI-FC-19B				
28	17	Silver Sands State Park		105600.00		105600.00
29	20	Woodmont Shore (1959) 5 stone groins constructed and 170,000 yd^3 of sand fill placed between Oyster River and Merwin Point.	53838.00	46442.00	65237.00	165517.00
		BI-FC-17 A&B				
30	20	Woodmont Shore (1964) 5 groins reparied, 63,000 yd^3 of sand fill placed.		42160.00	81840.00	124000.00
		BI-FC-46 A&B				
		Town Total				1488191.00

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	Local COST	TOTAL
		NEW HAVEN				
31	23	Lighthouse Point Park (1958) 380' long stone groin constructed west side of beach.	3390.00	4556.00	3843.00	11789.00
		BI-FC-21				
		Town Total				11789.00
		NEW LONDON				
32	36	Neptune Park (1964) 63,000 yd ^{3} of sand fill placed along 800' of shore.		68499.00	65901.00	134400.00
		BI-FC-26				
		Town Total				134400.00
		NORWALK				
33	3	Calf Pasture Beach (1958) Two existing groins lenthened,94,000 yd ^{3} of sand fill placed.	56386.00	56164.00	54005.00	166555.00
		BI-FC-22 A&B				
		Town Total				166555.00
		OLD LYME				
34	32	Point O'Woods (1965) 600' of revetment constructed along Champion Road, 24,000 yd ^{3} of sand fill placed along 950' of shore, training wall modified.		39398.00	78795.00	118193.00
		BI-FC-52				

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		OLD LYME (Con't)				
35	31	White Sands Beach (1957) Stone groin constructed at west end of beach, 51,000 yd^3 of sand fill placed.		24723.00	47990.00	72713.00
		BI-FC-9 A&B				
36	31	White Sands Beach (1966) 2 stone groins constructed		19403.00	30994.00	50397.00
		BI-FC-32				
37	31	White Sands Beach (1967) 37,000 yd^3 of sand fill placed between 3 existing groins.		65028.00		65028.00
		BI-FC-44				
		Town Total				306331.00
		OLD SAYBROOK				
38	30	Chalker Beach (1961) 97,00 yd^3 of sand fill placed along 1600' of shore.		33542.00	65890.00	99432.00
		BI-FC-15				
		Town Total				99432.00
		STAMFORD				
39	2	Cove Island (1958) 400' stone jetty constructed at eastern end of Island 61,000 yd^3 of sand fill placed along 1300' of shore.	47131.00	47584.00	46668.00	141383.00
		BI-FC-23				

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		STAMFORD (Con't)				
40	1	Cummings Park (1960) Existing jetty raised and existing groin lengthened, 45,000' yd ^{3} of sand fill placed between structures.	26886.00	40708.00	20354.00	87948.00
		BI-FC-30				
		Town Total				229331.00
		STRATFORD				
41	14	Long Beach (1966) 7 stone groins constructed, 600,000 yd ^{3} of sand fill placed between groins.		276708.00	138354.00	415062.0C
		BI-FC-41				
42	15	Short Beach (1955) Sand fill placed along 3500' of shore between Sniffen and Stratford Points.	No cost fill from Fed. Navig. project Housatonic River			
		Town Total				415062.00
		WATERFORD				
43	35	Seaside Regional Center (1967) 3 stone groins rebuilt,810' of revetment constructed, 15,615 yd. ^{3} of sand fill placed between grions.		118593.00		118593.00
		BI-FC-59				
		Town Total				118593.00

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		WEST HAVEN				
44	20	Aimes Point (1965) 1600' of revetment constructed along Ocean Avenue between Baldwin and Hurbut Streets in front of existing seawall.		35800.00	57188.00	92988.00
		BI-FC-60				
45	21	Prospect Beach (1957) 6 stone groins constructed and 440,000 yd ^{3} of sand fill placed along Ocean Avenue between South and Ivy Streets.	104573.00	139540.00	114394.00	358507.00
		BI-FC-12				
46	21	Prospect Beach (1973) 6 existing groins repaired, 2 additional groins constructed, 25,000 yd ^{3} of sand fill placed.		110667.00	55333.00	166000.00
		BI-FC-71				
		Town Total				617495.00
		WESTPORT				
47	6	Burial Hill Beach (1957) 17,000 yd ^{3} of sand fill placed along 500' of shore east of Burial Hill Creek.	5810.00	5810.00	5810.00	17430.00
		BI-FC-7				

ID NUMBER	LOCATION NUMBER	LOCATION (CONSTRUCTION DATE) DESCRIPTION PROJECT NUMBER	COST TO FED. GOV'T	COST TO STATE	LOCAL COST	TOTAL
		WESTPORT				
48	4	Compo Beach (1957) 2 stone groins constructed east and west of Cedar Point 260,000 yd ^{3} of sand fill placed between groins.	84544.00	71333.00	133667.00	289544.00
		BI-FC-13 BI-FC-2				
49	5	Sherwood Island, State Park (1957) 2 training walls constructed at the mouth of Burial Hill Creek, one groin constructed at west end of beach, 1,070,000 yd ^{3} of sand fill placed along 6,000 of shore.	186830.00	581002.00		767832.00
		BI-FC-1				
50	5	Sherwood Island State Park Existing training walls repiared.		19262.00		19262.00
		BI-FC-48				
		Town Total				1,094,068.00
			GRAND TOTAL			7425887.00