COASTAL DYNAMICS AND ENVIRONMENTS ON SANDY HOOK, NEW JERSEY

NORBERT P. PSUTY & LINDSAY NAKASHIMA

Center for Coastal and Environmental Studies,
Rutgers University, New Brunswick, New Jersey

GEORGE THEOKRITOFF

Department of Geology, Rutgers University,
Newark, New Jersey

INTRODUCTION

Sandy Hook is a complex and compound recurved barrier spit located at the northern end of the ocean shoreline of New Jersey (Figure 1). The spit is formed from the northerly transport of beach material derived from the erosion of beaches extending approximately 40 kilometers to the south. The shoreline of Sandy Hook consists of several distinct segments with different rates and forms of development. The spit system may be conveniently broken down for analysis into a set of subsystems, each with differing shoreline orientations to the approach of ocean swell and each experiencing different equilibrium conditions. These subsystems, or beach segments are identified on Figure 1 as numbers 1 through 7. Certain beach subsystems may be further divided into subunits, identified by lower case letters on Figure 1. Each of these experiences slightly different shoreline development. These smaller subunits are strongly affected by man-made beach protection structures. The effect of these structures in producing longshore movement of sediment through the spit system is considerable, as revealed in the conspicuous erosion downdrift of the beach protection structures in Segments 1 and 5.

The majority of high energy deep water waves approach the region from the east-northeast and east (Saville, 1954). However, wave refraction on the inshore portion of the continental shelf causes the shallow water waves to approach from the east-southeast (Fairchild, 1966). This region is also subject to the effects of mid-latitude and tropical cyclones, as well as to ocean swell generated by winds far out in the Atlantic Ocean. On the bayside of the spit, the limiting variables of wind speed, duration, and fetch distance favor wave generation from the northwest. Evidence of the importance of these northwest winds is seen in the orientation of bayside beaches perpendicular to this compass direction and also in micro-spit development to the south of these beaches.

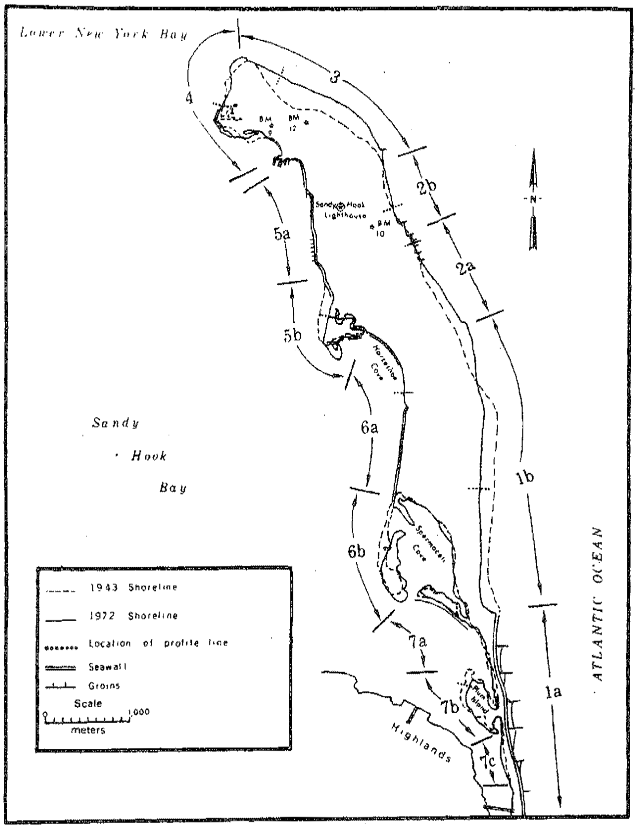

Fig. 1 Shoreline Change at Sandy Hook, 1943-1972.

Tides at Sandy Hook are semi-diurnal with a 1.4 meter mean range and a 1.7 meter spring range. However, during passage of a storm, strong easterly and northerly winds will pile water against the shore and raise water levels considerably whereas westerly and southerly winds will lower water levels. Foreshore sediments on oceanside and bayside beaches are composed of well sorted sands in the medium size range. The sands consist primarily of quartz particles with less than 5% by weight of potash and sodium-lime feldspars, and less than 1% by weight of heavy minerals concentrated in the size range of fine sand (McMaster, 1954).

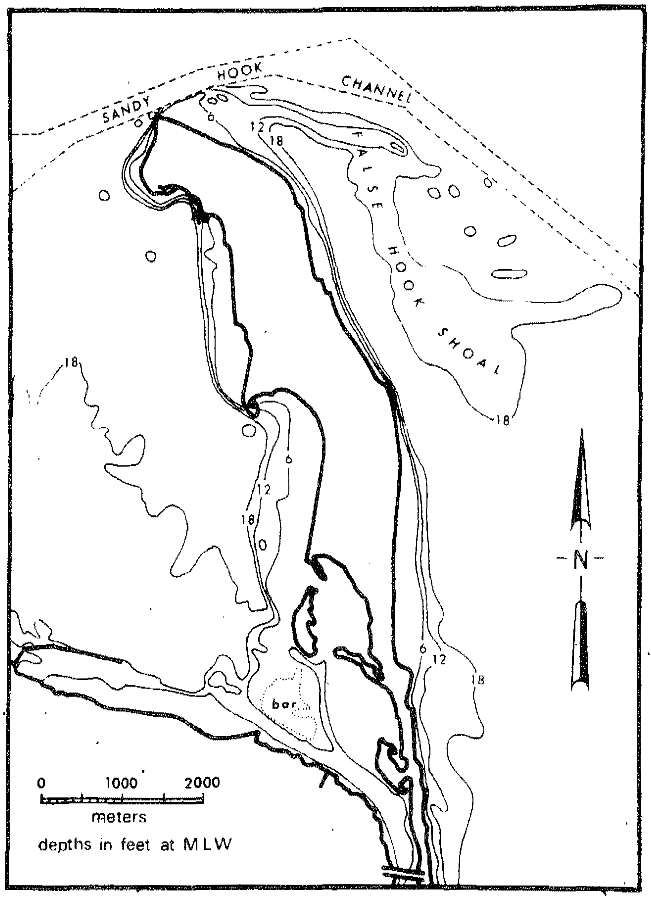

Fig. 2 Hydrography at Sandy Hook.

Figure 2 identifies the hydrographic features which influence the transport of sediment through the system. The Sandy Hook navigation channel at the distal terminus of the spit is the access route to Raritan Bay and Arthur Kill. It is used by large sea-going vessels and is maintained at a depth of about 10 meters. Periodic dredging of this channel precludes further northward growth of the spit. Channel maintenance, therefore, has a direct influence on the development of Segments 3 and 4. The sediments dredged from the channel are predominately sand and may be used as beach fill.

The spit platform, delineated by the 6-foot, 12-foot, and 18-foot contours, is the subaqueous extension of the headland beach upon which the spit ridge (beach and dune system) has formed. The platform extends out a considerable distance on the bayside and has a filtering effect on the higher bayside waves during low tide. This condition is most pronounced when strong northwest winds occur. These winds generate high energy waves and blow water out of the bay. During such periods, spilling waves may occur across the width of the shelf and a considerable amount of material may be moved alongshore within this broad surf zone. However, the presence of deep coves downdrift of Segments 4 and 5 prevents significant transfers of sediment between segments by this mechanism. False Hook Shoal appears to be the seaward extension of the spit platform formed by ebb tidal currents passing the distal portion of the spit. This shoal affects wave refraction and thus controls shoreline orientation and beach development on Segments 2 and 3.

Table 1 reveals the magnitude of beach processes within each of the subsystems. Table 2 identifies the amount of shoreline change which occurred within each segment from 1943 to 1972. The two tables reveal that bayside beaches are retrograding at surprisingly high rates. This is due to a reduction in the quantity of sediment being passed to downdrift segments, and to higher wave steepnesses.

The differences in response to changing wave processes on oceanside and bayside beaches at Sandy Hook have been discussed in detail in Nordstrom (1975). It was concluded that bayside beaches (Segments 4 through 7) appeared to be more in equilibrium with storm conditions than oceanside beaches (Segments 1 through 3). Lower bayside wave energies occurring between storms have little effect on profile development, and foreshore slopes inherited from previous storms undergo minor change. There is little or no deposition between storms. The rate of return is too low to provide adequate protection against dune erosion during the next storm, and dune and foreshore erosion will continue. On the oceanside, in contrast, long, high energy, constructive waves occurring between storms rapidly restore the sediment. These deposits provide a buffer zone to protect the beach and dune against the direct attack of storm waves. The net displacement of the shoreline, therefore, is reduced because of the beach recovery between storm periods.

Table 2: Change in the location of the Sandy Hook shoreline, by segment, from 1943 to 1972. The values were determined from Figure 1 and represent the change, in meters, along representative lines running perpendicular to the 1973 shoreline.

Shoreline Change 1943 - 1972

Site	Along line of maximum change	Average for entire segment	Average for segment per year
1a	*+90 meters*	*+50 meters*	*+1.7 meters*
1b	*−190*	*−153*	*−5.3*
2a	*+150*	*+142*	*+4.9*
2b	*+60*	*+31*	*+1.1*
3	*+460*	*+325*	*+11.2*
4	*−90*	*−20*	*−0.7*
5a	*+40*	*+40*	*+1.4*
5b	*−120*	*−95*	*−3.2*
6a	*0*	*0*	*0*
6b	*−170*	*−104*	*−3.6*
7a	*+25*	*+9*	*+0.3*
7b	*−85*	*−69*	*−2.4*
7c	*+100*	*+43*	*+1.5*

Sandy Hook As A System

The net sediment migration along Sandy Hook spit is from south to north on the oceanside and from north to south on the bayside. This implies that the movement of sediment from Segment 1 to Segment 7 may be treated as one continuous system with unidirectional flows of energy and matter. Shoreline development within any of the subsystems will then be dependent upon perturbations in the energy-matter relationships in all updrift segments as well as changes in the direct application of energy to the individual subsystem. Perturbations in the system may be man-induced such as the construction or removal of groins and seawalls, dune destruction, or beach fill operations. Natural perturbations, usually associated with storm events, may also occur.

Oceanside beach segments are highly dependent on activity in the updrift segments and yet exhibit distinct differences in form because of variations in wave energy and sediment supply. The ocean beach system is characterized by alternating natural and controlled beaches, and by discrete segmental orientations that differ from the equilibrium logarithmic spiral form. [For a discussion of planimetric curvature as a definition of the state of adjustment of the spit form, see Yasso (1964a, pp. 66-68)]. As such, the distinct character of the segments defines complex subsystems within an open ocean system extending around the distal recurve from Segment 1 through Segment 4.

Although the application of an open system model appears suitable for the study of the oceanside segments, it may be argued that the bayside behaves more as a series of closed systems where deep coves and extensive seawalls prevent the transfer of sediment into, or out of, some of the subsystems. This is particularly true of Segment 5. The use of an open system model for the entire spit is not incompatible with bayside beach development, however, since inevitably, such barriers to longshore sediment movement will be bypassed. However, because this paper is intended to establish a model which can be used to solve short-term beach protection problems, Segment 5 will be considered a closed system.

The broad shallow spit platform which extends from Segment 6 to Segment 7 may allow transfers of sediment and this may be considered a separate open system. At present, however, little is known of sediment transfers within this complex region, and this definition is quite tenuous.

Therefore, Sandy Hook spit may be separated conveniently into several units. The highly interrelated ocean beach segments can be considered as an open system. Because of the lack of sediment exchange between the bayside segments, Segments 5, 6, and 7 can be viewed as closed systems.

Marine Biota

In addition to providing intertidal and shallow subtidal essentially sandy substrate, Sandy Hook separates two distinct, albeit transitional into each other, bodies of water: the open water on the east side lying on the continental shelf; and the partly enclosed waters of Sandy Hook Bay on the west side.

These bodies of water differ environmentally. Perhaps the most immediately obvious factors bearing on the environment are the waves generated over the ocean and continental shelf that affect most strongly the east side of Sandy Hook, the partial enclosure and generally shallower bathymetry of Sandy Hook Bay, and the influx of fresh water, and silt and other terrigenous matter into Sandy Hook Bay from the Navesink and Shrewsbury Rivers. These factors can be expected to result in a greater degree of mixing and turbulence of the open water on the east side of the hook resulting in smaller ranges of water temperature and salinity, and in the maintenance in suspension of cells and particulate organic matter. In contrast, the waters of Sandy Hook Bay, particularly at the Shrewsbury Inlet, are subject to dilution by fresh water and the entry of silt and other terrigenous matter which is responsible for the development of tidal mud-flats locally on the south eastern shore of Sandy Hook.

These expectations appear to be confirmed by data interpreted by Powers and Backus (1951) who show annual surface temperature ranges of 44 to 75 °F off Horseshoe Cove; 45 to 71 °F off the northern tip of Sandy Hook; and 46 to 68 °F off the southeastern shore of Sandy Hook. Furthermore, Stockton and Backus (1951) show annual surface salinity ranges of 24 to 27 ‰ off Horseshoe Cove; 25 to 27 ‰ off the northern tip of Sandy Hook; and 27 to 30 ‰ off the southeastern shore of Sandy Hook. Temperature and salinity data for Sandy Hook Bay taken by Ayers (1951) in December 1948 and by Ichiye (1965) in August 1963 are consistent with the interpretations of Powers and Backus (1951).

These, and other environmental differences result in and are reflected by the geographic distribution of the marine biota. For the purposes of the present trip, the shells and fragments of benthic organisms washed into the intertidal zone provide a relatively accurate and conveniently studied sample of such organisms in the vicinity.

SEGMENT DESCRIPTIONS

East Shore Biota

The intertidal and shallow subtidal substrate on the east side of Sandy Hook is overwhelmingly sandy with a minute, but important, aggregate area of hard substrate provided by the artificial rock groins built to control the erosion of sand.

Owing to its unstable nature, the sandy substrate of the intertidal zone carries a sparse biota principally of anthropods (May, 1980): *Ovalipes ocellatus* (lady crab) and *Hippa talpoida* (sand bug) at its lowers limit, and various amphipods. More or less complete and fragmentary shells washed up on the beach are indicative of shallow subtidal benthic species. In point of numbers, these are dominated by *Spisula solidissima* (Atlantic Surf Clam), infaunal in sand at shallow depths from the strand line to 30 meters. Less abundant, but still common, is *Mytilus edulis* (Common Blue or Edible Mussel), a byssate epifaunal bivalve that is capable of establishing itself on stable bottoms. In addition, there are small numbers of *Aequipecten irradians* (Atlantic Bay Scallop), *Crassostrea virginica* (Eastern Oyster), *Crepidula fornicata* (Common Atlantic Slipper Shell), *Anomia simplex* (Atlantic Jingle), *Anadora transversa* (Transverse Ark), *Lunatia heros* (Common Northern Moon Snail), *Bittium?* sp., *Cancer irroratus* (Rock Crab) and *Limulus polyphemus* (Horseshoe Crab).

The localized hard substrate, represented by artificial rock groins, shows vertical zonation: a barnacle zone overlying and merging into a blue-mussel zone.

SEGMENT 1

This portion of Sandy Hook, aligned on a north-south axis, is made up by two distinct subsystems. The southern subunit, 1a comprises the groin field and seawall protected section. North of this, Segment 1b is a natural unprotected beach whose orientation to storm and swell waves is the same as Segment 1a but the location is offset to the west. The artificially stablized shore extends south to Long Branch and thus Segment 1a represents an armored barrier spit beach system. Segment 1b can be viewed as being representative of the equilibrium state of the total Segment in the absence of beach protection structures.

Segment 1 is the portion of the spit most exposed to hydrodynamic processes because of the minimal refraction of dominant waves from the eastern quadrant. Energy inputs to this subsystem are therefore higher than to the other subsystems (see Table 1 for wave statistics). Sediment transfers within this high energy subsystem are not correspondingly high because of sediment entrapment in the groin field within Segment 1a. This deficit of particulate matter results in removal of stored sediment from Segment 1b during storms when the energy to sediment disequilibrium exists. Beach profile development in response to erosional and depositonal waves is along classic lines and the beach in Segment 1b demonstrates the cyclic form of development noted by Hayes and Boothroyd (1969) on high-energy East Coast beaches (Nordstrom, 1975). Analysis of the sweep zone profiles presented in Figure 3 reveals the beach to be a narrow equilibrium beach with the profile responding to changes in wave energy by sediment migration between the upper limit of swash and the surf zone, with the beach pivoting about an intertidal fulcrum.

The cumulative effect of beach processes is the extension of Segment 1b into Segement 2a by both beach and longshore bar drifting processes. In the absence of beach protection structures, high wave and current energies transport a considerable volume of sand

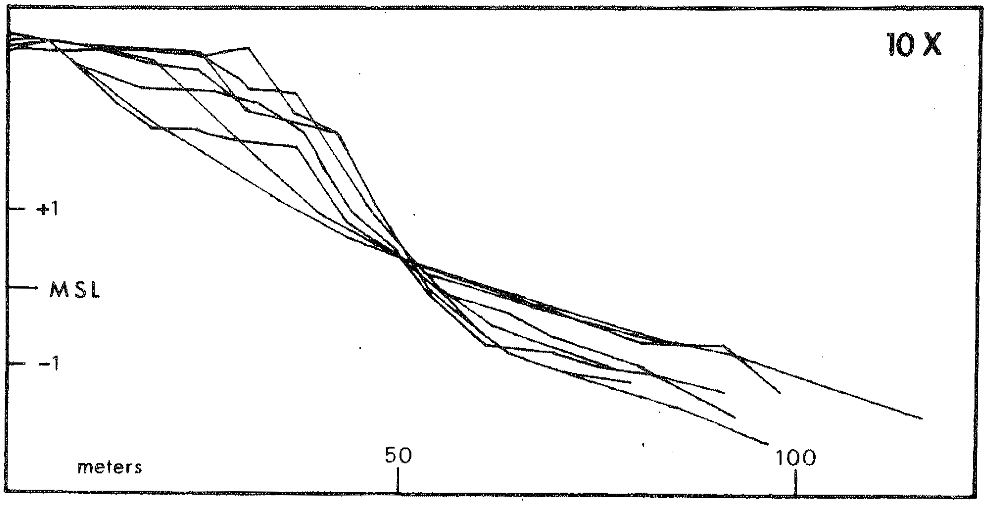

Fig. 3 Sweep Zone Profiles, Segment 1b.

alongshore, resulting in conspicuous Segment growth. It is thought that the segmental extension primarily occurs during storm periods when the disequilibirum exists between the alongshore sediment budget and wave energy input. This, in turn, suggests a pulsating sand conveyor system along the oceanside beaches that might be profitably studied through the application of the kinematic wave theory suggested by Leopold, Wolman, and Miller (1964, pp. 212-214).

In the kinematic wave context, the transport rate is minimized when the linear concentration approaches zero. [Linear concentration at any place is measured by the quantity of sediments per unit of distance alongshore]. This occurs in low energy states when few particles are in motion. The transportation rate is also minimized when linear concentrations are large and sediment concentrations are very dense. This occurs during high energy states when, because of high frictional energy losses, little energy is available for sediment transportation. This condition occurs during the storm stage following the peak erosion of the beach. As storm energy decreases, sedimentation will occur. The location of the disposition will be downdrift of the source area because of sediment movement during the build up of energy prior to maximum concentration. Following sedimentation, the linear concentration is reduced to a point where the transportation rate again is maximized. The kinematic wave theory thus suggests that longshore transport is higher prior to, and just after, the maximum concentration of suspended sediment occurs. This pulsational sediment transport model is much different than the common model of the "conveyor belt" that transports an increasing quantity of sediment with increasing storm intensity and deposits the material when the storm dies out.

The general model of storm-caused sediment pulses can be applied to the segmental extensions along the ocean beaches as the matter linkage between the various subsystems. Allowances must be made, however, for decreasing energy states and man-controlled fluctuations in the alongshore sediment budget and the types of processes that are operative when applying the model to any specific segmental growth. The model also defines the dynamic interfaces across which the subsystems are linked and, thereby, the downdrift limits of each segment.

SEGMENT 2

The orientation and lower energy equilibrium state of Segment 2 has been shown by wave refraction and simulation studies of Sandy Hook (Allen, 1972 and 1973b) to result from the location and north-westerly alignment of False Hook Shoal (Figure 2). This middle shoreline segment is made up of two distinct subsystems. Subsystem 2a consists of a high, steep beach that is planar in form and profile. The beach is sheltered from the major disruptive effects of storms by the longshore bar representing the extension of Segment 1b.

Segment 2a has been studied in some detail by Strahler (1964) and Nordstrom (1975), who noted that the offshore bar favors an equilibrium shoreline configuration. Due to the sheltering effect of the offshore bar, beach erosion does not always occur with the passage of small storms. When erosion does occur on Segment 2a it is not always accompanied by conspicuous change in foreshore slope as it is on Segment 1. Usually there is considerably less slope variability here than is experienced on Segment 1. The cumulative effect is the deposition of beach material derived from Segment 1b with little change in beach slope and shoreline orientation. The progradation of the foreshore, then, is both parallel and planar.

Segment 2a and Segment 2b are separated by a groin field at the north end of Segment 2a. The groin field prevents beach drift of sand through this portion of the system because the downdrift groins are not quite full. The offshore bar continuation from Segment 1b along Segment 2a terminated at this groin field and therefore does not favor a stable shoreline. The higher wave energies and decreased inputs of sediment to the foreshore result in a readjustment of the equilibrium state of the shoreline from the stable linear form characterizing Segment 2a to the retograding log-spiral shoreline configuration suggested by Yasso (1964b) for headland-bay beaches. A longshore bar, representing the offshore extension of beach Segment 2a, has recently extended across the reentrant created at Segment 2b. This bar creates a situation similar to that at Segment 2a, and beach response at Site 2b is similar to Site 2a. The beach has a steep slope with parallel and planar shape dynamics, retreating because of the decreased alongshore sediment supply showing the necessity of the system to maintain itself by drawing on sediment storage within the system. The removal of sand from storage at Segment 2b thus represents the most important source of sediment input into Segment 3.

SEGMENT 3

The northwest extension of Segment 2b has been the most conspicuous change along Sandy Hook in recent years. Figure 4 reveals a growth of about 360,000 square meters from October, 1969 to September, 1973. In October, 1969 a single micro-spit form is shown arcing from the segmental break. By May, 1970 this had attached onto the shoreline but was breached by lagoon tidal-head energies. Creation of a second spit, curving from the fulcrum of the primary spit is also shown, along with some lagoon infilling from high tide

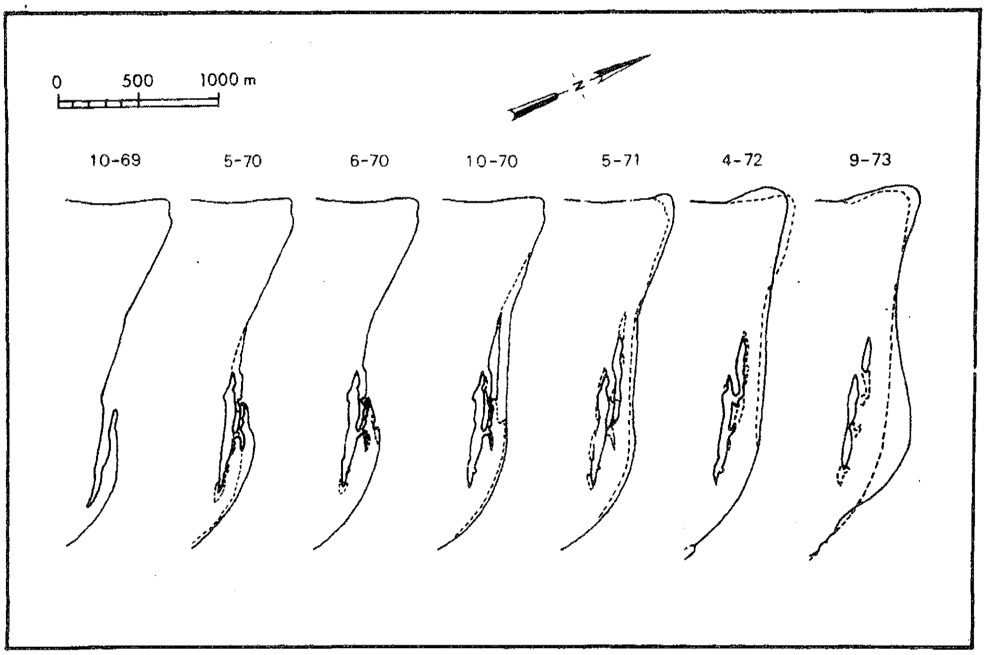

Fig. 4 Accretionary Extention in Segment 3, 1969-73.
The dashed line represents the beach outline in the previous temporal unit.

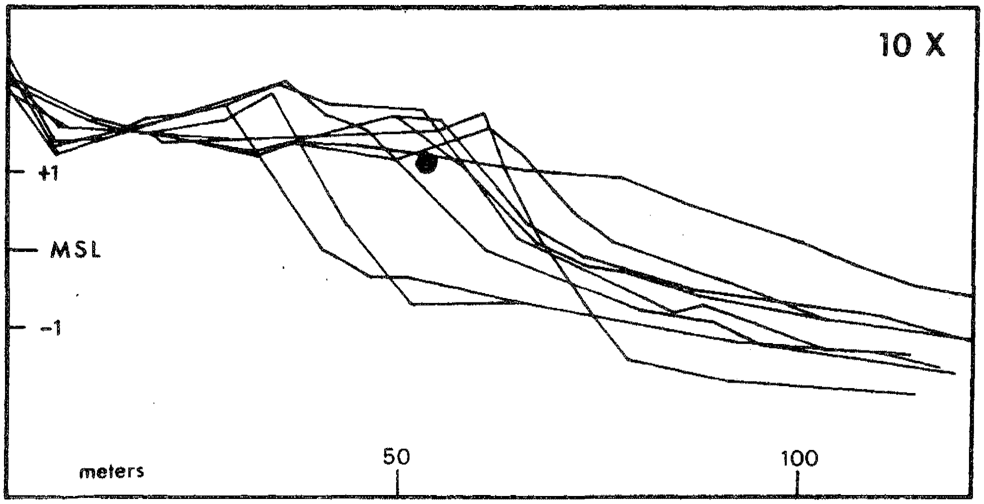

Fig. 5 Sweep Zone Profiles, Segment 3.

washover. One month later (June, 1970) the size of the second spit had attached its downdrift terminus to the beach of Segment 3. During the 1970-71 winter, the complex lagoon was separated into two parts with connecting flow occurring only at high tide. This was accompanied by further accretion around the distal point of the Hook. The April, 1972 shoreline shows continued lagoonal readjustment from overwash and internal circulation, a general oceanside straightening (with alternate erosion and deposition), and continued growth of the distal lobate beach. Another wedge of sediment, representing a future extension of Segment 2b, also appears to be entering the system. The September, 1973 shoreline shows even further lagoonal infilling and distal accretion. The wedge of sediment from Segment 2b has been greatly enlarged and has resulted in considerable progradation at the arc.

The complex form of the segmental extension is favored by the sharp break in shoreline orientation. Allen (1973a) showed this extreme recurve angle to be a function of extreme wave refraction caused by very shallow water and the orientation of the north end of False Hook Shoal. Field work conducted at this site in the summer of 1970 to determine rates and mechanisms of formation suggested that the primary method was beach drifting. The extreme break in orientation appears to diffuse the longshore component causing general nearshore sedimentation which, in turn, results in spit platform construction. The beach itself shows accretion by swash bar processes and subsequent extension of the spit to close the tidal inlet. Afterwards, the profile development displays continued accretion with little change in foreshore slope (Figure 5). The prograding equilibrium is favored by the low wave energies that, in turn, are constrained by feedback caused by growth of the spit platform. The wide, shallow platform decreases the available ocean swell energy that can be applied to the foreshore. Reversing shallow water currents generated by waves and ebb and flood tides also enhance the depositional trend. The general accretion has resulted in the straightening of the shoreline and the promotion of sediment transport through beach drifitng in Segment 3. In this sense, the rate of progradation is lessening with the new shoreline shape, and sediment input for lateral segmental growth along the shoreline axis is increased.

The extension of Segment 3 is complicated because of its location at the distal portion of the spit. Not only does it thus represent a partial sediment sink but energy inputs are correspondingly complex. Steep, storm-generated bayside waves may represent higher energy spectra than the filtered ocean swell. NOAA tidal charts reveal high velocity tidal races. All of these in combination appear to modify the segmental extension to a lobate shoal form at the end of this spit recurve. General shoreline advancement appears to result, as in the extension from 2b to 3, predominately from beach drifting. Spit platform progradation and filling of the Sandy Hook Channel appears to result from nearshore sedimentation from longshore currents. The redistribution of nearshore deposits prevents this area from being termed a true sediment sink in that tidal currents move the outputs of Segment 3 towards False Hook Shoal. This shoal increases the feedback control by filtering ocean swell energy through bottom friction losses and wave refraction. Furthermore, there is evidence that the oceanside system effectively bifurcates at the distal portion of the spit into beach drifting outputs towards Segment 4 and longshore component outputs to the spit platform and eventually towards False Hook Shoal.

The recent extension of Segment 3 is largely associated with recent erosion along Segment 2b (this erosion is not revealed in Table 1 or Figure 1) and, less so, with the erosion at Segment 1b. In future dredging operations in Sandy Hook Channel, much of the dredged spoil may be pumped back to Segments 1 and 2. The implementation of this sediment recycling operation would result in the establishment of a closed exchange of sediment in the ocean beach system.

SEGMENT 4

Despite having the highest bayside wave energies and high wave steepness (Table 1), Segment 4 experienced very little erosion over the period from 1943 to 1972 (Figure 1). This is due to the inputs of sediment from Segment 3 offsetting some of the loss through bayside processes. The profiles indicate that erosion and deposition occur with little change in foreshore slope, particularly on the lower part of the foreshore. This zone is protected by the shallow spit platform that causes the larger storm waves to break about 150 meters offshore. Considerable quantities of sediment may be moved on the spit platforms during these periods when the surf zone is exceptionally wide. With return to non-storm conditions, the surf zone is limited to a narrow band on the foreshore by low wave heights and the steep foreshore slope.

The cumulative effect of beach processes at this location has been the straightening of the shoreline and an increase in the area of the spit platform. The material deposited represents the residual foreshore, dune, and ocean drift sediments. The deep cove, Coast Guard dock complex, and seawall in the northern portion of Segment 5 impede longshore transport out of Segment 4. This segment therefore represents the terminus of the ocean-wave dominated transport system.

WEST SHORE BIOTA

As on the east side, the substrate is predominantly sandy with artificial hard substrate represented by local seawall, wood pilings, and rocks. In addition, there are mud and silt flats on the east side of Spermacetti Cove and the east of Plum Island.

The sandy substrate in the intertidal zone between Sandy Hook lighthouse and Horseshoe Cove carries a sparse biota principally of arthropods: *Ovalipes ocellatus* and *Cancer irroratus*. Shells and fragments, representative of the shallow intertidal benthos, are dominated in point of numbers by *Mya arenaria* (soft shelled clam) with somewhat smaller numbers of *Mytilus edulis* and *Mercenaria mercenaria* (Northern Quahog or Hardshelled clam). In addition, there are *Modiolus demissus* (Atlantic Ribbed mussel), *Crepidula* sp., and *Limulus polyphemus*. There is a peat bed exposed on this beach at low tide.

The sandy beach located south of Spermacetti Cove and extending to Plum Island shows a greater area of silty and muddy sand deposition as well as silt and mudflats bound by smooth cord-grass, salt meadow grass, and marsh spike grass. *Modiolus demissus* occurs in the plant-bound silt. The most abundant shells and shell fragments on the beach are *Mya arenaria* with lesser numbers of *Modiolus demissus* and *Mercenaria mercenaria*, and rare examples of *Aequipecten irradians* and *Ensis directus* (Atlantic Jacknife clam). *Littorina* sp. grazes on algae in shallow pools left on mud substrate at low tide. The polychaete *Glycera dibranchiata* (Bloodworm) occurs as an infaunal element in the organic-rich sediment. *Limulus polyphemus* and rare individuals of *Cancer irroratus* can also be seen in the intertidal zone. There are poorly developed encrustations of barnacles on some of the few wood pilings and artificially placed rocks.

The western shore of Plum Island has a sand and pebbly sand beach; a peat bed, exposed at low tide, ranges up to 18 ins. in thickness. The dominant molluscan species represented by shells and fragments on the beach is *Mya arenaria* with lesser numbers of *Mercenaria mercenaria* and *Crassostrea virginica. Aequipecten irradians* and *Modiolus demissus* are rare. A sponge (*Chalinopsilla* sp.) is represented by rare detached fragments. *Limulus polyphemus* is common in the vicinity of the Shrewsbury Inlet: many individuals bear barnacles and *Crepidula.*

SEGMENT 5

Segment 5a is protected by a long seawall and there has been no change at this location. At Segment 5b, however, the rate of shoreline retreat is about 3.2 meters per year which is the highest of the bayside beach segments. The erosional imbalance results from seawall construction and is somewhat analogous to that occurring within Segments 1 and 2. Very little beach material passes the seawall to replace that lost in longshore transport and the beach experiences a negative sediment budget. The sediments derived from the eroding shoreline at Segment 5b are forming the prominent spit at the south end of the Segment. [This spit has been described in considerable detail in Antonini (1962), Wright (1962), and Yasso (1964)]. Considering the sharp break in orientation at the tip of this spit and the depth of water in Horseshoe Cove, it is unlikely that, much sediment is moved from Segment 5 to Segment 6.

Wave heights on Segment 5b are lower than at Segment 4 (Table 1) and tidal currents are not very well developed on the broad spit platform. The beach accordingly experiences little change as shown in the plotted profiles (Figure 6).

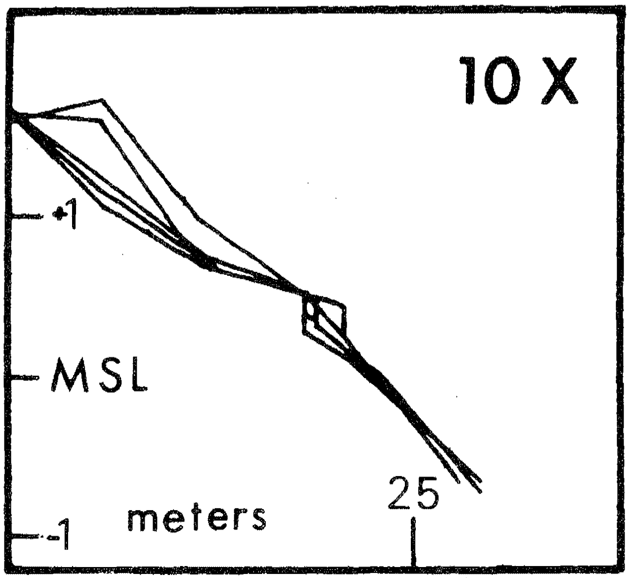

Fig. 6 Sweep Zone Profiles, Segment 5b.

SEGMENT 6

Segment 6 consists of two segments with dissimilar equilibrium conditions as a result of seawall construction. Segment 6a experiences minimal shoreline alteration - largely due to seawall protection and low wave energies (Table 1). Beach profile development is also minimized through low wave energies and a sheltered position relative to tidal currents. The profiles show considerably less change than that which occurs on the unprotected portions of Segment 4 and 5 which experience considerably higher wave energies.

Segment 6b has been subjected to extreme shape disruption recently where the bayside spit has been breached (Figure 1). This probably occurred under extreme storm conditions, which, in this case, may be considered cataclysmic. The return to equilibrium conditions is incomplete, pointing out the inability of low energy-low sediment mobility systems to readjust to prior conditions following extreme (low recurrence interval) events. This demonstrates the fragility of the limited oscillatory equilibrium levels of bayside beaches.

There is some accretion at the breach. This appears to represent storm overwash deposition and subsequent tidal modification with a small contribution from beach drifting. The slight southward extension, however, can be explained by normal wave processes - the shallow inlet would allow for the longshore transport of shelf sediments to the southern terminus of the island.

SEGMENT 7

The shoreline from Segment 6b to 7c represents the interaction of complex tidal and wave processes. Segment 7a and 7c have experienced less change than 7b (Plum Island). This is due to their sheltered position with respect to waves and tidal currents. Plum Island, however, is more exposed to bay waves and, more importantly, to high tidal current velocities. The latter probably account for the rather high rate of shoreline retreat in this segment compared to the unprotected portions of Segment 6 despite the higher average wave heights on that segment (Table 1). These tidal currents have been observed on the foreshore at 0.28 meters per second during periods when wave action was negligible.

The beach at Plum Island changes very little in form despite retrogradation. Beach development is, in that sense, similar to Site 5. The cumulative result is shoreline retrogradation with much of the sediment being lost to the spit platform or to spits which have formed to the north and south ends of Plum Island. Spit formation on the north end of the island attests to the importance of ebb tidal currents as mechanisms of sediment transport. The south spit has been shown to be affected by wave and flood tide deposition (Lipman, 1969). Internal tidal current gyres also appear to be the mechanism for accretion within Segments 7a and 7c.

BEACH MANAGEMENT PROBLEMS

The value of the application of systems theory in this study of the linkages of Sandy Hook is that information is provided on the sensitivity of the several parts of the spit system. The foundation is laid for an evaluation of many alterations of the spit system proposed for development of the spit into a Federal recreation area.

These include:

1. removal or relocation of groins and seawalls;
2. beach fill;
3. dredging of False Hook Shoal;
4. dredging of Sandy Hook Channel;
5. location and character of access roads and park structures.

REMOVAL OR RELOCATION OF GROINS AND SEAWALLS

The removal of groins and seawalls from selected locations along the spit would initiate a return of predisturbance shoreline geometry. The removal of the groins in Segment 1a would probably result in a rapid loss of sediment from storage, placing great stress on the seawall. The system will tend toward establishment of a locational equilibrium in line with Segment 1b. The enhancement of alongshore drifting, however, will add to inputs of sediment to Segment 1b and thus buffer Segment 1b from erosion. The inputs from Segment 1a will negate the need for retrieval from storage of sediment at Segment 1b and increase the connectivity between these subsystems. The effects of removal of groins from Segment 2 would be similar to those at Segment 1 with Segment 2b benefitting from increased sediment inputs. Losses from Segment 2a would not be as critical as at Segment 1a however, since the beach would still be protected by the longshore bar discussed earlier. Further, sediment storage is considerably greater here than on Segment 1 which lacks the broad high backshore and prominent dune line.

Some beach protection structures may be necessary for portions of the bayside shoreline where erosion is critical. Each extension of the seawall will lead to a reduction of the erosional zone, but will also reduce the exchange of sediments from one unprotected beach to another. Rock (rip-rap) and other static forms should be viewed as viable alternatives here for protection of buildings and roads. However, the attendant personal safety and aesthetic problems associated with these static forms would limit land use options.

BEACH FILL

Proposals for beach fill in Segments 1a and 1b exist. The result would be that added sediment inputs to Segment 1a will fill the groins (increasing the seawall protection) and enhance beach drifting. Offshore losses, while unknown, might be considerable. Beach fill at Segment 1b, on the other hand, would displace the equilibrium shoreline seaward. Beach fill in Segment 2b would help restore the shoreline of the whole second segment to its pre-disturbance geometry. Beach fill operations at this location were conducted in two phases during 1975 and 1976. This involved deposition of 270,000 cubic meters of sand dredged from the Sandy Hook Navigation Channel. The operations resulted in stabilization of the shoreline. Similarly, a short-term beach fill project was conducted in 1977 at Segment 1b to deter a serious erosion problem. The project included excavating and trucking approximately 153,000 cubic meters of sediment from Segment 2b. The project was successful in protecting the access road throughout the winter. A large-scale beach fill operation involving 1.5 million cubic meters of sand is presently being considered for this segment.

In most cases, bayside retreat does not presently offer a threat to buildings and roads nor does it result in a reduction of bathing space since bayside beaches are, as yet, undeveloped. In some cases (as in Segment 5b where the main road is being undermined), beach protection measures are required, and beach fill offers an alternative. The dominance of erosional conditions on the bayside sites and discontinuity of the closed systems suggest that much of the beach fill would be lost under winter (storm) conditions and not naturally replaced. Sand fill is thus viewed as inefficient.

Beach fill materials may be derived from the navigation channel during maintenance dredging operations or may be derived from any reasonable offshore borrow area. If the dredging operation in the borrow area is carefully controlled, desired changes in the offshore contours may be simultaneously effected. This will introduce changes in wave refraction patterns and thus affect the distribution of wave energy along the coast.

DREDGING OF FALSE HOOK SHOAL

The dredging of False Hook Shoal is attractive in that material which would otherwise be permanently lost to the system could be recycled updrift or passed on to the bayside beaches as beach fill. However, the presence of this shoal is highly associated with the present upper spit shoreline dynamics. Loss of the energy filter would lead to higher energy inputs to System 3 effecting less distal growth. This would appear to reduce sediment transport into the ship channel but with uncertain shoreline displacements. Dredging the northern portion of False Hook Shoal would also theoretically result in a displacement of the distal recurve to the west, thus lessening the problem of channel filling. [The displacement of the offshore tidal shoal of a spit towards the proximal portion of the spit has been simulated by computer by King and McCullagh (1972) and Allen (1973b) who point out that the major effect is a tendency for the distal portion of the spit to recurve more sharply bayward.]

LOCATION AND CHARACTER OF ACCESS ROADS AND PARK STRUCTURES

As an alternative to permanent coastal facilities which must be protected by standard beach protection measures, limited or temporary facilities (e.g., graded roads rather than black top, removable bath houses) may be constructed which may be dismantled and reused or "written-off". Care should be taken that such structures, when eventually reached following long term erosion, do not form obstacles to sediment transport along the foreshore and introduce undesired perturbations in the natural system.

SUMMARY AND CONCLUSIONS

The spit system is seen to be the result of complex energy (wave and current) and matter (sediment) flows within, and between, several very distinct beach segments. Each of the segments is characterized by different equilibrium conditions resulting from its orientation to ocean swell, winds, and tidal currents. Some of the subsystems, such as Segments 5a and 6a are protected by seawalls and undergo no change. In others, such as 5b and 7b, storage of matter is being rapidly reduced without replenishment. The latter condition shows a tendency toward destruction of system identity, and such segments are considered closed systems. Still other systems, such as 2a and 3 are open systems and there is a continued rapid influx and outflow of energy and matter. Examination of the rate and form of the extension of Segment 2b into Segment 3 indicates that this influx and outflow may be periodic rather than continuous and that accretion and erosion between adjacent segments are highly related, as expected of open systems.

Once the mechanisms for transport and the quantities of sediment moved are known, recommendations can be made for recycling sediment in the open system of the ocean beaches and for sediment augmentation in the bayside closed systems. Given a calibrated model, it should be possible to predict the effects of different energy levels and different sediment inputs and thus more completely anticipate the future development of the Sandy Hook spit.

ROAD LOG

Mileage	Description
0.00	Entrance gate to Sandy Hook Unit of Gateway National Recreation Area. Proceed straight (north) on Hartshorne Dr. Segment 1a. Seawall to the right (east) was constructed at the turn of the century and fronts the narrowest portion of the spit.
1.15	Enter parking lot on right (east) and walk out to seawall. Segment 1a. This represents the northern terminus of a seawall and groin field that extends 8.5 miles (14 km) southward. Beaches in this segment are either non-existent or very narrow. High wave energy, a low littoral drift rate, and excessive downdrift erosion combine to produce a negative sediment budget.
1.20	Turn right (north) at parking lot exit and continue along Hartshorne Dr.
1.40	Segment 1b. At this point the road parallels the most critical zone of erosion on Sandy Hook. The beach here is narrow and forms a log-spiral in plan. Recent beach nourishment and sand bag dike operations have been employed as shore protection measures. Note the absence of dunes and the presence of overwash deposits on left (west) side of the road.
1.75	Segment 1b. Site of bath house destroyed by storm activity in February, 1978. Parking lot forms on extensive impervious surface which facilitates backbarrier flooding.
1.90	Turn right (east) into National Park Service Visitors Center parking lot and walk out to beach. Segment 1b. Regressive log-spiral shoreline of Segment 1b and offset terminus of seawall in Segment 1a are evident in a southward view. This Segment experiences cyclic beach response and very high erosion rates (Table 2). Ocean swell and wave-induced currents are dominant processes. Sands on the oceanside are well-sorted and medium size. Beach cusps are a frequent occurrence. The site of a second bath house lies 100 yards (30 m) to the north.
2.05	Return to Hartshorne Dr. and proceed north (right).
2.35	Continue through main gatehouse.

2.75 Bear right (east) on gravel road to South Fishing Beach. Segment 2a. This Segment primarily responds to waves and wave-driven currents. and experiences relatively high storm and swell energies. Backshore features a natural dune belt. Beach is wider than that found in Segment 1.

3.50 Return to Hartshorne Dr. Turn right and continue north.

4.30 Bear right (east) on paved road (Atlantic Dr.)

4.50 Continue left (north) along Atlantic Dr.

5.20 Enter gravel parking lot on right (east) at Battery Gunnison and walk to beach. Segment 2b. The nearshore in this Segment is characterized by a longshore bar which shelters the beach under high wave conditions. Cyclic beach response is solely associated with major storms. Ocean waves and wave-driven currents are dominant processes. The entire Segment is backed by a natural dune system. The beach north of the timber groin is used as a beach fill borrow area for nourishment of Segment 1b.

5.30 Exit parking lot and turn right. At intersection turn right (north) on Atlantic Dr. Lighthouse to the left (west) marked the terminus of the spit in the 18th century.

5.75 Turn right (east) on gravel road to North Fishing Beach parking lot and walk to beach. Segment 3. This beach is sheltered by longshore bars and False Hook Shoal. Net deposition occurs in this Segment which is effected by the complex interaction of waves (ocean and bay) and currents (tidal and wave-induced). The shoreline in this Segment is not straight but displays a concave seaward geometry as one walks northward. The tip of the spit exhibits the highest dunes and an ebb shoal which forms False Hook Shoal. Spit growth occurs to the northwest but is limited by annual dredging of Sandy Hook Ship Channel.

5.90 Return to Atlantic Dr. and turn right (north).

5.95 Bear left (west) and proceed straight to bayside.

6.20 Continue through intersection and turn left (south) on Hartshorne Dr.

6.40 At this point a seawall fronting large houses (Officer's Row) is visible. Segment 5a. Tidal currents and bayside waves are important processes. Bayside Segments possess shore protection structures and deep coves which inhibit sediment transfers to adjacent Segments. The highest bayside waves are experienced here and Segment 4 to the north. Segment 4 lies under jurisdiction of the U.S. Coast Guard and is a restricted area.

6.90 Bear right (south) at intersection.

7.10 This is the terminus of the seawall in Segment 5. The formation of a log-spiral beach is occurring immediately to the south of the seawall. This Segment is undergoing the greatest amount of erosion due to locally generated swell and storm waves. A peat bed is exposed on the low tide foreshore and a transgressive sequence is forming over the salt marsh deposit. Sediment eroded from this beach is important to development of a spit farther south.

7.60 The aforementioned accreting spit can be seen to the right (west) across Horseshoe Cove. Segment 6a. Wave activity and tidal currents are less important here than other bayside sites. The beach is extremely thin and erosion is threatening the road adjacent to the seawall.

8.40 Limited access parking area. Segments 6a and 6b. This Segment experiences net erosion. Sediments are continuously eroded from behind the timber bulkhead and a deep cove updrift limits input of sediment. The southern extent of this Segment exhibits a small flood tidal delta formed in a breach at Spermacetti Cove. Sediments in this Segment are primarily coarse sands and lag gravels.

9.40 Return to Hartshorne Dr. and turn right (south).

11.60 Segment 7. This permits a view of Plum Island and the Shrewsbury River. As would be expected, the lowest wave energies are encountered here. Plum Island is undergoing erosion with accretion occurring at both ends. Such accretion favors formation of a salt marsh habitat. Coarse sands and lag gravels are present. Much of the sediment composing this island is fill, including the land that connects it to Sandy Hook.

End of trip.

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