Vol Pt. 1

DELAWARE'S CHANGING SHORELINE

SOUTH COASTAL SUSSEX COUNTY

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SOUTH COASTAL SUSSEX COUNTY

Introduction

The Delaware shoreline, both of Delaware Bay and the Atlantic Ocean, is an unstable, ever-changing environment subject to the conflicting natural processes of deposition on the one hand and erosion and submergence or transgression on the other hand. The first process increases the landward side of the shoreline and the latter processes decrease the landside. In a natural state, without human interference, the shoreline is constantly shifting, moving inland here and seaward there, but in large scale terms of the entire Delaware coastline over a very long period of time the sea has advanced at the expense of the land. This slow but steady advance of the sea goes on today and is expected to continue for the foreseeable geologic future.

The purpose of this publication is to describe, in non-technical terms, the nature of the physical forces of the sea acting upon the shoreline, the effects of mans' devices upon these forces and the resulting configuration of Delaware's Bay and Ocean shoreline. Some specific questions this publication attempts to answer are:

What are the forces of erosion and deposition that cause some beaches to diminish and others to grow?

What are the shoreline geomorphological and geological features that are acted upon and shaped by these forces?

What are the consequences to mans' use of the shoreline and coastal area of these physical forces and processes?

What is the geological history of changes in Delaware's shoreline and what is the probable (foreseeable) geological future?

What actions has man taken to reduce or re-direct the natural processes of shoreline change and what are the results of these actions?

How can man work with nature so that over generations of time he may safely and productively use the shoreline and coastal resources without irreparably damaging or destroying them?

To answer these questions, the State Planning Office commissioned the Department of Geology, University of Delaware, to study the Delaware shoreline. This paper summarizes the findings of that study and includes some supplementary material from other sources. General principles of processes of shoreline change and of mans' measures to control those processes are described, followed by a description of the coastal features and shoreline changes from the Smyrna River to Broadkill Beach; Indian River Inlet to Fenwick Island.

General Principles

The basic natural process occurring over a long period of time and along the entire Delaware coast is the advance of the sea over the land, that is, a rise of sea level with respect to the land surface called transgression. Figure 1 illustrates this advance of the sea over the past 12,000 years and the coming 75,000 years.

Three geologic processes cause this transgression. The first is the actual rise of sea level. During the Pleistocene age until about 15,000 years ago much of the Northern Hemisphere was covered by ice caps that advanced and retreated over thousands of years as the earth's climate cooled or warmed. Since the retreat of the last great ice cap until now the sea is believed to have risen by about 440 feet. Evidence along the Delaware coast indicates that this rise of sea level is continuing. The second geologic process causing the sea level rise is the compaction of sediments in the earth's crust causing the sea floor and nearshore land surfaces to sink. The third process is that of movements of the earth's crust called the tectonic effect.

Although sea level rise is a continuing long term process it has been very irregular over the centuries. In some periods it may rise dramatically while in others it may be slight or even temporarily cease. Before 5,000 years ago sea levels rose at rates of more than one foot per century along the Delaware coast; over the last 2,000 years it has risen at a rate of less than one-half that rate (0.41') per century.

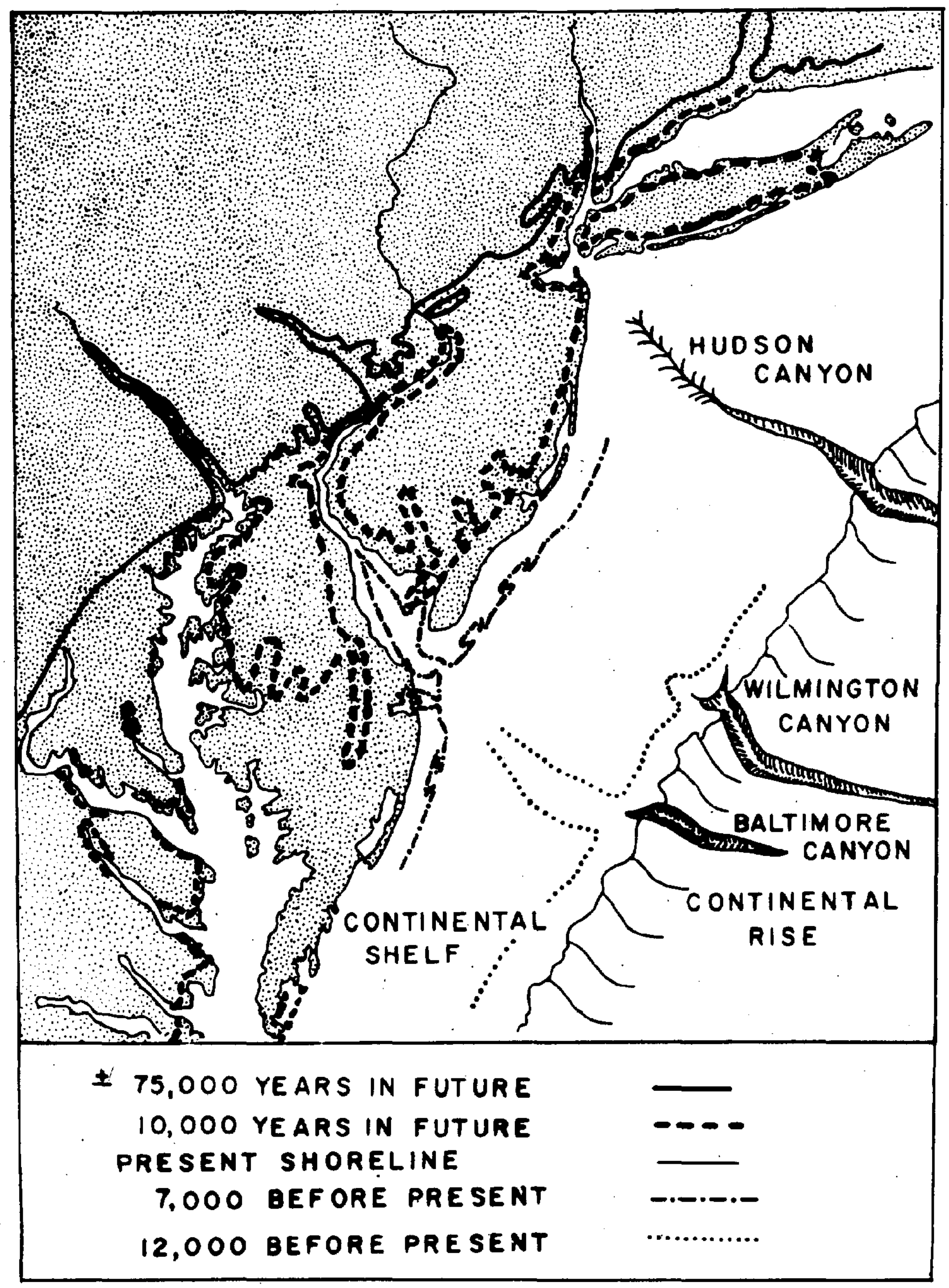
When sea level changes have been plotted for an area, local effects such as compaction of sediments can then be determined. For example, at South Bowers the surface may be subsiding at about one-half foot per century in addition to being subjected to a sea level rise of about one-half foot per century. On the older, firmer Pleistocene upland just north of the Murderkill River at Bowers compaction is not significant. Thus, building at South Bowers is a more hazardous enterprise than it is at Bowers just a few hundred feet away. At South Bowers in the past a one foot rise of the sea level has resulted in up to 700 feet of landward erosion; demonstrating that one foot per century is significant indeed to mans' use of the South Bower's shoreline.

The rise of sea level has a marked effect on Delaware's barrier beaches as shown in Figure 2. As the sea rises its waves attack the beach at a higher elevation. The resulting increased coastal erosion and dune movement caused by blowing sands results in a slow but steady landward and upward movement of the shoreline. That is, the relative positions of dunes and beaches remain the same, but the entire coastal system is moved landward.

In addition to the process of transgression (relative sea level rise) two other geologic processes affect coastal change. These processes are littoral transport and coastal washover.

Littoral transport is the movement by waves and currents of sediments near the shore both parallel to shore (longshore transport) and perpendicular to shore (onshore-offshore transport). Sediment movement is a continuous and

FIGURE 1



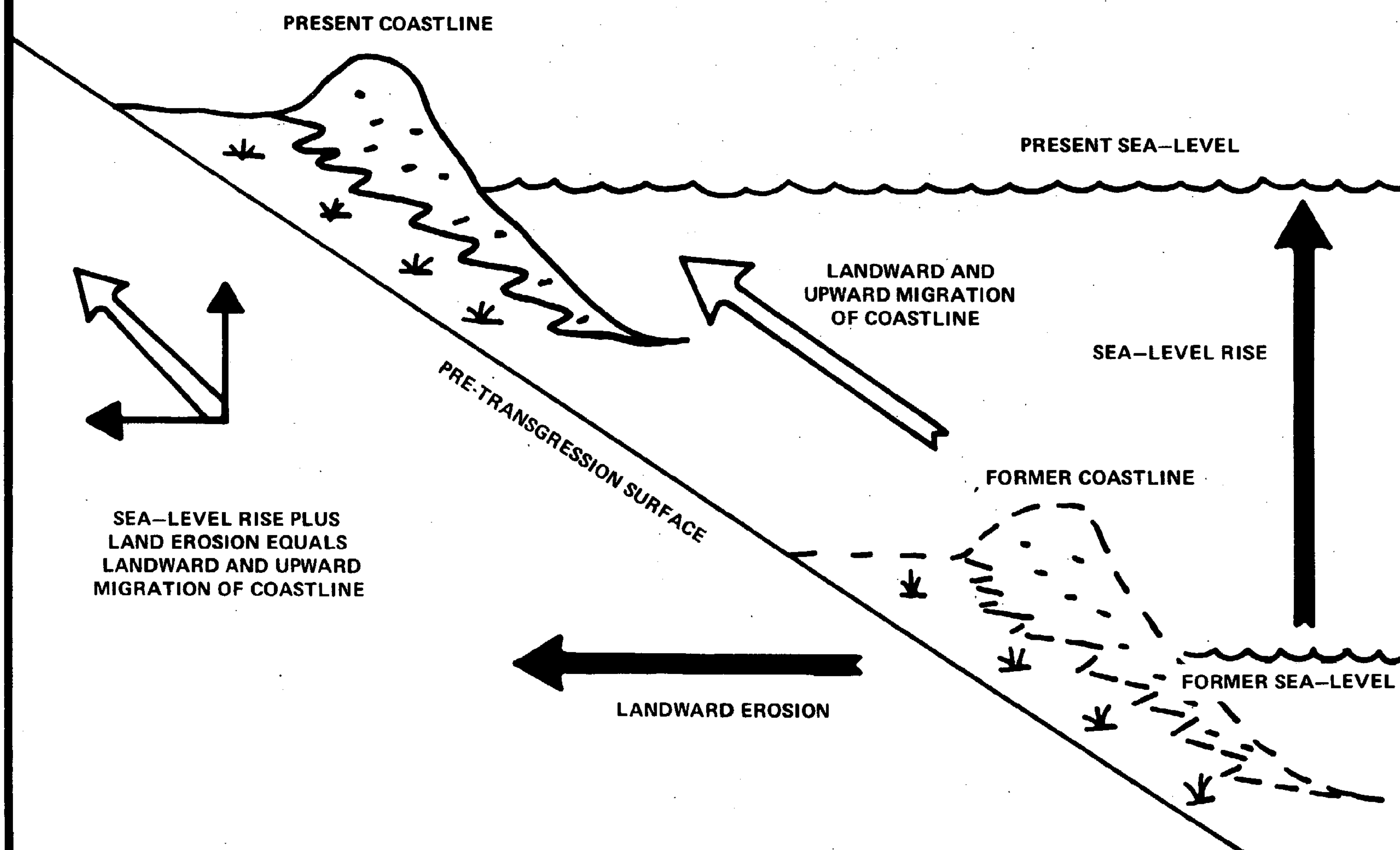
PALEOGEOGRAPHY OF DELAWARE'S SHORELINE DURING THE HOLOCENE EPOCH OF THE LAST 12,000 YEARS AND TENTATIVELY PROJECTED INTO FUTURE INTERGLACIAL AND NONGLACIAL CONDITIONS.

Source: The Coastal Zone of Delaware, The Final Report of the Governor's Task Force on Marine and Coastal Affairs, 1972.

FIGURE 2

THE BRUNN THEORY

OF SEA–LEVEL RISE AS A CAUSE OF COASTAL EROSION



cyclical process varying in time and place. A single storm can remove as much sediment as several months or even years of normal movement.

Understanding of littoral transport requires some knowledge of wave characteristics. Waves are generated by disturbances of the sea surface. Undersea earthquakes, volcanic eruptions and submarine landslides can cause waves, but usually the cause is the friction effect of winds over the ocean surface. Wave dimensions are caused by wind velocity, duration of time the wind flows, the distance it blows across the water (the fetch) and the distance the wave travels after it is generated by the wind. The stronger is the wind, the longer the wind blows and the longer the fetch the larger the waves will be.

In southern Delaware Bay (at Lewes) prevailing winds are from the southwest, but northeast, north and south winds occur nearly as often. Winds of gale force (30 miles per hour or higher) occur most frequently from the northwest; highest velocity winds are most often from the northeast.[1] (pg. x.6, Appendix X, Charles T. Main report).

Wave terminology includes:

1) the crest - the highest part of a wave

2) the trough - the lowest part of a wave

3) wave height - the vertical distance between a crest and the preceding trough

4) wave length - the horizontal distance between two adjacent wave crests

5) the wave period - the time for two successive wave crests to pass a given point

As waves approach the shore moving into shallower water, the bottom affects wave motion in several ways:

1) wave velocity decreases

2) wave length decreases as velocity decreases

3) wave height first decreases, then increases just before the wave breaks on the shore

4) wave steepness increases with the increase of wave height and decrease of wave length

Wave refraction is a characteristic important to the understanding of erosional effects of waves on a shoreline. In shallow water when a wave crest

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[1]Charles T. Main, Inc., Recreation Potential: State of Delaware Interim Report, Appendix X, p. x.6.

moves at an angle to bottom contours segments of the wave front travel in different water depths, thus at different speeds. The variation in speed causes the wave crest to bend into alignment with the bottom contours. This bending effect is refraction. Figure 3 illustrates wave refraction on four different types of shoreline. The orthogonals shown are simply trajectories of selected points along the wave front. Where they converge (Figure 3'b') waves are higher, wave energy is concentrated and there is accelerated erosion; where they diverge (Figure 3 'c') waves are lower, wave energy is dispersed and there tends to be sediment deposition and shoreline accretion (increase). In Figure 3(d) the headland is eroding and the bays are filling-in with sediments eventually resulting in a relatively straight shoreline.

Longshore transport is the littoral movement of sand parallel to the shore. When waves break on the shore at an angle the effect is to move sand-laden water along the shore in a direction related to direction of wave approach and angle of the wave to the shoreline. Figure 4 illustrates longshore transport.

Most shores have net annual longshore transport in one direction. North of Bethany Beach littoral transport along Delaware's Atlantic shore is northward, south of Bethany Beach net transport of sand is southward.

The second component of littoral transport is the onshore-offshore movement of sediment perpendicular to the shoreline. This movement is determined primarily by wave steepness, sediment size and beach slope. In general, high, steep waves will move material offshore, low waves will move it onshore.

Onshore-offshore transport varies with the season. Figure 5 illustrates generalized summer and winter beach profiles associated with onshore-offshore transport processes. Fair weather in summer favors sand accretion on the berm. Stormy winter weather moves sand seaward narrowing the berm and building-up one or two offshore sandbars. Figure 5 is simply a generalized illustration, in actuality winter beach profiles can occur in summer and vice-versa. A berm is simply the flat, above-water features of the beach - what most people think of when referring to "the beach".

Storm wave attacks on beaches increase the onshore-offshore littoral transport of sediments beyond that normally occurring. Figure 6 diagrams storm wave attack on a beach and dune. Profile A shows the beach under normal wave action and the other profiles show it at the various stages of storm wave attack. The destructiveness of storm waves is increased by the storm surge, a rise of water level above normal caused by storm winds that pile the water against the land, raising the water level. Profile D shows the beach after the storm wave attack - the dune and berm have lost much sand, resulting in a landward displacement of both the dune crest and high tide line.

At the waves return to normal the process of berm buildup begins. Long, low waves move sand landward that eventually adds to the berm. The berm grows seaward and resumes its pre-storm profile. Thus, onshore-offshore littoral transport of sand is a continuous, cyclic process.

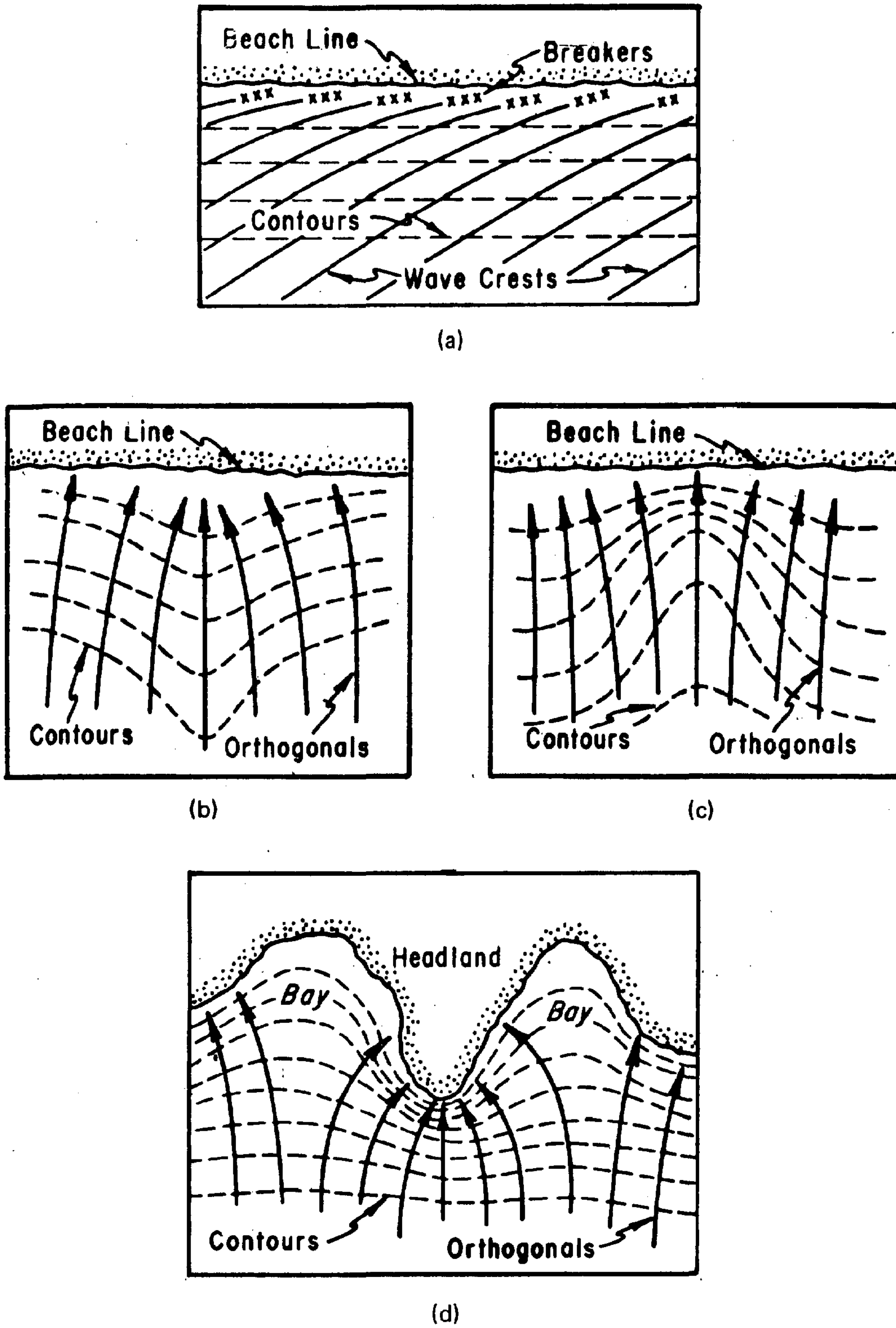

FIGURE 3 Effects of nearshore topography and coastal configuration on wave refraction. (a) Refraction along a straight beach with parallel bottom contours. (b) Refraction by a submarine ridge. (c) Refraction by a submarine canyon. (d) Refraction along an irregular shoreline (from U.S. Army Coastal Engineering Research Center, 1973).

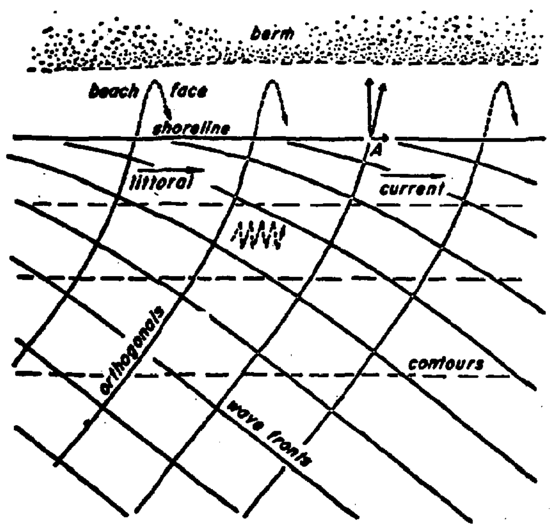

FIGURE 4 Waves approaching a straight shoreline at an angle are not completely refracted. The remaining alongshore component (marked A) is responsible for the littoral current. Paths of sand grains moving to the right with every wave are shown by dotted lines (Bascom, 1964).

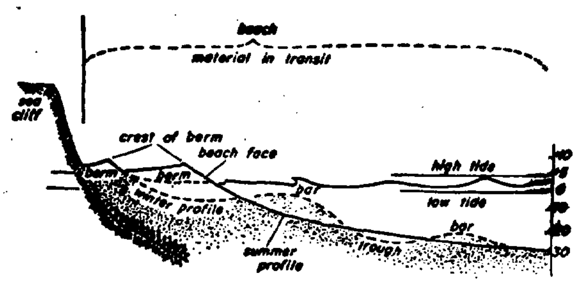

FIGURE 5 Generalized beach profile showing seasonal changes in the distribution of sand (Bascom, 1964). In the summer the beach is wide, with a prominent convex-upward beach face and usually flat, barless submarine profile. In the winter, large waves move sand offshore, producing a narrow berm and one or more submarine bars.

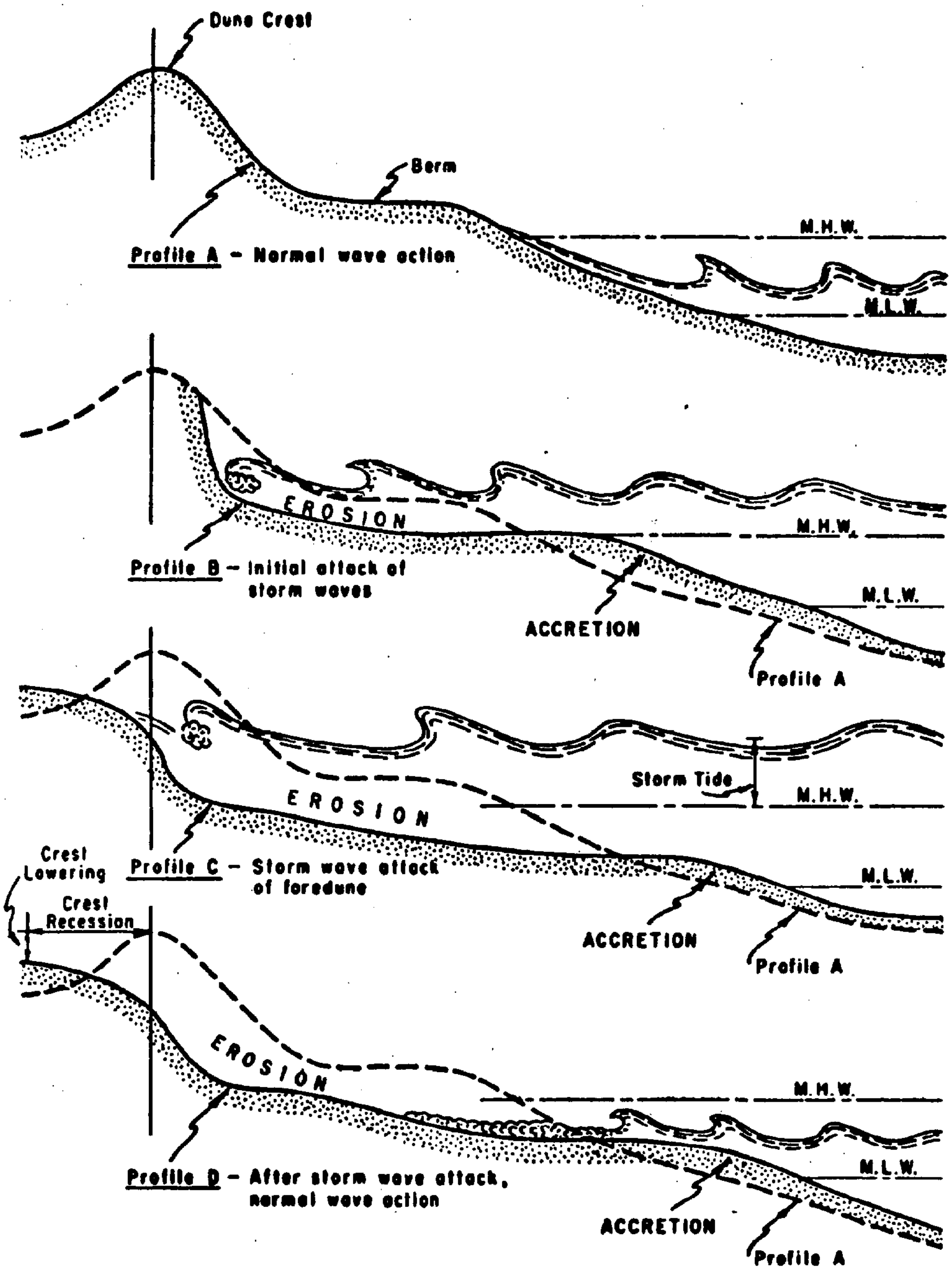

FIGURE 6 Schematic diagram of storm wave attack on beach and dune (U.S. Army Coastal Engineering Research Center, 1973).

The erosional affect of the severe March 1962 storm on Delaware's Atlantic beaches is illustrated in Figure 7. Many miles of beach retreated by 60 to 75 feet.

The "northeaster" of December 1 and 2, 1974, caused extensive shorefront damage. Peak tide levels were nearly as high as in the March 1962 storm but damage was much less because the 1974 storm lasted only through two to three tidal cycles. Along Delaware Bay high tide waters rose through the marshes and the discontinuous beach areas. Washovers were extensive where low dunes offered little protection, as at Broadkill Beach shown in Figure 8.

Washovers are the third process causing coastal change. Storm waves carry sand eroded from the beach, breach the dunes, and deposit large quantities of sand on top of the barrier island and in back-barrier marshes (see Figure 8 above). The result of washover is a landward migration of the shoreline and a building-up of the barrier island.

The washover is a periodic, natural process associated with all barrier islands. It is inevitable that storms will bring future washovers to Delaware's shore; the only questions are when and what the effects will be.

Natural Shore Protection

According to a report of the Army Corps of Engineers Coastal Engineering Research Center man has contributed to the scope of destruction wrought by Atlantic storms by failing to preserve protective features provided by nature.

The structure of a beach serves as natural protection against wave action. During normal conditions, the slope of the beach face absorbs most of the wave energy. In times of elevated water levels when waves wash over the berm, coastal sand dunes form an effective barrier to storm waves. Even when breached by severe storms dunes can gradually rebuild themselves provided vegetation can become established on them. Not only are dunes barriers to high waters and onshore winds they also serve the important function of a stockpile of sand to replenish the beach as the dune builds outward and wave action on a high tide carries some of the sand to the foreshore.

Vegetation plays a critical role in the development and maintenance of sand dunes. Grasses and other plants serve to trap overwash and wind blown sand, to dissipate wave energy and to stabilize dunes. This vegetation should be undisturbed by man. Access to beaches should be limited to elevated walkways placed over (not through) dunes at a few locations. The wooden walkways at Cape Henlopen State Park beach are a good example of this principle. The value of dunes and dune vegetation has been recognized in Delaware and a program of dune maintenance and restoration is underway. See Figures 9 and 10 for examples of natural dunes and the State dune stabilization program.

Studies of North Carolina's Outer Banks, a shoreline similar to Delaware's Atlantic coast in many respects, have shown the dynamic ever-changing nature of the shore area and the environmental relationship between coastal dunes and the

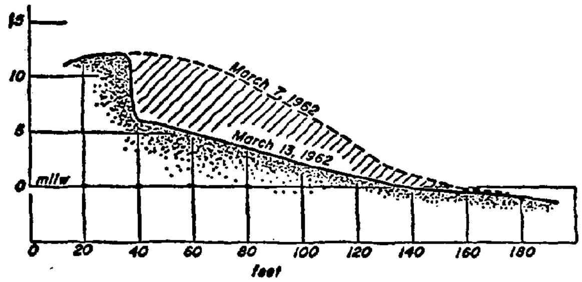

FIGURE 7. Typical erosion pattern of Delaware beaches during the storm of March 1962. Many miles of beach retreated 60 to 75 feet (Corps of Engineers profile in Bascom, 1964).

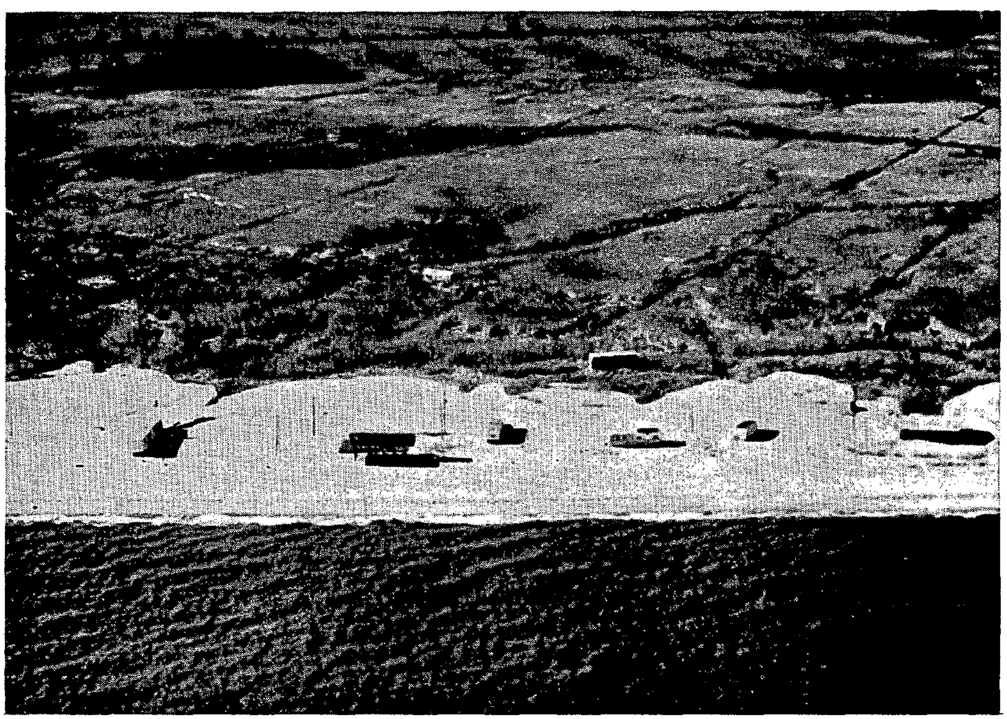

FIGURE 8. Aerial photo of Broadkill Beach area, Delaware Bay, following the December 1974 storm. Breached dunes and washover fans are typical consequences of even mild storms.

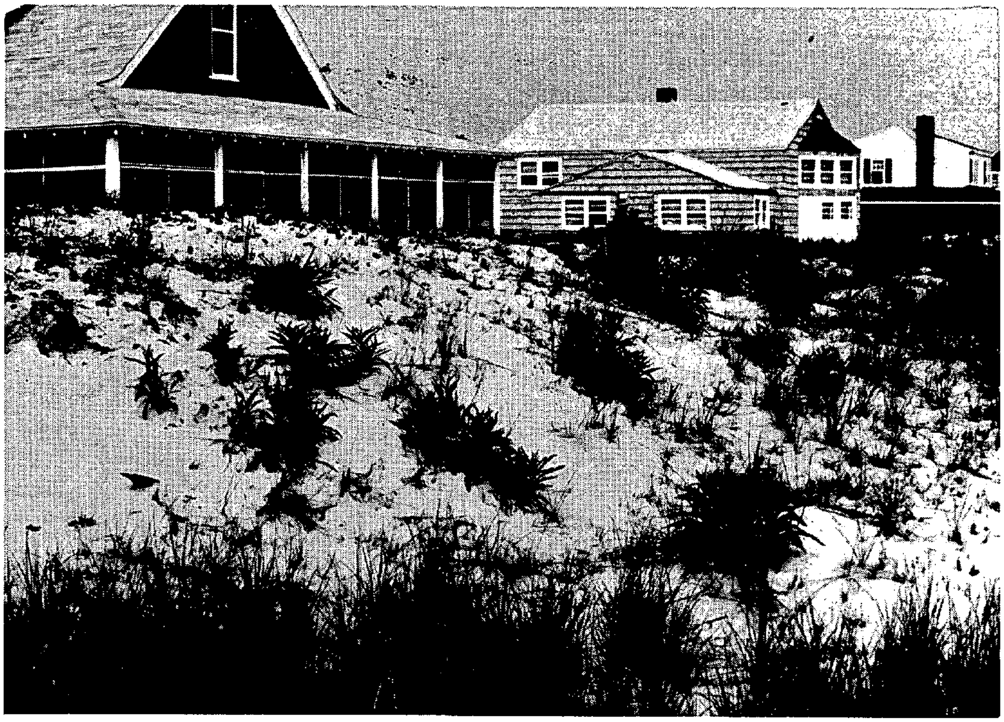

FIGURE 9. Natural dunes and dune vegetation, Lewes Beach.

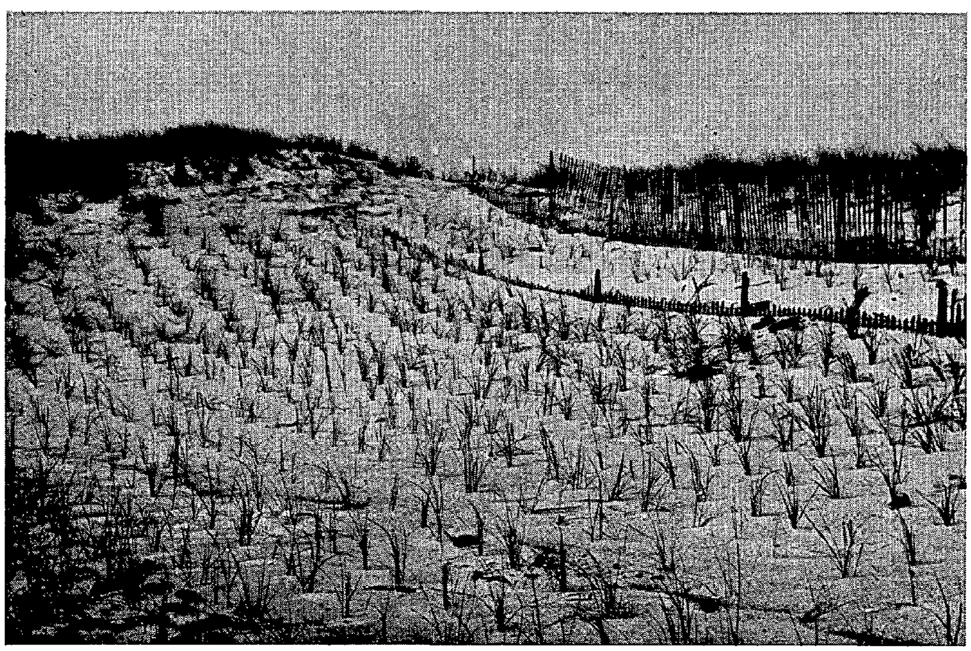

FIGURE 10. Dune maintenance program at Indian River Inlet State Park. Fences and vegetation help stabilize dunes by trapping sand.

occasional overwash of ocean waters into lagoons behind the washover barrier beaches and dunes (see Figure 11 for a schematic diagram of shoreline features).

The base level of the berm is determined by the sea and where sand is in short supply, the sea keeps moving the berm back. In such an environment, scattered dunes, dense grasslands and salt marshes represent the natural ecology. If overwash is halted, such lands will be drowned and only a dune line remain. Building a high manmade dune line may lead to future disaster when the sea finally breaks it down. Erosion on the lagoon side will begin and coupled with beach erosion will jeopardize the barrier island.

The studies of the North Carolina shore area concluded that a barrier island - lagoon environment can be harmed by a high barrier dune system, while a structure of a wide berm with scattered dunes of various heights to allow water flow and extensive grasslands and salt marshes is more compatible with natural forces. The wide berm provides resistance to storm waters and supplies sand for natural dune building. Dunes will buildup one behind the other with low areas between the dunes which will serve to slow storm waters. Grasslands behind the dunes will further break wave energy and cause some sand deposition. The sea water will then reach the lagoonal marshes having lost most of its energy and sand load, with little damage beyond flooding. The secret of this structure is flexibility and lack of excessive resistance to natural forces; enough sand is conserved to preserve the barrier island system.

Manmade Shore Protection

Shore Protection Devices

In his eagerness to be close to the water, man ignores the fact that land comes and goes, that the sea may reclaim tomorrow the land nature provided in the past. Once seaward limits of a resort are established there is considerable pressure to protect the large investments involved at great cost in terms of storm losses and expenditures for protective measures.

In a natural state and in the early stages of resort development, the beaches and dunes provide adequate storm protection. As development continues the beach is narrowed, the dunes are destroyed or diminished and storm losses increase. To replace the natural defenses against the sea, man has devised a variety of protective measures.

One of the most common protective measures is a bulkhead (see Figure 12). Built of timber, concrete or steel pilings these are a type of wall built approximately parallel to the shoreline to combat erosion. More elaborate variations of bulkheads are solid stone or concrete seawalls and revetments. A revetment has a sloping face of rock or concrete blocks to break the force of waves hitting the seawall. While such devices provide upland protection they do nothing to hold or protect the beach - the greatest asset of shoreline property. In fact, a seawall is detrimental to the beach because the force of waves striking the wall is directed downward, rapidly eroding beach sand.

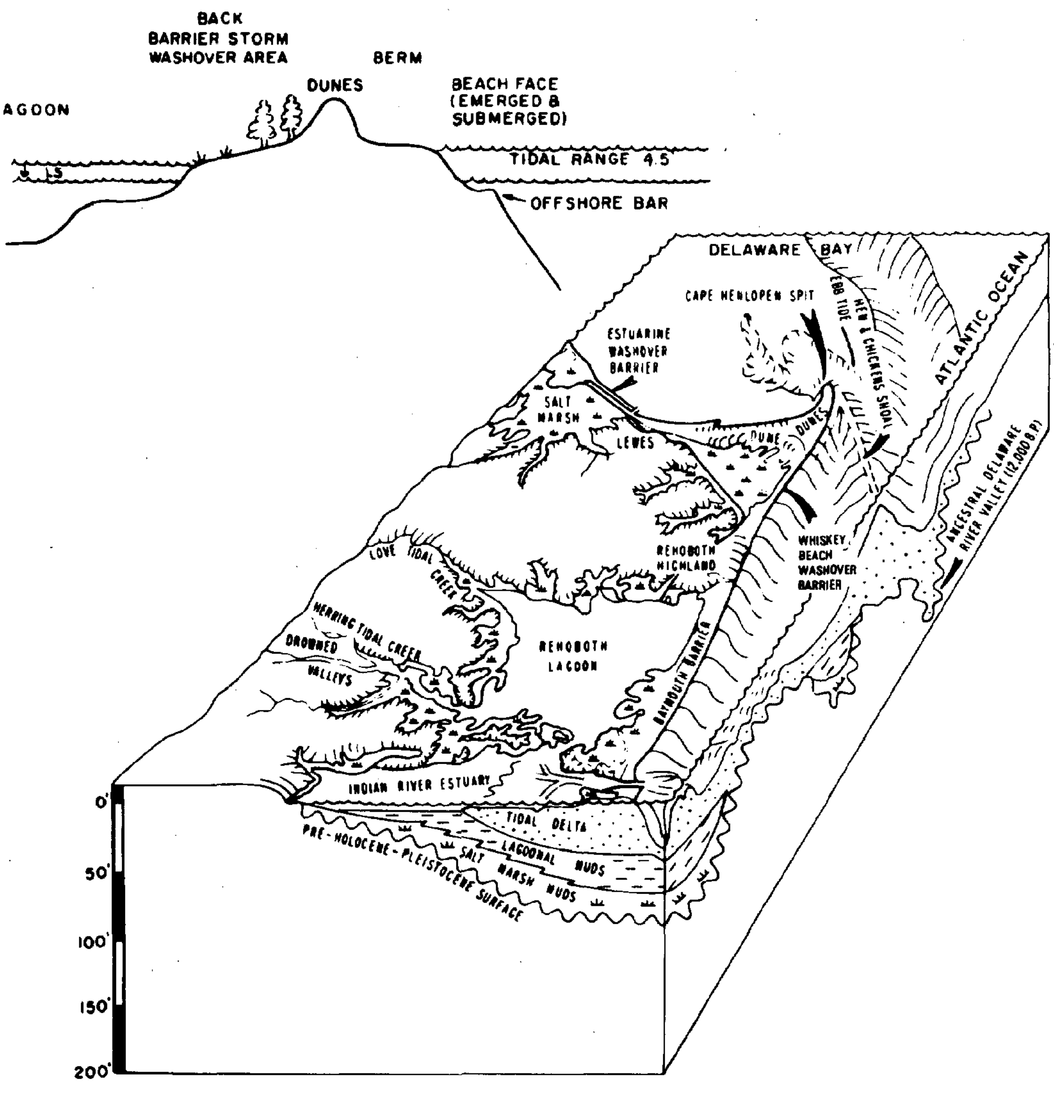

FIGURE 11. TERMINOLOGY USED IN DESCRIBING THE COASTAL ZONE ILLUSTRATED ON A DIAGRAM OF THE GEOMORPHIC ELEMENTS OF DELAWARE'S COASTAL AREA AND THEIR RELATIONSHIPS TO SUBSURFACE GEOLOGIC CROSS SECTIONS OF COASTAL AND NEARSHORE MARINE AREAS.

Source: The Coastal Zone of Delaware, The Final Report of the Governor's Task Force on Marine and Coastal Affairs, 1972, page 93.

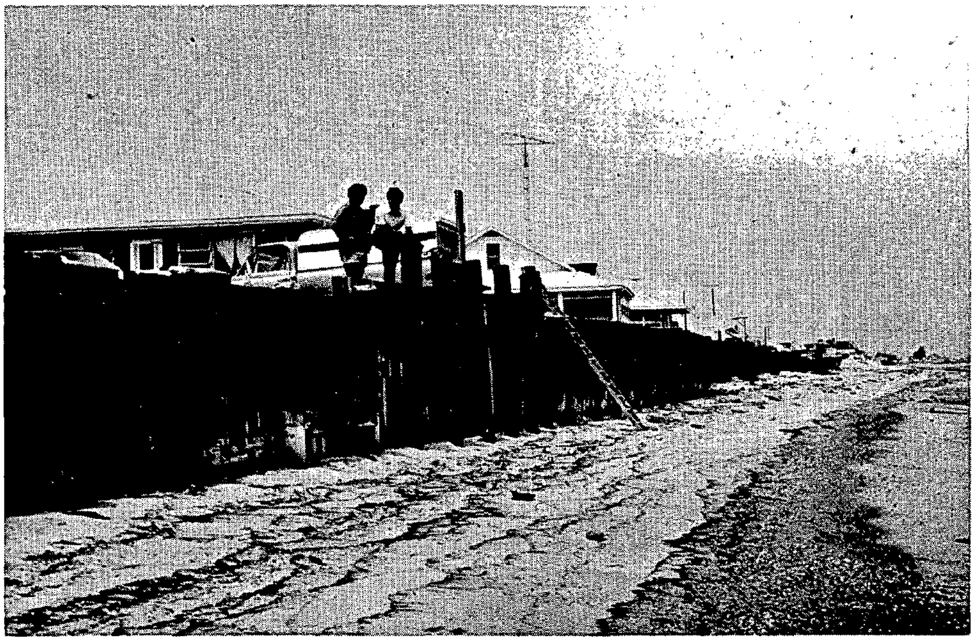

FIGURE 12. Bulkhead at Slaughter Beach, Delaware.

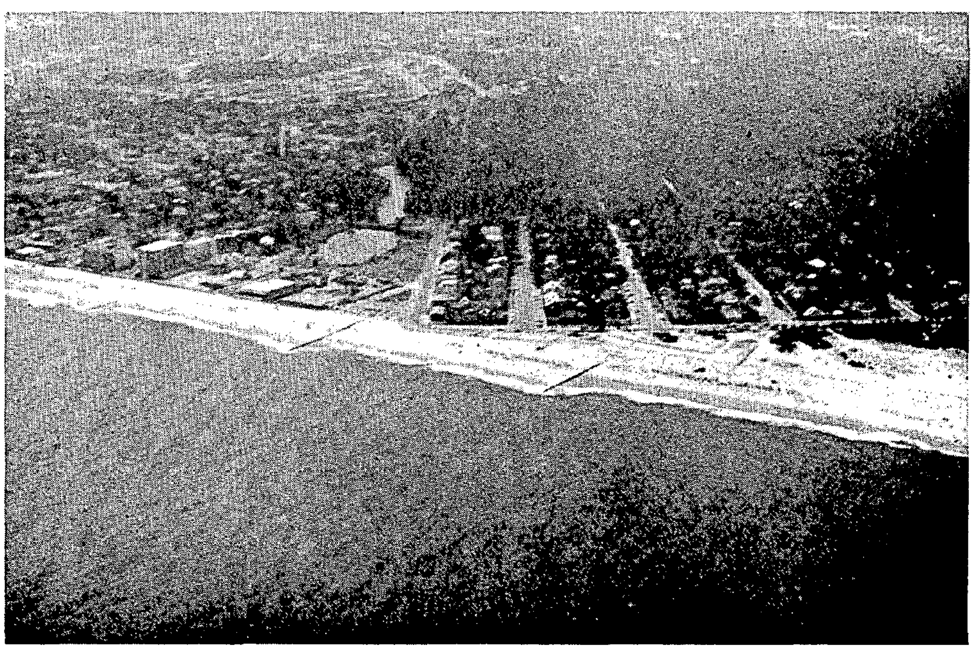

FIGURE 13. Groin field at Rehoboth Beach.

As a way of retaining beach sand or building-up a beach the groin has been devised. This is simply an obstacle of timber or stone, like a fence or wall, that extends perpendicular to the shoreline across the beach from a dune or bulkhead to a shallow depth in the water. Figure 13 shows a series of groins. The affect on the beach generally is to substantially widen it on one side of the groin and diminish it on the other side. The reason is that the groin traps sand carried in the littoral current increasing beach width on the side facing the direction the littoral current is coming from; the opposite side of the groin is deprived of sand supplied by the littoral current and eroded sand is not replaced by nature. The effect is a jagged, sawtooth-like beach as shown in Figure 13. Since more and more beaches are artificially protected and less and less littoral current sand is available to fill beaches between groins it is frequently necessary to replenish the beaches artificially. Groins should be built only after their affects on adjacent beaches are studied and only if properly designed for the particular site.

Another structure developed to modify or control sand movement is the jetty. Its function is similar to that of the groin, but it differs from groins in being much larger, extending from the shoreline to a water depth equal to channel depth, it is built at inlets to protect navigation openings from shoaling, and it must be high enough to completely obstruct sand movement (whereas most groins allow some sand to flow over the top). While jetties protect channel navigation, they have affects like those of groins by cutting off the longshore supply of sand to the downstream side of the channel. Figure 14 showing the jetties at Indian River Inlet dramatically illustrates the erosional-depositional affects of jetties.

When properly used beach structures have a place in shore protection, but according to the Army Corps of Engineers Coastal Engineering Research Center the best protection is afforded by methods as similar as possible to natural ones.

South Coast of Sussex County

Effects of coastal processes of sea level rise, erosion and deposition, described previously in general terms, are different in the several distinctive segments of the Delaware shoreline. This part of the paper examines the Atlantic Ocean shoreline from Indian River Inlet to the Maryland border at Fenwick Island.

Geologists have classified Delaware's shoreline into six types. The area from Indian River Inlet to Fenwick Island is part of the shoreline classified as a baymouth barrier complex that extends from Whiskey Beach north of Rehoboth Beach to the Delaware-Maryland border and on into Maryland and Virginia.

Components of the baymouth barrier coastal complex include beach washover barriers and baymouth barriers, back barrier marshes, tidal deltas and beaches and dunes. These features are illustrated in Figure 11.

The barrier shoreline in general is straight with minor indentations and bulges, the latter occurring where resistant sediments are present on the beach face. Continuous from Dewey Beach to Fenwick Island except for the opening at Indian River Inlet, the barrier varies in width from two-tenths to nine-tenths of a mile.

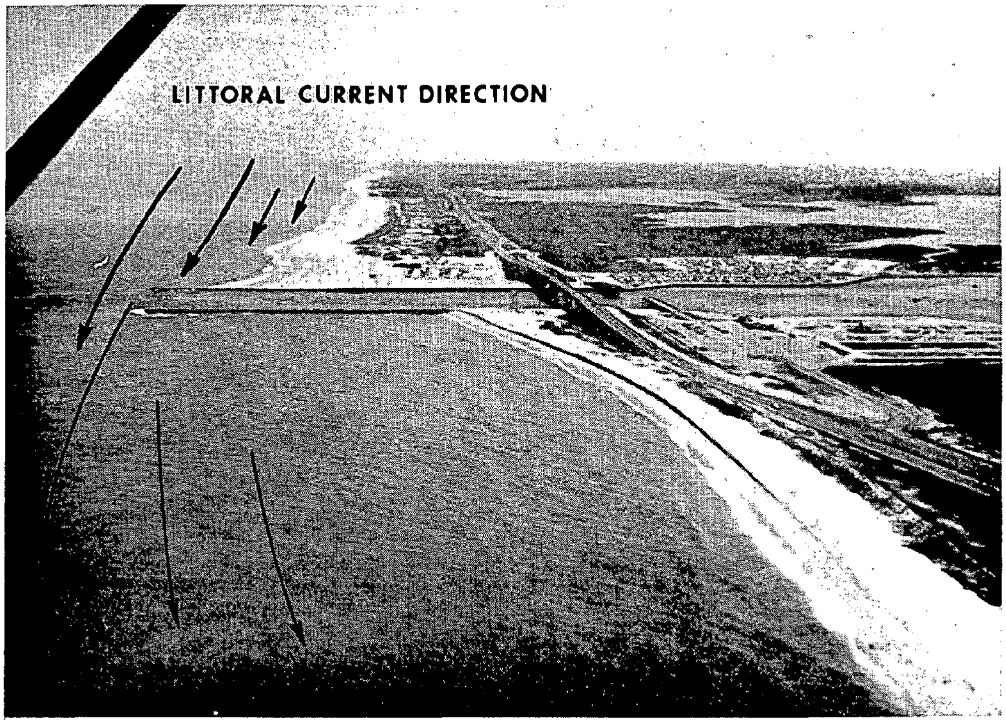

FIGURE 14. Aerial photo of Indian River Inlet showing jetty effect.

FIGURE 15. Coast Guard Station north of Indian River Inlet (Note washover fans in upper left) - March 1962. (Courtesy of Delaware State Highway Department)

To the west of the baymouth barrier are three major lagoons Rehoboth Bay, Indian River Bay and Little Assawoman Bay, each being very shallow with a sand and mud bottom and fringed by tidal marshes.

Supplying sand to the barrier are highlands, formed in Pleistocene times, at Cedar Neck, Bethany Beach, Burtons Island at Indian River Inlet and behind Fenwick Island.

On the barriers from Dewey Beach to Fenwick Island coastal washovers are the dominant erosion and sand transfer process. Storm washovers carry beach sands across the barrier into the back barrier marshes and lagoons. Figure 15 shows the washover effects of the March 1962 storm that washed beach sand through the dunes, over Route 14 and into the marshes and waters of Rehoboth, Indian River and Little Assawoman Bays. The coastal barrier is thus a constantly changing, moving physical feature. It tends to erode on the Ocean side and to build in a landward direction on the lagoon side. Construction on washover barriers must be considered subject to violent destruction as these barriers are normally subject to rapid change.

Dunes behind the barrier beaches provide major protection from storm flooding and erosion. Natural openings in dunes on a wide, low washover barrier allow some water to flow through during storms preventing major sea water buildup on one side or lagoon tidal and storm water buildup on the other side. A high, narrow dune without some low areas, on the other hand, can lead to catastrophic storm flooding if the water builds up and then suddenly breaks through the dune line in one great surge.

In addition to providing storm protection the dunes serve as a stockpile to replenish beach sand eroded by the sea. The dunes build outward toward the beach as sand is deposited on the seaward side. This material may then be returned to the foreshore by wave action on high tides, serving to nourish the beach.

At Indian River Inlet the natural inlet was unstable, shifting north and south by three to four miles in historic times. In 1939 two parallel jetties were built on either side of the Inlet stabilizing its location and providing passage for small boats between the Atlantic Ocean and Indian River and Rehoboth Bays. The unforeseen result of these jetties has been a severe alteration of natural patterns of erosion and accretion. The littoral current here is northward. The south jetty interrupts this current and catches the sand carried in the current resulting in an average annual shoreline accretion of five to six feet on the south side compared to an average annual net beach loss of four to five prior to jetty construction. However, the effect on the beach immediately north of the northern jetty has been to drastically increase annual beach erosion from seven feet in the period 1843 to 1929 to over 21 feet per year between 1939 and 1954, and this high erosion rate continues. In the ½ mile adjacent to the north jetty annual beach loss above mean low water is estimated at 52,500 cubic yards. Erosion on the north side of Indian River Inlet is so severe that it endangers Route 14; only periodic artificial replenishment of beach sand here prevents the undermining of the highway and the Inlet bridge.

Coastal erosion is considered critical for the entire 24.5 mile beach from Cape Henlopen to Fenwick Island except for approximately one mile just south of Indian River Inlet. At Bethany Beach the annual loss of sand above mean low water has been estimated at 69,000 cubic yards. This is a serious rate of loss due to a lack of re-supply by littoral drift. Bethany Beach is a nodal area, that is, the longshore littoral current changes direction here; to the south the current is southward and to the north for the remainder of Delaware's Atlantic coast it is northward. There is a shifting of this nodal area from summer to winter.

Storm waves in the Bethany area will cause serious damage because of minimal dune protection and the large scale building going on here, such as the high rise shorefront apartments shown in Figure 16. Such buildings can be undermined by wave action and there can be flooding of lower floors during storms.

Relatively little erosion has occurred on beaches at Cotton Patch Hills (north of Bethany Beach), on the barrier at Little Assawoman Bay and at Fenwick Island. Wave energy impacting the beach differs from place-to-place and some areas such as these have less erosion due to offshore linear ridges refracting the incoming waves and lessening their impact.

Storm wave and erosion damage at Fenwick Island could be considerably more costly than in the past if that community should develop to the intensity and in the manner of Ocean City, Maryland to the south. A substantial number of large and expensive dwelling structures crowding the shoreline would mean severe economic losses and possible losses of life in the next major coastal storm.

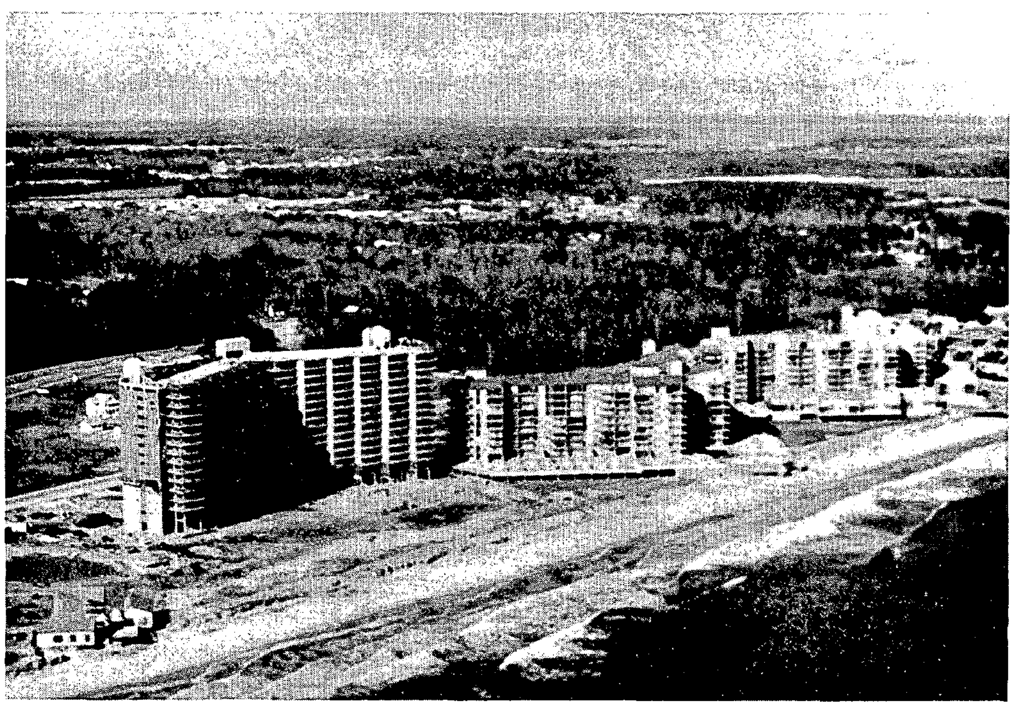

FIGURE 16. High rise buildings facing the eroding Atlantic Ocean shore at Bethany.