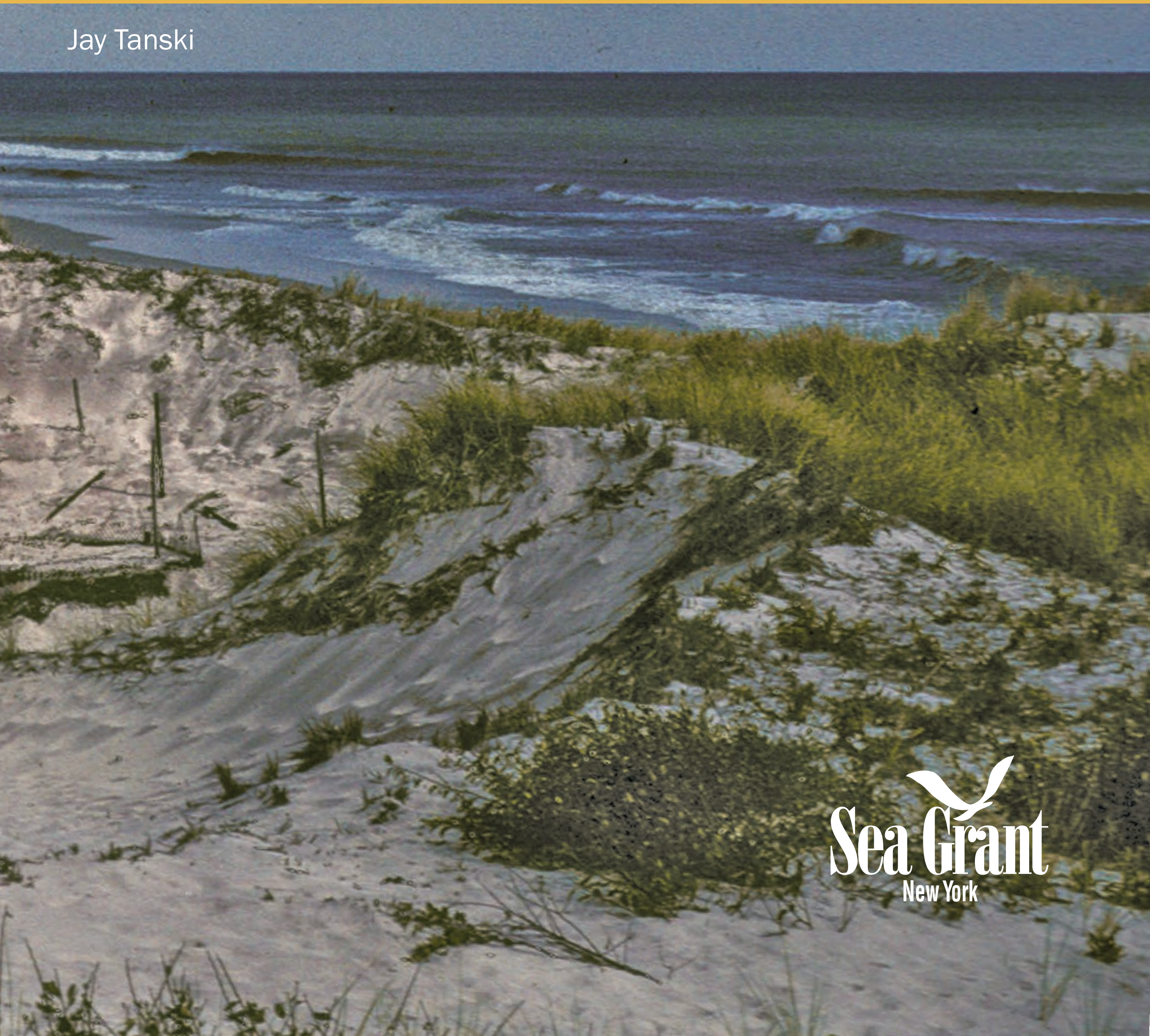
Long Island's Dynamic South Shore

A Primer on the Forces and Trends Shaping Our Coast

Jay Tanski



Sea Grant
New York

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Introduction

Long Island's Atlantic coastline is a special place for many reasons. The south shore is home to a wide variety of habitats which support a vast array of plants and animals, some threatened or endangered. It is also the place where millions of people live, work, and play. The 120-mile coast stretching between Coney Island and Montauk is remarkably diverse in terms of its physical characteristics, use, and development. This shore contains everything from heavily developed urbanized barrier islands to New York State's only federally-designated wilderness area. Area beaches are a prime recreational resource, attracting millions of visitors every year and serving as the foundation of a multibillion-dollar regional tourism industry.

Long Island's coast is also extremely dynamic, constantly changing in response to natural processes associated with wind, waves, and tides as well as human activities. The dynamic nature of the shoreline coupled with people's desire to use and enjoy the shoreline presents unique challenges in managing this resource. Making decisions that balance conservation of the natural environment with significant demand for use of the shore requires a sound understanding of the processes shaping and impacting the coast.

This primer provides a brief overview of what we know about coastal processes and erosion on Long Island's south shore, based on the best available scientific information. While by no means an extensive treatment of the subject, the information presented here is intended to familiarize the reader with the major shoreline trends and technical issues associated with erosion and erosion management on the south shore.

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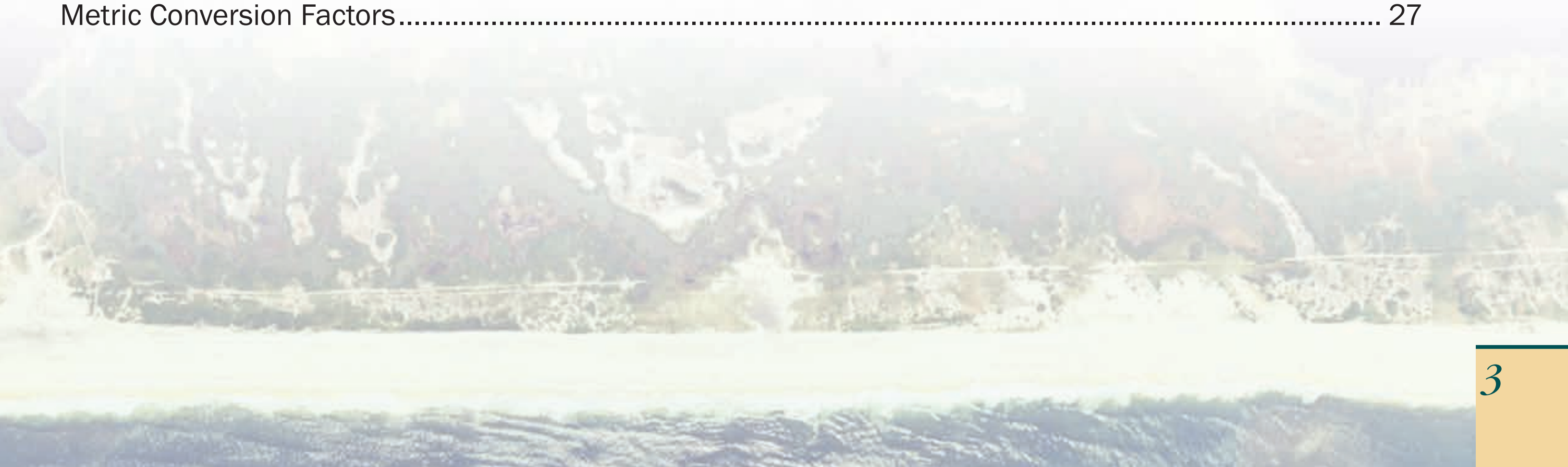

Long Island's South Shore

The south shore of Long Island can be divided into two distinct regions based on the physical characteristics of the coast *(Figure 1)*. Stretching almost 100 miles from Coney Island in New York City to Southampton in the east, the shore is composed of narrow, sandy islands and peninsulas separated from the mainland by shallow bays. These features are called barrier islands and barrier spits because they form a barrier between the ocean and the bays and the mainland. There are five barrier islands (from west to east: Coney, Long Beach, Jones, Fire and Westhampton) and two spits (Rockaway and Southampton). Six openings or tidal inlets separate the barriers and connect the bays with the ocean. All of the inlets are artificially stabilized with structures and are dredged to allow for navigation by commercial and recreational boats.

East of Southampton, the barrier island system gives way to what is known as the headland region. Here, the mainland directly abuts the ocean all the way to Montauk Point. In the western portion of this 30-mile stretch of coast, sandy beaches separate the ocean from a low-lying plain that is made of material laid down by waters melting from glaciers tens of thousands of years ago. To the east, the flat plains are replaced by 40- to 60-foot high bluffs formed when the glaciers stopped their advance southward and dropped the material they were carrying which ranged from large boulders to fine clays.

Development and use of the coast also changes from west to east along the south shore *(Figure 2)*. Heavily urbanized barrier islands and mainland shores are common in the west. Not many people realize it, but Coney Island in New York City is (or was) a barrier island. The western barriers (Coney Island, Rockaway and Long Beach) are home to year-round communities with residences, commercial businesses and industry. Beaches in the eastern and central sections of the south shore are heavily used for recreation due to their proximity to dense population centers. For example, Jones Beach State Park, created in 1929 on Jones Island, receives some six to eight million visitors per year. Fire Island is less densely developed with federal (Fire Island National Seashore), state (Robert Moses) and county (Smith Point) recreational park facilities interspersed with 17 primarily seasonal communities. The Otis Pike Fire Island High Dune Wilderness, the only federally designated wilderness area in New York, occupies seven miles of this island and another 14 miles of the national seashore is undeveloped. From Westhampton to Montauk Point, the shore is characterized by summer resort and residential communities. The well-known "Hamptons" are found here.

Despite the development found along the coast, Long Island's south shore, like many ocean coasts, is subject to change. Sand comes and goes from the beaches. Some areas are lost to the sea while in other areas beaches are actually building seaward. Most people are aware erosion problems exist on Long Island's south shore beaches.
But exactly how is the coast changing and what causes these changes?

Figure 1. Long Island's south shore includes a variety of different shoreline types including an extensive barrier system with islands separated by tidal inlets in the west and a headlands section with high glacial bluffs in the east. (Satellite photo: NASA Visible Earth *http://visibleearth.nasa.gov/*)

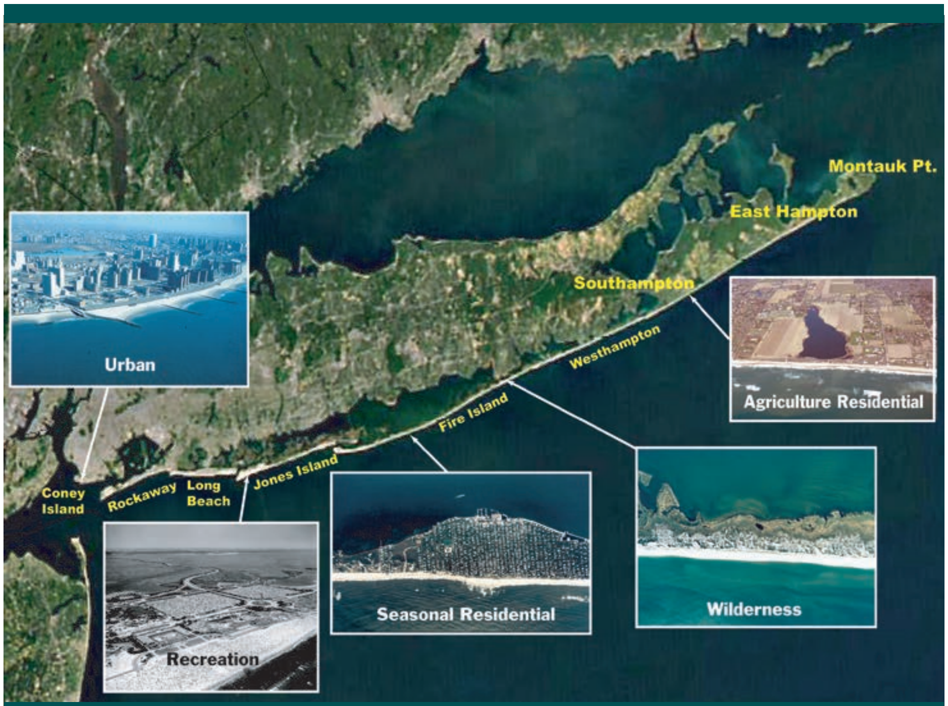

Figure 2. The south shore is characterized by a variety of different land uses. (Jones Beach photo: U.S. Army Corps of Engineers Beach Erosion Board, Satellite photo: NASA Visible Earth *http://visibleearth.nasa.gov/*)

The Dynamic Shore

Although Long Island's coast contains a variety of shore types (barrier islands and spits, mainland beaches and glacial bluffs), they are all primarily composed of small, loose materials such as gravels, sands and clays. Most of these sediments can easily be moved and reworked by wind and water, so the shorelines are inherently unstable and constantly changing in response to natural and human forces. The actual behavior of Long Island's shore is dependent on four major factors:

1) . the amount of wave and current energy striking the coast, which is largely related to storm intensity and frequency;
2) . the supply of sand available for building the beaches or shoreline;
3) . short- and long-term changes in sea level; and
4) . human activities in the coastal zone that alter or disrupt natural processes and movement of sand.

While simple in concept, these factors interact in complex ways and over different time scales. The relative magnitude and importance of each factor in determining shoreline behavior varies depending on the particular stretch of coast being considered and the period of interest, making erosion a deceptively difficult process to fully understand, predict and manage.

The Beach

When many people think of the coast, they automatically visualize the beach since this is where they spend most of their time at the shore. But the beach is not just that sandy strip of land between the waterline and the toe of the dune (or bluff, as the case may be) where you put your towel during the summer. Technically, beaches are usually defined as the accumulation of material (usually sand) moved by the action of waves and currents. Comprised of different parts *(Figure 3)*, the true beach really includes everything from the dune toe seaward to the outermost point where waves begin to break which can be in water 20 to 30 feet deep or deeper in major storms. The breaking waves exert force on the sea floor and create currents which move material on the bottom. Larger waves start breaking in deeper water so the beach extends even further seaward.

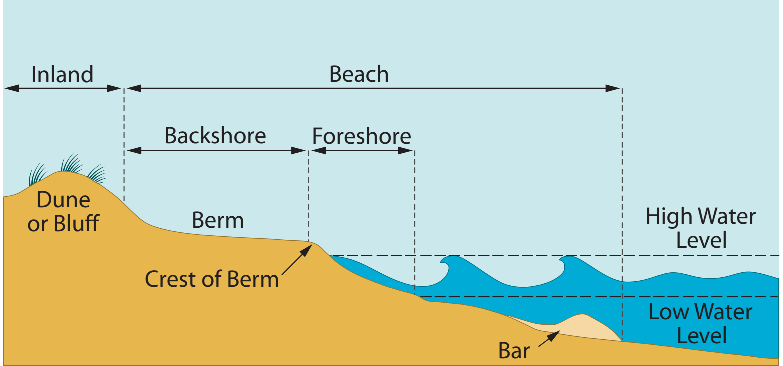

Figure 3. Beach terminology. (Illustration by John Norton)

Although not technically part of the beach, dunes are closely linked with the beach and are often considered as part of the beach system. In natural settings, dunes are the mounds of sand deposited landward of the active beach, usually by the wind. Dunes may be artificially created by either placing sand or creating obstacles (sand fencing or vegetation) to trap sand blown by the wind. Dunes are a common feature along the south shore. They take many forms and can be an important component of the beach system. You will learn more about dunes later in this primer.

Day-to-Day Changes: The beach is constantly changing from day-to-day, week-to-week, month-to-month and year-to-year, primarily in response to the waves. The size and even the presence of any part of the beach at a given time is influenced by a number of factors including the size and direction of the waves, the size and shape of sand grains on the beach, the level of the water at the time the waves strike the shore, and the initial shape of the beach, just to name a few.

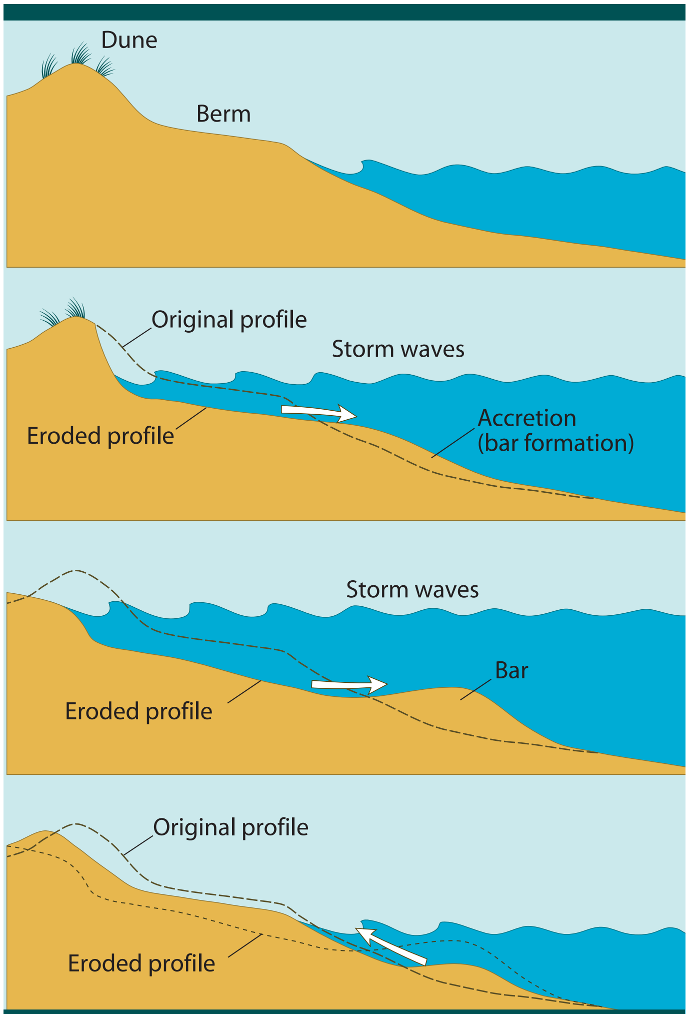

Figure 4. Beach response to storm waves. (Illustration by John Norton)

Waves play a major role in controlling the form, position and size of the beach. They are the primary agents responsible for picking up and moving sand along the coast. The beach responds quickly to changes in wave energy *(Figure 4)*. In general, very large, choppy waves, like those associated with big storms, tend to pick up and remove sand from the beach berm (that relatively flat part of the beach where you sunbathe in the summer) and, if the storm is strong enough, the dunes behind the beach. This lowers the elevation, flattening the beach profile, and causes the berm and shoreline to move landward. (For the purposes of this primer, shoreline is the boundary between the land and the water.) The material picked up by the waves can move in a variety of directions (landward, seaward or along the coast) depending on a number of factors. Frequently, material is moved offshore and is deposited in a bar during storms. As this bar grows, it causes bigger waves to break and dissipate their energy before they reach the landward beach berm. In this way, the beach actually helps protect itself. Although you may not be able to see it standing on the shore, the sand in the bar is still part of the beach and has not been lost from the "system."

In calmer weather, long, gentle waves can actually pick up much of the sand that had been transported to the bar and bring it back onshore, building up the berm, raising the height of the backshore and moving the beach berm and shoreline back seaward.

Thus, there is a cycle where the beach erodes and builds back up in response to wave action. In some coastal areas, this is referred to as the winter/summer seasonal beach cycle, because beaches tend to be narrower in the winter when there are more storms and wider in the summer when weather conditions (and waves) are generally calmer. However, research has shown this seasonal cycle is not as regular for Long Island ocean beaches as it is in some other regions. Here, the width of the beach depends more on the amount of time since the last storm rather than the season. You often find wide beaches in the middle of winter and narrow beaches in the summer depending on recent weather conditions.

Figure 5. Erosion along the shore can be highly variable, even over short distances, as evidenced by this erosion "hot spot" adjacent to a wide beach. (Photo: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

Figure 6. Storms can remove sand from the beach leaving steep scarps (top). In most cases, much of the sand returns to the beach (bottom), usually within a few weeks after the storm.

Year-to-Year Changes: Measurements made along the south shore show the position of the waterline on some ocean beaches may move back and forth by as much as 270 feet over the course of a year as the beach alternately grows and erodes in response to wave action. These changes are largely controlled by the frequency and intensity of storms hitting the coast.

Storms not only generate high waves, they also cause the water level to increase above the elevations expected with the normal tides. This difference in actual or observed water height from the predicted tide level is known as storm surge. Storm surges allow the waves to attack higher up on the beach and cause erosion. As a result, storms can move large amounts of sand from the visible beach very quickly. In some cases, one stretch of the shoreline may be severely eroded while adjacent beaches will have remained stable or even gained sand *(Figure 5).* While these erosion "hot spots" are frequently observed, the underlying causes are not well understood but are thought to have something to do with the presence or absence of the bar offshore.

Even after relatively modest events, beachgoers often see scarps cut by the waves on the beach *(Figure 6).* Much of the sand removed from the beach above the waterline is still in the beach system and may return to the upper portion of the beach under the right conditions. Surveys of some beaches on the south shore show they usually rebuild fairly quickly, generally within a month after most storms.

While the beach may be constantly changing and the waterline moving back and forth, the position of the shoreline fluctuates around an "average" position that won't change very much on a yearly basis as long as the sand is not lost from the beach system. However, this may not be the case if the storms are very severe and sand is being removed from an area without being replaced.

Effects of Storms

Storms play a major role in shaping our shoreline. Long Island experiences both hurricanes and the winter storms known as nor'easters. Hurricanes are usually smaller in size but more intense than nor'easters, with stronger winds and higher storm tides. Hurricane

Figure 7. Damage in Saltaire, Fire Island, caused by the 1938 hurricane. (Photo: U.S. Army Corps of Engineers 1958)

storm surges can increase sea level more than ten feet above the normal tide level. These storms usually pass through this area in a matter of hours but, if they happen to coincide with a high tide, the abnormally high water levels threaten human life and can cause extensive damage to the beach and properties along the shore. The September 1938 hurricane, known as the "Long Island Express," passed over Westhampton and reportedly had winds of 96 miles per hour and a storm surge of nine feet. This storm caused more than 50 fatalities on Long Island and destroyed hundreds of homes on the coast *(Figure 7).*

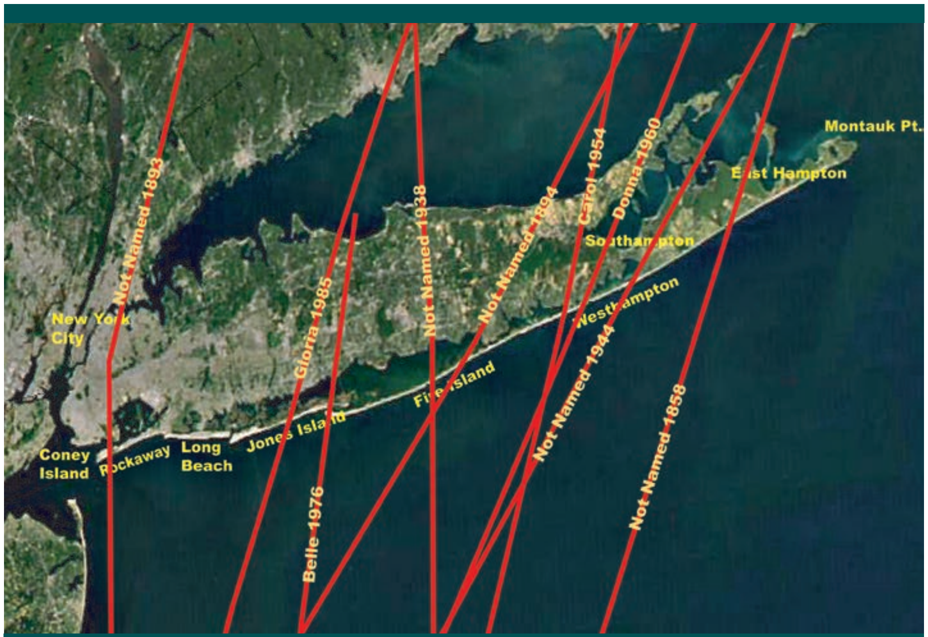

Figure 8. Tracks of hurricanes making landfall in the New York City/Long Island area since 1858. (Storm data from: *http://maps.csc.noaa.gov/hurricanes/*)

More recently, Hurricane Gloria struck our coast in 1985. However, this storm moved very fast and passed quickly over the south shore close to low tide. Although the storm surge was seven feet in some areas, the actual storm tide or water level elevation was only two or three feet above normal high tide levels. As a result, most of the damage from Gloria was caused by the wind rather than the water. The situation could have been considerably different if the storm had hit six hours earlier or later, nearer to high tide. Fortunately, because New York is fairly far north, we have not seen very many hurricanes. Only nine have actually made landfall in the Long Island and New York City area since 1858 *(Figure 8).*

While not as powerful as hurricanes, nor'easters occur much more frequently in this area. Because they cover a bigger area and are slower moving than hurricanes, nor'easters usually affect a larger portion of the coast (hundreds of miles of shoreline as opposed to tens of miles) for a longer period of time (days versus hours). Nor'easters can also produce waves larger than those generated by hurricanes.

During the 1992 December nor'easter, gauges off the south shore of Long Island measured waves over 30 feet high. Storm surges associated with winter storms, while generally lower than those of hurricanes, are still substantial. Measurements taken at the Battery in New York City showed the December 1992 nor'easter caused water levels to rise more than 4.5 feet above normal, allowing waves to reach dunes and bluffs behind the beach. Statistically, storms with similar tide levels have a high probability of occurring over any 30 year period and are sometimes referred to as "30 year storms." (This does not mean that two or more storms of this magnitude could not occur in a shorter time interval.) Because of their long duration, large waves and high storm tides, these intense storms can have a devastating impact on the coast.

The worst hurricanes and nor'easters move vast quantities of sand, rearranging the beach which can have long lasting effects on the

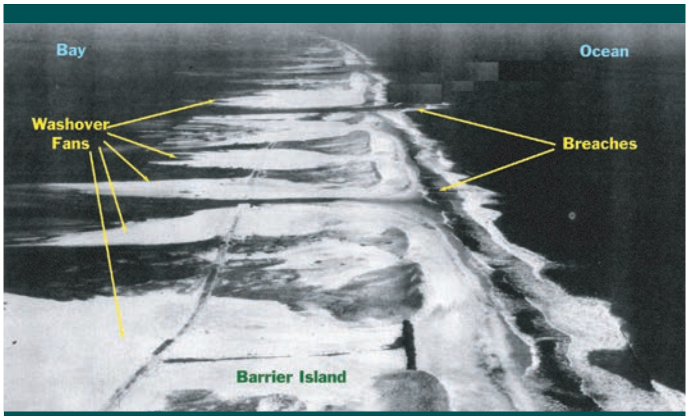

Figure 9. Washover fans and breaches caused by the 1938 hurricane in the Westhampton area. (Photo: U.S.Army Corps of Engineers 1958)

Figure 10. Shinnecock Inlet today and as it looked shortly after it opened during the 1938 hurricane (inset), before it was stabilized. (1938 Photo: U.S. Army Corps of Engineers Beach Erosion Board, Recent Photo: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

shoreline. During major storms, the elevated water levels and big waves can erode large volumes of sand from the shore and attack the dunes or bluffs behind the beach. The storms move material along the shore to adjacent areas, but some of the sand eroded from the beach and the dune may be carried seaward and deposited in water too deep for it to be brought back by the gentler waves during calmer conditions. This sand is lost from the beach system. If enough sand is transported into deeper water, the beach will not be able to fully recover and the shoreline will move landward resulting in long-term erosion or recession.

If the storm surge is high enough, the waves powerful enough, and the beach and dunes low enough, storms can erode the beach and dunes and cause an overwash. Water carries sand over the beach and through the dune depositing it on the landward side in a feature known as a washover fan *(Figure 9).* The 1962 Ash Wednesday storm reportedly created some 50 such washovers. The material in the washover fan is also lost from the beach system. On the south shore barrier islands or spits, the overwashes can reach the bay. However, studies looking at the impact of storms and the characteristics of the resultant washover fans indicate this rarely happens, except occasionally on the eastern barriers which tend to be lower in elevation. Washover fans do help to increase or maintain the elevation of the barrier island behind the dunes, often burying swales and marshes but providing habitat for shorebirds and other organisms and providing a place for new dunes to form in a more northerly location.

During very extreme events, overwash channels can grow and deepen, eventually forming a breach, or opening in the barrier island or spit, that allows water to flow between the bay and the ocean. Breaches are more frequently formed by hurricanes because they tend to have higher storm tides than nor'easters. The 1938 hurricane reportedly opened nine breaches in the barriers west of Moriches Inlet. Sand moving along the coast usually fills most of these breaches naturally, often during or soon after the storm. However, larger breaches can remain open and grow larger for long periods. Breaches that stay open and that are maintained by normal tidal currents become inlets. Both Moriches and Shinnecock Inlets started out as breaches created by storms that were then kept open artificially for navigation *(Figure 10).*

Inlets and breaches have a tremendous impact on the way sand moves around the coast, which, in turn, exerts a major influence on the behavior of the adjacent shorelines. Currents running through the breaks in the barriers can transport large quantities of sand landward into the bays and seaward into the deeper waters of the ocean. This material usually ends up in large underwater shoals or bars in the bay and in the ocean adjacent to the inlet that are created by the flood and ebb tides, respectively. The shoals on the bay side are known as flood tidal shoals or deltas; ocean shoals are known as ebb tidal shoals or deltas. The amount of sand found in the tidal deltas on the south shore far exceeds the volume of sand moved by the overwash processes. Inlets are a far more important mechanism for moving material in a cross shore direction (that is, perpendicular to the shoreline, rather than parallel to the shoreline) than overwash. Some of the marshes found on the bayside of the barrier islands are actually built on the flood tidal deltas of historical inlets that opened and closed over the last several hundred years *(Figure 11).*

Figure 11. Marsh growing on sediment deposited in the bay by a historical inlet that opened and then closed in the 1800s. (Photo: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

Long-Term Shoreline Changes

Although major storms are relatively short in duration and do not occur very frequently, they play an important role in shaping how the coast looks and behaves over time. The immediate impact of a single storm is apparent to everyone, but it is the cumulative effects of these storms that determine how the shoreline moves and changes over time scales ranging from tens to hundreds of years.

On these longer time scales, much of the south shore of Long Island is relatively stable compared to many other coastal areas. Estimates of shoreline change over the last 100 years or so show that large portions of the shore have been eroding at average rates of approximately one to two feet per year *(Figure 12).* However, these rates vary widely along the coast. Some areas were actually stable or even moving seaward over the same time span. Averaged erosion rates have to be used with caution. For much of the shore, the long-term changes occurring along the coast are too small to accurately determine with the data and measurement techniques presently available. Part of the problem in making these measurements is that the beach (and shoreline) can move back and forth hundreds of feet on a yearly basis in response to the waves, as described earlier. Yearly fluctuations can be as large, or even larger, than the movement we would expect to see due to longer-term erosion or accretion trends. These large yearly changes make it very difficult to detect long-term shoreline change rates unless the changes are very large. The highest shoreline erosion rates and accretion rates, which may exceed five feet per year, are both usually found near stabilized inlets and other man-made structures and are the result of interruptions in the natural movement of sand along the coast. (For more information, see section on Longshore Sediment Transport.)

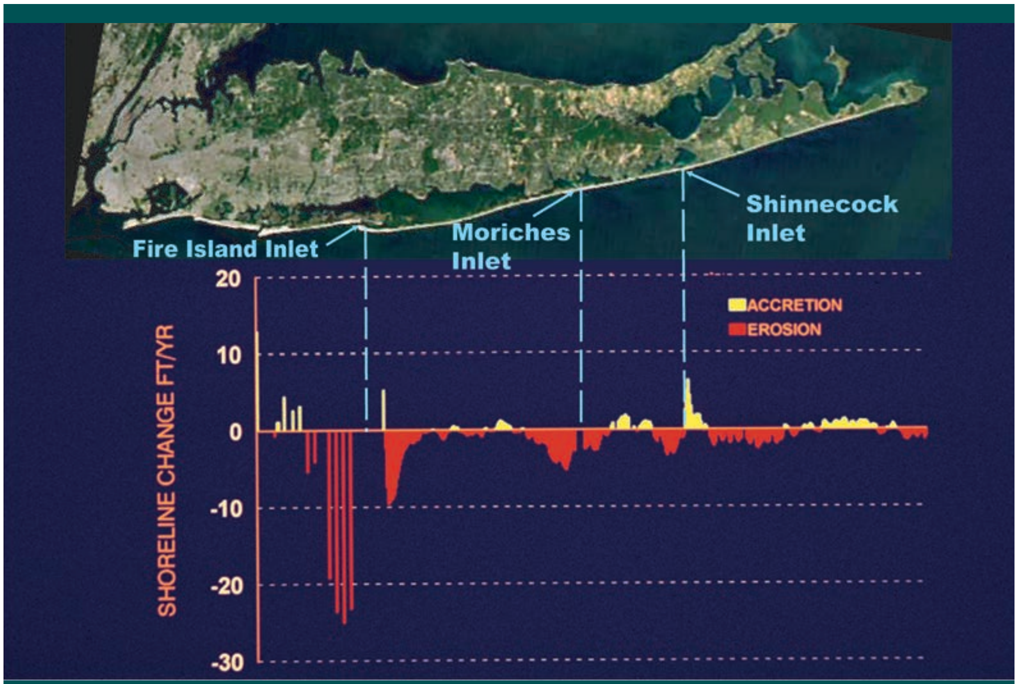

Figure 12. Long-term average shoreline change rates for the area between Jones Inlet and Montauk Point. These rates are calculated by comparing the position of historical shoreline positions dating back to 1873 to more recent shorelines. Most of the shore is eroding but some areas have been stable or even accreting during this period. (Data from Taney 1961 and Leatherman and Allen 1985)

Historical Changes — Sea Level Rise and Barrier Island Migration

A Look at the Past

Shoreline changes over time frames spanning decades to centuries vary considerably ranging from erosion to accretion depending on where you are on the south shore. However, if one considers longer periods of thousands of years, all of Long Island's shorelines have moved landward in response to rising sea level. Twenty thousand years ago, glaciers covered the land and stored a significant amount of the planet's water. With all this water locked up in the glaciers, sea level was some 450 feet lower than it is today and our ocean coastline was more than 80 miles south of its present position *(Figure 13).*

As the climate became warmer and ice in the glaciers melted, water poured back into the ocean and sea level rose. The shoreline started migrating landward, moving north up the gently sloping continental shelf. The rate of sea level rise during this time was not constant. Sea level rose very rapidly between 20,000 and about 8,000 years ago and then slowed down to a rate of about three feet every 1,000 years. The origins of the south shore barrier islands are not fully understood but they may have formed when this slowing of sea level rise occurred. There is evidence that barrier islands existed at a location about a mile offshore in water about 50 feet deep.

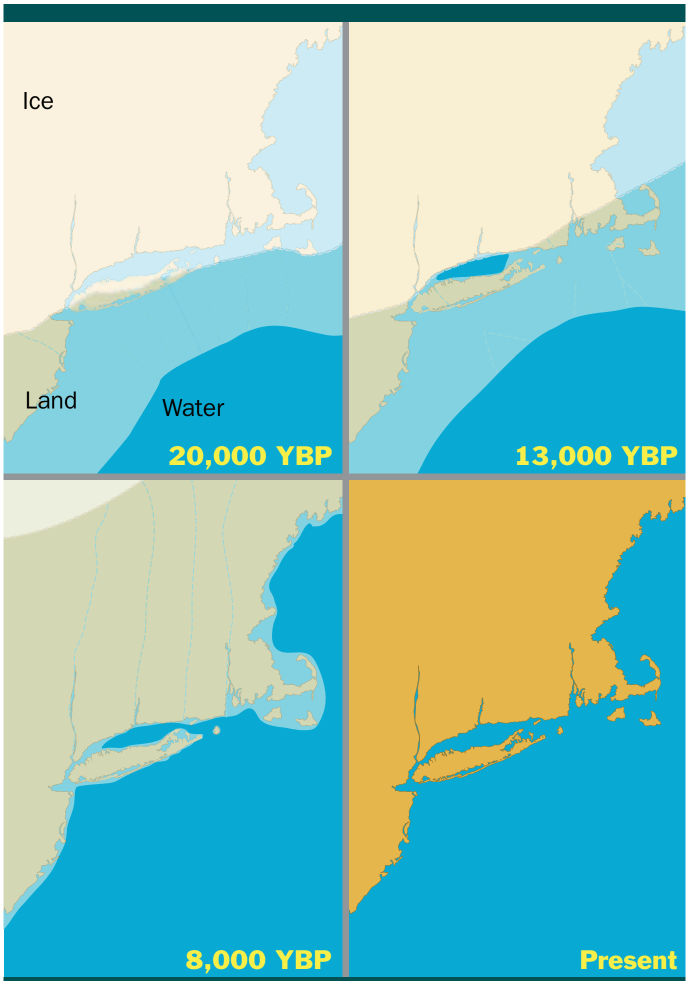

Figure 13. Over geologic time, the shoreline has retreated landward over the last 18-20,000 years as the glaciers melted and sea level rose. YBP = Years Before Present. (Illustration by Loriann Cody)

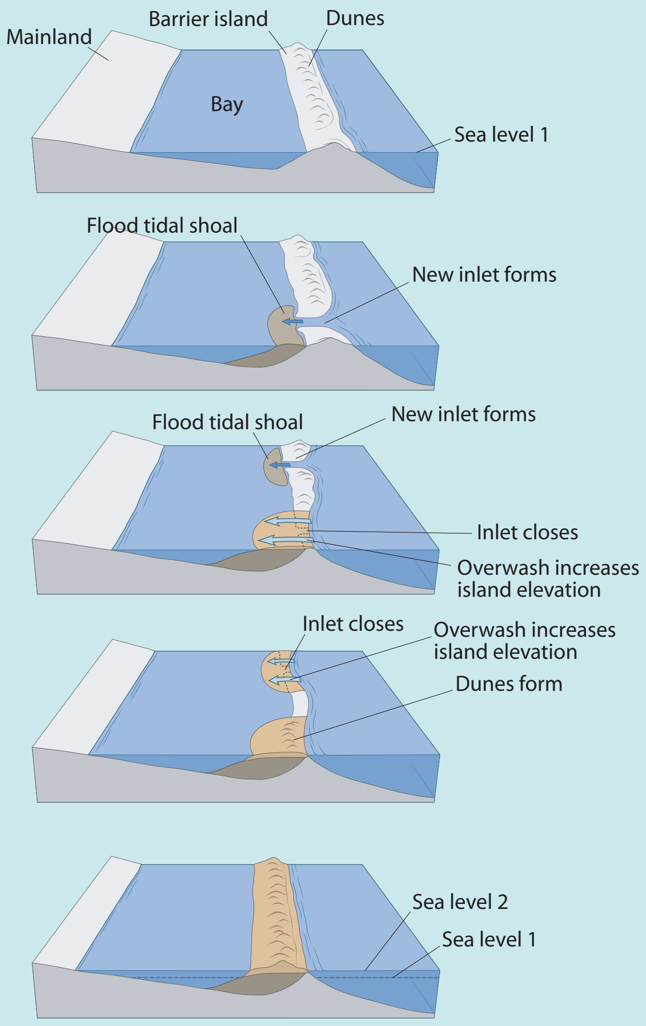

Figure 14. Simplified schematic of barrier island migration on the south shore in response to sea level rise. Inlets transport sand to the bays in the form of flood tidal shoals which provides the platform that allows the island to move landward. Overwash processes then raise the elevation of the island. This migration is a slow process occurring over periods of hundreds to thousands of years. (Illustration by John Norton)

Barrier Island Migration

These barrier islands retreated or migrated northward as the ocean continued rising. There is some debate about how the barriers actually moved. Some research suggests that the barriers slowly drowned in place and then “jumped” or “skipped” landward to a new position coinciding with the new position of the shoreline. More recent studies indicate the islands move in a more continuous process where sand is transported across the island from the ocean to the bay, allowing the island to migrate landward. There are three primary ways that sand can be transported across a barrier island: inlet formation, overwash processes and eolian (or wind) transport. On Long Island’s south shore, the inlets are actually far more important than either overwashes or the wind in terms of moving sand landward and driving barrier migration. The flood tidal shoals created by historical inlets provide the platform that allows the island to maintain itself while moving landward over time in response to rising sea level *(Figure 14).* Regardless of the actual mechanisms by which the barriers move in response to the rise in sea level, they have moved landward over the historical time frame of thousands of years.

However, the rate at which the barriers migrate varies along the south shore when one considers shorter time scales on the order of centuries. Geologic evidence indicates that the central portion of Fire Island between Ocean Beach and Watch Hill has not migrated for the last 750 to 1,300 years. This section of the island has experienced erosion on the ocean and bay shorelines, but the position of the island has remained in the same location. Interestingly, there is no evidence of historic inlets in this area over the last several centuries *(Figure 15).* The stable location and absence of historic inlets in this area suggest that barrier migration may not be a continuous process over timescales of a thousand years or less. Further to the east, the barriers are more mobile and one can find evidence of barrier island rollover processes such as old flood shoals in the bay that were associated with inlets that have opened and closed naturally over the last several hundred years.

Sea Level Rise and the Future

Along the New York coast, sea level is not only rising, the land is also slowly sinking, or subsiding due to geologic processes. The rise in the water level in relation to the land surface due to the sinking of the land and the raising of the sea is known as relative sea level rise. In our area, the average rate of relative sea level has been about a tenth of an inch per year, or about one foot per century. As can be seen in Figure 16, there are considerable monthly, yearly and decadal fluctuations in the elevation of the water. Short-term changes in sea level caused by storms are much larger than those associated with the long-term trends. Daily tides change sea level by two to five feet and storms with return periods of 30 years can raise water levels four to six feet above normal elevations in just a few hours.

It is not known exactly how much of the erosion we see on the south shore is directly attributable to the slow rise of relative sea level. Calculations based on measurements of beach changes going back to the 1950s show that the sea level increase might account for less than one foot per year of erosion and even this may be an overestimate. Studies also show that the changes a beach may go through in a single month can be over 200 times more than that expected from relative sea

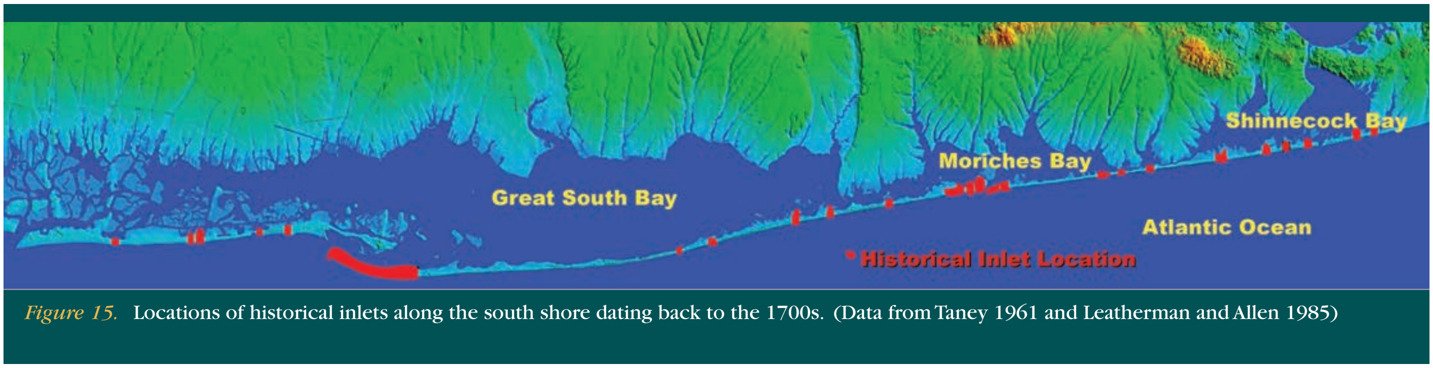

Figure 15. Locations of historical inlets along the south shore dating back to the 1700s. (Data from Taney 1961 and Leatherman and Allen 1985)

level rise alone. In terms of our most severe erosion problems, long-term sea level rise is of secondary importance compared to other factors acting on shorter, decadal time scales.

Long-term relative sea level rise is important, however, in that it ultimately controls the position of the shoreline. An increasing sea level means we will be faced with erosion problems for the foreseeable future. There is a growing consensus that human activities are contributing to global warming, which in turn can increase the rate at which the oceans will rise. While there is considerable uncertainty regarding the magnitude and timing of this increase, the most likely scenarios indicate the rate of sea level rise may double or triple over the next 100 years. In 50 years this could result in water levels that are 1.0 to 1.5 feet higher than present (as compared to 0.5 feet higher if the present rate of rise did not change).

From a planning perspective of 30 to 50 years, the biggest impact of an increased rate of relative sea level rise will be the submergence of the flat, low lying areas around the bays on the south shore. Communities in these areas could be subject to increased flooding. Coastal wetlands may also be affected by long-term sea level rise. Salt marshes, one of the most productive ecosystems on earth, are very sensitive to the position of sea level. Fine-grained material deposited in the marshes raises the surface, keeping it in the same relative position to a rising sea surface. If sea level rises faster than the sediments can be supplied, marshes could be flooded and replaced by open water. If deposition and sea level rise are in balance, some marshes may be able to migrate landward if there is room for them to retreat. Retreat will probably not be possible if the slope of the land behind the marsh is too steep or the path is blocked by structures such as roads, seawalls, or houses.

On time scales of hundreds to thousands of years, increased sea level rise could accelerate the migration of barriers landward or even lead to their disappearance altogether if the rise is very fast. The projected increases in sea level could make sections of the ocean coast more vulnerable to erosion over time. However, over planning time frames of 30 to 50 years, even increased sea level rise would not significantly change the actual observed rates of shoreline change in those areas experiencing the most severe erosion. On these time scales, sea level rise is of secondary importance compared to other factors in controlling what happens on the coast. The frequency and intensity of the storms, discussed above, and the supply of sand in the system available for building the beaches play a far bigger role in shaping the coast. In most cases, our most severe erosion problems are caused by disruptions in the transport of sand, due to either natural processes or human activities.

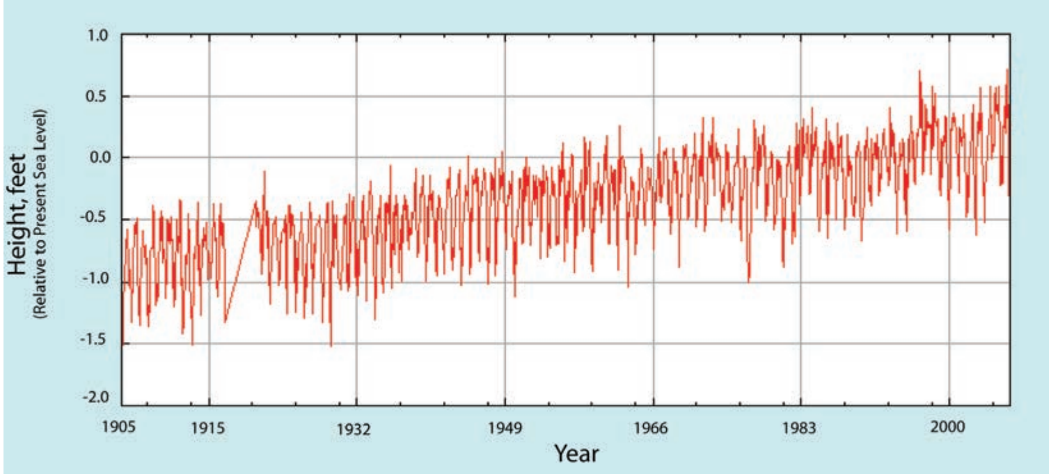

Figure 16. Monthly mean sea level measured by a tide gauge in New York City. Sea level has been rising at a rate of about one foot per century in this area. (Data from: NOAA NOS Battery Tide Gauge, *http://tidesandcurrents.noaa.gov*)

Sand — A Valuable Resource

The south shore is composed of material left by the glaciers that has been reworked by waves and currents to form the coastline we see today. Compared to many other coastal areas, the south shore has a relatively abundant supply of sand for building beaches. The condition of the beaches and position of the shoreline is the result of a balance between the sand lost from an area and new sand brought into the area. Where this balance is positive, beaches can build up and the shoreline can actually move seaward. If more sand is leaving than arriving, the shoreline erodes. For this reason, the way sand moves around in the system and the amounts moved are very important. This "sediment transport" is very complex and not well quantified on the south shore. Even though precise amounts of sand and exact pathways of movement are not known at this time, some general patterns and trends are recognized.

Figure 17. The direction and magnitude of sand transport along the shoreline varies depending on wave conditions as evidenced by the pattern of erosion and accretion around these structures in East Hampton. The top photo shows transport to the east (right) with accretion on the west (left) side and erosion on east side. The bottom photo shows the opposite pattern at the same location at a different time. (Photos: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

Longshore Sediment Transport: Not Quite a "River of Sand"

As already described, waves hitting the shore can move sand landward or seaward in a cross shore direction. Waves approaching the shore at an angle also create currents which carry sand parallel to the coastline in the surf zone. This movement of sand is called longshore sediment transport (the sand moving in the surf zone is also referred to as longshore or littoral drift). Longshore transport has often been described as a "river of sand" picking up and depositing material on the beach as it moves along the shoreline. This analogy is somewhat misleading for the south shore, however. While a river usually flows in one direction, the longshore transport can be to the east or the west depending on the direction of the waves and even where you are on the shoreline *(Figure 17)*.

The amount of sand moved depends on the size and frequency of the waves. Bigger waves move much more sand, which means that storms, with their large waves, are very important in controlling the distribution of sand along the shore. The size of the waves responsible for moving most of the sediment on the south shore is controlled by three variables: the speed of the wind over the water, the distance the wind blows over water (called the fetch), and the length of time the wind blows. The fetch of winds blowing towards the east is limited by the presence of New Jersey. This limits the size of the waves which carry sand east along the New York Atlantic shore. The fetch for winds blowing towards the west is virtually unlimited. As a result, the waves driving longshore transport to the west are generally stronger than the waves moving sand east. Although sand is moved in both directions, more sand tends to be moved to the west resulting in a net transport of sand from east to west in most years. The rate at which sand moves along the coast is usually measured in units of cubic yards per year. To envision a cubic yard, think of a volume of sand about the size of a typical clothes washing machine.

The net longshore transport rate of sand varies along the south shore *(Figure 18)*. While there is a good deal of uncertainty regarding the exact numbers, estimates indicate the rate of transport is approximately 100,000 to 300,000 cubic yards per year to the west in the eastern end of Long Island. The rate increases to as much as 600,000 cubic yards to the west at Fire Island Inlet and then decreases to about 450,000 cubic yards nearer New York City. Even given the uncertainties associated with the estimates, there are obviously substantial quantities of sand moving along the coast. This movement of sediment can have a major impact on what happens to the shoreline in an area. To give you an idea of how important it can be, the longshore transport of sand actually allowed the western end of Fire Island to grow or accrete more than four miles between 1825 and 1940 when a jetty was constructed to slow this westward migration of the island and stabilize the inlet. The original Fire Island Lighthouse was constructed in 1826, at what was then the western end of Fire Island, to guide ships through an inlet that existed there at that time. The current structure, constructed in 1857 just to the east of the original light, now sits well east of the new position of the inlet, which moved west as the island grew more than 150 feet per year with sand supplied by longshore transport.

Where does all this sand come from? For a long time, people thought the sand transported along the coast came from erosion of the bluffs at Montauk, but studies of the composition and erosion rates of these features indicate bluff erosion alone can't supply all of the material we see in the system. Some of the sand actually comes from the erosion of the mainland and barrier beaches themselves. More recent studies suggest that a significant portion of the material in the longshore transport system may come from offshore deposits of sand. The relative contributions of these three sources is not known.

The longshore transport of sand ties the south shore together as a system. Although we do not know precisely how much sand is flowing along the shore or exactly where it is flowing at any given time, we do know this flow of sand is critical to maintaining the shoreline. Actions taken in one area can affect adjacent areas. We also know that many of our most troublesome erosion problems are the result of disruptions of this flow either by natural processes or human activities.

Figure 18. Sand moves in both directions along the shore, but generally more sand moves to the west than to the east resulting in a net westerly transport. There is considerable uncertainty in the values shown here due to variability in the rates of movement at different times and places and difficulties associated with trying to measure the amount of sand moving along the coast.

Tidal Inlets — An Important Part of the System

Stabilized Inlets

Inlets exert a dominant influence on the behavior of the shoreline by interrupting the natural longshore transport of sand along the coast and capturing sediment that might otherwise reach adjacent beaches. The stabilized inlets are especially important. Jetties (the long stone structures built at a right angle to the shoreline to fix the navigation channel in place) trap sand moving along the beach, causing the beach on the updrift side (usually the east side on the south shore) to extend seaward *(Figure 19)*. However, the trapping of sand on the beach by the eastern jetty is a very minor impact compared to the problems caused by the formation of shoals associated with the inlets.

When the tide is flooding or rising, the inlets allow sand to be swept into the bay and deposited where it forms the flood tidal shoals landward of the inlet. During outgoing, or ebbing, tides, currents created by the water flowing out of the bays push sand offshore, depositing it in the ocean where it forms ebb tidal deltas. The ebb tidal deltas are less visible than the flood tidal deltas because they are submerged, but these ebb tidal deltas are more important in terms of their impact on the shoreline because of their sheer size. They are much larger than the flood shoals in the bays. For instance, the ebb tidal delta at Shinnecock Inlet is estimated to hold around 8 million cubic yards of material *(Figure 20)* compared to around 0.5 million for the flood tidal delta. Although very difficult to measure, estimates of the size of the ebb shoals range from about 4 million cubic yards for Moriches Inlet to over 40 million cubic yards for Fire Island Inlet. Imagine a mound of sand the size of 40 million washing machines under water!

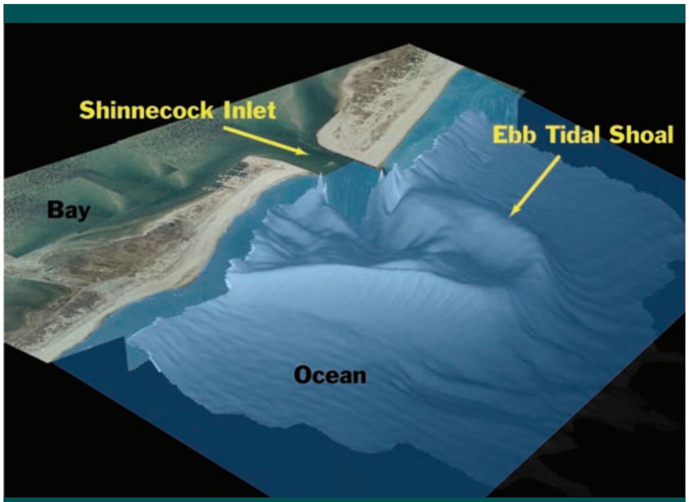

Figure 20. Shinnecock Inlet has trapped approximately 8 million cubic yards of sand from the longshore system in the ebb tidal shoal located seaward of the inlet. This representation of the shoal was constructed from high resolution surveys of the seafloor. (Survey data by R. Flood, GIS integration by B. Batten)

Given the size of the inlets and their related shoals, it is easy to see how they can have a major impact on the shoreline. However, these features are actually very complex systems and the full range and magnitude of their impacts are still not entirely understood. What is known is that inlets disrupt the natural flow of sand along the shore and can have a tremendous impact on the adjacent beaches. The vast amount of material stored in associated shoals is essentially lost from the nearshore beach system. Cut off from the natural supply of sand, the beaches immediately downdrift (west) of the inlets experience greatly accelerated erosion. While this erosion helps restore the flow of sand along the shore by replacing material trapped by the inlet, it also causes rapid shoreline recession adjacent to the inlet on the downdrift side. As a result, the inlets on the south shore exhibit a characteristic

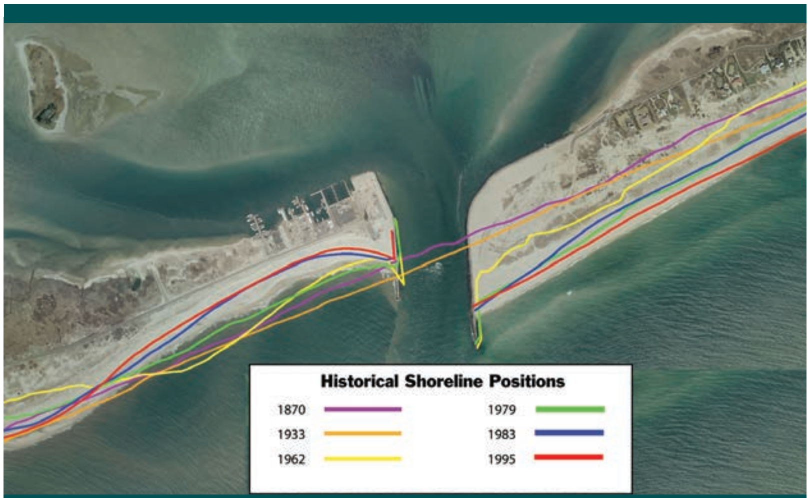

Figure 19. Inlets can have a major impact on adjacent areas as indicated by the historical shoreline positions near Shinnecock Inlet. After the inlet opened in 1938, the eastern or updrift shoreline (to the right) moved seaward while the western shoreline eroded and moved landward. (From: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

pattern of shoreline accretion on the east and erosion on the west seen in Figure 19. Based on long-term shoreline changes, the impact of each of the individual inlets appears to become more substantial to the west probably because the size of the inlets increases as does the magnitude of the longshore transport of sand. Measured recession rates of over 20 feet per year have been observed on the beaches downdrift of some of the western inlets *(Figure 12)*.

The large ebb tidal deltas also interact with the ocean currents and waves. In some cases, these interactions change local conditions around the inlets dramatically. Ebb tidal deltas can change the direction of sand transport by altering the direction of the incoming ocean waves. For example, the ebb tidal delta off of Fire Island actually bends the waves coming from the southeast. Waves striking the coast west of the inlet actually push sand east into the inlet setting up a net longshore transport to the east (opposite of the net westerly movement for the south shore as a whole). The "reversal" of sediment transport results in a situation where sand is moving both to the east and to the west at some point west of the inlet. Areas where the sand is being lost in both directions are known as nodal points and have very high erosion rates. One of these nodal points is thought to be near Gilgo Beach, west of Fire Island Inlet.

Presently, it is not known how long stabilized inlets continue to affect adjacent areas after they are opened or how far along the coast these effects extend. Generally, most experts believe the influence of inlets on shoreline change rates should decrease with time from the formation of the inlets and with distance from the inlet. However, determining where and when the influence of the inlet is overshadowed by the other factors causing shoreline erosion is extremely difficult. Ebb tidal deltas should eventually arrive at an "equilibrium" state where they reach their maximum capacity and stop growing. They no longer trap all the sand moving along the coast and allow some or all of the material to naturally "bypass" the inlet. Unfortunately, there are no universally accepted criteria for determining when an inlet has actually reached this theoretical equilibrium state. It is also not known whether all of the sand "bypassing" the inlet actually makes it to beach on the other side, as it would if the inlet were not present. Smaller inlets, like Shinnecock and Moriches Inlets, should reach this equilibrium state more quickly than the larger inlets to the west. Based on observations of the configuration of the ebb tidal deltas and the behavior of the adjacent shorelines, it appears that both inlets are bypassing sand to some extent. However, detailed surveys of Shinnecock Inlet, which opened in 1938, showed the ebb tidal shoal trapped significant amounts of sand (on the order of hundreds of thousands of cubic yards per year) especially in deeper waters between the years 2000 and 2002. This suggests that the inlet is not bypassing all the sand and is still disrupting the longshore sediment transport. Shinnecock and Moriches Inlets are probably bypassing some sand, but, at this time, no one can say with certainty what portion of the total amount of sand moving along the coast is actually able to flow across the inlets and back onto the beaches to the west. As a result, it is not possible to accurately assess how much of an impact the inlets are having on the shorelines in these areas.

The effects of inlets can be moderated by initiating artificial "bypassing" programs where material is mechanically moved across the inlet to restore the natural longshore sediment transport. But determining how much sand should be moved, where it should be moved and when it should be moved is not a trivial task. In the past, dredging projects at the inlets were designed solely for navigation purposes with safety and cost the primary concerns. In some cases, sand dredged out of the channels was actually disposed of offshore and lost from the beach because it was cheaper than placing it on the downdrift areas. The only inlet on the south shore that has had a regularly scheduled bypassing program is Fire Island Inlet. There, over 800,000 cubic yards are dredged from the inlet every two years, with most of this material being placed on the downdrift beaches of Jones Island.

Breaches and New Inlets

As we have seen, storms, particularly hurricanes, have periodically carved new inlets and breaches through the south shore barriers. Historically, these inlets have been concentrated in the eastern portion of the barrier system *(Figure 15)*. Inlets play an important role in barrier island migration by transferring sediment to the back side of the barrier, allowing the barrier to move landward and providing a platform for marsh creation if the conditions allow. However, an inlet must be open for decades to transport enough sand to the back side of the island to provide the platform necessary for barrier migration.

Short-lived inlets or breaches that are only open for less than a year or two are not as important in terms of barrier island rollover or marsh creation because they do not move enough sand to the back bay. They are, however, a concern from a management perspective because they can cause significant changes in the bay and mainland areas, as well as along the ocean shore. A number of potential impacts associated with new inlets or breaches have been identified.

New inlets or breaches can result in increased tidal ranges and storm water level elevations in the bays under certain conditions. This, in turn, can cause increased flooding and erosion on bay shorelines. Measurements taken when the Little Pike's Inlet *(Figure 21)* opened in Westhampton during the 1992 nor'easter showed the tidal range (the difference in elevation between low tide and high tide) in Moriches Bay increased by 30 percent, from 2.0 to 2.6 feet. There were also reports of increased flooding on the mainland shoreline of the bay. Dredging of new channels in Moriches Inlet in 1958 and 1968 increased the tidal range by about 0.3 feet which also represented an increase of about 30 percent of the tidal range at that time. Studies indicate the effect of new inlets would be greater in smaller bays, like Moriches, than in the larger bays, for the same size opening. It is unlikely an inlet the size of Little Pike's Inlet in Great South Bay would have affected the tidal range to the same extent.

New inlets can also cause changes in the physical and environmental characteristics, such as salinity, temperature, circulation and shoaling patterns in the bays behind the barriers. These changes can, in turn, affect biological resources, including finfish, shellfish and plants. In some cases, certain resources may benefit while others are adversely affected. For instance, a breach may help increase flushing and improve water quality by letting more ocean water into the bay, but it may also allow more predators of shellfish to invade the bay.

Inlets and breaches disrupt the longshore flow of sand on the ocean beaches leading to increased erosion. At the same time, they can supply the bay shoreline with sand. New inlets would also divert some of the tidal flow from existing stabilized inlets, which could cause the channels to fill in more rapidly and adversely affect navigation.

It is clear that inlets and breaches can cause substantial physical and environmental changes in the back bays and these changes could affect some of the important biological resources in these areas. Some these changes may be relatively small, or actually have beneficial impacts. Others may have significant impacts on traditional uses of the south shore bays and mainland coast. There are research efforts underway to identify and, to the extent possible, quantify the impacts of new inlets on the physical characteristics and biological resources of the bays but, presently, we do not have the information necessary to accurately predict the changes that might occur.

Figure 21. The Westhampton barrier breached during the December 1992 northeast storm forming Little Pike's Inlet in Moriches Bay. (Photo: First Coastal Corp)

Impacts of Human Responses to Shore Erosion

As would be expected in an area as densely populated as the New York City and Long Island region, human activity in the coastal zone is substantial and can have a significant impact on the shoreline. In addition to activities related to the stabilization and dredging of the inlets previously discussed, human responses to erosion and flooding problems probably have the greatest potential for affecting coastal processes and the beach. These responses include structural measures, such as groins and seawalls, as well as "soft" erosion control responses that often involve the placement or rearrangement of sand on the shoreline.

Structural Responses

Erosion control structures commonly used on the south shore of Long Island can be divided into two categories: "shore perpendicular" structures and "shore parallel" structures *(Figure 22)*. As the names imply, the shore perpendicular structures are built at a ninety degree angle to the trend of the shore and they extend across the beach toward the water. Groins and jetties are examples of these structures. "Shore parallel" structures are built in line with the shoreline, usually landward of the beach. These structures include bulkheads, seawalls and rock revetments. Because they have the potential to cause considerable damage if used improperly or in the wrong place, erosion control structures require permits from state and local jurisdictions as well as federal permits if they are placed below the spring high waterline.

Shore Perpendicular Structures: Although many people use the terms interchangeably, groins and jetties are not really the same thing. Groins are long, thin structures that extend from the dune to the water. They can be made of rock, steel, wood or concrete. Ideally, they are used in conjunction with sand fill projects and are designed to slow down the rate at which sand placed on the beach is removed by the longshore currents. The structures themselves do not provide any protection. Rather, the beach they create by trapping or holding the sand provides the protection for the landward area. Groins do disrupt the natural transport of sand along the beach and, if they are not designed and built properly, can cause problems.

Jetties, on the other hand, look like groins but are found only at inlets. Their primary function is to hold a navigation channel in one place and prevent it from filling in with sand. Jetties also trap sand moving along the shore. Since they are usually much longer than groins, jetties can have a much larger impact.

Figure 22. The most commonly used erosion control structures on the south shore are shore perpendicular structures like the groin on left and shore parallel structures like the bulkheads on right. (Bulkhead photo: First Coastal Corp)

Because of the net east to west flow of sand along the south shore, jetties and groins usually tend to trap material on the east side. As with the inlets discussed earlier, these structures interfere with the longshore transport of sand and can cause severe erosion problems on the shores to the west of the structures. The magnitude of the impact increases as the length and height of the structure and the rate of longshore transport increase. To help minimize adverse impacts of these structures, sand should be placed on the east or updrift side of the structure to create a protective beach. This helps minimize the disruption of the flow of sand along the coast (but does not necessarily eliminate all the impacts). The severely eroded area west of the 15 groins at Westhampton that eventually breached during the 1992 December nor'easter is a graphic example of the impact groin projects can have when not properly constructed *(Figure 23 and Figure 21).* The compartments between the groins were not filled with sand as they should have been. The structures trapped an estimated five million cubic yards of sand that was naturally moving along the shore, depriving the beach to the west of the material it should have received.

In certain situations, however, these structures can help maintain a recreational beach and provide upland protection. There are 69 major groins and jetties along the south shore. The 48 groins at Long Beach, built in the 1920s, have helped slow down erosion and preserve the beach in front of this heavily-developed area for over 80 years *(Figure 23)*.

Shore Parallel or Armoring Structures:

The other type of erosion control device found on Long Island is the shore parallel structure. This category includes bulkheads, seawalls and revetments. These structures can be made of different materials including rock, wood, concrete, and sand-filled bags, but they all function in the same way. They are built parallel to the shore, usually behind the beach. Since they function by hardening or armoring the upland, they are often called shore armoring structures. They are not designed to protect the beach.

Armoring structures built to protect individual private properties probably have minimal impact on the behavior of the shoreline over very long time scales (geologic time) because of their limited area of coverage and relatively short functional lifetime (usually less than 50 years). However, they may cause substantial short-term, localized impacts on the beach if used improperly or in the wrong place. The potential for adverse impacts depends primarily on the conditions at the site, especially longer-term shoreline trends in the area, as well as on the design and location of the structure on the beach. Multi-decadal studies on Long Island have shown that at certain sites

Figure 23. Groins interrupt the natural flow of sand and can increase erosion in adjacent areas (left). However, these structures can be designed to slow down erosion and minimize adverse impacts in certain situations. The 49 groins constructed in the 1920s in Long Beach (right) have helped maintain a recreational beach that protects the developed upland.

these structures can provide protection for the upland during storms without adversely affecting natural beach building processes *(Figure 24).* Typically, these are areas experiencing episodic damage from storms but that have a shoreline that is stable or accreting on decadal time scales and an adequate supply of sand in the longshore system. In these areas, the structures are often completely covered with sand during calm periods. They are exposed during severe storms, preventing erosion of the upland and then covered again as the beach rebuilds naturally after the storm.

On the other hand, in areas experiencing chronic shoreline recession and a deficit of sand, where these structures are frequently proposed, armoring the shoreline can adversely affect the beach and adjacent areas unless other measures are also taken to mitigate their impacts *(Figure 25).* These measures might include bringing in additional sand to make up for the sand impounded or retained by the structure. Where you have rapid shoreline retreat, shore armoring structures usually lead to a narrowing or loss of the beach, not because the structures increase erosion but because they prevent the beach from migrating landward. In extreme cases, the structures may end up being surrounded by water as the shoreline recedes on either side. These structures eventually fail because they are not designed to handle the forces found in the surf zone. Before failure, they can block the transport of sand along the shore, essentially acting as groins and causing increased erosion in downdrift areas.

“Soft” Responses

To overcome some of the disadvantages and negative impacts associated with the structural erosion control measures, so-called “soft” erosion control responses are gaining increasing popularity primarily because they are considered more environmentally benign. For the purposes of this primer on coastal processes, these soft solutions are defined as activities that involve adding sand to the system or artificially enhancing the dunes. Other non-structural alternatives such as relocating structures, requiring special building codes

Figure 25. In areas experiencing chronic recession, shore parallel structures like this bulkhead can prevent the landward migration of the shoreline eventually resulting in the loss of the dry beach. (Photo: H. Bokuniewicz)

Figure 24. In stable areas with an adequate sand supply, studies over the last thirty years have shown shore parallel structures like this rock revetment can provide erosion protection during severe storms without adversely affecting natural beach building processes. (Arrows indicate the same houses in the two photos for reference.) (2007 Photo: M. Slattery)

for structures in hazard zones and minimizing development in these zones are also often described as "soft" responses. These are management alternatives with limited impact on coastal processes, and therefore are not discussed here.

Beach Nourishment: The most popular soft response to erosion is beach nourishment or replenishment which involves placing sand on the shore to build up the beach, which in turn provides protection for the upland area *(Figure 26)*. New York has a long history of beach nourishment. In fact, the first beach nourishment project in the United States actually took place in Coney Island in 1923 when some 2.5 million cubic yards of sand were added to the shoreline. The objective of this project was not to protect the upland, but to create a wider beach for recreational purposes. Since the 1920s, Long Island beaches have been nourished with an estimated 128 million cubic yards of sand in various projects.

The main advantages of beach nourishment as an erosion management option are that it can create (or maintain) a recreational beach and that it is viewed as more environmentally compatible than some of the structural options because it involves adding sand to the beach. Nourishment doesn't really affect the processes causing erosion. Rather, it simply moves the shoreline seaward. Eventually, the shore will return to its pre-project position if more sand is not added as the beach erodes. Since it is not permanent, beach nourishment is considered somewhat reversible compared to structural alternatives.

Figure 26. Inlet bypassing and beach nourishment project on Jones Beach Island. Sand dredged from Fire Island Inlet (in the background) is piped to the site and deposited on the shoreline to build a beach to protect the Ocean Parkway. (Photo: American Dredging Company)

By the same token, beach nourishment requires a long-term commitment to maintain the project as well as an abundant source of sand. To provide adequate protection, beach nourishment projects must replenish the whole beach, which, as we have seen, can extend out to a depth of 20 to 30 feet below the surface of the water, not just the visible beach. A crude "rule of thumb" in coastal engineering that can be applied to the south shore is that one cubic yard of sand creates approximately one square foot of dry beach. This means a beach nourishment project would require one cubic yard of sand for every one foot of shoreline to move the waterline one foot seaward. To create a new 100-foot wide beach for a mile stretch of shoreline would require over 500,000 cubic yards of sand. This sand has to be similar in grain size (or slightly larger) and composition to the native sand or the restored beach will erode more rapidly. The restored beach also has to be replenished on a regular basis to replace the sand lost as the result of the natural background erosion, if continued protection is needed.

Because of its glacial origins, the area off of Long Island's south shore contains some of the most extensive sand deposits found on the east coast. However, the supply of sand available for beach nourishment is not inexhaustible. Some of the deposits may not be available for nourishment for environmental reasons and some are too far offshore to access practically with today's dredging technology. Others may not contain sufficient material of the right size or composition. In some cases, such as the central portion of Fire Island, recent studies suggest offshore sand may already be feeding the beaches through natural processes. Using this sand for nourishment could disrupt the natural transport of material and accelerate erosion in the future. An important component of any nourishment project is finding a suitable source of sand for the lifetime of the project that can be used without adversely affecting other areas. Since Long Island has significant amounts of sand, it may be feasible to maintain some nourishment projects for time periods on the order of decades depending on the size and the scope of the effort. However, offshore sources of sand are finite so these projects are not sustainable indefinitely. Unfortunately, at the present time, we do not have the necessary information on the total volume of offshore sands that may be available for nourishment to say how long the projects could be carried into the future. Similarly, our limited knowledge of how sand moves offshore does not allow us to quantitatively assess the long-term impacts on the shore that may be associated with using some of these resources for nourishment now.

Oceanfront beach nourishment projects are only practical when implemented on a regional or community scale due to technical constraints and cost considerations. These projects are usually fairly expensive because of the need for periodic maintenance and the large volumes of sand necessary to provide adequate protection. A properly implemented nourishment project can cost millions of dollars per mile of shoreline depending on the erosion rate, conditions of the shoreline, the level of protection required and the proximity of a suitable supply of sand. In most cases, nourishment projects are only economically justified in those areas where there is a high level of development or heavy use of the shoreline being protected.

Beach nourishment projects intended to protect upland areas are usually designed to provide a beach and dune system large enough to prevent wave attack and flooding by overwash and, in the case of barriers, by breaching and inlet formation. Since inlets are the primary mechanisms for transferring sediment landward along Long Island's barrier island systems, nourishment projects that cover large areas and are maintained for very long periods of time could lower the rate of cross shore sand transport and, eventually, affect barrier island migration. The lack of quantitative information on the relationship between barrier island migration and the rate of sand transport across the barrier by new inlets, makes it very difficult to determine exactly how a nourishment project might alter long-term barrier migration rates or how long it would take.

The time frame being considered is an important factor. Most major beach nourishment projects are usually designed to last 50 years or less. In areas where the barrier may not be migrating over periods of hundreds to thousands of years and there is no evidence of historic inlet activity, nourishment may have minimal impact on the cross shore sand transport processes that drive barrier migration processes over the lifetime of such a project. However, there may be more of an impact in those areas where there is evidence of migration, such as historical inlet formation, occurring on time scales closer to the design life of the project. In these areas, more detailed information on the amount of sand actually transported and the rate at which it was carried across the barriers by historic inlets is needed before we can accurately assess how and when beach nourishment projects may affect barrier migration.

Dunes

Dune Characteristics

Dunes are a common coastal landform along the south shore. These features are created when wind carrying sand encounters an obstacle, such as vegetation or a fence, and slows down causing the windborne sand to be deposited. On the south shore, the dominant winds are from the west and northwest so highest rates of wind (also called eolian) sand transport are actually in a west to east direction parallel to the shore. Much less sand is blown in a cross shore direction. Based on measurements of sand transport on the south shore, it is estimated that the amount of sand carried landward across the crest of the dune from beach is about 0.08 cubic yards of sand per foot of dune or less than one cubic yard per year for a 10-foot wide stretch of beach.

Dunes vary greatly in size and form depending on site conditions. In general, the size of the dunes increases from west to east on Long Island. In the urban areas to the west, most of the natural dunes have been heavily impacted by human activities. In some areas, they have been entirely removed or replaced by development along the shoreline *(Figure 27).* Most of the dunes found along these heavily used areas have been artificially created or maintained, such as the dune fields on Long Beach in the Town of Hempstead. Further to the east, human manipulation of the dune is still common but there are also places, such as the

Figure 27. In some areas, development has replaced the natural dunes. Dunes along many developed shores are artificially created and maintained.

Wilderness Area on Fire Island, where development is less dense and natural dunes can still be found. These dunes can take many forms from low scattered mounds to high continuous ridges *(Figure 28)*.

In some areas there are multiple rows of dunes. The seaward dunes adjacent to the beach are called foredunes or primary dunes. These dunes interact with the beach, especially during storms. The dune landward is known as the secondary dune. In essence, these dunes are cut off from the beach and are no longer receiving sand. Some of these secondary dunes are actually the largest dunes in the area. It is thought they might have been created when more sand was available for dune building and became stranded when the beach accreted and a new foredune formed. The larger secondary dunes are often separated by a well-developed swale that may be tens of feet wide.

The volume of sand found in even the largest dunes is relatively small compared to the volume of sand making up the beach. Dunes usually contain less than five to ten percent of the amount of sand found in the beaches (remember, the true beach extends offshore). Because the beach has so much more sand, it actually provides the bulk of protection from erosion during storms. Nevertheless, foredunes do interact with the beach and are an important component of this dynamic system.

Dune Dynamics

As we have seen, high water levels during storms allow waves to attack the dune. Sand in the dunes is removed and redistributed along the beach contributing to the building of the bar and the longshore transport. Essentially the dunes act as a sand storage system that can provide material during storm events. Depending on the size of the dune and the intensity of the storm, high continuous dunes can also provide a barrier to storm surge and overwash, reducing flooding on the landward side.

Natural dune recovery after a storm depends on the severity of the storm and the resultant topography. If the front of the dune is eroded, or scarped, by the waves, the vertical face of the scarp eventually dries out and collapses, moving sand and the beach grass to the toe of the dune *(Figure 29)*. Windblown sand from the beach collects at the toe of the dune and the beach grass sends out rhizomes (underground stems and roots). This initiates new plant growth that traps and holds sand, allowing the dune to grow seaward if the beach is wide enough.

Dunes can be completely flattened or overtopped during a storm *(Figure 30)*. If the washover deposits are not too deep and the vegetation has not been eroded, new beach grass shoots can emerge and begin the dune building process. Otherwise, dune recovery has to start

Figure 28. Natural dunes can take many forms, from small mounds to high continuous ridges.

Figure 29. Beach grass slides down the face of an eroded dune, taking root at the toe and starting the natural recovery of the dune.

at the landward edge of the washover fan where there is vegetation or, in some cases, where there is a wrack line (the accumulation of vegetation and other natural debris left at the high waterline) that can begin trapping windblown sand. On the south shore, sand can be transported from the inland area towards the beach on these washover fans because dominant winds are from the west and north. As the landward side of the dune becomes vegetated, sand transport from this direction is slowed down and more sand comes from the beach. In response, the dune tends to grow seaward.

The seaward growth of dunes is limited by the width of the beach and distance from the waterline. A wider beach can provide more windblown sand and protection for the dune from the ocean. Since dunes are primarily composed of finer sands, they are very susceptible to damage from even small waves. While dunes can provide some protection from episodic storm events, even the largest dunes are not effective in combating long-term or chronic erosion where they are consistently exposed to wave action. The foredune is dependent on the beach. In a sense, the dune and beach can be thought of as linked components that move together in response to changes in the shoreline position.

Natural dune rebuilding processes operate relatively slowly. Left solely to natural processes, dunes may take years or even decades to recover after a severe storm. Because of the protection they provide and their aesthetic and environmental benefits, maintaining and enhancing dunes are common shoreline management practices.

Figure 30. Dunes can be overtopped and flattened during storms by waves and elevated water levels leaving washover deposits. The dunes can rebuild naturally but this is usually a slow process and complete recovery can take years to decades.

Humans and Dunes

Coastal dunes can be affected by human activity especially when it prevents the movement or alters the position of the dunes. The potential impacts of houses on the dunes is of particular concern, but studies looking at dune dynamics on the south shore found that properly built houses that are elevated on piles above the dune height and free of obstructions underneath do not significantly weaken the dune's integrity or its protective capabilities. However, houses built directly on the ground can alter the deposition of windblown sand and, thus, may affect dune building processes. Studies have also suggested that removing these houses without revegetating those areas can create bare sand patches on the back side of the dune which can persist for long periods. Since these bare patches are susceptible to erosion and blowouts from the dominant westerly and northwesterly winds, they also have the potential to weaken the dune. Such complex scenarios illustrate the difficulties associated with trying to manage a resource as dynamic and fragile as the dunes. Management actions may have unintended consequences that can best be identified and rectified through comprehensive monitoring and research efforts.

Dune plantings and fencing: Human activity on the dunes and programs of dune stabilization may play a more important role than elevated structures in controlling what happens to these features. Most people are aware that dune vegetation, especially the beach grass, is very vulnerable to foot traffic. Uncontrolled pedestrian access over the dunes can remove the vegetation and allow wind erosion causing low spots that are more susceptible to overwash. Beach grass spreads by sending rhizomes out underground. The rhizomes can extend 20 feet from the plant. As we have seen, regrowth from rhizomes is an important mechanism in dune recovery after storms. However, the rhizomes are fragile and can be damaged by vehicle traffic even though they are beneath the surface. For this reason, beach vehicle traffic should be discouraged within 20 feet of the dune vegetation line.

Long stretches of sand fencing and artificially planted vegetation used in dune building programs probably have more of an impact on dune processes than either elevated houses or pedestrian traffic. While the amount of windblown sand in the system is not large, these efforts can be extremely efficient at capturing the sand that is available. When not sited, planned, or implemented properly, dune building projects can result in a dune that is much closer to the water than would be found under natural conditions. Dunes built too close to the water will experience more erosion due to more frequent wave action at the toe. These dunes may appear to have a high steep face but they usually will not have as much sand as a dune placed further landward, due to the constant removal of material. Less sand usually means less protection during storms. The high continuous crest of artificial dunes may also interfere with the landward transport of sand and prevent more natural dune formation further inland.

Beach scraping: Beach scraping is a technique that has also been used to build or repair dunes. A thin layer of sand is scraped from the top of the berm and pushed landward in an attempt to restore a dune *(Figure 31)*. These projects are regulated by the state in terms of when the scraping can take place, how much sand can be removed and where it can be placed. The present regulations allow scraping about two cubic yards of sand per foot of beach. While the effects of beach scraping have not been rigorously examined on Long Island, limited studies of this activity elsewhere suggest it has a limited impact, either positive or negative, on coastal processes or protection of the upland area where it occurs.

Basically, scraping simply redistributes the sand within the system and does not change the amount of sand available for dune and beach building. The volume of sand allowed to be moved is very small. Measurements on Fire Island, where many of the beach scraping projects take place, show the average volume of sand contained in the active beach (out to a depth of 24 feet) is about 925 cubic yards per foot of beach This means beach scraping rearranges only about 0.2 percent of the total amount of sand on the beach in those areas where it is permitted. Projects are limited to 60-foot wide lengths of shoreline, further minimizing their impacts.

Beach scraping probably has minimal adverse effects on the beach, but, by the same token, it also provides minimal benefits in terms of protection for the landward area. The small amount of sand added to the dune would provide limited protection against even a small storm. If the scraped sand is placed seaward of the position where the natural dune would normally form, the resultant feature is more susceptible to erosion. Equipment operating within 20 feet of the existing vegetation line could also damage beach grass rhizomes, hindering natural dune recovery. Because of the drawbacks associated with these projects, some experts have suggested efforts might be better spent on bringing in beach-quality sand from an outside source for dune building rather than relying on scraping. However, the difference in cost between these alternatives could vary considerably depending on site access and has to be evaluated on a case by case basis.

Figure 31. Beach scraping projects remove a thin layer of sand from the beach berm and push it landward to form a mound. This redistribution of a relatively small amount of sand on the beach probably has minimal impact, either positive or negative, on coastal processes or protection of the upland.

In Conclusion…

Long Island's south shore ocean coast is a remarkably diverse and complex place. It is this diversity and complexity that provide the many environmental, recreational and economic benefits the coast has to offer. This area is also very dynamic and, in many ways, very fragile. The shoreline we value and enjoy today was created by a variety of forces and processes operating on time scales ranging from hours to millennia. The result is a coastline that is naturally changing all the time. In some cases, human activities have altered or disrupted the natural system, creating some of our most severe erosion problems.

Proper management of this important area requires a solid understanding of the factors affecting a particular stretch of shoreline, the way the shoreline is actually responding to these factors, and the desired uses of the area. It also requires a variety of strategies that can be tailored to match the diverse conditions found along the south shore. In some areas, the best management strategy may be to do nothing and let the natural processes continue unimpeded. In other areas, some form of intervention may be warranted. However, care must be taken to ensure that efforts to mitigate erosion problems work in concert with, and not against, natural processes. Management strategies must be adaptable to changing conditions to ensure future generations can also enjoy this unique resource.

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Selected On-Line Resources

Atlantic Coast of New York Erosion Monitoring Website	*http://dune.seagrant.sunysb.edu/nycoast*
Fire Island National Seashore	*http://www.nps.gov/fiis*
National Park Service Northeast Region Science Website	*http://www.nps.gov/nero/science/*
New York Sea Grant	*http://www.seagrant.sunysb.edu/*
U.S. Geological Survey Studies in the New York Bight	*http://woodshole.er.usgs.gov/project-pages/newyork/index.html*

Metric Conversion Factors

MULTIPLY	BY	TO OBTAIN
inch	2.54	centimeter
foot	0.305	meter (m)
yard (yd)	0.914	meter (m)
mile	1.609	kilometer (km)
cubic yards	0.764	cubic meters

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