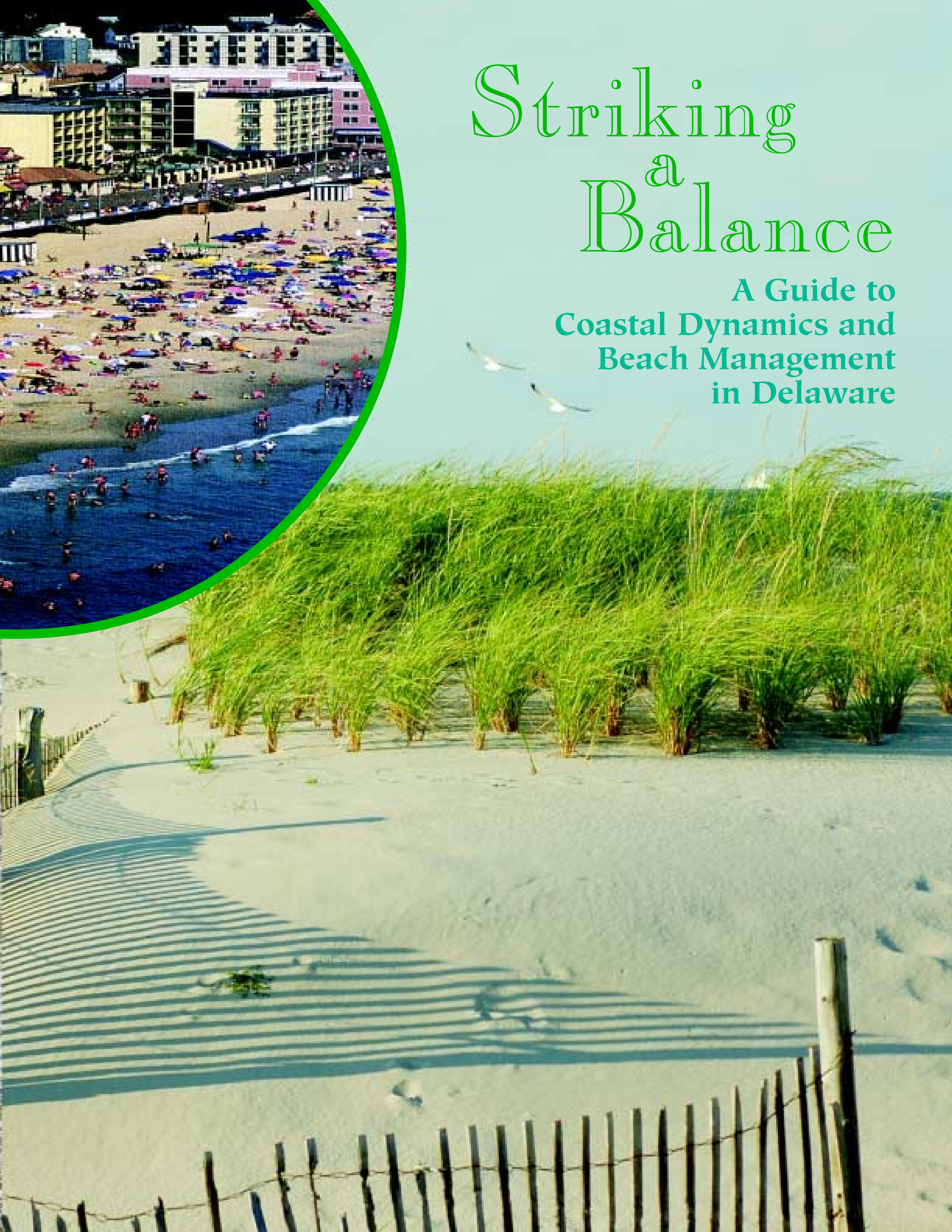
Striking a Balance

A Guide to Coastal Dynamics and Beach Management in Delaware



This document was developed with funding from: (1) Delaware Department of Natural Resources and Environmental Control (DNREC), Division of Soil and Water Conservation, Shoreline & Waterway Management Section; and (2) DNREC Delaware Coastal Programs, pursuant to the Coastal Zone Management Act of 1972, as amended, administered by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration Award No. NA17OZ2329.

Document No. 40-07-01/04/08/06

Striking a Balance

Our shoreline is a dynamic environment, constantly changing with the effects of waves, winds, tides, and currents. Coastal evolution and beach erosion are ongoing natural processes, and it is important to understand and recognize the complex causes and dynamic forces that created, shape, and continue to maintain this critical resource.

Beach management in Delaware integrates coastal and ecological management principles, sound planning, and wise design, siting, and construction criteria. The ultimate goals are to preserve coastal resources, maintain human use and economic resources, and strike a balance between the realities of nature and impacts of coastal development.

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Second Edition • 2004





Introduction: Striking a Balance

Delaware's coastal areas are unique resources valued for their natural beauty, recreational opportunities, economic benefits, and environmental significance. Each summer, thousands of people visit our many miles of beautiful beaches to enjoy the sun, sand, and surf. [1; see photo at right] More and more people are choosing coastal Delaware for their second home or primary residence. The wide diversity of available activities suits a variety of tastes and preferences. Beachgoers are attracted to the calm waters and scenic vistas of marshes along the Delaware Bay; the tranquility and solitude provided by the natural surroundings of Cape Henlopen, Delaware Seashore and Fenwick Island State Parks; the excitement of a visit to the Rehoboth Beach boardwalk; the challenge of surf fishing for bluefish and sea trout; clamming and wading in the Inland Bays; and boating and sailing in our many coastal waterways. In addition, birdwatchers mark the change of seasons with the comings and goings of thousands of migratory birds.

Few summertime visitors have witnessed first-hand the unrelenting fury of the sea during a coastal storm. [2] In just a few hours, waves, winds, and tides can dramatically alter the beach by moving vast quantities of sand. The wide sandy beach enjoyed during the summer can disappear rapidly as waves wash under the boardwalk or through the dunes. Once the protective beach is eroded, natural features such as dunes, and manmade structures such as homes, businesses, roads, and bridges are subject to the destructive forces of nature.

Delaware's beaches are dynamic features, changing constantly in response to winds, waves, tides, and currents. Unlike most upland areas, which are comparatively stable over time in their natural state, our barrier beaches are shifting landforms. They have been moving landward due to rising sea level since the end of the last Ice Age approximately 15,000 to 17,000 years ago. On such a non-permanent landform, development must take place with the understanding and acceptance of the inevitable changes that will occur in the natural environment. Attempts to stabilize and control these areas can damage the natural system. Placing structures that are expected to last for decades on a dynamic and constantly changing landform requires

1 *Summertime visitors enjoying Rehoboth Beach and the boardwalk.*

2 *South Bethany during a coastal storm.*

significant input and analyses from coastal scientists and engineers, along with integrated coastal management considerations, decisions, and strategies. The science and art of shore protection have evolved from building structures designed to protect buildings (seawalls and bulkheads) to practices that protect and enhance the natural beach (construction setbacks, dune protection, and beach nourishment).

The social value of Delaware's coast is visually evident through the extreme development in place for housing, tourist facilities, and commercial establishments. Our beaches host millions of visitors annually and the coast is the fuel for a large economic engine. The amount of money spent in pursuit of living near the coast or for an annual beach vacation, and the jobs that have developed to support this demand are a tremendous boost to the Delaware economy. The flow of money and the taxes that are derived from the coastal service industry are vital to the state's economy. While social demand for rest and relaxation at the beach is unparalleled, the very things that attract people to the shore are threatened by the sheer numbers of visitors and everything required to accommodate their needs. [3]

When this booklet was first published in 1985, Delaware's population was 618,284. By 2003, it had increased to 818,010, and is now projected to reach 1,007,382 by 2025. In Sussex County alone, the population was 103,943 in 1985, increased to 167,904 in 2003, and is expected to reach 247,211 in 2025. Clearly, more people are living near the coast, and demands for using its natural resources are increasing.

Ideally, beaches should remain totally open and natural, to be used indefinitely by local residents and visitors. Realistically, however, land development and re-development will continue in the coastal strip. Proper management and planning, based on scientific information, knowledge of basic principles, and common sense will ensure compatibility of the many uses of our coast.

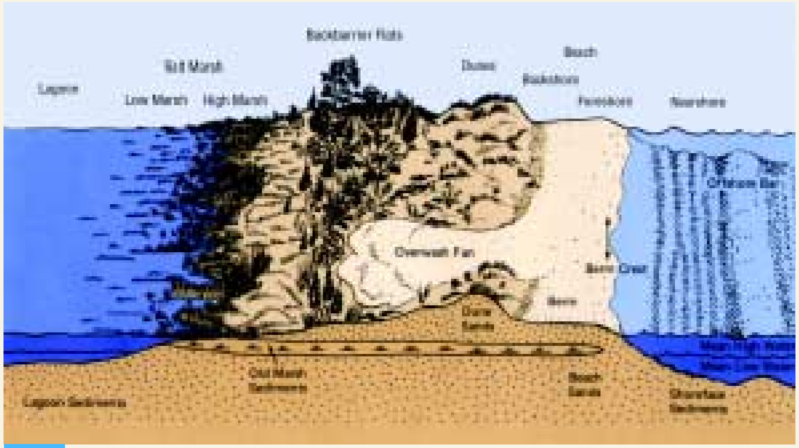
This booklet has been prepared to give you a general background and knowledge of coastal dynamics and beach management in Delaware. Understanding the forces affecting the beach is essential to appreciating the delicate balance between development and protection of our fragile coastal resources. This publication also explains statewide coastal management policies and the measures taken to mitigate the effects of erosion. ■

3 *The economic and social values of the Delaware coast are evident through residential and commercial development. Each year, millions of visitors enjoy Delaware's beaches, supporting a flourishing economy.*

Beaches and Coastal Processes

Coastal Environments

To most people, a beach is the sandy area where land meets the sea. To a scientist, a beach is one component of the larger coastal barrier system that also encompasses many other associated environments such as offshore sand bars, dunes, backbarrier flats, and marshes. This entire system consists of sediments (sand and mud) that are continuously moved and reposited by winds, waves, tides, and currents. These physical forces are responsible for changing the shape of this highly dynamic system.



4 *Components of a natural barrier beach system.*

The various components of a natural barrier beach system are shown in [4]. The beach does not stop at the water's edge, but extends offshore to include sediments in the nearshore zone affected by wave action. The nearshore bottom may be relatively flat and smooth, may consist of sand ripples, or may be marked by the presence of one or more submerged sand bars. The foreshore, or beach face, is the steeper section of the beach along the water's edge between the high tide and low tide lines. This is the section of the beach affected by the uprush and backrush of waves. The slope of the beach face depends on grain size and wave energy. Steeper beaches are characterized by larger grain sizes and larger waves. The berm crest is the highest point, and usually marks the normal limit of tidal action and wave uprush. Though usually linear, the waterline can consist of a series of scallop-like ridges and depressions at regular intervals. These features—beach cusps—form in response to wave action. On occasion, nearly vertical cliffs—scarps—are cut into the beach face, where the sand elevation drops from several inches to several feet. These are erosional features that form during storms or heavy surf. [5]

5 *Erosional scarps are cut into the beach face during storms or periods of heavy surf.*

The berm, or backshore, is the dry part of the beach used mostly for recreational purposes. This flat sandy area is ideal for sunbathers, since under normal circumstances it is generally not subject to wave and tide action.

The landward margin of the backshore is marked by sand dunes. These ridges—or mounds of loose, dry, windblown sand—are protective features and also serve as reservoirs for sand. The nature and extent of dune formation depends on prevailing wind direction and velocity, and availability of sand. Where there is a large supply of sand, a high, wide dune field can form. Vegetation is also critical in building and stabilizing dunes. In Delaware, the native American beachgrass is commonly found on dunes. Sea-rocket is frequently found at the toe of the foredune. The more protected backdune area supports a greater variety of plants—including dusty miller, beach heather, and seaside goldenrod. [6] Scattered throughout the low areas are interdunal swales—wet depressions that support a variety of wetland grasses, sedges, and rushes, as well as shrubs such as bayberry and cranberry. Vegetation tends to build up the dune by trapping windblown sand, whereas unvegetated areas tend to lose sand due to wind erosion, forming low areas called blow-outs. Beachgrass is a very hardy plant, and can tolerate the harsh environmental conditions that commonly occur on sand dunes, such as salt spray and sand burial. However, the grass is susceptible to destruction by pedestrian and vehicular traffic, so it is important not to walk or drive on the dunes.

6 *The protected backdune area supports a variety of plants and animals.*

Backbarrier flats consist of low-lying sandy deposits formed by storm overwash. During storms, surges of water move sand from the beach and dune, where it is deposited on the relatively flat area landward of the dune line. The newly deposited sand is at first colonized by grasses, and eventually by shrubs and trees. Native vegetation in these thickets typically consists of bayberry, highbush blueberry, red cedar, beach plum, and poison ivy. Some low trees, such as blackjack oak and loblolly pines are also present. The trees are usually short and gnarled as a result of stark environmental conditions imposed by strong winds and salt spray.

Back barrier salt marshes form along the bay shoreline at the landward edge of the barrier system. The substrate can consist of sand, with mud and organic material in the surficial layers. The low marsh, adjacent to the bay, is alternately submergent (under water) and emergent (above water) daily during normal high and low tides. Vegetation in this area is adapted to twice-daily tidal inundation, and is dominated by smooth cordgrass. The high marsh, slightly higher in elevation and located farther away from the lagoon edge, is flooded only during spring high tides. Salt hay and spike grass are dominant in this region. The upper limit of the backbarrier marsh is usually marked by shrubs including marsh elder and groundsel bush.

Where backbarrier marshes are wide, it is an indication that a tidal inlet connecting the ocean and bay once existed at that location at some time in the past. Inlets become more and more shallow as sand accumulates, and they may eventually close up entirely. No longer affected by strong tidal currents, former flood tidal shoal deposits may become partially emergent and colonized by marsh vegetation.

A bay or lagoon is a shallow waterbody, usually less than 10 feet in depth, that separates the barrier island system from the mainland. The water is brackish, not fresh, but not quite as salty as the ocean. The bay bottom can consist of sand or mud, or a mixture of both. Many types of shellfish—such as hard-shell clams, soft-shell clams, and razor clams—live within the sediment of the bay. Their shell material is often also present in the sediment.

8 *Remnants of a drowned pine forest at Cape Henlopen State Park. These trees grew on dry land 200-300 years ago.*

Geologic History and Long-Term Coastal Processes

Sea-Level Rise; Barrier Migration. The Delaware coast has been shaped by geological processes that began approximately 17,000 years ago, when glaciers covered much of North America. At that time, sea level was more than 400 feet lower below its present level. Delaware's Atlantic Ocean shoreline was located at the edge of the continental shelf, approximately 75 miles east of its present location. [7] Delaware Bay was a narrow freshwater river flowing across the continental shelf, forming a delta at the shelf edge where water depths drop off. Although the glaciers did not cover Delaware, their location just to the north of us greatly influenced the climate. Delaware was much colder then, much like present-day arctic Canada, with tundra and boreal forests. These ice sheets were several miles thick, and they began to thaw as the climate warmed. Melting water raised the level of the ocean, and water began to flood the land surface. By 11,000 years ago, the shoreline had migrated landward, barrier islands formed along the outer coast, and the Delaware Bay estuary had begun to form. This inundation of the land surface has continued over time, and evidence of previous land surfaces now covered by water can be seen at several locations along the coast. For example, a drowned pine forest is occasionally visible at Cape Henlopen State Park at Herring Point. [8] This forest, similar to the existing forested areas within the park, was located on dry land approximately 200 to 300 years ago. Farther to the south, layers of marsh peat are occasionally exposed at the low tide line at the beach near Gordon's Pond. These marshes were landward of the beach and dune lines several hundred years ago. Along the Delaware Bay shoreline, off of Fowler Beach, an old marsh outcrop bayward of the beach shows

7 *17,000 years ago, when glaciers covered portions of Pennsylvania, New Jersey, and Long Island, New York, sea level was more than 400 feet below its present level. Delaware's Atlantic Ocean shoreline was located at the edge of the continental shelf, 75 miles east of where it is today.*

9 *Sand is transported from the ocean beach landward toward the bay by overwash.*

remnants of the grid pattern typical of mosquito ditching. Ditching was likely conducted in the 1930s, when the marsh was located landward of the sandy beach.

As sea level continues to rise, the sandy beach and its associated coastal environments move in a landward direction, while also building upward. Along Delaware's ocean coast, this occurs when sand from the ocean side of the beach is transported landward toward the bay side. One way that barrier systems migrate landward is by overwash, when waves carry sand from the ocean side of the barrier beach to the bay side. [9] Most barriers experience overwash periodically during storms. Sand transported from the beach and dune is deposited on the backbarrier flat and marsh, raising the elevation and extending barrier sands into the shallow waters of the lagoon. The higher areas of the overwash deposit are first vegetated by dune grasses. Eventually, woody shrub and scrub vegetation, such as bayberry and beach plum colonize the sandy area, followed by trees such as pines and cedar. The lower areas along the lagoon are eventually colonized by marsh grasses, including salt hay and smooth cordgrass. The vegetation help to stabilize the new part of the backbarrier and lagoon edge. Thus, the barrier system has "migrated" as a unit in a landward direction.

Another mechanism for sand transport for landward barrier island migration is via tidal inlet processes. In an active tidal inlet, flood (incoming) tidal currents bring sand from the ocean side of the system through the inlet. As the current velocity diminishes, sand is deposited in the bay just landward of the inlet. These shoals are called flood tidal shoals (also flood tidal deltas, or inner shoals). They are usually submerged at high tide, and may be exposed or under very shallow water at low tide. The ebb (outgoing) tide may transport some of this sand out of the inlet toward the ocean. However, natural inlets are dynamic features that do not naturally remain constant over time. They tend to migrate, shoal, and close; and can re-open elsewhere along the coast. Once an inlet closes, the sand in the flood tidal shoals provides a source of sand for continued landward migration of the barrier system as the sea rises.

Delaware's Shoreline Types and Coastal Features

The Delaware coast is characterized by a variety of shoreline types, ranging from marshes along the northern parts of Delaware Bay to wide, sandy beaches and dunes along the Atlantic Ocean. Characteristics of the shoreline are controlled by a number of factors, including source and abundance of coastal sediments, and wave energy available for redistribution of sand.

Delaware's river, bay, and ocean shorelines, extending from the northernmost part at the Pennsylvania border, to the southernmost part at the Maryland border, exhibit a wide range of characteristics.

Marsh Shoreline. Much of the shoreline along the Delaware River and Bay in the northern part of the state consists of tidal wetlands. From the northern border of the state southward to the Wilmington area, the coastline consists of a narrow, generally marshy coastal zone. There is a sharp change in topography as this area meets the rolling hills of the Piedmont Province to the west. This northernmost section of Delaware's shoreline has been extensively developed and filled; only small elements of the original coastal environment remain. South of Wilmington to the Port Mahon area, the Delaware estuary shoreline is characterized by broad tidal marshes backing up to the level fields of the Coastal Plain. This section of the coast is typified by numerous tidal creeks, such as Blackbird Creek and Duck Creek and broad marsh islands, such as Kent and Kelly Island in the Bombay Hook area. [10] This type of shoreline results from low wave energy and very small amounts of coarse-grained sand in the nearshore zone. The shoreline consists of marsh mud banks vegetated by salt marsh cordgrass and salt hay. In some areas, the giant reed has taken over much of the wetland area.

10 *Marsh shoreline along Delaware Bay, Bombay Hook area.*

Estuarine Barrier Beaches. The shoreline along the central and southern section of Delaware Bay, where wave energy increases, consists of broad coastal marshes and sandy beaches along the shoreline. Along the

11 *Sandy estuarine barrier beach and marsh along southern Delaware Bay at Primehook Beach.*

central section of the Bay, the beaches are localized, and surrounded by marshland. Communities such as Pickering Beach and South Bowers are examples of this shoreline type. The beach is generally narrow, with a broad intertidal flat, exposed at low tide, and submerged at high tide. Dunes are sparse and low-lying. In some areas, such as Bowers Beach, headlands comprised of coarse sand and gravel are located along the shoreline. Waves and currents redistribute these sediments alongshore to adjacent beaches.

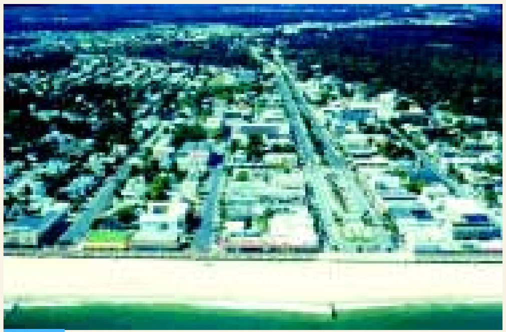
Farther to the south, toward the mouth of Delaware Bay, the beaches are wider, with relatively high, vegetated dunes. Dimensions of the beach and the presence of a dune field are a result of more abundant sediment as well as greater wind and wave energy. In fact, although waves along the bay coast are normally smaller in height than ocean waves, the southern portion of the Delaware Bay coast can sometimes be impacted by large ocean swell and waves, especially during storm events. Primehook Beach and Broadkill Beach are example of these wider beaches near the mouth of Delaware Bay. [11]

12 *Cape Henlopen spit, advancing northward towards Delaware Bay.*

Cape Henlopen Spit System. Cape Henlopen is a narrow point of land at the mouth of Delaware Bay, where it meets the Atlantic Ocean. [12] Geologic and historic evidence shows that Cape Henlopen has been advancing northward toward Delaware Bay for thousands of years. Sand transported northward by ocean waves approaching from the southeast has steadily moved sand to the north forming this spit. Construction of the inner and outer stone breakwaters in the 19th century appears to have altered currents in the vicinity of the cape, causing an acceleration of growth of the spit tip. This process is continuing at the present time, and Cape Henlopen is one of the few naturally accreting beaches in Delaware. Cape Henlopen contains an abundance of sand for the formation of an extensive dune field, wide, gently sloping beaches, a broad tidal flat, and numerous sand bars. One of the unique features found on Cape Henlopen is the Great Dune.

This landform rises to a height of 80 feet above sea level, and is approximately 2-3 miles long. Most coastal dunes are parallel to the coast; the Great Dune is perpendicular to the Atlantic Ocean shoreline. Historic information indicates that the dune formed as a shore-parallel coastal dune along the Delaware Bay shoreline in the early 19th century, where the bay met the ocean at that time. It is believed that workers building the large stone breakwater in Breakwater Harbor in the 1800s cut trees and vegetation, which led to formation and eventual southward migration of the dune. The dune is continuing its southward migration at rates of up to 6 feet each year over a maritime forest. Sand at the steep southern edge is burying oak, maple, and pine trees. The eastern (seaward) edge of the dune is eroding and forms a steep bluff along the ocean shoreline. Like the eroding dune farther south at Herring Point overlook, the eroding dune face provides sand to the longshore transport system for continued northward growth of the Cape. Another interesting feature associated with Cape Henlopen is the submerged sand bar, Hen and Chickens Shoal, a linear sand feature extending southeast from the tip of Cape Henlopen. Unlike the sand bars off many beaches that run parallel to the shore, the shoal is oriented at an angle to the shoreline. It is closest to the shoreline off of the point of Cape Henlopen, where the crest of the shoal rises to within 5 feet of the water's surface. Breaking waves are occasionally visible on the shoal. The submerged feature trends southeasterly, and extends gradually farther offshore to the south. The shoal is approximately 2 miles offshore of Rehoboth Beach, and is under 25-30 feet of water. The origin and migration of Hen and Chickens Shoal is related to the interaction of flood and ebb tidal currents, and wave action. The shoal is estimated to contain approximately 100 million cubic yards of sand.

Beach-Headland Coast. Along the Ocean coast, there are several areas where highlands meet the shoreline. The towns of Henlopen Acres, Rehoboth Beach, the northern section of Dewey Beach, and Bethany Beach are located on such headlands. [13]



13 *Rehoboth Beach along Delaware's Atlantic Ocean coast is an example of a beach-headland coast.*

These areas are 10 to 20 feet above sea level, and are topographically higher than surrounding lands to the north and south. The headlands consist of compacted sand and gravel, which are winnowed by waves and currents to form the sandy beach. By virtue of their elevation, these areas are less susceptible to flooding and overwash than lower-lying areas, yet the immediate oceanfront may be subject to extensive wave damage and erosion during storms.

Barrier Beach/Inland Bay System. Much of the Atlantic Coast south of Rehoboth Beach consists of a barrier beach system. Included in this region are Delaware Seashore State Park and Fenwick Island State Park, as well as the southern section of Dewey Beach, Indian Beach, South Bethany, and Fenwick Island. A sandy strip of land, varying in width from several hundred to several thousand feet, separates the ocean from the Inland Bays (Rehoboth Bay, Indian River Bay, Little Assawoman Bay). The barrier beach on the ocean side is exposed to the waves and tides of the Atlantic, and reflects these high-energy environments. The sandy beaches are wide (usually 100 to 150 feet from dune to water), with a fairly steep beach face as a result of relatively coarse grain size and larger wave forces. The dunes form a continuous well-vegetated ridge that rises 15 to 20 feet above sea level. The backbarrier area consists of flat, sandy overwash deposits. Native vegetation in these thickets typically consists of shrub/scrub vegetation, including bayberry, highbush blueberry, red cedar, and beach plum, with some low blackjack oak and loblolly pines also present. This area is visible to the east of Route 1 in undisturbed areas, such as Delaware Seashore State Park and Fenwick Island State Park. [14] Back barrier salt marshes form along the bay shoreline. Typical vegetation consists of high tide bush, salt hay and, closer to the water's edge, smooth cordgrass. The backbarrier marshes are narrow (several hundred feet) just south of Dewey Beach, and increase in width to over 3,000 feet in the vicinity of Little Reedy Island and Little Bacon Island, adjacent to Rehoboth Bay north of Indian River Inlet. This area represents a former inlet which connected Rehoboth Bay and the Atlantic Ocean several hundred years ago.

14 *Barrier Beach/Inland Bay system at Delaware Seashore State Park (south of Dewey Beach). The barrier lies between the Atlantic Ocean and Rehoboth Bay.*

Barrier beach shorelines are easily overtopped in coastal storms and, historically, temporary inlets have been common. During the flooding (rising/incoming) tide, ocean waters and sediments are carried into the bays and are deposited to form sand bars known as flood tidal deltas, flood tidal shoals, or inner shoals. These features are sometime emergent at low tide. During an ebbing (falling/outgoing) tide, water and sediments are flushed out of the lagoon and are deposited offshore as sand bars, called ebb tidal deltas or outer shoals. Waves often break over these shallow areas in the ocean. Today, Indian River Inlet is the only active tidal inlet along Delaware's Atlantic coast. However, several other inlets that were open in the 17th and 18th centuries, but no longer exist today, have been documented in other areas along the Delaware coast.

Shoreline Processes and Sediment Transport

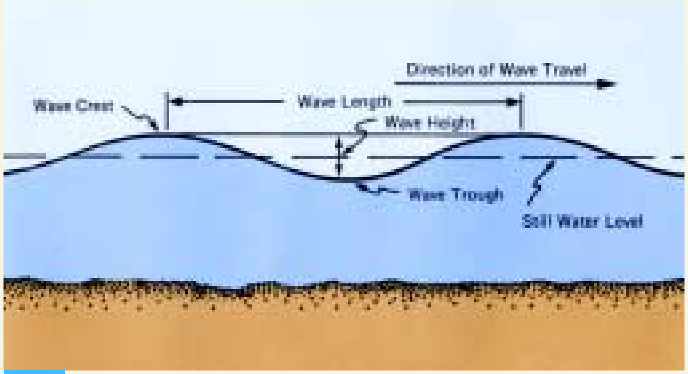
The shoreline and associated coastal environments are shaped by daily processes of wind, waves, tides, and currents. These forces constantly change, from season to season, day to day, even hour to hour. A calm day at the beach can suddenly turn stormy as winds kick up, generating large, choppy waves and strong currents. A storm can result in tremendous volumes of sand movement in just a few hours.

Winds. In coastal areas, winds are important in generating waves and currents. Winds are the most common disturbing force acting on the ocean surface, and they cause most of the ocean waves. Winds are highly variable and can generate small ripples or large waves. The largest wind-generated waves are caused by storms at sea.

In coastal Delaware, the prevailing (most frequently occurring) winds vary seasonally. Northwesterly winds (blowing from the northwest) are most common during the winter months, whereas southwesterly winds are most common during the summer. Variable winds occur in spring and fall. There is often a daily variation in wind direction at the beach, with onshore breezes (blowing from the sea towards land) during part of the day and offshore breezes (from land to sea) at other times. Highest velocity winds (dominant winds) tend to blow from the northeast, and are associated with the passage of storms.

Waves. Wave action is the main force moving sediment on the beach. Waves represent the transfer of energy across the water surface, and not actual motion of the water. Waves in Delaware are primarily the result of wind blowing over water. They are also generated by catastrophic events that disturb the sea floor, such as earthquakes, volcanic eruptions, and submarine landslides or avalanches, but these types of waves rarely occur in Delaware.

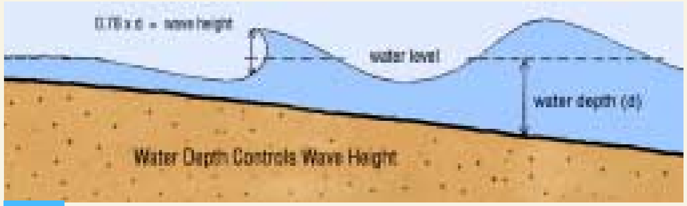
Wave terminology is shown in [15]. The highest part of a wave is the crest, and the lowest part is the trough. The vertical distance from crest to trough is the wave height. Half of the wave height, from still water level to crest, is often called the wave amplitude. The horizontal distance between two successive wave crests is the wave length. Wave period is the time, in seconds, it takes a wave to



15 *Wave terminology.*

travel its own length. This is the same as the time it takes for two successive crests to pass a fixed point.

Wave dimensions are determined by the wind velocity, duration of time the wind blows, the distance of water over which the wind blows (called the fetch), and, as the wave nears the shore, the water depth. Generally, strong winds blowing for several days over a long fetch produce larger waves. As waves travel away from where they were formed, they move across the ocean in groups. This is why we can see ocean waves reaching the shoreline during a perfectly calm day.



16 *Waves tend to break when wave height (h) is approximately 0.78 times the water depth (d).*

As ocean waves approach shallower water near the shore, friction with the sea floor slows the wave's velocity. The distance between wave crests decreases, and waves begin to peak. As the waves continue their approach toward the shoreline, friction with the bottom continues to slow the velocity of the bottom of the wave, while the top (crest) of the wave continues its forward motion. [16] The net result is instability of the wave, as the wave breaks. Waves tend to break when wave height is approximately 0.78 times the water depth. Thus, a 5-foot wave will break where the water depth is 6.4 feet, and a 7.8-foot wave will break in an area where the water depth is 10 feet. Much of the Delaware shoreline is protected against huge breaking waves due to depth limitations and the presence of large offshore sand shoals. For example, a 30-foot high wave (which could occur in deeper ocean waters off the Delaware coast) would break in 38 feet of water. This depth occurs anywhere from 1,000 to 6,000 yards offshore.

Breaking waves in Delaware are generally plunging breakers, in which the front of the wave develops a *curl*, due to the moderately steep slope of the beach face. [17] When the slope of the beach is gentler, spilling breakers occur. These waves spill down their face from top to bottom as they approach the shoreline.

Tides. The twice-daily rhythmic rise and fall of the sea is called the tide. The average vertical distance between a normal low tide and a normal high tide is known as the mean tide range. Mean tide ranges in Delaware are approximately 4 feet along the Atlantic Coast, 4-6 feet along Delaware Bay, and 2 feet or less in the Inland Bays. The Delaware coast experiences two tidal cycles per day of approximately equal heights (semi-diurnal). Each day's two high tides (and two low tides) are approximately 50 minutes later than those of the previous day. For example, if a high tide occurs at 10:00 a.m. on a Saturday morning, Sunday morning's high tide will occur at 10:50 a.m.

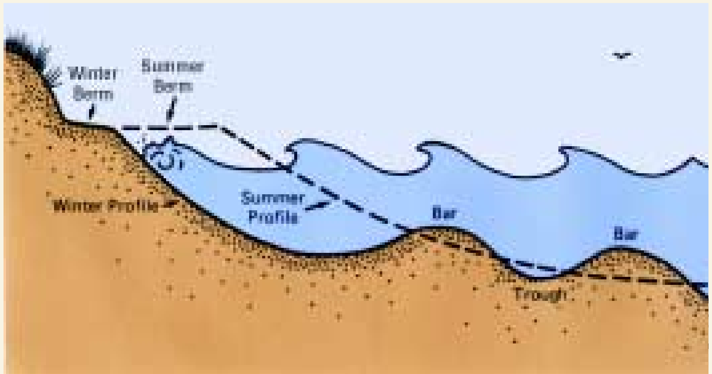
17 *A plunging breaker.*

Tides play an important role in beach development and coastal processes, because they constantly change the depth of water in which waves approach the coastline and strike the beach. The twice-daily rise and fall of water level under the influence of tides submerge or expose parts of Delaware's beaches every 6.5 hours. Tides are also important in controlling the horizontal extent of the beach and the types of plants and animals that inhabit it.

The gravitational attractions of the sun and moon on the ocean's waters cause tides. Because it is closer to the Earth, the moon is the more important force in producing tides. The gravitational attraction of the moon raises bulges of water both on the side of the earth facing the moon and the side of the earth opposite the moon. The moon revolves around the earth every 28 days. When both the moon's and the sun's gravitational forces are in line, spring tides result. During spring tides, which occur every 2 weeks around new and full moon stages, the water level rises higher and falls lower than usual. This larger tide range, approximately 20% greater than mean tide, lasts approximately 3 days. When the moon is in the first or last quarter, at right angles to the sun, lower tides, called neap tides, result. During neap tide conditions, the range is approximately 10–30% less than average.

The tide level is also affected by wind conditions. Strong offshore winds (blowing from the westerly quadrants, from land to sea) push water away from the land surface, and result in lower-than-normal tides. This is especially noticeable along the Delaware Bay shoreline, and in the Inland Bays. Strong onshore winds (blowing from water to land) tend to cause water to "pile up" along the shoreline, resulting in higher-than-normal tides.

Associated with the vertical rise and fall in water level are horizontal motions of the ocean known as tidal currents. Ebb tidal currents result from falling tides, when water moves out of inlets and bays. Flood currents occur on rising tides when water flows into inlets and bays. Tidal currents are important in inlets, the Inland Bays, and Delaware Bay, but have relatively little influence on the open ocean coast.



18 *Beach profile showing emergent and submerged portions of the beach.*

Cross-Shore Transport. The shape of the beach varies daily and seasonally, and often changes over the long-term as sand moves onshore and offshore. This process of sand movement perpendicular to the shoreline is called cross-shore transport. It is important to realize that the beach is actually a 3-dimensional system, and sand is also moving alongshore, parallel to the shoreline, as described in a subsequent section.

A cross-section (profile) of the beach is shown in [18]. The beach consists of an emergent (dry) section, called the berm, and a submerged section, below the water level, but still affected by waves and currents. During fair weather and low wave energy conditions, typically in the summer months, the beach above low tide builds up, and becomes high and wide. This occurs as low height waves pick up sand and move it in a landward direction. In the winter months, when high energy storm wave conditions prevail, large waves move sand from the beach to the offshore zone, forming one or more submerged sand bars. Thus, the visible beach becomes narrower while the submerged supply of sand is increased. The presence of a submerged offshore sand bar also causes waves to break farther from the beach. This sand is stored in the offshore bar until the cycle is repeated. During the summer months, the beach is usually wide enough to accommodate the many people who enjoy sunbathing, strolling, fishing, building sandcastles, and collecting seashells. [19] The same beach during winter months is narrower, with the water line near the boardwalk. [20] Many people who visit the beach in the summer become alarmed when they see the narrow beach in winter, but should understand that the sand is usually offshore, and will normally return the following spring.

19 *Bethany Beach during calm conditions, when onshore transport of sand results in a wider beach.*

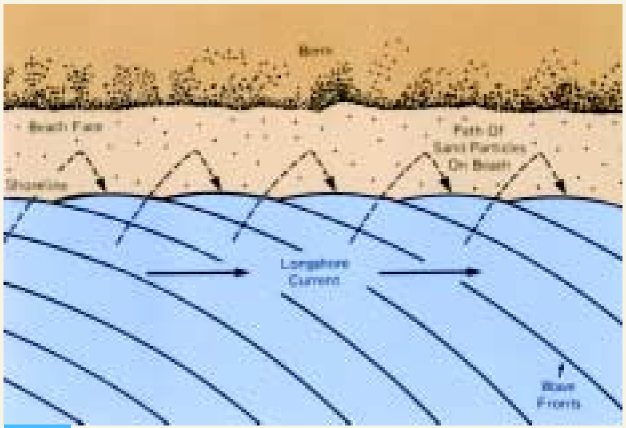
20 *Bethany Beach during high wave energy conditions, when offshore transport of sand results in a narrower beach.*

Rip Currents. Rip currents are channelized currents of water flowing away from shore at surf beaches. They typically extend from near the water's edge, through the surf zone, and past the line of breaking waves. Rip currents are important in seaward sediment transport. Often incorrectly called rip tides, they are not caused by tides. The primary driving force generating rip currents is the nearshore circulation pattern resulting from wave forces. As waves transport water toward the shoreline, water returning to the sea can form channelized currents, which transport water (and sand) offshore. Rip currents most typically form at low spots or breaks in offshore sandbars when seaward flowing water is confined to these narrow breaks. They also may form near structures such as groins, jetties, and piers which may deflect water seaward. The location of rip currents can be recognized by a narrow channel of choppy, churning water; a difference in water color; a break in

21 *Rip currents can be identified in this photograph as the sandy-colored water moving past the surf zone out to sea.*

incoming waves; or a line of foam, seaweed, or debris moving offshore. [21] Rip currents are a major threat to swimmers, and account for 80% of surf zone rescues by lifeguards. Average rip current velocities are 2 to 3 feet per second. Rip currents are most dangerous during high surf conditions, when outgoing currents can reach speeds up to 8 feet per second. If caught in a rip current, try to escape the current by swimming parallel to the shoreline. Once you feel the current diminishing, swim toward the shoreline at an angle.

Longshore Transport. This term refers to the movement of water and sand parallel to the shoreline. This movement of sand can be compared to a conveyor belt, in that sand is moved from one portion of the beach to another, and is replaced by sand from nearby areas. Longshore transport results from currents generated when waves strike the beach at an angle. [22] This sets up a current along the beach in the direction that the waves are breaking. Swimmers often notice this current when they are in the surf zone and slowly drift down the beach. Unlike rip currents, longshore currents generally do not pose a threat to swimmers, as velocity is relatively slow, and they usually occur in shallow water near the shoreline.



22 *Waves approaching the beach at an angle generate a longshore current that transports sand parallel to the beach.*

The direction of longshore transport varies as the direction of incoming waves varies. When waves approach Delaware's Atlantic coast from the southeast (from the right as you are standing on the shore looking out to the ocean), the sand will move northward (to your left). When waves approach from the northeast (from the left as you are standing on the shore looking out to the ocean), the sand will move southward (to your right). Just as the direction of incoming waves can vary from day to day, so does the direction of longshore transport.

The volume of material moved by longshore transport is related to the size and velocity of incoming waves, and the angle at which they approach the shoreline. If waves approach straight toward the beach, there is no wave-generated longshore transport. The maximum transport occurs when waves approach the coast at a 45º angle, although this rarely occurs in nature, due to wave refraction. As may be expected, larger waves can generate a stronger longshore current, and therefore can transport greater amounts of sand. Thus, longshore transport volumes along the Atlantic Ocean Coast are much greater than those along Delaware Bay or the Inland Bays.

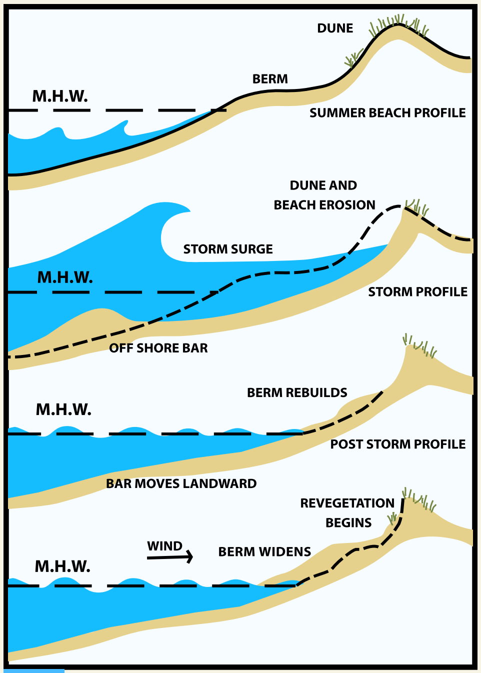
Along most sections of the coast, waves approach the coast more frequently from one direction than another. Along much of Delaware's Atlantic coast, waves most often approach from the southeast, setting up northward longshore sediment transport. Sand moves northward along the coastline, and is ultimately deposited at the sand spit, Cape Henlopen, causing it to grow in a northerly direction. Calculations show that approximately 200,000 cubic yards of sand reach Cape Henlopen every year. This is the equivalent of over fifty dumptruck loads per day, each carrying an average load of 10 cubic yards. The total volume of material moving past a given point in a given year, regardless of direction, is called the gross longshore transport. It is the sum of northward and southward moving material. It is estimated that as much as one million cubic yards of sediment passes along the shoreline at Fenwick Island. This is equivalent to approximately 100,000 dumptruck loads of sediment per year.

Indian River Inlet, stabilized by jetties, results in an interruption of the northward longshore sediment transport along Delaware's Atlantic coast. Sand accumulates at the south side of the southern jetty, causing a wide beach to form. In the past, very little sand reached the beaches on the north side of the inlet, so that the north beach eroded. The pattern of sand accumulation and erosion is just the opposite at the Ocean City Inlet in Maryland. Here, sand is moving in a net southerly direction, and accumulates on the north side of the north jetty at Ocean City, building a wide beach, whereas Assateague Island, south of the inlet, is eroding rapidly. In an area along the coast somewhere between South Bethany and Fenwick Island, Delaware, the net direction of longshore transport diverges. This is called the nodal zone, north of which there is net northward sand movement, and south of which there is southerly sand movement.

Coastal Storms. Delaware's beaches are affected by two types of coastal storms: tropical systems and northeasters. [23] Tropical systems may originate in the warm waters of the Atlantic Ocean, Caribbean Sea, or Gulf of Mexico. These storms are characterized by extremely low pressure, heavy rainfall, and high wind velocities. A tropical storm with winds of 74 MPH or more is called a hurricane. Tropical storms usually occur from June through November. Northeasters (also called extratropical storms, because they develop "outside" of the tropics) generally result from one or more low pressure systems off the coast, in which the winds blow from the northeast. While usually lower in velocity, wind speeds can exceed those of a hurricane. Northeasters can be accompanied by rain or snow, and in rare cases, there is no precipitation at all. Although they may occur at any time of year, most destructive northeast storms occur during the winter and spring months.

Although their origins differ, tropical systems and northeasters share many characteristics, and their impacts on the coast can be similar. Both types of storms are accompanied by strong winds, high waves, and high storm tides. Wind circulation is in a counter-clockwise direction around the center. The greatest damage usually occurs in the northeastern quadrant of the storm. Damage from strong winds is often extensive. High velocity winds can blow shingles off of roofs and knock down trees and power lines. Large objects can be lifted and hurled through the air, acting as battering rams and causing additional destruction. High waves and tides result in extensive flooding of low-lying coastal areas.

23 *Storm waves and tides along the Delaware coast.*



24 *Effects of storm wave attack and storm surge on the beach and dune system.*

Coastal storms also cause extensive beach and dune erosion, which results in scarping of the dunes, narrowing of the beach, or overwashing. Under normal wave conditions, the berm is wide, with a high dune crest. The berm is above the influence of waves and tides, and waves break on the sloping intertidal beach face. [24] During the initial stages of a storm, higher than normal tides flood the berm, and waves break at the base of the dune line. This often results in formation of a near-vertical erosional scarp. Sand is eroded from the beach and deposited offshore, flattening the beach profile. The net result of storm erosion is a narrower, flatter beach; and scarping of the dune face. Sand eroded from these areas is deposited offshore in the form of one or more submerged sand bars. In extreme cases, the dune is overtopped or breached, with sand transported landward by overwash surges. The return of normal low energy wave conditions following the storm eventually moves this sand back on the beach in the form of a repair bar. This ridge of sand gradually moves landward as a result of wave action. During this process, there is often a low area filled with water, called a runnel, landward of the repair bar. Ultimately, the repair bar welds onto the berm. Although the beach usually regains its pre-storm shape, some of the sand eroded by storm waves may be lost from the active beach system.

Large storms can cause extensive erosion resulting not only in scarping of dunes but possible overwash of the beach and dune system. When these storms occur, sand eroded from the beach can be carried landward by surging water. The sand and water may wash over or break through the dunes, and spill out onto the landward side of the barrier. This deposit is usually fan shaped, and therefore known as an overwash (or washover) fan. Low-lying areas such as breaks in the dune system are particularly vulnerable to overwash. Vegetation usually colonizes the overwash fan, and new dune growth is initiated. This process of landward movement of beach sand is considered vital to the long-term survival of the barrier beach system.

The Ash Wednesday storm that struck the mid-Atlantic Coast on March 6-8, 1962, was one of the most devastating in Delaware history. This was not a hurricane, but rather a northeaster, resulting from two low-pressure systems that combined and stalled over the U.S. East Coast. The slow-moving storm lasted through five high tide cycles over a period of 2.5 days. High northeasterly winds, with gusts in excess of 70 mph, generated waves estimated to be 20-30 feet in height. Maximum tide height was 5 feet above normal. The extraordinarily high tides and waves combined to inflict great damage to the Delaware coast. In Rehoboth

Beach, the boardwalk and many oceanfront buildings were destroyed. [25] The ocean washed through to Rehoboth Bay in several locations, flattening the dunes and flooding the highway (Route 1). When the storm receded, 4-6 feet of sand covered the road [26]. Damage to public and private property exceeded $70,000,000.

25 *Destruction of Rehoboth Beach boardwalk and oceanfront buildings as a result of the March 1962 northeast storm.*

On January 4, 1992, an intense northeast storm moved across Delaware. The storm occurred during the new moon (spring tide), when tides are higher than normal. Wind velocity of nearly 50 mph (as recorded at Indian River Coast Guard Station) generated 20-foot waves off of the coast. A maximum tide height of over 9 feet was recorded at Breakwater Harbor in Lewes. Although the storm lasted only one day (one high tide cycle), there was extensive flooding in low-lying coastal areas. Boardwalks at the north end of Rehoboth Beach and Bethany Beach were damaged. Dune breaching and overwash occurred in several locations along the Atlantic coast, including Bethany Beach, Dewey Beach [27 and 28] and north of Indian River Inlet, where the road was closed due to flooding and sand accumulation. Overwash and dune breaches were noted in Broadkill Beach, Primehook Beach, Slaughter Beach, Big Stone Beach, and South Bowers.

26 *Sand on Route 1 as a result of flooding and overwash deposition, March 1962 storm.*

Six years later, back-to-back northeasters occurred on January 27-29 and February 4-6, 1998. Tide height at Breakwater Harbor was the third highest of record on January 28, just below the record set in March 1962, and the second highest tide level in January 1992. Dune erosion, breaching, and overwash occurred along the Atlantic coast from Fenwick Island to Cape Henlopen. The main road along South Bethany was damaged, and the north end of the boardwalk at Rehoboth Beach was broken apart by surging tides and breaking waves. There was significant beach erosion along most of Delaware's Atlantic shoreline, and much structural damage in the community of North Shores, just north of Rehoboth Beach. [29] There was extensive flooding and overwash along Delaware Bay communities, including Big Stone Beach and South Bowers.

29 *Damage at Broadkill Beach, 1998 northeast storm.*

Coastal Erosion. Most beachgoers are accustomed to seeing a nice, wide sandy beach when they visit the coast on hot summer weekends. There is plenty of room for beach chairs, blankets, umbrellas, coolers and all the beach gear families and groups of friends typically bring to the beach. Some people enjoy being as close to the water's edge as possible, to take advantage of the cool ocean breezes and to take a quick dip in the ocean without having to walk too far. Others prefer being closer to the boardwalk, perhaps sheltered from the ocean breeze, and a few steps closer to the many shops. There is room for all, and all can be accommodated. When some of these visitors return to the coast for a winter weekend getaway and first see the beach, they may be shocked at the narrow width, and to see the tide come up to, and even in some cases, under the boardwalk. This is what most people perceive as beach erosion. However, the sand has not been lost from the beach system, it has simply moved from the dry (emergent) beach, offshore to the submerged (underwater) section of the beach. This seasonal exchange of sand from the berm to

27 *Damage at Dewey Beach, January 1992 northeast storm.*

28 *Damage to Bethany Beach boardwalk, January 1992 northeast storm.*

30 *The post-storm beach at South Bethany, showing a sand ridge (repair bar) that moves onshore to rebuild the beach after storm erosion.*

the submerged bar is a natural seasonal cycle. The sandy beach that everyone enjoys so much will slowly build up again during the spring months. [30]

Many people think of beach erosion as landward movement of the shoreline. However, in nature, the location of the shoreline fluctuates on several time scales. The position of the shoreline can change 50 feet or more over a single 6-hour tidal cycle, due to the rise and fall of the tide on a gently-sloping beach. There can be a 100-foot or greater seasonal change in the position of the shoreline from summer to winter, as sand moves onshore and offshore in response to changes in wave conditions. During storms, the location of the shoreline (as well as the dune line) can move dramatically landward in a period of hours to days. Over the long-term (centuries to millennia), sea-level rise results in encroachment of the sea onto the land.

Coastal erosion occurs when there is a net loss of sand from the beach system. The loss may be temporary, or it may be permanent. An understanding of sediment sources, pathways, and sinks is necessary to determine if there is a net loss (or gain) of sand from the system.

Shoreline Changes Along the Delaware Coast

Delaware shoreline changes over the past two centuries have been documented using a variety of techniques and databases. Shoreline positions in the 19th century were depicted on historical surveys, maps and charts. Starting in the 1930s, aerial photographs were used to identify shoreline locations. Beach profiles, showing the beach in cross-section, can be compared to document changes over time. However, caution must be exercised with each of these methods to avoid misinterpretation. For example, accuracy of early documents must be established to draw quantitative conclusions. Factors such as tide stage, season, and recent storm activity should be taken into account in interpretation of aerial photographs. Impacts of nearby structures and placement of beach fill must also be considered when analyzing beach profile changes. Daily or seasonal fluctuations in shoreline position can be orders of magnitude greater than long-term changes. Long-term trends may be masked by extreme events.

Atlantic Coast. By utilizing a variety of databases (historic maps and charts dating from the 1850s; aerial photographs, and beach profiles from 1964 through 1993), the U.S. Army Corps of Engineers has documented that the Atlantic Ocean coast of Delaware from Cape Henlopen to Fenwick Island has a history of net erosion ranging from an average of one to five feet per year. The south side of Indian River Inlet has a long-term accretion rate of 2 feet per year, due in part to the presence of jetties interrupting the net northerly long-shore sand transport. There is a range of coastal change, with each area going through short-term periods of erosion and accretion, with only the area north of Indian River Inlet undergoing continuous erosion over the long term.

Cape Henlopen. The sand spit Cape Henlopen is one of the few naturally accreting beaches along the Delaware Coast. The spit is accumulating approximately 200,000 cubic yards of sand each year, a result of northward transport of sand from beaches to the south. This has resulted in the spit advancing over 6,000 feet northward into Delaware Bay during the past two centuries.

The location of Cape Henlopen Lighthouse, constructed on the Atlantic Coast of Cape Henlopen, provides an accurate reference point to document shoreline change. The earliest accurate source of information pertaining to shoreline position along the Atlantic Coast of Cape Henlopen is based in a 1765 survey prepared in connection with construction of the Cape Henlopen Lighthouse. At the time of its construction in 1765, the structure was approximately 1,600 feet from the ocean coastline. The structure collapsed into the sea in 1926, so that means it took 161 years for the sea to encroach 1,600 feet, at an average long-term rate of nearly 10 feet per year. [31]

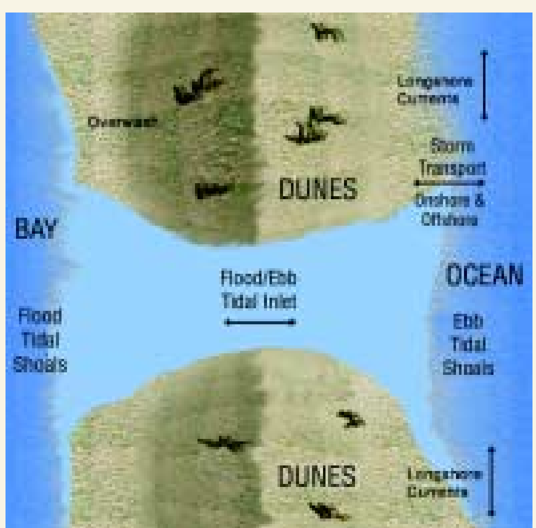
Delaware Bay. Shoreline changes along Delaware Bay from the mid-1800s to the late 20th century have been documented from historic maps and aerial photographs. Highest rates of shoreline retreat (in some cases, more than 17 feet per year) tend to occur along marsh shorelines such as Kelly Island and Port Mahon in the northern section of Delaware Bay. Lower erosion rates (less than 5 feet per year) occurred along the central section of the bay characterized by narrow, low-lying sandy beaches. The southern section, with wider and higher beaches, eroded less than 2 feet per year. These rates, like those along the ocean coast, are highly variable over time. Some areas exhibited accretion over shorter time frames.

31 *Aerial photographs of Cape Henlopen from 1926, 1968, and 1997 showing northward progradation of the spit. The red star marks the location of the 1765 Cape Henlopen Lighthouse, which fell into the sea in 1926.*

Sediment Sources, Pathways, and Sinks

The sand that forms our beaches is a limited resource. To develop a sound management plan for this resource, it is important to understand where the sand comes from (sources), how it moves (pathways), and where it ends up (sinks). This knowledge will help planners and managers to maximize sand available for Delaware's coast to ensure that wide, sandy beaches will be available to fulfill recreational, property protection, and habitat needs.

Sediment Sources. Sand that comprises a beach is supplied by one or more sources. In some parts of the country, such as California, rivers transport a vast quantity of sand directly to the coastline, where it is reworked by wave action. In other areas, such as New England, wave erosion of large-scale glacial deposits provides a sand supply to the beaches. At the present time, there does not appear to be a large amount of river-borne sediment reaching the Delaware coast. There are localized sedimentary headlands (such as Bowers Beach along Delaware Bay), which contribute sand to the beach system. In most cases, though, the immediate source of sand forming our beaches is often an adjacent beach. Longshore currents moving sand parallel to the shoreline feed one beach at the expense of another. For example, sand moving northward along Dewey Beach eventually passes on to Rehoboth Beach. If the volume of sand reaching the beach from updrift sources is equal to the volume continuing downdrift, there will be no perceptible change (erosion nor accretion) in the beach as the sand will continue its northward journey. If there is a structure (such as a groin) in place to trap the sand, the beach will become wider. During storms, the dune becomes a source of sand to the beach as storm waves and tides attack the foredune and move sand onto the beach. Nearshore sediments, such as sand bars, can also provide sand to the beach, but this is simply an exchange of sand. In contrast, ebb tidal shoals associated with former tidal inlets may provide new sediment to the beach. For example, the old Broadkill Inlet at Broadkill Beach closed in the mid-1900s. The sand shoals that formed in Delaware Bay off of the inlet may contribute sand to the beach at Broadkill. Over the long term, sand in the landward sections of the coastal barrier, such as washover deposits and flood tidal shoals, supply sand for continued barrier island migration in response to sea level rise. Since the 1950s, renourishment has provided an additional source of new sand to many of Delaware's beaches. Sand, either trucked from inland sources, or pumped hydraulically from underwater sources, represents a net input of sediment into the beach system.



32 *Sediment sources, sediment pathways, and sediment sinks.*

Sediment Pathways. The beach is a 3-dimensional system—with sand moving onshore, offshore, alongshore, and upward over time, as described in previous sections. These pathways transfer sand from its source to its final destination. [32]

Sediment Sinks. Sand can be lost from the beach system to a variety of sinks. Some of these sinks are temporary, others more or less permanent. Sand transported offshore as a result of seasonal cross-shore transport may be viewed as a temporary loss, as much of the sand returns to the emergent beach in a matter of months. Similarly, much of the sand lost from the beach to the offshore by storms also finds its way shoreward during post-storm recovery of the beach. However, there may be some net offshore loss of sand from a major storm, if the sand is transported so far seaward, into deep enough water, that "normal" wave action cannot return the sand to the beach. Storms also cause landward transport of beach sediment by overwash. Sand is lost from the beach as it is deposited on the backbarrier flats and at the edge of the lagoon. Eventually, this sand will be incorporated back into the beach system (hundreds or even thousands of years from now) as sea level rises.

The spit Cape Henlopen represents a significant sediment sink in Delaware. It is estimated that the spit is accumulating 200,000 cubic yards of sediment each year, derived from northward transport of sand from beaches along our Atlantic coast. Most of the sand is contributing to the northward growth of the Cape. [33] However, a small volume of sand is continually moved offshore by ebb tidal currents to form Hen and Chickens Shoal.

33 *Cape Henlopen spit—end of the conveyor belt of sand.*

Inlet processes also result in a net loss of sand from adjacent beaches. Ebb tidal currents move sand from the beach offshore, to form ebb tidal shoals. It is estimated that the ebb tidal shoal in the Atlantic Ocean off of Indian River Inlet contains up to 8 million cubic yards of sand. In contrast, flood tidal currents move sand from the beach into the inlet, and result in deposition of the sand in the form of flood tidal shoals in the lagoon. Like overwash sands, flood tidal shoals will eventually become long-term sources of sediment for barrier migration as sea level rises.

Human Impacts on Natural Beach Systems

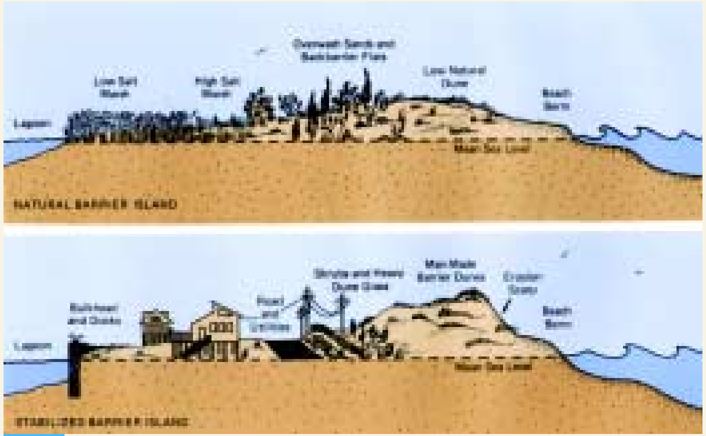
A natural barrier beach system consists of a number of interrelated environments (beach, dune, backbarrier flats, and salt marsh), each created by and adapted to the physical forces that affect it. The physical shape of each zone and the vegetation that stabilizes it are dependent upon elevation relative to sea level, distance from the sea, availability of sediment, amount of salt exposure, and frequency of overwash. The system and its components adapt to the continuing natural stresses and forces. The result is that over time, the entire system maintains itself. A natural barrier beach system [34] has a wide, gently sloping beach berm, a low natural dune system, vegetated backbarrier flats, and a low-lying backbarrier marsh along the lagoon shoreline. During storms, waves and tides overtop the beach and dune system, and overwash deposition occurs on the backbarrier, where sand is deposited to build the barrier upward and landward. The newly deposited sand is then colonized and stabilized by vegetation.

In contrast, an artificially stabilized barrier beach system, one that has been altered by human intervention, assumes a different shape than a natural system. Stabilization of dunes and beaches is often necessary to protect developed areas that could be damaged by flooding and storm overwash. Dune stabilization usually involves placing additional sand to form a continuous, high ridge to prevent flooding on the landward side. Other impacts of development on a barrier system may include construction of roadways and houses on the backbarrier; placement of fill material on the backbarrier marsh; and construction of bulkheading along the lagoon edge. These activities may have an adverse effect on the long-term maintenance of the barrier system by inhibiting or preventing overwash deposition. Artificially stabilized dunes are usually higher and steeper than low, natural dunes. Instead of being transferred landward by overwash during storm events, sand is transported offshore and alongshore. Any overwash that does occur is often removed from roadways and residential areas, and lost from the system. Ultimately, the elevation and width of the barrier system will not maintain itself as sea level rises.

Survival of structures built along our barrier beaches depends upon maintenance of the beach and dune system. Although storms and sea-level rise are causing the shoreline to move landward, prudent management of beachfront development and wise engineering practices can minimize the adverse effects of these changes to the natural system.

Summary

The components of the barrier beach system are all interrelated. Their dimensions, and thus their use for recreation, property protection, and habitat value, are dependent upon the physical forces affecting them. The amount of sand available to the system is limited; therefore it is important to understand sediment sources, pathways, and sinks for regional sediment management purposes. This enables coastal planers and managers to maximize and make the best use of this important resource.



34 *Comparison of natural and artificially stabilized barrier beach systems.*

The Beach as a Natural Resource

While many residents and visitors appreciate Delaware's beaches for their obvious recreational value, the important functions of the beach as a natural environmental resource are sometimes overlooked. Beaches have been too often viewed as a part of an urbanized coastal landscape that visitors seek for their recreational time. Beaches are natural landforms that support a wide variety of plants and animals, including people. [35] The sandy beach and dune areas provide unique habitat for a number of plants and animals that have adapted to the stressful environment found along Delaware's Atlantic coastline.

35 *The beach environment is a natural resource that provides biological habitat for a variety of plants and animals.*

Beach managers and the government entities that provide funding for competing demands for natural resource management must look at the functions and values that beaches provide. If we break down beaches into the various categories of benefits they provide and their related values, it helps determine how best to manage the resource.

The many benefits of Delaware's beaches include:

- *Biological habitats provided for beach-dependent plants and wildlife.* Our beaches provide important habitats for native, threatened, and endangered species such as the piping plover, the common tern and the least tern.
- *Storm protection and damage reduction.* Physical coastal features such as beaches and dunes provide a safety buffer between the ocean and our coastal communities, thus reducing storm damage to public infrastructure, private development, and important habitats.
- *Recreational, educational, and aesthetic values of a wide sandy beach, and access to the sea.* Our coastal areas provide irreplaceable recreational and educational opportunities. and visually pleasing vistas. They also provide recreational access to the sea for millions of residents and visitors to the state.
- *The contribution of beaches to the local, state, and national economies.* Our beaches inject millions of dollars into the economy through recreation and tourism.

Biological Habitat

At first glance, the beach may seem to be an environment barren of living things (with the exception of shorebirds and occasional jumping dolphins). In fact, many of the animals that live at the beach are so small that they may escape notice, especially because they're typically burrowing animals, hidden from view most of the time. Plants and animals that live in beach environments must be able to survive many physical stresses that create rather hostile surroundings—salt spray, occasional overwash by sea water, freshwater rainfall, strong winds, shifting sands, and extreme heat and sun. Many species are specialized to a dune/beach/nearshore existence, making a beach system the unique environmental niche for these plants and animals.

Plants and Animals in Ocean Beach Zones. In the turbulent surf zone where conditions are particularly harsh, relatively few species occupy the substrate in this area of breaking waves and churning sands. [36] Beyond the surf zone, there may be a longshore trough, sand flat and sandbar system that is covered by seawater and characterized by well-aerated water and stable water temperatures. Here conditions are more favorable, a number of animals burrow in and crawl over the bottom, or feed close to it. Some of the animals found in the sub-tidal areas include whelks and crabs. Several different types of fish such as dogfish, skates, weakfish, bluefish, and puffer fish swim in nearshore waters, often in the breaking waves.

36 *Turbulent surf zone environment and intertidal zone.*

Life in the intertidal zone (between the tides) on an ocean beach is full of extreme physical stress—not only from the alternating submersion and exposure as the tides rise and fall, but also from the turbulence of the water as waves break and the constant movement and shifting of the sandy sediment. Except when exposed by the falling tide, the sand is in almost constant motion, and animals must adapt by burrowing into the sand to survive. Some sand-dwellers are blind, while others have reduced eyes or eyes that rise above the sand on long stalks. Most sand-dwellers feed on organic detritus trapped between sand grains, or filter particles of suspended food from water passing overhead. Many tiny animals and plants live between sand grains—from microscopic organisms, to slender worms and tiny crustaceans. This unstable habitat is such a severe environment that no higher plants can exist here and only a few larger animals call this turbulent area home—lug worms, the mole crab, and tiny shellfish such as the coquina clam.


37 *Mole crab.*

Mole crabs (or sand crabs) can be seen burrowing up and down in the surf zone as the water swashes around them. [37] Their round, compact shape helps them dig quickly into the sand as waves crash over their bodies. Mole crabs are a food source for shorebirds, fish and other types of crabs (such as the calico crab or blue crab) that live in the shallow water near the beach. The mole crab is well known to beachgoers, sought after by fishermen for bait, dug up by children for amusement, and eaten by other crabs, shorebirds, and fishes. With its special adaptations for coping with churning water and sand, it is able to burrow and migrate up and down the beach slope with the rising and falling tides.

Another animal found in the beach intertidal zone is the coquina clam. Tiny, multi-colored coquina clams can also be seen burrowing into the beach slope as a wave breaks on the beach and the water recedes. [38] As the water rushes back down the sandy slope to the sea, coquinas extend their feeding siphons and filter plankton. The coquina seems to thrive in the shifting swash zone, and moves up and down the beach slope with the tide. Although it is not a swimmer like the mole crab, the coquina clam can anchor itself quickly and dig itself into the sand.

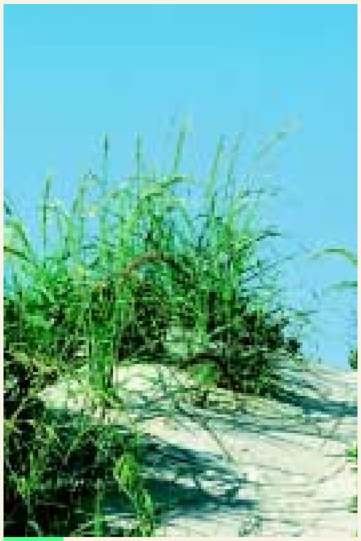

38 *Coquina clam.*

In contrast to the high energy surf zone of Delaware's Atlantic coast beaches, the sandflats along Delaware's bay shoreline are home to greater numbers of bottom-dwelling and intertidal organisms. Waves are usually smaller along the Delaware Bay coast, and consequently, the physical stresses on plants are animals are not as severe. Some of the more typical plants and animals living on the sandflats of Delaware Bay's intertidal zone include: sea-lettuce and brown algae (types of seaweed), horseshoe crabs, mud snails, hermit crabs, sand shrimp, and various tiny amphipods. In certain areas along the bay coast, worm reefs or dense clusters of worm tubes and nodules constructed by tubeworms are prevalent. Many other types of burrowing worms live within tidal flat sediments such as plumed worms, cellophane tube worms, red-gilled mud worms, and sand-builder worms. Additionally, razor clams and hard clams are examples of bivalves that can be found living below the surface of the intertidal sandflats.


39 *Sea rocket—a pioneer beach plant.*

The area above the reach of every day waves and tides is the most sparsely populated of all the beach zones. Salt spray, shifting/blowing sand, and occasional flooding by storm waves and tides are some of the physical stresses exerted on animals living in upper beach and foredune environments. While resident species may be few, there are a number of animals that hunt, feed and rest on the upper beach area, including many types of shorebirds, sparrows, grackles, red-winged blackbirds, fish crows, raccoons, and red foxes.

Due to the dynamic nature of the beach and the constantly shifting sands, only a limited number of plants are found in this environment. Sea rocket is a tough plant found in the upper beach zone, with thick, fleshy leaves to help hold in water. [39] Sea rocket is often the first plant to grow on a stretch of bare sand, typically sprouting in the wrack line at the upper edge of the winter's highest tide reach. Sea rocket can be found growing from the toe of the dune to the high tide line, but can quickly disappear when high tides and



40 *American beachgrass thrives in the dune environment.*

waves scour beach sands. Other plants that can be found growing on the narrow upper beach strip include beach pea, seaside spurge, common saltwort, and American beachgrass.

American beachgrass is a good example of a plant that has developed specialized adaptations that allow it to actually thrive in the harsh conditions found at the beach. [40] American beachgrass is the most common type of vegetation found along Delaware's sandy shores. This hardy plant is found in upper beach and dune areas, helping to hold the sand in place with upright green leaves and stems that deflect erosional wind, and an extensive network of underground stems and with roots that grow deep in search of fresh water. Beachgrass knocks down windborne sand, resulting in sand accumulation or dune building. This specialized grass actually thrives when it is buried by sand.

Living and dead plant material can be found in the upper beach zone in the wrack line. The wrack line comprises an assortment of animal fragments, organic matter, and sometimes trash transported by the waves and deposited at the high tide line. The cast-up debris usually includes an accumulation of various seaweeds, fragments of shells and plants carried by currents from other areas, remains of horseshoe crabs, fish, and other marine animals, and driftwood. [41] Beach wrack provides a food resource and furnishes shelter from drying winds and predators. One tiny animal found abundantly in beach wrack is the small amphipod known as the sandhopper, sand flea, beach-hopper, or beach flea. Beach fleas are scavengers, feeding upon decaying plant and animal matter. They are eaten by many shorebirds such as sanderlings and plovers, and are an important food source for the ghost crab.

41 *Organic wrack line debris can be found at the high tide line.*

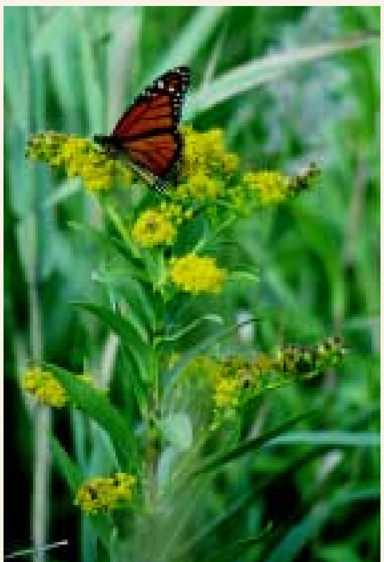
The beach is a harsh environment for most animals. In winter, storm waves pound the shore and cold winds blow sand and salt spray. In the summer, the sand can be incredibly hot and dry as a desert. However, the sandy beach is home to a few very specialized animals. The most common resident animal of the upper beach and foredune area in Delaware is the ghost crab. [42] The sandy-colored ghost crab spends most daytime hours in holes burrowed into dry beach areas, venturing out at night to feed. The ghost crab is uniquely adapted to life on the dry beach, and is almost impossible to see on the beach unless it's moving. Even then, it's a challenge for most beachgoers to catch a glimpse of a ghost crab—only the sharpest eyes will see the nearly invisible swiftly moving crab with unmatched burrowing ability. Ghost crabs are primarily nocturnal, but it is sometimes active in the daytime, standing watch at the entrance of its burrow. Their burrows are usually found on the upper beach near the toe of the dune, but they can be found just above the high tide line. While they can remain out of the water for long periods of time, a ghost crab may venture into the surf to wet its gills from time to time.

42 *Ghost crab.*

American beachgrass is the dominant vegetation found in Delaware's primary coastal dunes (immediately adjacent to the beach). This grass is specially adapted to the extreme environmental conditions that arise from exposure to wind, salt spray, periodic blowouts and sand deposition, and extreme temperature fluctuations. Temperatures at the sand's surface may reach 120 degrees on a hot summer day! In more sheltered dune areas, other types of vegetation can be found, including seaside goldenrod, prickly pear cactus, dune sandbur, dune panic grass, joint-weed, and seaside spurge. Gradually dune vegetation may grow higher and more dense, creating a more stable area with increased organic material where additional kinds of plants including shrubs and trees can grow. The shrubs and trees in the back-dune zone are often pruned to smaller sizes by windborne salt spray. Low-lying areas between and behind dunes, also called interdunal swales, are often occupied by wetland vegetation. However, despite colonizing vegetation, no dunes should be considered a permanent part of the coastal landscape; the whole area is subject to extensive change due to powerful winds and churning water (waves and tidal currents) breaking through during storms. On very windy days, the tops of dunes may appear to be "misty" with windblown sand and salt spray. [43] When overtopped by stormy seas, the dunes serve as reservoirs of sand for the rebuilding of wave-cut beaches.

43 *Blowing sand is trapped by grass on dunes.*

A variety of plants and animals live on the dunes, from beachgrass and ghost crabs to hairy wolf spiders, velvet ants, and digger wasps. In the spring, terns are among the shorebirds that rely on the dunes for nesting grounds. Their well-camouflaged eggs match the color of the sand. In the fall, the yellow blossoms of seaside goldenrod attract monarch butterflies on their southward migration. [44]



44 *Migrating monarch butterfly on seaside goldenrod.*

Birds. Beaches are especially important feeding, resting, breeding, and nesting areas for many species of birds and shorebirds. Perhaps the most commonly seen birds along Delaware's beaches are the gulls, resting in large groups, sleeping, eating, or searching the sand for food. Gulls are usually considered to be scavengers of the beach, and they eat anything they can find, dead or alive. Somewhat smaller and more energetic shorebirds are often seen at the water's edge, searching for food in the sandy slope where the waves rush onto shore. These quick-footed shorebirds may be sanderlings or sandpipers, darting back and forth at the water's edge. They probe the wet sand with their long bills, finding food such as tiny clams or mole crabs. [45] Other shorebirds commonly seen searching for food in the wrack line or at the upper edges of surf beaches include ruddy turnstones, black-bellied plovers, and willets.

45 *Beaches provide habitat for many species of shorebirds.*

The common tern and other tern species are also frequently seen at Delaware beaches, and may often be observed diving into the ocean to catch small fish with their bills. Terns may look somewhat like gulls, but they are smaller, more slender, and more graceful in appearance and motion. Many tern species, including the royal tern, use the beach as a breeding and nesting site. They often nest on the back part of wide, broad beaches, away from the water's edge.

The sandy beach and coastal mud flats also provide important habitat for the American Oystercatcher, a large (chicken-sized) bird with an easily identifiable blackish-brown/white pattern and a long red bill. Oystercatchers were named for their ability to insert their long, bladelike bills into mussels, clams, oysters and other shellfish, cutting the bivalves' powerful muscles before the shells can close; they also feed on barnacles and snails. The oystercatcher was once over hunted along the Atlantic Coast, but because they are now a protected species, the oystercatcher population has once again become more numerous in coastal areas.

46 *Piping plovers build their nests in secluded beach area, usually near the base of a dune.*

An endangered species, the piping plover, is a small shorebird that also nests high up on the beach, away from the ocean. [46] Piping plovers are endangered, because their preferred nesting habitat—a safe, secluded beach area—is getting harder to find. Each nesting pair of plovers finds an isolated spot in the sand to make a nest, typically laying a clutch of 2-3 eggs. The birds and the eggs are so well camouflaged in the sand that they are sometimes difficult to see. Upon hatching, light-colored plover chicks are ready to run and feed in the upper beach. However, many young chicks are killed before reaching adulthood either by natural predators or by unintentional human activity.

Ongoing Research Advances the Science of Beach System Resource Management

The proper management of Delaware's beaches involves more than simply managing sand to maintain a recreational beach. Delaware's beaches have multiple functions and values – from those associated with a recreational resource and storm protection functions to those associated with environmental and habitat considerations. DNREC sponsors coastal research projects that provide coastal managers with information needed for beach system resource management. Here are highlights of just a few:

48 *Horseshoe crabs mating.*

Delaware Shorebird Monitoring Programs. Every spring and fall, the Delaware Bay shoreline plays an important part in the migration of shorebirds as they travel the thousands of miles between the Arctic tundra and the wetlands of South America. As an important link in the migratory flyway, the sandy beaches and tidal wetlands of the Delaware Bay provide critical resting and feeding sites for more than 40 species of migratory shorebirds. [47]

Since 1997, the Delaware Shorebird Monitoring Team, led by DNREC's Delaware Coastal Programs Section (DCPS), has been conducting research into the population dynamics and health of key shorebird species in the Delaware Bay region. The team conducts shorebird population studies by catching and releasing, counting, tagging, measuring and marking individual shorebirds. Over time, complete and thorough records of population numbers, body size/condition, and weight gain will provide invaluable information on shorebird migration and the critical feeding and resting areas provided by Delaware Bay shoreline habitats.

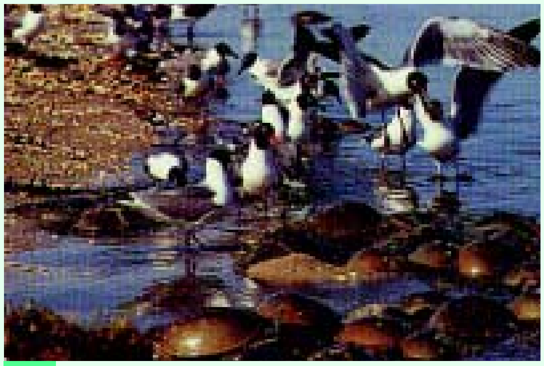
47 *Shorebirds feasting on horseshoe crab eggs.*

Horseshoe Crab Habitat Study. While beach nourishment projects are often discussed relative to creating recreational beach and storm protection barriers, beach nourishment is also an effective management tool for habitat restoration. DCPS recently conducted experiments to gain a better understanding of the role beach nourishment can play in improving spawning habitat for the horseshoe crab along Delaware Bay shorelines.

Horseshoe crabs can be seen along the shoreline of many Delaware Bay beaches, especially at high tide during the months of April, May and June. In fact, the Delaware Bay estuary hosts the highest concentration of spawning horseshoe crabs in the world. During peak spawning periods, female horseshoe crabs crawl out of bay waters onto shore to lay eggs on the upper beach. [48] The eggs mature in these sands and gravels until they hatch when high tides reach them again in four to eight weeks.

Horseshoe crab eggs are an important food source for fish, gulls, and migratory shorebirds. An important connection has been identified between the arrival of spawning horseshoe crabs on Delaware Bay beaches and the spring migration of many species of shorebirds that stop at Delaware Bay to rest and feast on horseshoe crab eggs. [49] The recent decline in the horseshoe crab population has prompted concerns that these migratory shorebirds may not have adequate food sources to complete their long journey to Arctic nesting areas.

The Delaware Coastal Programs Section has conducted studies to examine specific beach characteristics such as grain size on the sand/gravel



49 *Horseshoe crab eggs are an important food source for fish, gulls, and migrating shorebirds.*

50 *Close-up view of horseshoe crab eggs and beach sediment.*

mixed beaches that are critical to horseshoe crab spawning habitat. The overall objective of these studies is to compare spawning levels at nourished beaches to those that had not been nourished, and to determine whether beach nourishment could be used as an effective management tool to restore, create, and enhance horseshoe crab spawning habitat. [50] Preliminary results show that there was an increase in the amount of spawning activity on nourished beaches, suggesting a positive impact of beach nourishment on spawning, egg density, and egg development. While more research is required to assess specific beach design characteristics, this work has shown that beach management and nourishment projects can be used to improve horseshoe crab habitat and wildlife use. The Delaware Coastal Program plans to continue assessing beach nourishment as an opportunity for habitat restoration through the building of beaches with sediments that are most suitable for horseshoe crab spawning habitat.

Piping Plovers. The piping plover is designated as a threatened species along the Mid-Atlantic coast, and is protected under the Endangered Species Act that provides penalties for taking, harassing or harming the plover. This small sandy-colored bird uses the beach area as a feeding and nesting habitat. Each spring, migrating plovers arrive in Delaware during March or April to breed on uninhabited beaches, building nests in the sand near the base of the dune. The breeding population of piping plovers in Delaware has ranged from two to six nesting pairs each year since 1989, and these nests have only been found on state park beaches along Delaware's Atlantic Ocean coastline. A nesting pair usually incubates three to four sandy-colored eggs for four weeks until the chicks hatch. [51] Plover chicks are unable to fly for their first 25-35 days, and they must travel across the beach to the water's edge for food.

51 *Plover nest on beach.*

Both adults and chicks feed on small worms, crustaceans, and insects that are found in the wet sand or in high-tide wrack lines.

Even though young plover chicks are so well-camouflaged that they are likely to be undetected by beachgoers, intruders, or predators, there are many threats to their survival. [52] Extremely high storm tides can cause flooding of the back beach and dune areas that could destroy nests and drown chicks. Predators include foxes, dogs, cats, raccoons, skunks, gulls, and fish crows.

Along the Delaware coast, increasing commercial, residential, and recreational development have reduced the habitat available for piping plovers to nest and feed, resulting in a declining population. Although human disturbances may be unintentional, they often result in severe impacts to plover survival. Vacationers enjoying the beach may step on or walk right past a well-camouflaged nest, disturbing adults and chicks without knowing it. A simple activity such as flying a kite in a plover nesting area may interrupt feeding, nesting, resting behaviors that are critical for the plovers' growth and preparation for their southward migration. In some areas where vehicles are permitted on the beach, the deep tire tracks themselves may trap small chicks, making them more vulnerable to predators or to other vehicles.

52 *Plover chick and eggs.*

DNREC's Nongame and Endangered Species Program has developed management strategies for the state's breeding population of plovers that include: fencing off plover nesting habitat, protection of nests with predator exclosures, and education of beach users about how they can protect the piping plover. Perhaps the most effective management strategy is to preserve, maintain, and protect the remaining natural beach areas in Delaware that are suitable plover habitat. [53] State agencies are working cooperatively to ensure that proper beach management practices are in place to enhance plover habitat and avoid interference with natural processes that shape the landscape at these sites. Similar efforts and coordination are underway regarding DNREC policies that eliminate human disturbance and vehicular traffic in plover nesting and foraging areas during the breeding season.

53 *Plovers prefer wide isolated beaches for nesting habitat.*

Storm Protection and Damage Reduction

Estuarine Protection. Another function of beaches that has not been described very often is the protection provided by beaches to valuable coastal landforms on their leeward side. There has been much written about the high values that wetlands provide in terms of both water quality issues and biological functions or benefits. Did you ever stop to think what these marshes would be like if they were exposed to direct wave attack? The likelihood that they would exist at all under the duress of a full blown northeaster is very low. The beach's role as a shock absorber is a critical function to landward, quiet water habitats or landforms. [54]

54 *Protective beach and tidal wetlands, Delaware Bay shoreline.*

Storm Protection. The concept of beaches as shock absorbers, described above, is not foreign to residents along beaches who have witnessed coastal storms first hand. When the wind blows hard over the ocean it generates waves that can grow to the height of a 3-story building. At the same time, tides can be elevated several feet above normal. The combination of high waves hitting the coast at the same time that tides are running higher than normal allows these very large waves to get closer to the coast before they break. The waves also have a greater velocity in their forward movement to the coast due to their size and the high winds pushing them; this in turn greatly imperils coastal development. The power of the waves and tides is what is so damaging to structures built along the coast. As sand is moved across and along the shore, a wide sandy beach can absorb the wave energy and provide a buffer between crashing surf and developed property. During a storm event, high waves, tides, and currents reconfigure the shape of the coast and redistribute the sand along a beach (alongshore and cross-shore). The expenditure of wave energy used to move sand reduces the power of waves before they impact structures. With wave energy expended on the beach, less damage is inflicted on adjacent coastal structures. [55]

55 *Waves pounding beach and eroding sand.*

The federal beach nourishment project in neighboring Ocean City, Maryland, provides an example. Designed to provide storm protection, the project involved construction of a beach and dune system north of the boardwalk, and a seawall and sandy beach along the boardwalk. While the project was expensive to build and maintain ($74 million dollars for initial construction phases and renourishments in 1992, 1994, and 1998), government officials have determined that the wide beach prevented approximately $214 million in property damage during the 1992 and 1998 northeasters.

56 *Crowded, wide recreational beach—Rehoboth.*

Recreation

The beach is the top destination for tourists in the United States. Each year, millions of vacationers flock to the nation's coastline for rest, relaxation, and recreational opportunities. [56] On a hot summer day, the high quality experience that comes from being near the ocean's edge is something sought out by millions of people each year.

The ritual of returning to the beach you have enjoyed in the past, of staking out your turf/territory early each morning, being surrounded by family and friends, enjoying a sea breeze, taking a cool swim in the ocean, letting the sun bake you dry, enjoying lunch on the beach, flying a kite, digging for crabs, catching a fish, finding a seashell—these activities are what make people return in droves each year to our nation's shorelines.

Delaware, like so many other states, has seen the development of coastal communities along its beaches. The demand for a summer day at the beach by millions of people has created a vital segment of the economy. But fundamentally, it is the ability of the beach to provide adequate space for families to sit by the ocean on a hot summer day that is one of the highest values of the beach. People enjoy having space on a beach to spread out towels or blankets; to set up chairs; to have family and friends join them as part of their recreational day. The ability of a beach to provide ample space for these activities for all of those people who arrive to enjoy it on any given day in the summer is one of the functions that beach managers must try to continue to provide. There have been studies conducted about the beach space that a group of four people might need in a day, but in general, we all have a sense of how much space we would like to have on the beach to enjoy our beach day without being in close proximity to the next group of people. As a beach erodes, one of the first threats to the value of a beach is the loss of recreational space that results in a diminished recreational experience for people who have sought out that beach. [57]

57 *Narrow beach provides diminished recreational area.*

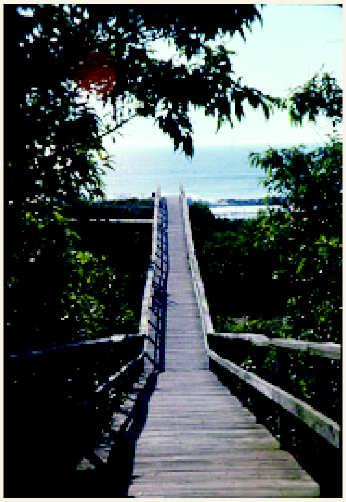
The investment made by beach users in driving time, travel expenses, and lodging and meal expenses should be reflected by a high-value recreational opportunity on the beach. Many beach communities have seen that as their beach diminishes in width and the recreational experiences diminish because of overcrowding, there follows a downturn in the economic vitality of their community. There is a direct correlation between beach width (or beach quality) and the recreational expenditures made within a community. Every beach community wants to maintain its economic vitality and high-level recreational experience.

The beach is typically thought of as a recreation area—a popular vacation destination where people can relax through a variety of activities such as sunbathing, swimming, reading, walking, and fishing. However, our beaches are much more than a popular target area for vacationers. Beaches and dunes also act as a physical buffer to storm winds, waves, and tides. The beach environment provides critical habitat areas for a variety of unique animals. While all of these varied beach functions and values are important, an often-overlooked value of our sandy beaches is the role they play in the state's economy. In fact, the sandy beaches provide the fuel for a critical part of Delaware's economic engine.

The Beach as an Economic Resource

Beaches are a vital part of the nation's valuable tourism economy. Coastal areas are now some of the most densely populated and developed parts of the country. There is high demand for residential, commercial, recreational, and environmental use of coastal lands.

The numbers are staggering. According to the U.S. Census Bureau, 54 percent of America's population lives within 50 miles of the coast, and more people are moving to coastal areas every day. More than 90 million Americans and foreign tourists visit coastal communities each year to enjoy a beach vacation full of food, fun, sun, surf, and sand. In fact, beaches are the United States' largest tourist attraction—approximately 40% of vacationing Americans list beaches as their favorite vacation destination. The tourism/travel industry is the nation's largest employer, and coastal states receive about 85% of all tourist-related revenues in the United States. It has been estimated that beach tourism generates billions of dollars of local, state, and national tax revenues.



58 *Busy beach and boardwalk in Rehoboth.*

In coastal Sussex County, tourism revenues, real estate values, and recreational use are largely dependent upon the quality of its beaches. Coastal residents, business owners, property owners, and visitors alike have relied on the presence of wide, healthy beaches. Their expectations are reflected in property values and decisions to purchase property, make business investments, and plan vacations at the state's ocean beaches.

The interaction between the shoreline and the economy in Delaware is dynamic and fragile. The coastline of Delaware draws nearly 5 million visitors each year to swim, sunbathe and enjoy the many environmental amenities unique to the coastal area. [58]

These visitors bring tourism dollars to the region and the state, representing a strong economic input to both. While visitors pay for parking, lodging, food and other purchases during their visits, access to public beaches is free. The vast majority of tourism is from other states, so the expenditures represent a true influx of dollars into an otherwise rural and correspondingly sleepy economy.

While it is somewhat difficult to determine the total economic benefits of our beaches, consideration of the far-reaching economic activity generated by beach tourism can serve as an example. Tourism dollars bring life and jobs to the Delaware economy. In order of importance, tourists spend money for lodging, restaurants, entertainment, food and sundries and transportation. Tourist spending brings on increased economic activity with resulting benefits and revenues to local businesses. Profits generated by these expenditures exceed $25 million and the expenditures support more than 7,400 jobs with wages in excess of $145 million. State and local taxes on these wages exceed $23 million. These jobs represent about 19% of the jobs in Sussex County, the location of Delaware's ocean beaches. Benefits of this tourist-based economic activity go far beyond retail businesses, affecting many citizens and facets of thriving coastal communities. The beach tourism industry supports the general work

force—lifeguards, hotel and restaurant employees, entertainment activities, construction-based jobs, property and utility maintenance, retail businesses, real estate, and local government jobs. Additionally, the beach tourism industry extends to those businesses that attract tourists to a beach location—advertisements via radio, television, billboards, newspapers and other media. Getting people to the beach is another tourist-based economic consideration—state roads and road maintenance, gas stations, roadside stands, convenience stores, and other such amenities and services.

The flow of important tourism dollars is vitally linked to a healthy coastline. When erosion robs the shoreline of beach area, tourism falters. The state dedicates funding resources to protecting those beaches to prevent the loss of tourism from erosion. In just 2 years, without the state's careful management of beach areas, an estimated 45,000 tourists each year would choose other destinations. After just 10 years, more than 2 million visitors would stop visiting Delaware's beaches, devastating the local economies and seriously damaging the state's economy.

Understanding and quantifying the functions or services that beaches provide is an essential first step for beach managers in determining if management actions are needed to protect those functions. The next step would be to determine both the cost of taking a management action, as well as the cost of not taking an action and allowing time and erosion to continue. Assigning values to the functions of beaches is the way that managers can determine the return for their management expenditures. If the value to society at large of a particular beach function can be determined, then appropriate levels of funding for protection of those values can be determined. This is commonly done in economic analysis of the natural resource. Funding for beach protection is competing in state and federal budgets with many other needs, and in almost all cases, the decision of whether of not to nourish a beach is based on both cost benefit analysis and political will. The full functions and values of beaches as a natural resource with high societal value must be taken into consideration to determine the best way to manage the resource as well as the appropriate amount to spend to protect or enhance that resource. ■

Human Use and Development Along the Delaware Coast

Evolution of a Beach Management Program. Geologically speaking, it has not always been necessary to have a beach management strategy for Delaware's coastline. For the past 10,000 years, our shoreline and associated coastal environments have evolved under the influence of sea-level rise, coastal storms, and the dynamic impacts of waves, tides, and currents.

In terms of human history, the earliest occupants or seasonal visitors to Delaware's coast were members of several Native American tribes: the Lenape, the Sikkonese, the Assateagues, and the Nanticokes. They lived along the coast in dwellings and communities that would be considered temporary by today's standards. Delaware's Native American tribes did not build permanent structures along the coast with the expectation of holding the line against the sea.

59 *Busy beach scene in 1906, Rehoboth Beach.*

As the first European explorers arrived in the 1600s, the earliest farms, homes, land grants and deeds were established along the Delaware Bay and Atlantic Ocean coasts. However, society's occupation of the coast with some sense of permanence toward property development did not occur until the late 1800s and early 1900s. [59]

Coastal Development: Pre World War II. Coastal Delaware was not always the highly developed area that we know today. Historical records show that the coast of Delaware did not develop as rapidly as other parts of the state due to its lack of accessibility, inhospitable nature (storms and insect pests) and the relatively low productivity of the lands for agricultural purposes (few tilling or grazing possibilities). In fact, the first development of the coast, other than port communities such as Lewes, came in the late 1800s and early 1900s, as religious camp meeting sites were established in Rehoboth, Dewey, and Bethany Beach.

To encourage economic development in the early 1900s, the State Public Lands Commission actually tried to put surplus state owned coastal property into hands of private individuals for development. However, at that time, no one really had an interest in owning beach lands and paying associated taxes because there was no obvious return or profit. The land that didn't fall into private hands at that time is now part of the Delaware State Parks system, and provides important natural habitat and environments along with well-used public access to beaches.

As is often the case today, railway and roadway improvements and transportation systems seemed to control and impact the location and rate of development in coastal Delaware. Improved access and roadway construction enhanced real estate opportunities through the 1920s and 1930s. Substantial growth occurred in areas that were easily accessible, such as Bethany and Rehoboth, which were located on headlands where no bays or waterways had to be crossed for access. In 1932, the state built a road from Dewey Beach to Indian River Inlet, and both residents and vacationers were able to enjoy longer stretches of Delaware's ocean beaches. With greater demand by residents and tourists for homes, hotels, cottages, food, and entertainment, development eventually spread out along the coast from there.

60 *Beach erosion threatened to undermine homes in Rehoboth Beach, 1920.*

Early Years of Beach Management. One factor that discouraged early development of the coast was the devastating effects of coastal storms. Once permanent structures were constructed in Rehoboth and Bethany, the Legislature was called upon for assistance when coastal storms destroyed or damaged beachfront property. [60] The first request that we are aware of came in 1915 when the Commissioners of Rehoboth Beach requested authorization from the Legislature to borrow funds to recover from storm damage. Following more storm damage several years later, the town returned to the Legislature with a request for direct state funding to recover from coastal storm damage. The state eventually responded by building structures in the early 1920s to alleviate what was considered to be only storm damage at that time. [61]

In 1934, the State Highway Department was given responsibility for carrying out beach lands management recommendations. Coastal erosion was a problem that was dealt with, but developed areas of the shoreline were few, so they managed a 0.5-mile section at a time with no consideration of possible impacts downdrift. At that time, the state of the art solution for erosion management included groin construction, intermittent beach nourishment projects, planting dune grass, and erecting dune fencing. From the 1930s through the1950s, beachfront management was characterized as treatment of specific erosion problems at specific locations along Delaware Bay and the Atlantic Ocean coast.

61 *Old timber structures built to control erosion, Rehoboth Beach, 1920.*

Coastal Development After World War II. A new wave of coastal development and population growth began in the 1950s with a general post-war economic boom for the nation that resulted in much greater demand for family vacations at the beach. More free time in the business world enabled people to take vacations, have weekends free, and general social change resulted in much more active use of beaches. Additionally, coastal Delaware became much more accessible to vacationers from Washington and Baltimore after completion of the Chesapeake Bay Bridge in the mid-1950s. Expansion of real estate development continued through the 1960s and 1970s as more and more people purchased coastal property for investments, businesses, or vacation residences.

The increase in coastal population and infrastructure resulted in the need to regulate construction along the shoreline. Additionally, severe impacts of coastal storms on property and communities provided additional impetus for the state to develop an improved management program for its beaches. The devastating impacts of the 1962 storm resulted in an increased awareness that the State of Delaware must regulate construction and provide funding for managing beach improvements.

The 1972 Beach Preservation Act was a landmark piece of legislation that established a comprehensive beach and dune management program within DNREC. The program was designed to: (1) include regulation of construction that could adversely affect the beach and protective primary dune, and (2) promote programs and projects that improve the overall recreational and protective aspects of beach and dune systems. In the 1970s, emphasis was placed on regulation of construction because there was so much open private land in coastal Delaware that had not yet been developed. Through implementation of the building restriction line, the regulatory program was successful during the 1970s in confining construction in new subdivisions to the area landward of the primary dune. The early developments in the areas north of Bethany Beach are good examples of the positive impacts of the set back line.

Beach erosion control and management through the 1970s included dune management and implementation of projects to maintain beaches and restore them after storm events. Projects included small beach nourishment projects and groin construction. Along the Delaware Bay shoreline, groins were built in Slaughter Beach and Broadkill Beach in the 1950s and 1960s. Expansion of groin fields in Bethany continued through the 1960s, and in Rehoboth Beach [62] through the 1970s (Deauville, Henlopen Acres, North Shores). The last new groin constructed in Delaware was completed at the Gordons Pond area at Cape Henlopen State Park in 1980. At the time, groin construction and periodic nourishment were the recommended practices for "controlling" erosion along developed stretches of the coast.

Along with the direct management of beach lands being conducted by DNREC in the late 1970s, there were various other entities involved with aspects of beach management.

62 *Groin field in Rehoboth Beach.*

The Geology Department and the Department of Civil Engineering at the University of Delaware were involved in research work associated with beach processes, particularly the trends and mechanics of beach erosion and accretion, beach response to waves and currents, and the effects of storms and sea-level rise. A tremendous amount of knowledge has contributed to our understanding of beach erosion and the evolution and trends of our beaches. What emerged from the research was that beach erosion is complex, that it involves not only storm erosion, but is also driven by sediment availability, sea-level rise, and human influences. These research results were applied to coastal management strategies and activities with improved knowledge and understanding of the dynamic coastal environment.

From the 1980s to Today. The decade of the 1980s brought an unprecedented development boom to Delaware's coast. People moved to the coast in droves, property values soared, and real estate developments proliferated along the entire length of Delaware's Atlantic coast. [63] The real estate boom of single-family homes meant growth in other areas, as retail and commercial establishments were needed to service the new residential growth. [64]

63 *Construction has dramatically increased in coastal areas over the past 50 years, as shown at the top in Fenwick Island (1954 and 1997), and below in North Bethany (1968 and 1997).*

The compounding effects of continuing shoreline erosion, increased construction and the soaring value of coastal real estate and beach tourism has brought increased demands and pressures on our coastal management program. Delaware beaches must be managed as natural resources for multiple uses that have equal importance: biological habitat, storm protection, recreation and economic benefits. Beach management strategies have been enhanced through the 1980s and 1990s through valuable inputs from the coastal engineering research community. Improvements have been made in our ability to understand and predict nearshore movement of sand and the forces at work on the beach face, resulting in more effective and efficient beach restoration programs and projects.

One outcome of former Governor Castle's Environmental Legacy Program in 1986 was the development of a beach management goal for the State of Delaware: "to assure the continued existence of beaches in Delaware that will provide for anticipated recreational needs and a cost-effective level of storm protection for coastal properties, structures, and infrastructure for the next 25+ years." ■

64 *The demand for coastal property impacted previously undeveloped areas in North Bethany between 1968 and 2003.*

Beach and Sand Management Strategies

General knowledge about the causes of beach erosion has improved greatly over the past few decades. As described in previous sections, scientists and coastal managers understand that sea-level rise results in a long-term trend of landward movement of the shoreline. Research and observations have also demonstrated that waves and longshore currents, especially those that accompany coastal storms, are significant factors in the movement of sand and the changing face of Delaware's shoreline.

The dynamic nature of coastal environments results in an ever-changing shoreline—cycles of erosion and sand accumulation over both long and short time frames in any one location. Although these cycles of erosion and accumulation are often reported in terms of average long-term trends, fluctuating periods of stability and change may occur over a period of days, weeks, months, or years. For example, in the Fenwick Island area, a section of coast that had been rather stable for many years was impacted by rapid and unexpected change. DNREC survey records show that over the 2-year span from 1977-1979, the Delaware shoreline moved landward at an average rate of more than 30 feet each year, resulting in a permanent displacement of over 60 feet at the end of the 2-year cycle.

65 *Sequence of beach changes at Dewey Beach (1970s-1990s).*

Similar changes were observed in Dewey Beach [65] and in Rehoboth, where a beach that had been stable for decades experienced a period of rapid change. Although the exact cause of these quick changes in erosion rates has not been determined, many of these beaches did return to more average annual rates of erosion following these short cycles of rapid change.

The combined effects of wave forces, longshore transport, storms, and sea-level rise generally result in landward retreat of the shoreline. These changes may be sudden and dramatic, such as a hundred feet of beach erosion within hours during a northeaster or hurricane. Or, the changes may be slow and nearly imperceptible, due to sea-level rise. The net result usually is evident over a period of decades, when fixed-position structures originally located a safe distance from the shoreline become threatened by waves and tides. Increased development along the coast in recent years has put homes, hotels, businesses, and roadways in danger as the shoreline continues to move landward.

Coastal managers must evaluate past histories, present day characteristics, and future predictions for our beaches. Long-term shoreline change rates have been documented for the Delaware Bay and Atlantic Ocean shoreline. They allow improved prediction of future shoreline behavior and position. However, short-term changes in shoreline position may be dramatically impacted by the magnitude and frequency of coastal storms. Management of beach erosion in Delaware is focused not only on long-term historical shoreline change, but also on the most recent 10-15 year time frame, with an eye on possible future coastal changes resulting from impacts of longer term forces such as sea-level rise. While evaluation of short-term and long-term physical coastal processes impacting our coast is a critical component for beach management policies, social and economic factors must also be incorporated into Delaware's coastal management strategies.

Four Management Options

The dynamic nature of the Delaware coastline, the importance of the beach as a natural habitat, the tremendous value of properties along the coast, and the economic value of the coastal tourism industry combine to create a significant management challenge. Any course of action chosen to deal with the issue of manmade structures on a migrating shoreline will likely carry a very high cost and require changes in attitudes and land use practices at the individual, local, regional, and statewide levels.

Management options available for beach erosion control and property protection fall under four basic categories: no action, shoreline hardening, strategic retreat, and beach nourishment.

No Action

This alternative would involve the abandonment of state policies and responsibilities in all matters related to beach erosion control and coastal storm protection. [66] Without state involvement, federal participation in coastal protection studies and projects would likely disappear without support of a capable "local sponsor." With responsibility falling to local governments and private homeowner groups, remedial actions would likely fall under the "hardening" category (see below) as these actions provide initially affordable, site specific protection of coastal areas and can be accomplished with little or no area-wide organization, cooperation, or comprehensive and long-range planning.

66 *Consequences of "No Action" management alternative.*

Management Implications of No Action. Coastal erosion would continue to impact our shoreline, and there would be no overall planning program in place to be implemented as a regional sediment management strategy. A likely result would be a narrowing of the active beach face, contributing to greater likelihood of storm damage to structures and a diminishing recreational beach. This scenario would eventually adversely affect the tourism industry, and eventually the real estate trade, construction industry, and related service industries:

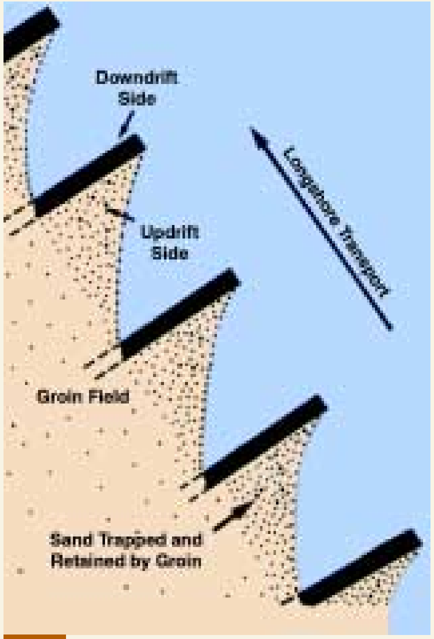
- Reduction in number of beach visitors
- Diminished quality of "recreational beach experience"
- Loss of tourism revenue
- Lower rental prices
- Less beach repair work and reduced beach maintenance costs

Shoreline Hardening

The term shoreline hardening refers to construction of all types of structures (groins, jetties, and breakwaters) built to retain sand or to interfere with waves or currents to reduce their impacts, or to protect property by reflecting waves and holding back tidal waters (revetments, seawalls and bulkheads). Installation of hard structures for the purpose of protecting buildings and property is usually one of the first actions considered by individual property owners and homeowners associations once the threat of storm damage and erosion has been perceived. Prior to implementation of regulatory control, these projects were often implemented without consideration of the effects the structure may have on adjacent properties or the beach itself.

Over the past century, a number of structural protective measures designed to reduce potential damage have been implemented along the Delaware coast. However, since the late 1970s, the State of Delaware has not included shoreline hardening as part of its primary coastal management strategy. This section presents a description of common structural methods of shoreline protection, the anticipated benefits of each, and some of the adverse effects that may result. A general overview of the various types of hard structures is presented in the following paragraphs.

Groins. A groin is constructed across the beach, perpendicular to the shoreline, and is designed to trap sand moving in the longshore transport system. Commonly, the term *jetty* (actually a structure used to stabilize an inlet) is misused to refer to a groin. As sand accumulates on the updrift side of the groin, the beach at that location becomes wider. [67] However, this is often accompanied by accelerated erosion of the downdrift beach, which receives little or no sand via longshore transport. Groins do not add any new sand to the beach; they merely retain some of the existing sand on the updrift side of the groin.



67 *Groins are structures designed to trap sand moving along the shoreline.*

Groins are usually constructed from steel, timber, or stone. The length, elevation, and spacing between groins should be designed on the basis of local wave energy and beach slope. Groins too long or high tend to accelerate downdrift erosion because they trap too much sand. Groins too short, low, or permeable are ineffective, because they trap too little sand. Flanking may occur if a groin does not extend far enough landward. Groins are generally constructed in groups called groin fields, such as those at Rehoboth Beach and Bethany Beach. [68] Since the net direction of longshore transport is northward at these locations, sand generally accumulates on the south side of the groins, and erosion occurs on the north side.

68 *Bethany Beach groin field.*

In the early 1920s, timber groins were often the only practical alternative available to coastal engineers and managers. Historic photographs of timber structures document the evolution of coastal engineering practices in the state, and provide an interesting history of coastal management strategies. For example, this archive photograph [69] shows timber groins that were built at Cape Henlopen in the early 1920s.

69 *In the 1920s, timber groins were installed at Cape Henlopen to prevent beach erosion.*

Engineering design of groins has evolved significantly in recent years. The concept of notched groins and adjustable groins is a recent coastal engineering concept that has been implemented in some coastal areas. The State of Delaware has maintained groins in Bethany Beach and Rehoboth Beach over the past 70+ years. The U.S. Army Corps of Engineers considered these groins in their evaluations of these two locations, and they recommended that the groins remain in place.

Jetties. These structures are built at tidal inlets to stabilize the locations of the inlets. Jetties constructed of a variety of materials have been placed at several tidal inlets along the Delaware coast. Indian River Inlet, on the Atlantic coast, is stabilized by steel and stone jetties that were built in 1939 [70]. Stone jetties are located at Roosevelt Inlet in Lewes, and timber and stone jetties stabilize the mouth of the Mispillion River near Slaughter Beach.

70 *Indian River Inlet before bypass—inlet jetties interrupt the flow of sand along the beach.*

Because jetties also interrupt longshore sand transport, the effect of jetties on adjacent beaches is similar to the effect of groins: accretion occurs on the updrift side, and erosion occurs downdrift of the inlet. The offset is generally more extreme at jettied inlets, due to the length and relative impermeability of the jetties and the inability of any sand to be transported across the inlet opening. Material that does pass through or around the jetties contributes to shoaling either in the interior of the inlet or offshore, depending upon the direction of tidal currents.

The process of sand bypassing is a management tool that has become an effective method of reducing the impacts of interruption of longshore transport caused by jetties and associated navigation improvements at inlets and harbors. Sand bypassing can be conducted through the use of conventional dredges, or by using a permanent sand bypass pumping system that imitates natural processes by continuously pumping sand across the inlet to continue in the longshore transport system.

71 *The Indian River Inlet bypass system pumps sand across the inlet, putting sand back into the longshore transport system.*

To solve a beach erosion problem caused by jetties at Indian River Inlet, a fixed sand-bypass system was installed in the late 1980s, and bypassing of sand began in January 1990. [71] The U.S. Army Corps of Engineers and the State of Delaware have partnered on this project that serves as an international example of a successful inlet bypass system. A specially designed pump system and crane have been installed on the south side of the inlet. Sand is pumped from the sand accumulation area at the south jetty, through a pipe on the inlet bridge, and is deposited on the north side of the inlet. The sand bypass volume and pumping rate has been determined through an engineering analysis of historic erosion rates at the north inlet beach and the natural rate of sediment transport in the vicinity. These analyses have led to the adoption of the rate of 100,000 cubic yards of sand per year as the target volume of sand to be bypassed at the site. The state has monitored the response of beaches both north and south of the inlet since the bypass program was implemented. Continued monitoring and analysis of bypass data will enhance project management decisions made with the ultimate goal of protecting the Route 1 bridge approach, and stabilizing the north beach while minimizing impacts on the south beach pumping site and adjacent shoreline areas.

Sand is not pumped year round, but an operation schedule has been developed based not only on beach erosion rates, but also on public safety and recreation in the area. During summer months when there is high recreational use of the beach area, pumping does not occur.

72 *Failed bulkheads – Dewey Beach.*

Bulkheads, Seawalls, and Revetments. Bulkheads, seawalls, and revetments are structures built parallel to the shoreline, usually on the upper portion of the beach, to protect the land behind them from wave forces. These structures are not used to protect or enhance the beach in any way. They may be constructed from a variety of materials such as timber, steel, concrete, or stone. A bulkhead acts as a retaining wall to prevent land from slumping and being washed away by waves. A seawall is generally a more massive structure designed to resist the full impact of wave forces. The reflection of wave forces by the vertical face of bulkheads and seawalls may aggravate erosion of the beach in front of these structures. A revetment is a sloping layer (or layers) of stone or concrete built to protect an embankment or shore structure against erosion.

Several design problems are commonly associated with the failure of these types of structures. If the elevation of the structure is too low, waves may overtop it causing erosion and scouring behind the structure, leading to collapse or failure of the protection. If the structure does not extend deep enough, toe scour, erosion at the base of the structure that occurs as a result of wave reflection or erosive currents, may eventually cause the structure to be undermined and slump or collapse. If the structure does not extend far enough landward, flanking, or erosion at the ends of the structure, occurs when waves wash around it. Finally, a structure literally can be torn apart by waves crashing against it if improper building techniques or undersized materials are used in its construction. [72] Even properly designed and built structures will fail if wave energy exceeds the design strength of the structure or if long-term erosional trends continue. This would result in extreme vulnerability from direct wave attack on the home or building that had previously depended on the bulkhead for protection.

Breakwaters. These structures are designed to reduce wave energy reaching the shoreline. In most cases, the breakwater is there to create a sheltered harbor for boats and ships rather than to protect the shoreline from wave erosion. A breakwater may be located offshore, such as the inner and outer breakwaters in Breakwater Harbor, Lewes, or it may be connected to the shoreline and extend out into the water, such as the Cape May-Lewes Ferry Terminal breakwater in Lewes. Although the reduction of wave energy due to the sheltering effect of the breakwater is beneficial to the safe anchorage of vessels, a negative side effect is that the lowered energy conditions contribute to accelerated shoaling and sedimentation in harbors. Shore-connected breakwaters may interrupt longshore transport, resulting in downdrift sand starvation similar to the effects of the jetties at Indian River Inlet. Prior to the construction of the outer and inner breakwaters in the 19th century, Breakwater Harbor was more than 30 feet deep. Today, most areas are less than 12 feet deep.

These types of offshore breakwater structures are not applicable as effective protective measures along Delaware's open ocean coast due to the much larger waves encountered there.

Management Implications of Shoreline Hardening. Although installation of hard structures was a common shoreline protection strategy used from the 1920s to the 1970s, they are seldom used now as a sole solution to beach erosion. Many of the structures used to armor the shoreline were designed and installed as "defensive structures," built as a last line of defense against the threat of breaking waves, rolling surf, and high tides. Between the 1940s and 1960s, groins were a popular way to trap sand and build a modest beach area, without much consideration given to overall sand supply in adjacent areas. We now know that counting on a long-term, and endless supply of sand is unwise and unrealistic. While groins may provide localized success, they may not be appropriate in areas with little or no sand supply unless sand is added to the system in conjunction with a groin project.

While structures such as bulkheads and seawalls may be effective in protecting upland properties, they are not effective in protecting the beach itself because they do not address the beach erosion problem seaward of their location. In fact, in many communities that have bulkheaded or seawalled their waterfront, the beach continues to erode. Some states have imposed bans on construction of seawalls and bulkheads to avoid these results. Groins and groin fields have been popular beach protection strategies in the past, but they function best when used in combination with sandy beach fill. Remember, it is the sand that provides a biological habitat and a recreational beach, and it is the beach that protects adjacent properties, not the groins themselves.

The successes and failures of using hard structures to manage a beach erosion problem have been reported in many professional journals and conferences. For the most part, armoring the shore is not considered to be the preferred method of preserving beaches in Delaware.

Strategic Retreat

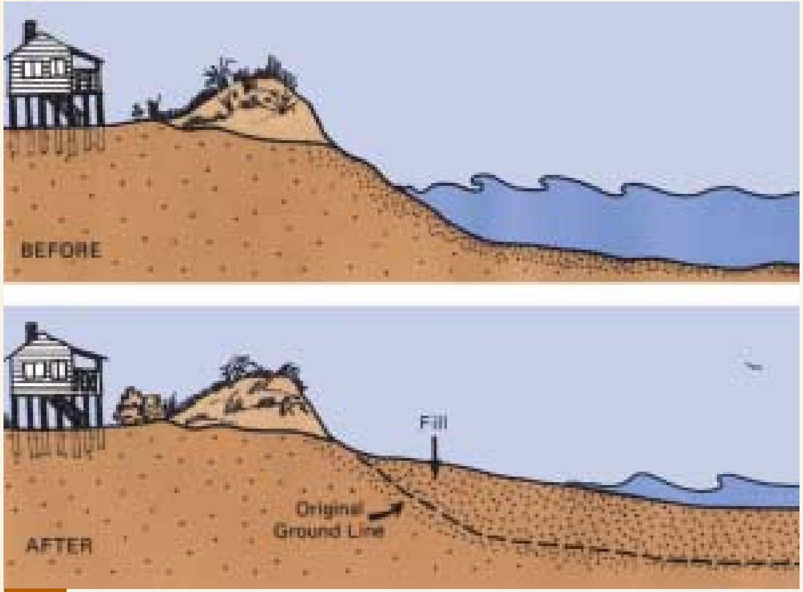
The concept of strategic retreat is that of removing oceanfront buildings as the shoreline erodes to maintain a beach width or certain distance between buildings and the water. An effective strategic retreat plan would involve systematic removal of structures as the beach migrates inland and the buildings become threatened by waves and surf. In this way, a wide sandy beach area can be maintained as the beach position migrates landward.

A study conducted in 2001 at the University of Delaware examined the economics of strategic retreat in Delaware. The study explained that there are social and economic costs associated with strategic retreat that include capital loss, transition loss, land loss, and proximity loss. Additionally, there are environmental impacts associated with retreat that include disturbance to beach and dune habitats during structure removal and demolition, introductions of toxins and pollution during removal, and disposal and/or recycling of the demolished materials.

Management Implications of Strategic Retreat. The realities of how to implement a strategic retreat policy must be considered before retreat can be considered an effective management tool. If strategic retreat is used to preserve beaches and dunes as recreational and protective features, then property acquisition will have to occur before properties are damaged by coastal storms, waves, and tides. Thus, the "buyout" cost to government would likely be greatest when properties are sound, landward of the dune, and not in a damaged condition. In minimally populated areas with low property values, strategic retreat may be a practical management approach, as it may be affordable to buy property and remove infrastructure. However, the University of Delaware study mentioned above concluded that the 50-year social cost of retreating from Delaware's Atlantic coast would be between $156 million and $319 million in current dollars. These estimates may vary depending upon assumed erosion rates and land loss assumptions built into the study; for instance, if erosion rates, housing stock, or structural proximity vary, a different outcome may be expected.

In another example, an analysis conducted for a community in North Carolina demonstrated that buying the oceanfront real estate at half its tax value would cost local and state taxpayers approximately half a billion dollars. For the same stretch of beach, the present value of the state and local cost of beach nourishment over the next 20 years is $25.2 million. This analysis suggests that buyout is not a strong economic alternative in this situation. On the other hand, government entities could act most frugally if lands were acquired in a damaged condition to avoid paying top market price for the property. This would most likely occur after a damaging coastal storm, at a time when human need and government compassion are often at their highest.

Indeed, there are no easy solutions or clear implementation strategies to accompany the issue of strategic retreat while accomplishing the management goal of preserving and maintaining recreational and protective beaches. Strategic retreat requires hard decision-making, funding, and firm commitment by the Administration and the Legislature if it is to succeed.



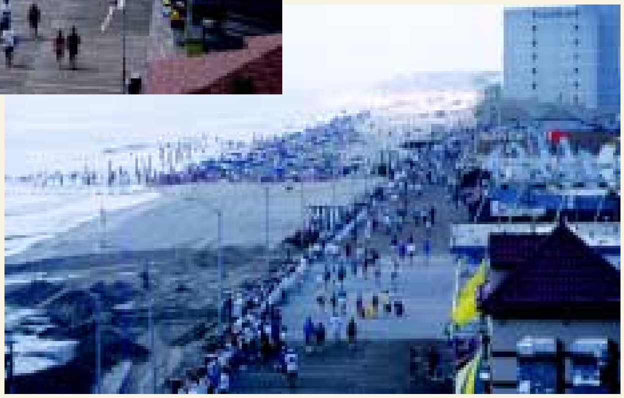
73 *Beach nourishment is the process of placing sand on a beach to restore its width and elevation to specified dimensions.*

Beach Nourishment

The process of adding sand to an eroding beach to restore its width and elevation to specified dimensions [73] is the only beach management tool that directly treats the problem of sand loss on beaches. Used almost exclusively in developed beach areas, nourishment is commonly accomplished by pumping sand onto the beach from an offshore source by using a dredge, although it may also be conducted by trucking sand onto the beach.

Beach nourishment does not prevent erosion or stop the movement of sand along a beach. It is actually a strategy that re-sets the erosional clock by adding sediment to the system and re-establishing the buffer of sand between the ocean and structures. Beach nourishment achieves the goal of providing reasonable storm protection to developed areas while providing a recreational beach area as well as biological habitat; all of the amenities that people want their beaches to provide. [74] To be effective over the long term, beach nourishment projects must be periodically maintained by re-nourishment projects.

The design and success of a beach nourishment project depends on many factors—including an evaluation of the causes of erosion and shoreline history of the area; a determination of the level of storm protection that the design beach is



74 *Aerial photos of the nourishment process, Rehoboth Beach, 1998.*

expected to provide; calculation of desired beach dimensions, including height, width, dune area, and quantity of sand needed for the project; an assessment of environmental impacts of the project; development of benefit/cost analysis, economic analysis, and funding plan for the initial project and maintenance; and establishment of a long term monitoring program to allow a quantitative assessment regarding the performance of the project. The success of the project is typically determined by the longevity of the project and whether or not the project provided the expected benefits.

In recent decades, beach nourishment has been viewed as a reasonable management option for many coastal communities. Beach nourishment is a management strategy that deals directly with the issue of sediment budget of a beach system. The direct and obvious benefit of nourishment is that the fundamental nature of the problem (loss of sand) is directly treated by adding sand from a source outside of the eroding system. In this way, an entire beach system benefits by the investment of new sand into the sediment budget. Typically, an added benefit is realized by beaches adjacent to the nourish-ment project beaches, as sand is often transported into neighboring shoreline areas.

75 *Wide recreational beach (post nourishment).*

A 1995 National Research Council (NRC) study on beach nourishment reports that while beach nourishment is suitable for some, but not all locations where erosion is occurring, it is a viable engineering alternative for shore protection and is the principal technique for beach restoration. The NRC report suggests that "government authorities with responsibilities for coastal protection should view beach nourishment as a valid alternative for providing natural shore protection and recreational opportunities, restoring dry beach area that has been lost to erosion."

76 *Narrow beach—no room for recreation (Photo not taken in Delaware).*

Benefits. The primary benefits of beach nourishment include storm damage reduction and enhanced recreational/tourism opportunities. A wide beach not only acts as a direct buffer to absorb wave energy during storm events, but it also provides a reservoir of sand that may be transported to an offshore bar. During storm events, large waves will break on the offshore bar, reducing the amount of wave attack on the upper beach, thereby reducing the amount of erosion. Coastal engineers report that reductions in wave height and wave forces due to relatively small additional beach widths are surprisingly large. In Florida and North Carolina, several studies have documented that damage to structures after hurricanes was significantly reduced in areas that had wider beaches.

A wide recreational beach increases tourism opportunities—people like to visit beaches, and the wider the beach is, the more that people can enjoy it. Studies have demonstrated that wide recreational beaches result in increased income to resort areas, and healthy beaches are a major draw for both domestic and foreign tourists. Along Delaware's Atlantic coast, millions of visitors annually flock to the beautiful state park beaches as well as beaches in the coastal communities of Rehoboth, Dewey, Bethany, South Bethany, and Fenwick Island. [75] If a wide sandy beach were not accessible, or if water washed up to the sand dunes or under the boardwalk at each high tide, the recreational value of the beach would be significantly diminished. [76] If the recreational beach experience is too crowded, unpleasant, or simply not available, many visitors to the Delaware shore might decide to travel to another coastal destination for a beach vacation the next year.

Although the most obvious benefits of a nourishment project include improved storm protection and creation of a wide recreational beach, additional benefits may be

77 *A wide beach provides habitat for a variety of plants and animals.*

realized by restoring habitat in areas where it has been eliminated or degraded through sand loss. [77] Maintenance of a wide upper beach and dune area results in benefits to plants and animals that have adapted to living in the beach environment. Additional benefits may be derived from nourishment by the various animals and birds that use the beach as foraging and nesting sites.

Experience with other tools and strategies utilized to safeguard structures from the consequences of beach erosion has led many beach managers to most often decide to use the nourishment strategy to protect beaches. In fact, 2-3 decades ago, a beach manager might have been more focused on ways to protect buildings from storms and sea level rise. In contrast, many beach managers are now more highly focused on preserving and protecting the beach itself for all of its important contributions as a natural resource. Building hard walls or impediments to sand flow (e.g., groins, jetties) has grown into disfavor, while beach nourishment has been a way to protect and enhance the sandy coastline in a manner that creates a more natural beach system. [78] Managers must weigh any impacts this kind of work may bring to the system against the coastal management benefits gained.

Potential Drawbacks. The use of beach nourishment as a management strategy is not without controversy and criticism, usually focused on the temporary nature of the solution provided by nourishment projects. Properly designed and implemented beach nourishment projects typically provide storm and flood damage protection on decadal time scales rather than centuries. Additionally, beach nourishment may not be justified or technically feasible in some areas. Other drawbacks of beach nourishment include economic considerations and environmental issues.

The process of beach nourishment can disrupt existing biological communities in borrow areas where dredging occurs, and in beach areas and shallow underwater habitats where nourishment sand is deposited. Potential negative environmental impacts can be both short-term and long-term; some losses are temporary and accompanied by recovery over time, while other losses may be considered more permanent disruptions.

There are several environmental issues related to the borrow sites that are used as the source of sand for beach nourishment projects. The most common source of Delaware's beach fill material are sand deposits in open ocean areas that are found in water depths appropriate for dredging operations and are far enough offshore to avoid any possible detrimental effects to the beach. The primary biological effect of dredging borrow sites is the removal of the animals that inhabit the sandy sediments, which may also indirectly affect other species that use these bottom dwelling animals as a food source. Additionally, physical impacts may result from changes water quality, and increases in turbidity due to sediment being suspended in the water column.

78 *Wide nourished beach provides benefits including storm protection and recreation.*

There are some studies underway that will help document the long-term physical alterations and environmental impacts resulting from the dredging of sand in offshore borrow sites, but the impacts on marine habitats have not been well documented at this time. Until more information is available, the most prudent action would be to design projects so that changes in the physical condition and biological resources of a borrow site are minimized and are short term.

Most of the animals living in sandy beach areas are burrowing organisms that are adapted to the stresses of the high-energy and constantly changing environment found in a surf zone and nearshore area. Many beachgoers are familiar with the animals found in the surf and swash zones of an intertidal beach—ghost crabs, mole crabs, burrowing shrimp, worms, and small mollusks. When a beach is nourished, large volumes of sand are placed on the beach and in adjacent shallow nearshore areas where many of these animals live.

Placement of nourishment material on a beach may mimic the naturally occurring cycle of erosion and deposition that occurs during and after high surf and storm events along a coast. The volume of nourishment sediment placed on a beach usually occurs on a much greater scale and more rapid time frame than would occur naturally. Some studies have shown that the larger, more mobile animals such as ghost crabs are able to avoid impacts by leaving the nourishment area in response to the physical disruption or associated loss of food resources. Less mobile animals such as worms, mollusks, and mole crabs, are not able to move out of the project site, and the extent of nourishment impacts would be dependent on the depth of sediment deposited and the animals' ability to burrow up through the sand.

The temporary loss of animal communities that live in sandy intertidal areas is largely unavoidable during beach nourishment operations. The more important issue is how quickly these communities can recovery after the project is completed. There are a limited number of monitoring studies available that have investigated recovery times, and many of these have documented temporary alterations in the abundance, diversity, and species composition of animals living in a nourishment area. Monitoring studies have not yet fully documented the time it takes for a population to recover at a nourished beach site, but some studies have demonstrated that the time frame may range from a few weeks to a few months.

Secondary or indirect impacts of nourishment projects should also be considered in future monitoring studies. Temporary losses or alterations to the sand dwelling animals will likely impact other animals such as fish and birds that may depend on them as a food source. Although nesting sea turtles are not an issue along the Delaware coast, studies have shown that beach nourishment may impact the nesting success of sea turtle species, and special permit conditions are typically placed on projects involving hopper dredges to minimize adverse impacts on sea turtles. For past Delaware nourishment projects, sea turtle spotters have been required to monitor the presence of sea turtles and document potential turtle impacts at the offshore dredge site.

Concerns have also been raised regarding the effects of beach nourishment on other threatened and endangered bird and plant species. For example, the piping plover is an endangered bird species that nests on Delaware beaches above the high tide line during spring and summer months. If improperly designed, nourishment projects could have adverse impacts on plover habitat by creating unsuitable nesting habitat (incorrect sediment grain size) or by conducting the nourishment project during the nesting and fledging season. This is an unlikely impact in Delaware because plovers prefer quiet beach areas without much human contact, and nourishment in Delaware is done only in the urbanized portions of the coast. There are permit requirements that mandate that a project must avoid any contacts with plovers—even if the entire project must be halted. Yet, studies have shown that beach nourishment can actually improve the quality and availability of plover habitat by creating a substrate that is higher, wider, and less vegetated compared to the eroded beach.

Borrow sites. Several environmental issues are related to the borrow sites used as the source of sand for beach nourishment projects. The most common source of Delaware's beach fill material are sand deposits in open ocean areas found in water depths appropriate for dredging operations and are far enough offshore to avoid any possible detrimental effects to the beach. There are some studies underway that will help document the long-term physical alterations and environmental impacts resulting from the dredging of sand in offshore borrow sites, but the impacts on marine habitats have not been well documented at this time.

The primary biological effect of dredging borrow sites is the removal of the animals that inhabit the sandy sediments. This may also indirectly affect other species that use these bottom dwelling animals as a food source. Additional impacts may result from increases in turbidity (due to sediment being suspended in the water column) if the site contains silts and clays. In areas with poor circulation, other changes in water quality may result if deep holes are created in borrow areas, including low dissolved oxygen levels or increased hydrogen sulfide levels, which may have negative impacts on certain organisms that cannot move out of the area. Secondary effects might also include impacts on organisms that normally feed on animals removed from the system, temporarily or permanently, by dredging operations.

Additional monitoring studies should be conducted to determine if these areas return to the physical and biological conditions that existed before dredging, and if so, how long it takes. Until more information is available, the most prudent action would be to design projects so that changes in the physical condition and biological resources of a borrow site are minimized and are short term.

79 *Delaware's coastline is a recreational, economic and natural resource.*

Management Implications. Faced with an increasing demand for the services that beaches offer to the public, at the same time beach widths were decreasing, DNREC developed a management approach that incorporates several different tools. [79] The regulation of construction along with a heavy reliance on sand replacement, as a response to erosion, combined with judicious use of hard structures such as jetties and groins, is the course followed by Delaware to manage sand resources. Beach preservation efforts in Delaware took a significant turn in response to the *Beaches 2000 Report* to the Governor in 1988. The committee behind the report saw the merits in beach nourishment as long as the benefits resulting from nourishment exceeded the cost of conducting the work. This remains the policy of the state and economic analysis of our beach nourishment work was conducted in 1998 and again in 2004 to make certain that nourishment costs return a value higher than the cost.

Economic Considerations. Although scientific and technical issues are critically significant to beach management strategies, economic considerations are also extremely important. Beach protection and beach nourishment projects are nearly always public decisions, often supported by large amounts of state and/or federal funding. Before beach protection or nourishment projects are initiated, evaluations are conducted to determine general costs and benefits; although not always easily achievable, the intent is to determine whether a given project provides benefits to society in general that are either equal to or more valuable than the project costs.

The most obvious costs of a beach nourishment project are the costs of labor, equipment, and management services. Due to re-nourishment considerations, beach nourishment costs are also indirectly linked to the rate of erosion at the specific project site. The site-specific costs must be weighed against the value of property, local economy and tax base, and many other intangible factors. The obvious benefits from beach nourishment projects are storm damage reduction, recreational benefits, and environmental/habitat enhancement benefits.

If nourishment becomes the favored solution for a stretch of beach, the next question is often "Who will pay for it?" Many times the cost is spread among a large population just as any major public works project would be. When the cost of a project outweighs the public benefit, there are several options: either alternative funding sources are pursued or the project is not done and some other solution is sought. Beach communities faced with erosion must weight the costs of beach nourishment against the value of property, cost of abandonment, or cost of structural shore protection. In many cases, adding sand is the most cost-effective solution for protecting private property and maintaining the aesthetic and environmental quality of the beach.

Hardening the shoreline produces minimal societal value; the beach itself may disappear, but the properties are protected and public infrastructure is protected from storm damage. However, no beach amenities are present. The no action alternative results in structure losses in the surf zone and an unusable, unsafe beach. Nourishment enhances all of the societal values (storm protection, recreation, and habitat). Strategic retreat does the same thing as nourishment, but at a higher cost. Based on analyses that have been conducted, the cost associated with buy-out of oceanfront property is extremely high and exceeds the cost of periodic nourishment. ■

Summary and Conclusions

Delaware's coastline is an extraordinary natural resource of significant economic, environmental, recreational, and aesthetic value. Barrier beach migration and beach erosion along the coast are natural processes. However, these natural processes have been affected by human activities such as construction of structures, roadways, businesses and homes along the shoreline that have altered the natural movement and migration of sand both along the coast and across the barrier. There is a compelling need to continue to adopt and implement coastal management policies to protect the state's substantial resources along the coast.

The benefits of our beaches are numerous and include recreational and aesthetic values of a wide sandy beach, the considerable contribution of beaches to the economy, habitats provided for beach dependent life, and benefits of beaches for human access to the sea. The need for a comprehensive, coordinated, and proactive approach to shoreline management is emphasized by numerous factors: the coast is actively moving; storm activity alters the coast; and coastal population and development continues to increase. Throughout the mid-20th century, state and federal agencies frequently implemented strategies for reducing coastal erosion and protecting coastal development on a case-by-case basis. However, the natural processes and human activities that influence coastal erosion and beach loss do not follow political jurisdictional boundaries.

By the late 20th century, comprehensive planning and regulatory programs continued to evolve with coastal science. Coastal geologists and engineers have demonstrated that any alteration of sediment transport within a region will likely impact, to some degree, the movement and availability of sand elsewhere within that region. This can result in either positive or negative impacts on coastal resources and development, and these impacts must be better understood. Today, broader regional interactions are being considered by coastal managers and scientists and are incorporated into the decision making process. A regional approach to addressing coastal erosion and the reduction in sand supply, based on coastal watershed and littoral cell (a portion of coastline where sand flows in, along, and then out of an area) boundaries, is most effective in the long-term. Coordination of federal, state, and local agency activities is necessary to support such regional approaches.

What does the future hold for our beaches? The State of Delaware will continue to work toward a program that includes: the concept of regional sediment management; dedicated funding to assure wide beaches in the long term future; coastal research that will help drive management decisions; continued public education; and minimization of environmental impacts of beach nourishment. The state is committed to conserving, restoring and enhancing Delaware's coastline and beaches. Coastal management cannot eliminate sea level rise, storm activity, or the natural process of sediment movement and erosion along our shoreline. However, a comprehensive management plan for our beaches has been developed with consideration of a wide range of environmental, economic, and social factors. These factors vary from the need to protect public health and safety, marine life and associated habitats, and recreational uses and facilities, to providing full consideration of the rights of public and private property owners along the coast. ■

Beach Preservation Regulatory Program

Regulations and ordinances governing beaches and coastal development in Delaware are administered by federal, state, and local authorities. These regulations and ordinances are designed to protect the natural coastal environment and to reduce storm damage to coastal properties. Certain programs require permits for activities conducted in the beach area, and appropriate authorities should be consulted before alterations are made to the beach environment or before construction activities commence.

Federal Regulation

The regulation of activities on beaches and in adjacent coastal waters and wetlands is controlled by several federal agencies. The principal regulatory activities are administered by the U.S. Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA), and the Office of Ocean and Coastal Resource Management (OCRM. In addition, all federal agencies must comply with Federal Executive Order 11988, Flood Plain Management, and Executive Order 11980, Protection of Wetlands. These regulations establish the federal policy to avoid direct or indirect support of development in floodplain or wetlands areas, and to avoid adverse environmental impacts associated with activities in the protected coastal zone area.

State Regulation

The Delaware coast is managed and protected by the Delaware Department of Natural Resources and Environmental Control (DNREC). Delaware's Coastal Management Program is the umbrella policy program that serves to determine appropriate land and water uses in the coastal area while protecting the state's natural resources. The state has established a number of policies, standards, and regulations that condition, restrict, or prohibit some uses in parts of the coastal zone. Four state laws form most of the basis for management of Delaware's coastal areas. These include the Underwater Lands Act, the Wetlands Act, the Coastal Zone Act, and the Beach Preservation Act. Of these four laws, the Beach Preservation Act primarily controls the uses of Delaware's beaches and dunes, and requires a permit or letter of approval for anyone wishing to perform any land disturbing activity within the area of the defined beach.

1. Beach Preservation Act (1972 and 1983) Title 7, Delaware Code, Chapter 68

The Beach Preservation Act controls land uses on beaches and dunes, with no construction generally allowed on beaches or on primary dunes. The Beach Preservation Act first became law in 1972 and was revised in 1983. It declares the beaches of the Atlantic Ocean and Delaware Bay shorelines of Delaware to be natural features that furnish recreational opportunities and provide storm protection for persons and property, as well as being an important economic resource for the people of the state. The Beach Preservation Act acknowledges that natural forces have created and will continue to alter (via beach erosion and shoreline migration) the beaches of the state, and that development of beaches must be done with consideration given to the natural forces impacting on them.

The purposes of the act are to "…enhance, preserve, and protect the public and private beaches of the state, to mitigate beach erosion, to create civil and criminal remedies for acts destructive of beaches, to prescribe the penalties for such acts, and to vest in the Department of Natural Resources and Environmental Control the authority to adopt such rules and regulations it deems necessary to effectuate the purposes of this chapter."

The Beach Preservation Act is administered by the DNREC, Division of Soil and Water Conservation, Shoreline and Waterway Management Section, through the Regulations Governing Beach Protection and the Use of Beaches. The original regulations were promulgated in 1974, with the most recently revised regulations adopted in 1983. The primary purpose of the regulations is to enhance, preserve, and protect public and private beaches of the state through a permit process. The regulations establish the concept of a building line which serves as a point of reference for construction activities. The function of the building line is to delineate a seaward boundary for construction activities, and to establish a protected dune zone. Along the Atlantic Coast, the building line is 100 feet landward of the seawardmost 10-foot elevation contour. Along beaches on Delaware Bay from Cape Henlopen to Primehook, the building line is located 100 feet landward of the 7-foot contour elevation, and from Primehook to Pickering Beach, the line is 75 feet landward of the 7-foot elevation contour.

The primary goal of the beach regulations is to require that all construction activities be conducted landward of the building line. Exceptions are made where there is inadequate room or space available on a lot to construct entirely landward of the building line or where the proposed project requires a shorefront location for its intended purpose (e.g., a beach access walkway structure). Copies of the regulations and the maps depicting the location of the building line are available from the Shoreline and Waterway Management Section office in Dover.

2. Delaware's Coastal Management Program

Delaware's Coastal Management Program was implemented in August 1979 to guide development along Delaware's coastline. The Coastal Management Program is designed to enforce and encourage sound management policies and to permit orderly growth in the coastal zone while protecting natural resources. A system of standards, guidelines, and controls to manage coastal land and water uses was developed under the Coastal Management Program to permit coordinated, rational evaluations concerning Delaware's coastal areas.

Delaware's Coastal Management Program offers four principal benefits to the State's residents. These include: (1) more effective protection and use of the land and water resources of Delaware's coast; (2) control over federal activities affecting the state's coastal areas (federal consistency); (3) financial assistance from the federal government for administering the program; and (4) increased public awareness of the coast, its resources, and the issues of its use.

3. **The Coastal Zone Act (1971) Title 7, Delaware Code, Chapter 70**

In 1971, Delaware's Coastal Zone Act was enacted to control industrial development in the coastal zone. The purpose of the act is to control industrial development along Delaware's coastline in order to "…better protect the natural environment of its bay and coastal areas and to safeguard their use primarily for recreation and tourism." The Coastal Zone Act prohibits heavy industry and bulk product transfer facilities from locating in the coastal areas of Delaware, and subjects manufacturing uses to a permit system to ensure protection of coastal resources. DNREC is responsible for administration of the Coastal Zone Act.

4. **The Subaqueous Lands Act, Title 7, Delaware Code, Chapter 72**

The Subaqueous Lands Act regulates uses in State subaqueous (submerged lands and tidelands) lands which include non-tidal streams, lakes, ponds and tidal waters channelward of the mean high tide line. The Subaqueous Lands Act is administered by DNREC, Division of Water Resources, Wetlands and Subaqueous Lands Section. The administrative rules used to enforce the act are outlined in the Regulations Governing the Use of Subaqueous Lands (adopted May 8, 1991 and amended September 2, 1992).

5. **The Wetlands Act, Title 7, Delaware Code, Chapter 66**

The Wetlands Act regulates activities in tidal wetlands, both saltwater and freshwater, to ensure preservation and protection of these resources. The Wetlands Act is administered by DNREC, Division of Water Resources, Wetlands and Subaqueous Lands Section. The administrative rules used to enforce the act are outlined in the Wetlands Regulations (adopted December 23, 1976; revised June 29, 1984, and November 4, 1994). Wetlands under DNREC jurisdiction are depicted on State Regulated Tidal Wetlands Maps.

Local Regulation

State regulations and restrictions are generally applicable to all beaches along the Delaware ocean and bay coastlines. However, local concern for coastal problems has resulted in the development and adoption of ordinances pertaining to flood hazards, coastal construction, and beach management by municipal authorities. Similarly, county officials have adopted ordinances and special regulations for coastal protection. The unincorporated developments and communities without their own zoning authority fall under the jurisdiction of the county planning and zoning authorities.

Along with their general zoning ordinances, local municipalities and Kent and Sussex Counties have adopted flood hazard zoning ordinances as required by FEMA. These ordinances outline criteria for flood-safe construction and placement of homes. Kent County has established ordinances which define minimum floodproof standards and construction standards for structures in coastal high-hazard areas (Section 9, Kent County zoning ordinances). Sussex County also has special ordinances for coastal protection. These zoning ordinances outline restrictions that serve to protect the dune and beach, and provide construction and land development controls within the designated flood-prone areas. The construction controls outlined in the ordinances include building criteria for: first floor elevations, anchoring and placement of structures, basement floors and foundation wells, interior floors, walls and ceilings, storage areas, electrical systems, and plumbing (Sections 12, 13, and 14, Sussex County Zoning Ordinances).

Coastal Property Checklist

If you live in a coastal area, you are vulnerable to the effects of coastal storms. High winds and waves damage and destroy improperly constructed homes. Floating debris can crack foundation piles causing collapse of the home or break windows and doors. Pressures from floodwaters on solid foundations can lead to collapse.

You can prevent or minimize damage! By taking precautions during initial construction or by making modifications to an existing home, you can minimize damage and loss.

Flooding

Do you know the projected flood elevation for your area? Ask your building department to see a flood map of your community.

- ❑ Is the first floor of the dwelling located above the projected flood elevation for your area?
- ❑ If your house is elevated on piles, do you have an open foundation, free of obstruction, that allows fast-moving waves and water to flow beneath the building?
- ❑ If storage areas or other enclosures are needed below projected flood elevations, they must be constructed with breakaway walls to allow water to flow-through unobstructed. Is your enclosure breakaway?
- ❑ Are steps used for accessing the beach from the structure or the pedestrian dune crossover elevated or removed out of the reach of waves and floodwaters?
- ❑ Are the main electric panel, outlets and switches located at least 12 inches above potential floodwaters?
- ❑ Are the washer and dryer, furnace and water heater elevated above potential floodwaters?
- ❑ Are outside air conditioning compressors and heat pumps elevated?
- ❑ Is the fuel tank securely anchored? It can tip over or float in a flood causing fuel to spill or catch afire. Cleaning a house inundated with water containing fuel oil can be difficult and expensive.
- ❑ What is the orientation of cross-bracing on the pilings? Diagonal bracing will obstruct velocity floodwaters and waves and will often trap debris, therefore bracing must be placed parallel to the primary direction of flow.
- ❑ Does the sewer have a back flow valve? Contact a licensed plumber to install the valve.
- ❑ Are there potential projectiles such as landscaping ties, cinder blocks, cement patio blocks, pile butts, or split rail fences located in the pathway of waves and flood waters? These objects can crack and damage piles and lower level enclosures causing possible collapse of the structure.

Wind

- ❑ Are windows and exposed glass surfaces protected by storm shutters? This is one of the best ways to protect your home against wind and flying debris. 5/8 inch thick exterior grade plywood works just as well.
- ❑ Is the roof fastened to the walls with galvanized metal hurricane straps? This will reduce the risk of losing your roof to high winds.
- ❑ Are the galvanized straps, hangers and joist to beam ties corrosion free? Corroded metal components can fail during extreme wind events. These should be replaced when corroded.
- ❑ Are the foundation piles notched less than 50% of the pile cross section? Overnotching can lead to failure of the piles.
- ❑ Are deck and lawn furniture which are likely to become airborne debris securely fastened or taken in doors?

Erosion

- ❑ Are your foundation piles deep enough to survive a coastal storm?
- ❑ Is the dune in front of your home well vegetated to prevent wind erosion?
- ❑ Is the dune of sufficient height and width to prevent overtopping by waves during a storm?
- ❑ Are there bare, low areas in the dune created by walking over the dune to access the beach? These areas are weak spots that will allow waves to flow over the dune and cause loss of the dune and subsequently allow waves and water into the house.
- ❑ Is your home built on a concrete slab and located on the ocean or bay front? Concrete slabs can be undermined and destroyed during storms causing the collapse of the structure. If possible, elevate the structure on pilings.

Structural

- ❑ Inspect strapping for corrosion and replace if necessary.
- ❑ Check roof for loose or missing shingles. Be certain gutters are clear of debris.
- ❑ Inspect condition of storm shutters or plywood used to protect windows and doors. Cover all large windows, doors (especially patio doors) with securely fastened, impact resistant shutters with proper mounting fixtures.
- ❑ Make sure all doors and windows are caulked and/or weather stripped.
- ❑ Inspect sewer backflow valves.
- ❑ Inspect condition of elevated utilities and supporting platforms. Be sure utilities are securely anchored to the supporting frame.

Lot and Land Area

- ❑ Remove, secure or store any objects that may be carried by waves or winds (i.e., deck furniture, landscaping, construction materials, etc.).
- ❑ Raise or remove steps accessing the beach.
- ❑ Check condition of dune (width and elevation). Inspect condition of beachgrass. Replant bare areas in the spring and fertilize as needed.
- ❑ Trim back dead or weak branches from trees.

This checklist is not all-inclusive and is not intended to replace local building code requirements or to serve as the only options for protecting your home from storm damage. For more information, contact your local building official or a building professional such as a coastal engineer, architect or experienced contractor.

Glossary

Accretion – Natural or artificial build up of land. Natural accretion is the buildup of land, solely by the action of the forces of nature, on a beach by deposition of waterborne material. Artificial accretion is a similar buildup of land by human action, such as the accretion formed by a groin, breakwater, or beach fill deposition by mechanical means.

Alongshore *(longshore)* – Parallel to and near the shoreline; same as longshore.

Armor stone *(armor layer)* – Number of relatively large quarrystone or concrete pieces that form primary wave protection on the outer surfaces of shore protection structures.

Armored shore – Shore with constructed shore protection.

A-Zone – Flood zone subject to still-water flooding during storms that have a 100-year recurrence interval.

Backbarrier flats – Low-lying sandy regions on the landward side of the sand dunes; often covered with salt-tolerant grasses and shrubs.

Backbarrier marsh – Marsh formed on the landward side of a coastal barrier, often containing significant coarse sediment that has washed in from the seaward side.

Backrush – Seaward return of water following the uprush of waves. For any given tide stage, the point of farthest return seaward of the backrush is known as the limit of backrush.

Backshore *(backbeach)* – That zone of shore or beach lying between the foreshore and the dunes and acted upon by waves only during severe storms, especially when combined with exceptionally high water. It includes the berm or berms.

Bar – Submerged or emerged mound of sand, gravel, or shell material built on the ocean floor in shallow water by waves and currents.

Barrier beach – Sedimentary land-form essentially parallel to the shore, the crest of which is above normal high water level. Also called a *barrier island*.

Barrier island – Barrier beach that is unconnected to the mainland.

Barrier lagoon – Bay roughly parallel to the coast and separated from the open ocean by barrier islands or spits. *Examples:* Rehoboth Bay, Indian River Bay, Little Assawoman Bay.

Barrier spit – Barrier beach connected to land at one end, with the other end extending into a body of water such as a bay, lagoon, or ocean. *Example:* Cape Henlopen.

Bathymetry – Measurement of depths of water in oceans, seas, and bays; also information derived from such measurements.

Bay – Recess in the shore or an inlet of a sea between two capes or headlands, not as large as a gulf but larger than a cove. *Example:* Delaware Bay.

Beach – Zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves).

Beach erosion – Carrying away of beach materials by wave action, tidal currents, littoral currents, or wind.

Beach face – Section of the beach normally exposed to the action of wave uprush. The foreshore of a beach.

Beach fill – Material placed on a beach to re-nourish eroding shores.

Beach material – Granular sediments (sand, stones) moved by the water and wind to the shore.

Beach nourishment – Process of replenishing a beach with material (usually sand) obtained from another location.

Beach width – Horizontal dimension of the beach measured perpendicular to the shoreline, from the still water level to the landward limit of the beach.

Berm – In a barrier beach system, the relatively flat sandy area between the berm crest and the dunes formed by the deposit of material by wave action. Some beaches have no berm; others have one or several.

Berm crest – Seaward limit of a berm.

Breaker – Wave breaking on a shore, over a reef, etc. Breakers may be classified into four types:

- **Collapsing** – Breaking over the lower half of the wave.
- **Plunging** – Crest curls over an air pocket and breaking usually occurs with a crash of the crest into the preceding wave trough.
- **Spilling** – Bubbles and turbulent water spill down front face of wave. The upper 25 percent of the front face may become vertical before breaking. Breaking generally occurs over quite a horizontal distance.
- **Surging** – Wave peaks up and slides up the beach face with little or no bubble formation.

Breaker zone – Area within which waves approaching the coast begin to break, typically landward of 16-33 feet (5-10 meters) water depths.

Breakwater – Linear or mound-like coastal-engineering structure constructed offshore parallel to the shoreline to protect a shoreline, harbor, or anchorage from storm waves.

Bulkhead – Structure or partition to retain or prevent sliding of the land. A secondary purpose is to protect the upland against damage from wave action.

Bypassing, sand – Hydraulic or mechanical movement of sand, from an area of accretion to a downdrift area of erosion, across a barrier to natural sand transport such as an inlet or harbor entrance. The hydraulic movement may include natural movement as well as movement caused by man.

Coast – Strip of land of indefinite width (may be several kilometers) that extends from the shoreline inland to the first major change in terrain features. The land regarded as near the shoreline.

Coastal processes – Natural forces and processes that affect the shore and the nearshore seabed.

Coastline – The boundary between coastal upland and the shore.

Crest – Highest point on a wave, beach face, berm, ridge, hill or shore structure.

Current – Flow of water. This flow may be persistent (as in a stream) or temporary (as a wind driven current).

Current, coastal – One of the offshore currents flowing generally parallel to the shoreline in the deeper water seaward of the surf zone; may be caused by winds or re-distribution of water mass.

Current, littoral – Any current in the littoral zone caused primarily by wave action, e.g., longshore or rip current.

Current, longshore – Littoral current in the breaker zone that moves, essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

Cusp – Scallop-like ridges and depressions in the sand spaced at regular intervals along the beach.

Downdrift – In the direction of the predominant movement of sediment along the shore; the side of a groin, jetty, or other structure that is deprived of sand.

Dredging – Removal of sediment or the excavation of tidal or subtidal bottom to provide sufficient depths for navigation or anchorage, or to obtain material for construction or for beach nourishment.

Dune – Any natural hill, mound, or ridge of sediment landward of a coastal berm deposited by the wind or by storm overwash; sediment deposited by artificial means and serving the purpose of storm-damage prevention and flood control.

Duration – In wave forecasting, the length of time the wind blows in nearly the same direction over a body of water.

Ebb tide –The period of tide between high water and low water; a falling tide.

Erosion – Wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or wind.

Estuary – Part of a river that is affected by tides. The region near a river mouth in which the freshwater of the river mixes with the saltwater of the sea.

Estuarine – Pertaining to an estuary.

Exposure – Something of value that could be damaged or destroyed by a loss. It can be tangible (building, land, income) or intangible (access, enjoyment).

Fetch – Distance over water in which waves are generated by a wind having a constant direction and speed.

Flood tide – Period of time between low water and high water; a rising tide.

Foredune – Front dune immediately behind the backshore.

Foreshore – The steeper part of the beach that extends from the low water mark to the upper limit of high tide; the beach face.

Gabion – Wire mesh basket containing stone or crushed rock, designed to protect a slope from erosion by waves or currents. Sometimes used as a backing or foundation for shore protection structures.

Gravel – Small, loose stone; approximately 0.08—3.0 inches (2-76 millimeters) in diameter.

Groin – Narrow, elongated coastal-engineering structure built on the beach perpendicular to the trend of the beach; its intended purpose is to trap sediment to build up a section of beach.

Hazard – Any condition that increases the likely frequency or severity of a loss.

Headland – Area of high elevation more resistant to erosion than surrounding areas and less susceptible to flooding. Headlands can supply sand and gravel to beaches.

High tide – Maximum elevation reached by each rising tide.

Hurricane – Intense tropical cyclone with winds that move counterclockwise around a low-pressure system; maximum sustained winds of 74 miles per hour or greater.

Impermeable groin – Groin through which sand cannot pass.

Inshore *(zone)* – In beach terminology, the zone of variable width extending from the low water line through the breaker zone.

Jetty – Narrow, elongated coastal-engineering structure built perpendicular to the shoreline at inlets; designed to prevent longshore drift from filling the inlet and to provide protection for navigation.

Lagoon – Shallow body of water, as a pond or sea, usually connected to the sea (cf barrier lagoon).

Littoral – Pertaining to the shore of a sea.

Littoral drift – Sedimentary material such as sand and stones moved near the shore in the littoral zone under the influence of waves and currents.

Littoral transport – Movement of littoral drift in the littoral zone by waves and currents; includes movement parallel (longshore transport) and perpendicular (cross-shore or on/off-shore transport) to the shore.

Littoral zone – In beach terminology, an indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

Longshore *(alongshore)* – Roughly parallel to and near the shoreline.

Low tide – Minimum elevation reached by each falling tide.

Marsh – Area of soft, wet, or periodically inundated land, usually characterized by grasses and other low growth such as shrubs.

Mean high water *(MHW)* – Average height of all of the high waters recorded at a given place over a 19-year period.

Mean low water *(MLW)* – Average height of all of the low waters recorded at a given place over a 19-year period.

Mean sea level *(MSL)* – Average height of the surface of the sea at a given place of all stages of the tide over a 19-year period.

Neap tide – Tide occurring near the time of quadrature of the moon with the sun (first and last quarters). The neap tide range is usually 10-30% less than the mean tidal range.

Nearshore – Zone extending seaward from the shoreline well beyond the breaker zone; typically to about 66 feet (20 meters) water depth.

Northeaster – On the U.S. east coast, a storm (low-pressure system) whose counterclockwise winds approach the shore from the northeast as the storm passes an area. Waves approaching from the northeast direction can cause coastal erosion.

Nourishment – Placement of sediment on a beach or dunes by mechanical means.

Overtopping – Passing of water over the top of a beach berm, dike, or other shore protection structure as a result of wave run-up or surge action.

Overwash – Uprush and overtopping of a coastal dune by storm waters. Sediment is usually carried with the overwashing water and deposited, usually in a fan shape, on the landward side of the dune or barrier.

Permeability – Ability of water to flow through soil, crushed rock or other material.

Permeable groin – Groin with openings large enough to permit passage of appreciable quantities of sediment.

Pile – Long, heavy section of timber, concrete or metal driven or jetted into the earth or seabed to serve as a support or to provide protection. (also, piling)

Porosity – Percentage of the total volume of a soil, or stones, occupied by air or water, but not by solid particles.

Reach – Section of coastline that has characteristics in common.

Recession – Landward movement of the shoreline, beach, or seaward edge of bank or bluff.

Revetment – Apron-like, sloped, coastal-engineering structure built on a dune face or fronting a seawall; designed to dissipate the force of storm waves and prevent undermining of a seawall, dune, or placed fill.

Rip current – Strong current flowing seaward from the shore. It is the return movement of water piled up on the shore by incoming waves and wind.

Riprap – Layer, facing, or protective mound of stones placed to prevent erosion, scour, or sloughing of a structure or embankment; also the stone so used.

Risk – Possibility of negative outcomes or a loss.

Salt marsh – A wetland periodically inundated by salt water, characterized by emergent herbaceous vegetation adapted to saturated soil conditions; an important interface between terrestrial and marine habitats.

Sand – Rock grains, most commonly quartz; that are 0.0025–0.19 inches (0.0625–2.0 mm) in diameter.

Scarp – Almost vertical slope along the beach caused by wave erosion. It may vary in height from a few inches to several feet, depending on wave action and the nature and composition of the beach.

Scour – Removal of underwater material by waves and currents, especially at the base or toe of a shore structure.

Seawall – Vertical wall-like coastal-engineering structure built parallel to the beach or duneline and usually located at the back of the beach or the seaward edge of the dune.

Sediment – Solid particles or masses of particles that originate from the weathering of rocks and are transported, suspended in, or deposited by air, water, or ice, or by other natural agents such as chemical precipitation and organic secretion.

Setback *(setback distance)* - Selected (or required) space between a building (or other structure) and a boundary.

Shallow water – Water of such a depth that surface waves are noticeably affected by the seabed. In terms of wave shoaling, it is water of depths less than one-half the wavelength.

Sheetpile – Planks or sheets of construction material designed to be driven into the ground or seabed so that the edges of each pile interlock with the edges of adjoining piles.

Shoal *(noun)* – Shallow area in the seabed, comprised of any material except rock, which may endanger surface navigation.

Shoal *(verb)* – (1) To become shallow gradually. (2) To cause to become shallow. (3) To proceed from a greater to a lesser depth of water.

Shore – Narrow strip of land in immediate contact with the sea, including the zone between high and low water lines. A shore of unconsolidated material is usually called a *beach*.

Shoreline – Intersection of a sea with the shore or beach.

Silt – Loose rock particles; smaller than sand particles and larger than clay particles.

Slope – Degree of surface inclination above a horizontal reference surface. Usually expressed as a ratio, such as 1:25 or 1 on 25 indicating 1 unit vertical rise in 25 units of horizontal distance; or in a decimal fraction (0.04); degrees (2* 18'); or percent (4 percent).

Soil – Layer of weathered, unattached particles containing organic matter and capable of supporting plant growth.

Spit – Point of land or projecting into a body of water from the shore. Example: Cape Henlopen.

Spring tide – Tide that occurs at or near the time of new or full moon (syzygy), and that rises highest and falls lowest from the mean sea level.

Squall line – Line of strong wind areas advancing ahead of a weather system along a boundary between air masses at much different temperatures.

Storm surge *(wind setup, storm rise)* – Rise above normal water level on the open coast due to wind stress on the water surface over a long distance (fetch).

Surf zone – Area between the outermost breaker and the limit of wave uprush.

Swale – Low area between two beach ridges.

Swash zone – Area of wave action on a beach face from the lower limit of wave backrush to the upper limit of wave uprush.

Tide – Periodic rise and fall of water that results from gravitational attraction of the moon, the sun, and other astronomical bodies acting upon the rotating earth.

Toe – Lowest part of a structure forming the transition to the seabed, or the lowest part of a slope forming a transition to a beach or terrace.

Trough – (1) Lowest part of a wave; (2) Depression in the seabed between bars—often created by breaking waves.

Updrift – Direction opposite that of the predominant movement of sediment along the shore; the side of a groin, jetty, or other structure where sand accumulates.

Upland – General term for land or ground that is higher than the floodplain.

Uprush – Landward flow of water up onto the beach that occurs when a wave breaks; Same as *runup*.

Velocity zone *(V-zone)* – Zone subject to velocity-water flooding during storms that have a 100-year recurrence interval. In coastal areas the V-zone generally extends inland to the point where the 100-year flood depth is insufficient to support a 3-foot-high breaking wave.

Washover – See Overwash.

Water wave – Moving ridge, deformation, or undulation of the water surface; the transfer of energy across the water surface.

Wave breaking – Breakdown of a wave profile with a reduction in wave energy and wave height due to an unstable wave shape.

Wave climate – Seasonal and annual distribution of wave heights, periods, and directions at a particular location.

Wave crest – Highest part of a wave.

Wave direction – Direction from which a wave approaches.

Wave height – Vertical distance between a crest and adjoining trough.

Wave length – Horizontal distance between two adjacent, successive wave crests.

Wave period – Time for a wave crest to travel a distance of one *wave length*.

Wave reflection – Process by which wave power and wave energy is returned seaward.

Wave refraction – The bending of waves as they travel through varying water depths. Wave direction generally turns toward regions of shallow water and away from regions of deep water.

Wave run-up *(swash)* – Rush of water up a structure or beach following the breaking of a wave; measured as the vertical height above still-water level to which the rush of water reaches.

Wave trough – Lowest water surface between two adjoining wave crests.

Wetland – Land where saturation with water is the dominant factor in determining the nature of soil development and the types of plant communities that live in the soil and on the land.

Delaware Contact Information

Delaware Department of Natural Resources
and Environmental Control
www.dnrec.state.de.us

DNREC Division of Soil and Water Conservation
302-739-4411
www.dnrec.state.de.us/dnrec2000/Divisions/Soil/Soil.htm

DNREC Shoreline and Waterway Management Section
302-739-4411
www.dnrec.state.de.us/dnrec2000/Divisions/Soil/ShorelineCons/Shoreline.htm

DNREC Delaware Coastal Programs Section
302-739-3451
www.dnrec.state.de.us/dnrec2000/Divisions/Soil/dcmp/index.htm

DNREC Division of Parks and Recreation
302-739-4401
www.destateparks.com

Additional Information on Coastal Issues

University of Delaware Sea Grant College Program
www.ocean.udel.edu

University of Delaware Center for Applied Coastal Research
www.coastal.udel.edu

Delaware Geological Survey
www.udel.edu/dgs

American Shore and Beach Preservation Association
www.asbpa.org/

U.S. Geological Survey Coastal
and Marine Geology Program
http://marine.usgs.gov

National Oceanic and Atmospheric Administration (NOAA)
www.noaa.gov

Coastal Services Center
www.csc.noaa.gov/

Marine Geology and Geophysics Division
www.ngdc.noaa.gov/mgg/mggd.html

Coast Survey Office
http://chartmaker.ncd.noaa.gov/

Office of Ocean and Coastal Resource Management
www.ocrm.nos.noaa.gov/

Office of Coastal Coastal Zone Management
www.ocrm.nos.noaa.gov/czm/

Resources for Additional Information

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Acknowledgments

Photographs

Cover Inset: Kevin Fleming from *The Beaches of Delaware and Historic Sussex County* by Kevin Fleming (Portfolio Books, Rehoboth, DE, 1999).

Back Cover: Kevin Fleming from *The Beaches of Delaware and Historic Sussex County* by Kevin Fleming (Portfolio Books, Rehoboth, DE, 1999).

Historic Cape Henlopen photographs (Figure 31):
1926: Delaware Air Photo Archive by John. E. Inkster.
1968: Delaware Geological Survey Archives.
1997: Delaware Department of Transportation.

1962 Storm Photos: Delaware Department of Transportation.

Figure 45: Shorebird (willet) inset, page 19: Rob Robinson.
Figure 46: Piping plover, page 19: Jay Davis.
Figure 47: Shorebirds, page 20: British Trust for Ornithology.
Figure 48: Horseshoe crabs, page 20: Susan Love, Delaware Coastal Programs.
Figure 49: Horseshoe crabs and birds, page 20: DNREC, Delaware Coastal Programs.
Figure 50: Horseshoe crab eggs, page 21: DNREC Delaware Coastal Programs.
Figure 51: Plover nest on beach, page 21: Jay Davis.
Figure 52: Plover chick and eggs, page 21: Laune MacIvor, U.S. Fish and Wildlife Service.

Other photos by Wendy Carey, Evelyn Maurmeyer, and Tony Pratt.

Graphics

Figure 5: Adapted from Kraft, J. C., page 32, in *The Delaware Estuary: Rediscovering a Forgotten Resource*, eds. T. L. Bryant and J. R. Pennock (Newark, DE: University of Delaware Sea Grant College Program, 1988).

Figure 13: Adapted from Rogers, S. R., and D. Nash, page 3, in *The Dune Book*, North Carolina Sea Grant Publication Number UNC-SG-03-03 (NC State University, Raleigh, NC, 2003).

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Written by Wendy Carey, Evelyn Maurmeyer, and Tony Pratt.

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