National Park Service
U.S. Department of the Interior

Northeast Region
Boston, Massachusetts

The Coastal Geomorphology of Fire Island: A Portrait of Continuity and Change
(Fire Island National Seashore Science Synthesis Paper)

Technical Report NPS/NER/NRTR—2005/021

ON THE COVER
Ocean beach and dunes at Fire Island National Seashore. Photograph courtesy of the authors.

The Coastal Geomorphology of Fire Island: A Portrait of Continuity and Change
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Technical Report NPS/NER/NRTR—2005/021

Norbert P. Psuty, Michele Grace and Jeffrey P. Pace

Sandy Hook Cooperative Programs
Institute of Marine and Coastal Sciences
Rutgers, The State University of New Jersey
74 Magruder Road
Sandy Hook, NJ 07732

September 2005

U.S. Department of the Interior
National Park Service
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This report was accomplished under Cooperative Agreement 1443CA4520-99-007, task agreement J4520037042, with assistance from the NPS. The statements, findings, conclusions, recommendations, and data in this report are solely those of the author(s), and do not necessarily reflect the views of the U.S. Department of the Interior, National Park Service.

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Please cite this publication as:

Psuty, N.P., M. Grace, and J.P. Pace. September 2005. The Coastal Geomorphology of Fire Island: A Portrait of Continuity and Change (Fire Island National Seashore Science Synthesis Paper). Technical Report NPS/NER/NRTR—2005/021. National Park Service. Boston, MA.

NPS D-114 September 2005

PREFACE

FIRE ISLAND NATIONAL SEASHORE
Science Synthesis Papers to Support Preparation of a General Management Plan

BACKGROUND AND PURPOSE

Fire Island National Seashore (FIIS) is scheduled to begin preparation of a new General Management Plan (GMP) in the near future. A GMP outlines how natural and cultural resources, public uses, and park operations should be managed over the next several decades. The GMP addresses significant issues or challenges that are facing the park, proposes management solutions, and establishes management priorities. The Fire Island GMP will be prepared by a team of planners, with input from the park, technical subject matter experts, and with substantial public involvement.

To insure that the GMP team has all relevant natural resource information available to them, a series of scientific synthesis papers has been prepared for a variety of natural resource topics that will be of special relevance to the Fire Island GMP. Based on a 2-day meeting with the FIIS Superintendent, FIIS Chief of Natural Resource Management, Northeast Region planners, and Northeast Region science staff, the following natural resource topic areas were identified;

- Geomorphology of beaches and dunes
- Physical processes of the bay shoreline
- Habitat ecology and water quality of Great South Bay
- Conservation of Living Marine Resources (habitats, finfish and shellfish)
- Vector-borne diseases
- White-tailed Deer ecology and management

For each of these topics, leading scientific experts were invited to prepare papers that synthesize our current state-of-knowledge. There is a wealth of published technical information on these topics. The purpose of these papers was to provide a scientifically credible summary of the available and relevant information and present this information in a succinct manner. The GMP team will receive papers that provide an objective, independent and expert synthesis of an extensive and often complex technical literature. Each paper was subject to the scientific peer review process.

Each synthesis paper is expected to accomplish the following;

- Synthesize and interpret the relevant literature and monitoring data to describe the fundamental processes controlling the natural resource, and describe historic and recent trends or rates of change for relevant processes, habitats, or species.
- Describe current and historic management, regulatory, and other activities that have been relevant to the particular natural resource.
- Identify gaps in our current understanding of the natural resource.

Because the synthesis papers are prepared prior to initiation of the GMP process, if information gaps are considered critical to decision-making for the GMP there may be adequate time to conduct the appropriate required studies or data analysis tasks. Moreover, the papers will serve to identify topics or issues that should be the focus of additional synthesis or review papers in support of the GMP information gathering and synthesis phase.

OVERVIEW OF THE PAPERS

These summaries are derived, with some editing, directly from the individual papers.

The Coastal Geomorphology of Fire Island: a Portrait of Continuity and Change
Technical Report NPS/NER/NRTR—2005/021
Authors: Norbert P. Psuty, Michele Grace, and Jeffrey P. Pace
Rutgers University

Summary: Fire Island has a well-developed beach on the ocean side and is dominated by a variety of dune features, reaching elevations of 11-13m. Much of the island is undeveloped and retains a wide array of coastal dune forms in near natural condition. However, there are a number of residential communities, primarily on the western portion of Fire Island, that have altered the landscape and geomorphological processes. The controlled inlets at either end of the island are a type of interactive feature that have particular roles in the passage of sand along the shore. Thus, the geomorphological characteristics and configuration of the island are products of a suite of natural processes, complemented by human actions. This paper describes the landforms (beaches, dunes, inlets, and barrier island gaps) and basic controls on these landforms, such as tides, wave climate, storm history, the availability and rate of supply of sediment, and sea level rise.

There is insufficient sediment coming to Fire Island from all of the potential sources to maintain the entire system. There is evidence of erosion on all parts of the island, except the artificially-created Democrat Point. The sediment deficits are greatest along the eastern portion of the island, but are buffered in the central and western area because of the contributions from an offshore source. The recent acceleration in sea-level rise, coupled with the general negative sediment budget, will result in continued beach erosion and dune displacement, with greater effects occurring in the eastern portion of the island.

During the peer review process, it was determined that a follow-up synthesis paper should be prepared that specifically focused on the response of Fire Island beaches and dunes to human activities, including ORV traffic, structures, sand fencing, beach scraping, and other activities. This paper is presently being developed.

Bay Shoreline Physical Processes, Fire Island
Technical Report NPS/NER/NRTR—2005/020
Authors: Karl F. Nordstrom, Rutgers University
Nancy L. Jackson, New Jersey Institute of Technology

Summary: Wave and current energies on the bay side of Fire Island are low, but much of the bay shoreline is eroding. The greatest changes occur near inlets or next to marinas and bulkheads. Inlets, overwash and dune migration deliver sediment from the ocean to the bay where it forms substrate that evolves into tidal flats, marshes and beaches. These sediment inputs allow barrier islands to maintain themselves as they migrate landward under the influence of sea level rise. The creation and migration of inlets in the past extended their influence well beyond locations of present inlets.

About 17.0 km of the 49.5 km long bay shoreline of Fire Island is marsh; 24.5 km is beach; and 8.0 km is fronted by bulkheads, marina breakwaters and docks. The biggest constraints to allowing Fire Island to undergo natural dynamism are the desire to protect private properties on the island from erosion and overwash and the need to protect the mainland from flooding due to formation of new inlets. Bulkheads are common on the bay shore in developed communities. These structures replace natural formations landward of them and prevent sand from entering the littoral drift system, causing sediment starvation in unprotected areas downdrift. These adverse effects can be reduced by replacing lost sediment by beach nourishment. Use of beach fill on the low tide terrace covers benthic habitat. This problem could be avoided by placing fill above the mean high water mark, creating an eroding feeder upland.

Dune building projects on the oceanside and construction of bulkheads on the bayside restrict the delivery of sediment by inlets, wave overwash and aeolian transport. Temporary inlets would provide some sediment, but artificial closure by human efforts would limit these inputs to a much smaller area than in the past.

Future sea levels are expected to rise at a greater rate, causing increased frequency of overwash and creation of new inlets if not prevented by beach nourishment and dune-building projects on the oceanside. Elimination of the delivery of sediment to the bayside by these natural processes will result in continued retreat of the bay shoreline into the higher portions of the barrier island, resulting in loss of marsh habitat, increase in open water habitat, and truncation of cross-shore environmental gradients.

<u>Water Quality and Ecology of Great South Bay</u>
Technical Report NPS/NER/NRTR—2005/019

Author: Kenneth R. Hinga
University of Rhode Island

Summary: The overall objective of this paper is to present a short synopsis of information on the characteristics of water quality and ecology of the Great South Bay, with particular attention to the waters within the boundaries of Fire Island National Seashore (FIIS), where possible. This report serves as an update and addition to the report *Estuarine Resources of the Fire Island National Seashore and Vicinity* (Bokuniewicz et al., 1993). Great South Bay is approximately 45 km long, with a maximum width of about 11 km. The Bay is shallow, with an average depth at mean low water of just 1.3m.

Regarding water quality, a review of bacterial indicator monitoring data suggests that some bayside beaches and marinas of Fire Island have had fecal coliform concentrations that are at or approaching levels of concern, but in general the levels are quite acceptable. Nutrient enrichment is an issue for all shallow, enclosed, lagoon-type estuaries, like Great South Bay. There is an encouraging trend of decreasing dissolved inorganic nitrogen in Great South Bay over the past quarter century. Coincident with the decline in nitrogen, there appears to be a trend of decreasing primary production, as determined by measuring phytoplankton chlorophyll concentration, over the past 15 years. Historically, portions of Great South Bay (e.g., near and in

Moriches Bay) experienced intense phytoplankton blooms, probably attributed to discharges from duck farms. Since 1985, a brown tide has occurred periodically to disruptive levels in the Bay. Brown tide blooms can cause significant mortalities of hard clams and can damage seagrass beds because the blooms prevent light sufficient to support growth of the seagrass species. The densest seagrass beds in the Bay are found along the shallow shoreline of the Seashore.

Conservation and Management of Living Marine Resources
Technical Report NPS/NER/NRTR—2005/023
Authors: David O. Conover, Robert Cerrato, and William Wise
Stony Brook University

Summary: The finfish species likely to be landed by commercial harvesters from Fire Island NS or nearby waters are bluefish, winter flounder, summer flounder, weakfish, Atlantic silversides, and menhaden. The recreational species landed within the Bay have not been described in detail since the 1960s, but total recreational landings for New York as a whole suggest that fluke, winter flounder, bluefish, weakfish, tautog, and black sea bass are the main species. Some of the fish species landed in the Seashore region are present only transiently as older juveniles and adults. Such species would include striped bass, menhaden, eels, and weakfish. These species do not use the Bay as a spawning and nursery area. Other species use Fire Island waters as both nursery grounds for young-of-the-year (YOY) stages as well as adults. The value of Seashore estuarine habitats for these species is great (bluefish, winter flounder, fluke, tautog, black sea bass). Ecologically important species, those that are an important forage species for piscivorous fishes, include Atlantic silversides, bay anchovy, sand lance, northern pipefish, and others. Killifishes are a major component of the fish fauna of salt marsh habitats. Shellfish of potential recreational or commercial value found within Seashore boundaries include surfclam, hard clam, blue mussel, soft clam, oyster, bay scallop, razor clam, conch, blue crab, Jonah crab, rock crab, lady crab, spider crab, and horseshoe crab (although not technically classified as shellfish). Generally, there has been a dramatic decline in the commercial harvest of shellfish species from the Bay. For example, since 1976 the harvest of hard clams has declined 100 fold. It is recommended that the Seashore take a leadership role in reaching out cooperatively to government and non-government agencies toward encouraging restoration of Great South Bay living marine resources and increasing public awareness of coastal zone management issues.

Vector-borne Diseases on Fire Island
Technical Report NPS/NER/NRTR—2005/018
Author: Howard S. Ginsberg
USGS-Patuxent Wildlife Research Center

Summary: This paper discusses eleven tick-borne and five mosquito-borne pathogens that are known to occur at FIIS, or could potentially occur. The potential for future occurrence, and ecological factors that influence occurrence, are assessed for each disease. Lyme disease is the most common vector-borne disease on Fire Island. The Lyme spirochete, *Borrelia burgdorferi*, is endemic in local tick and wildlife populations. Public education, personal precautions against tick bite, and prompt treatment of early-stage infections can help manage the risk of Lyme disease on Fire Island. The pathogens that cause Human Monocytic Ehrlichiosis and Tularemia

have been isolated from ticks or wildlife on Fire Island, and conditions suggest that other tick-borne diseases (including Babesiosis, Rocky Mountain Spotted Fever, and Human Granulocytic Ehrlichiosis) might also occur, but these are far less common than Lyme disease, if present.

West Nile Virus (WNV) is the primary mosquito-borne human pathogen that is known to occur on Fire Island. Ecological conditions and recent epizootiological events suggest that WNV occurs in foci that can shift from year to year. Therefore, a surveillance program with appropriate responses to increasing epizootic activity can help manage the risk of WNV transmission on Fire Island.

White-tailed Deer Ecology and Management on Fire Island

Technical Report NPS/NER/NRTR—2005/022

Author: H. Brian Underwood
USGS-Patuxent Wildlife Research Center

Summary: Deer populations have grown dramatically on Fire Island National Seashore (FIIS) since 1983. Trend data reveal a dichotomy in deer dynamics. In the eastern half of the island, deer density appears to have stabilized between 25-35 deer/km^2. In the western half of the island, deer densities are 3-4 times as high in residential communities. Concomitant with that increase has been a general decline in physical stature of some animals, visible impacts on island vegetation, especially in the Sunken Forest, and a perceived increase in the frequency of human and deer interactions. Intensive research on FIIS has shown that deer occupy relatively predictable home ranges throughout the year, but can and do move up and down the island. Impacts of deer on vegetation are most dramatic in the Sunken Forest. Most obvious are the effects of browsing on the herb layer of the Sunken Forest. The least obvious, but perhaps more significant impact is the stark lack of regeneration of canopy tree species since about 1970, which coincides with the initiation of the deer population irruption. A number of herbs and shrubs have been greatly reduced in the understory, and their propagules from the soil.

Deer do not readily transmit the bacterium that causes Lyme disease to other organisms, but deer are important hosts for adult ticks which underscores their importance in the transmission pathway of the disease to humans. Deer on FIIS, while occasionally docile, are still wild animals and should be treated as such. Some animals are relatively unafraid of humans due to the absence of predation and a lack of harassment. This in turn has contributed to a long-standing tradition of feeding deer by many residents and visitors, particularly in western portions of the island. Feeding affects both the behavior and population dynamics of deer inhabiting Fire Island. Recent efforts to reduce deer feeding by visitors and residents have been very effective. Ongoing experiments with Porcine Zona Pellucida immunocontraception demonstrate some promise of this technology as a population management tool. Success appears to be linked directly to factors affecting access to deer, which vary considerably among treatment locations. Continued high National Park Service visibility among communities in the form of interpretive programs, extension and outreach activities, and continued support of research and monitoring of deer and their effects on island biota are keys to successful resolution of persistent issues.

Preface prepared by:
Charles T. Roman
National Park Service
North Atlantic Coast Cooperative Ecosystem Studies Unit

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AUTHOR'S PREFACE

The goal of this paper is to bring together the wide range of scientific information pertaining to the geomorphological development of Fire Island and to provide a descriptive synopsis of the assemblage of landforms that contributes to the character of the island. The scientific literature treating the coastal geomorphology of the island is very uneven. Although there are a reasonable number of publications directed towards an understanding of the island's geomorphology, there are few long-term research projects focusing on these physical characteristics to provide an in-depth inquiry on the variety of topics. The greatest legacy of interest is documented by the U.S. Army Corps of Engineers in the projects associated with maintenance of the navigable inlets on both ends of Fire Island and projects associated with sediment budgets and shoreline change from Fire Island Inlet to Montauk Point (for example: Taney, 1961; Williams, 1976; USACOE, 1995; Rosati, et al. 1999, USACOE, 2002). Outside of this agency, the senior author of this paper has been conducting research on foredunes and beaches at Fire Island individually as well as with Dr. James R. Allen (deceased) for several decades (for example: Psuty and Allen, 1986; Allen and Psuty, 1987; Psuty and Piccola, 1994; Psuty, et al., in press).

However, whereas there have been many separate publications into aspects of the geomorphology of Fire Island, they do not combine to present a complete portrayal of the evolving physical development of the island. Therefore, portions of the geomorphological history are derived from neighboring areas. Other portions are derived from general concepts applied to the specifics of Fire Island. They all contribute to the understanding of the sequential creation and evolution of the island. Yet, there are a number of issues that would benefit from additional inquiry. To that end, the final section of this paper concludes with a listing of future areas for investigation to further the understanding of the geomorphology of Fire Island.

INTRODUCTION

The coastal geomorphology of Fire Island is both simple and complex. In general, it is a long narrow barrier island approximately 50 km in length and varying in width from 150 m to 1 km (Fig. 1). The island has a well-developed beach on the ocean side and is dominated by a variety of dune features on its surface, reaching elevations of 11-13 m. Much of the island is undeveloped and retains a wide array of coastal dune forms in a near natural condition (Fig. 2). However, there are a number of residential communities, primarily on the western portion of Fire Island, that have altered the landscape and the geomorphological processes (Fig. 3). In addition, there are a few places on the island where the continuity of the dune zones is interrupted and is replaced by morphologies related to positions of former inlets or areas of washover. The controlled inlets at either end of the island are yet another type of interactive features that have particular roles in the passage of sand along the shore. Thus, the geomorphological characteristics and configuration of Fire Island are the products of a suite of natural processes, which are, in turn, further affected by human actions that modify and reshape the surface forms. The bayside geomorphology is an additional feature of the island and it is covered in a separate publication in this series.

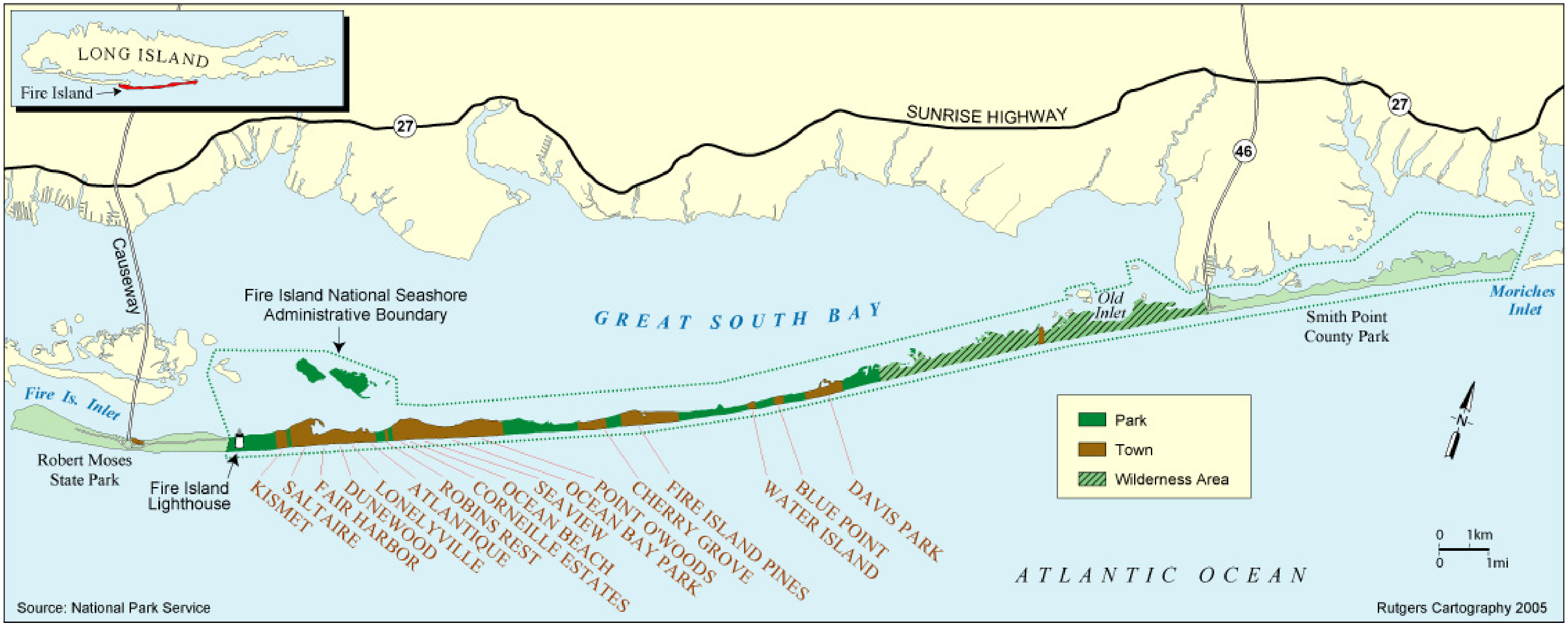

Figure 1. Parks and communities on Fire Island.

Figure 2. Example of natural dune-beach characteristics in Wilderness Area, eastern Fire Island, September 2003.

Figure 3. Example of some forms of cultural modification to the dune-beach system in areas of residential development. Davis Park, June 2002.

The geomorphological evolution of Fire Island is related to the formation of barrier islands along much of the East Coast of the U.S., but it is affected by the particular environmental controls of the local area. Specifically, the forms and their dimensions are causally related to the tidal range, the local wave climate, the availability and the rate of supply of sediment, and the influence of sea-level rise. Upon this natural framework is the imprint of humans as they manipulate and modify the characteristics of the island.

BASIC CONTROLS

Tides

The general characteristic of the ocean tide along Fire Island is a semi-diurnal oscillation (twice per day) with a mean range of 1.25 m, an average spring tidal range of about 1.5 m, and an average neap tidal range of 0.98 m. (NOAA/NOS web site; http://co-ops.nos.noaa.gov/tides04/tab2ec2a.html#20). The tidal range decreases into the inlets at either end of Fire Island (the average spring range is 0.95 m in Fire Island Inlet and is 1.1 m in Moriches Inlet), and becomes even less in Great South Bay (average spring range varies from 0.24 to 0.43 m). Tides are important because the dynamics of the waves and currents operate within the tidal range on the beach face, thereby defining the elevational range of the beach face and the elevational margin of the subaerial beach on the profile. Under storm conditions, the water level and waves reach above the intertidal zone and produce changes in higher portions of the beach/dune profile that are not as easily repaired and thus create a more lasting component of the morphology.

Wave climate

The wave climate affecting Fire Island is a combination of the general non-storm condition of wind and waves from the southwest through the southeast and those winds and waves associated with storms that create flows from the south through the east. A portrayal of the wave systems generated by actual weather events has been developed by the U.S. Army Corps of Engineers as part of their Wave Information Studies. The most recent of these wave climatologies is based on the weather conditions during the period of 1980 to 1999 (http://frf.usace.army.mil/wis), producing a computer-generated hindcast of the proportion of significant[1] wave heights from a series of offshore directions occurring in a water depth of 33 m off the eastern portion of Fire Island, Site 114 (Fig. 4).

The results of the simulation compare very well with the more limited data set recorded at the NOAA offshore buoy south of western Fire Island (Station #44025). This simulated distribution of waves is composed of lower swell waves usually occurring during the summer, height of 0.87 m, and larger, steeper swell during the winter, height of 1.39 m. The summer waves occur throughout the range from southwest to southeast. Winter waves may be out of the southwesterly quadrant but the larger storm waves are usually out of the east-southeast. The greatest wave heights were hindcast out of the east-southeast, 7.84 m, during December 1992.

[1] The significant wave dimension is the mean of the highest one-third of the observations and thus this simulation emphasizes the stormier conditions. Further, the site is in fairly deep water and the waves are refracted to change their inshore angles by the time they interact with the beach.

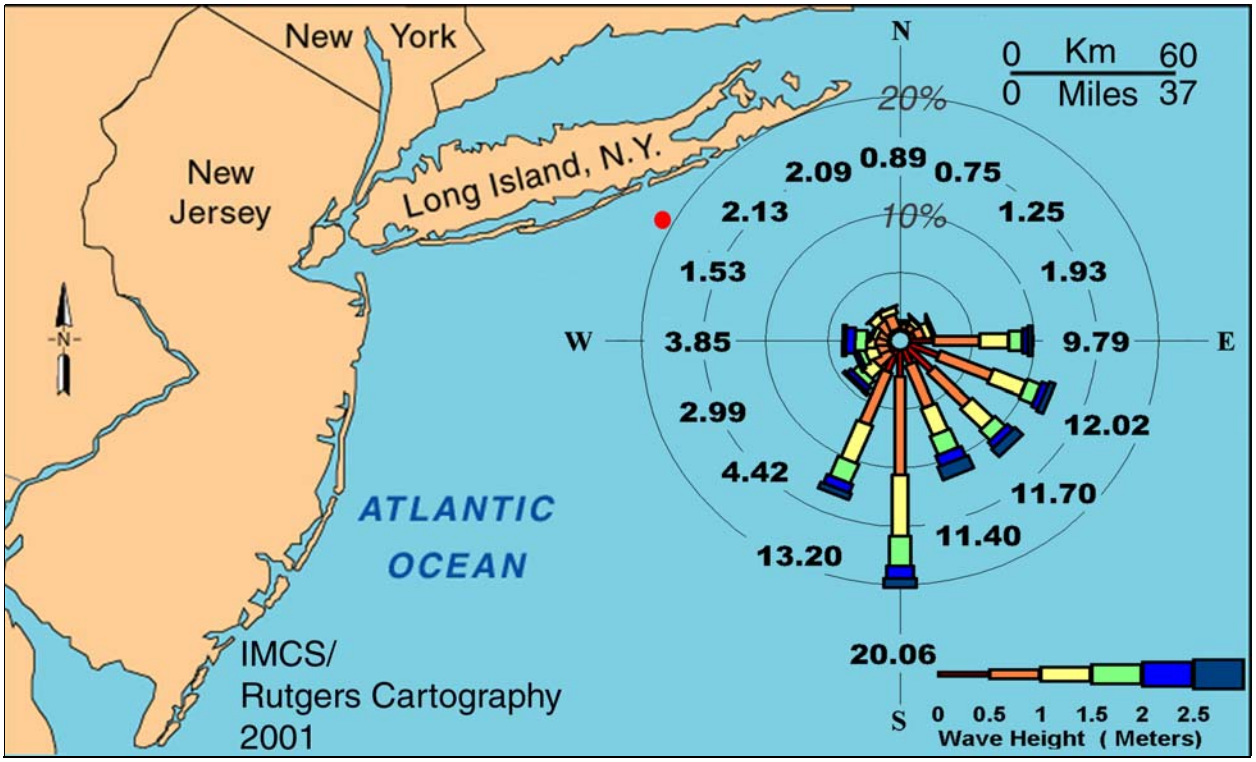

Figure 4. Wave rose of significant wave heights and percentage of occurrence, Site 114, Wave Information Studies, U.S. Army Corps of Engineers (the raw data set is available at: http://frf.usace.army.mil/wis, Station 114, Jan1980-Dec 1999). The location of Site 114 is represented by a red dot on the figure. The graduated circles in the wave rose are in increments of 5%. The radiating bars represent the percentage of occurrence of significant wave heights arriving from each 15 degrees of arc. The value at the end of each of the bars is the percentage of the total wave record with waves from that direction.

Allowing for the effects of wave refraction in shallower water and the dominance of lower waves from the southeast quadrant, the combination of wave direction and dimension results in a net annual alongshore flow from east to west, but with many instances of flows in the opposite direction. According to wave records for the years 1998-2000, nearly 70% of all waves came from the southeastern quadrant, with greatest frequency (20%) out of the east-southeast (USACOE, 2002).

Storm History

Large storm events such as tropical storms or hurricanes (dependent on wind speed), and extratropical storms, nor'easters, have contributed to significant alteration of the Fire Island shoreline. These storms generally cause rapid beach erosion, dune displacement, and coastal flooding. Hurricanes are the most severe storms experienced on Fire Island. A hurricane, by definition, is a low-pressure, synoptic-scale cyclone (large-scale weather systems that cover hundreds of kilometers) originating in a tropical area. Once storm winds exceed 120 kmph, in the Atlantic and eastern Pacific Oceans, these storms are referred to as hurricanes. These storms can inflict even greater damage when high astronomical tides, spring tides, and storm surge coincide. The time of year that this type of storm is likely to occur is from June through November (National Hurricane Center, http://www.nhc.noaa.gov).

Whereas hurricanes have been the most destructive for Fire Island, winter storms, or Nor'easters have also resulted in eroded beaches, property damage and loss of life. This type of storm usually does not reach the same wind speed as that of a hurricane, but Nor'easters tend to cover a broader area and move more slowly. As a result, these storms generate wave heights that far exceed those produced by hurricanes. This combination of increased wave heights along with storm duration encompassing one or more high tides is the main cause for extensive coastal damage. The threat of this type of storm occurring exists from October through April. Dolan and Davis (1992) have tabulated historic nor'easters and calculated that the most severe storms are more likely to occur along the East Coast in October and January.

Many storms, both hurricanes and nor'easters, have occurred and affected Fire Island during the past seventy-five years (Table 1). But, there were three major storms during this time frame that severely impacted the island, resulting in significant physical changes to the island as well as loss of life and property. The Great Hurricane of 1938 (September 21) was also known as "The Long Island Express". The storm produced winds that reached 200 kmph, generated 5-meter-high breakers, overwashed 1/3 to 1/2 of the island, and created about 12 new inlets. It was the worst storm in recorded history in terms of fatalities (50+ people) and property damage (hundreds of homes were completely destroyed or suffered extensive damage), attaining a cost estimated at $6.2 million in 1938 prices. If a similar hurricane were to occur today, it has been suggested that it could cause upwards of $6 billion in damage (McGinty, 2004).

March 6, 1962 was the date that a major extratropical Nor'easter struck the island. This storm, referred to as the "Ash Wednesday" storm resulted in over 50 washovers. It destroyed 47 houses and severely damaged 74 other properties on Fire Island. The cost of damages was estimated in the millions of dollars. President Kennedy declared Fire Island a disaster area and made it available for federal funding. The US Army Corps of Engineers constructed emergency shore protection measures with a project known as Operation Five High (named for the five consecutive tidal cycles that occurred with the storm). Over 1,700,000 cubic meters of material were used to rebuild over 37 km of beaches and dunes (http://www.nan.usace.army.mil/fimp/problem.htm). Beaches were raised to an elevation of about 3.75 m above mean low water. About 3,0 km of dune and 11.3 km of eroded beach were quickly restored.

Another Nor'easter, on December 10-17, 1992, caused over $2 billion in total damages and left 9 people dead and destroyed more than 100 homes (Figure 5) (National Weather Service, 1994). Many mandatory evacuations took place because of high storm surges – there were over 10 high tides with storm surge greater than 0.3 m, measured at Sandy Hook. The maximum surge on December 11 was 2.6 m above the predicted high tide. Two breaches occurred a short distance east of Moriches Inlet. This particular storm surge level had a recurrence interval estimated as about 30 years, and was especially devastating because of the very long duration (Schubert, 1994).

Sediment Supply

The availability of sediment to maintain the landforms of the island and their dimension is an important variable in the development of the Fire Island. The availability has not been constant and the island has expanded and contracted in response to the quantity of sand arriving at and passing through the system. Part of the history of sediment availability is related to the presence of a continental glacier that expanded to about the position of the southern margin of the mainland of Long Island on the order of 18,000 years ago (Walker and Coleman, 1987). The glacier brought great quantities of sediments into the area that were deposited as a blanket over much of Long Island and, in particular, the meltwaters from the glacier built a large outwash plain of well sorted material that extended as a deltaic deposit to the south and east of Fire Island in a area that is currently below sea level. Sediment derived from this submerged deposit as well as the sediments eroded from the glacial morainic deposits are the sources for materials that are entrained by the shallow water waves and currents to migrate westerly and accumulate on Fire Island (Williams, 1976; Williams and Meisburger, 1987; Williams and Morgan, 1993). Recent studies (Schwab, et al. 2000) have shown that the offshore is also the site of a sandy bedrock formation, which is very large and is located off the western portion of Fire Island. It is likely that this formation is releasing sand that is migrating toward the island and contributing to the sediment supply (Schwab, et al. 2000). However, the sources of sediment are not infinite and there is a limit to their capacity to feed the conveyor belt of sand moving westerly along the island. Fire Island has expanded and contracted in the past as more or less sand was input to the nearshore system (McCormick and Toscano, 1981).

Sediment Budget

Measurements of the gains or losses of sand on the entire island per some unit of time are referred as the sediment budget. This value is arguably the most important measure in the dynamic coastal area because it describes the basis for shoreline displacement in the spatial context and also the evolution of shoreline morphologies at the local and at the regional scales. Early estimates of sediment budget were based on the dredging records at either end of the island, indicating that more material was passing through Fire Island Inlet than Moriches Inlet, augmented by observations of an erosional shoreline along much of the island. The combination of these data inputs resulted in a calculation of a negative budget of about 115,000 m^3/yr (Taney, 1961). However, these values were general estimates and acknowledged to be "imprecise" because of the very poor knowledge of the configurations of the submarine deltaic forms at the inlets and the vagaries of shoreline fluctuation. More detailed analyses of the dredging records

Table 1. Significant Storms

DATE	TYPE/NAME of STORM	IMPACTS
March 4, 1931	Nor'easter	• Moriches Inlet was formed • Between 1933 and 1938 it widened to 400 m and deepened as tidal currents deposited large sand delta on both the ocean and bay sides of the inlet • Migrated west until stabilized by revetment in 1947
September 21, 1938	Hurricane: The Great Hurricane "Long Island Express"	• Category 3 wind strength • One of the most devastating storms in recorded Long Island history • Further widened Moriches Inlet to the west to over 1,300 m • Opened 12 other inlets across the barrier island; massive washovers along the shore • Ocean water level at least 3 m above predicted high tide • Resulted in over 50 deaths on Fire Island • Cost approximately $6.2 million ($15 million in $1998)
September 14, 1944	Hurricane	• Category 3 wind strength • Tide reached 1.8 m above msl, about 1.5 m above predicted tide • Dunes repaired after the 1938 hurricane were severely damaged
March 6-8, 1962	Nor'easter: Ash Wednesday Storm	• 5 successive high tides, during period of perigee • Resulted in 50 washovers and new inlet in Westhampton • Declared federal disaster area by President Kennedy • Emergency shore stabilization measures engineered and constructed by the US Army Corps of Engineers, named Operation Five High • 1,700,000 m^3 sand pumped onto beaches
October 30-31, 1991	Nor'easter: Halloween Storm	• Highly unusual meteorological event in that a nor'easter coincided with remnants of a hurricane • Included 3, possibly 4 high tides • Average wave height (as registered at offshore buoys) was 15 m with rogue waves up to 30 m • Winds over 160 kmph • Extensive beach erosion and overwash • Damages listed at $168 million
December 11, 1992	Nor'easter	• Referred to as "one of the epic storms of all time" by the National Weather Service because of strength and duration • Produced gale-force winds and gusts over hurricane strength • Occurred during a full moon with a high tide of 2.1 m above normal; lasted 3 high tides • Extensive coastal flooding and beach erosion • Caused 2 breaches east of Moriches Inlet • Destroyed more than 100 homes in affected area

Figure 5. Massive erosion and destruction of houses associated with December 1992 storm. Shoreline and foredune displaced inland, post-storm recovery occurred seaward and at lower elevations. Saltaire.

and the tidal delta morphologies show that the sedimentation amounts recorded at Fire Island Inlet (285,000-460,000 m^3/yr) are substantially greater than the sedimentation at Moriches Inlet (64,000-270,000 m^3/yr) (U.S. Army Corps of Engineers, 1993; Kana, 1995; Rosati, et al., 1999) and that the ocean shore of Fire Island may be losing the difference between the two values. A further complication in this calculation relates to storage capacity in the submarine deltaic forms that exist at each inlet. If they are not at equilibrium during the period of record, their storage or release of sediment would affect the sediment budget. Whereas the hydrographic mapping of the deltaic lobes has improved and there is a better appreciation of the stability of the lobes, there are still problems with extending the data to imply changes from earlier deltaic forms and volumes.

Further, it has been argued that the deficit for the entirety of Fire Island is too great when compared to the rates of shoreline change and westward extension of the island and thus some other source must be contributing sediment to buffer the island-wide loss. Kana (1995) proposed that portions of the Fire Inlet tidal delta, created when the inlet was farther to the east, was releasing sediment to support creation of the westerly growth of Fire Island and decreasing the sediment budget deficit. Schwab, et al. (2000) have suggested that up to 200,000 m^3/yr may be derived from an offshore source supplying sediment to the western half of the island through some unspecified mechanism, thereby ameliorating the losses there and contributing to the larger quantities of sand reaching Fire Island Inlet.

Although there are some questions about issues of equilibrium regarding the deltaic forms at the inlets and the beach profiles that characterize the island, it has been determined that the totality of the barrier island is losing sand as a function of mobilization of the beach profiles which produce an increasing quantity of sediment in transport from east to west and because of submergence due to sea level rise. Calculations applied to the surveys within the last decade converge on a total sediment loss on Fire Island of on the order of 200,000 – 212,000 m^3/yr (Rosati, et al., 1999; Allen, et al., 2002; USACOE, 2002). Whereas the number itself represents the best estimate, it is an estimate and comes with a variety of qualifications. However, the value has meaning beyond its absolute quantity because it represents a process of loss of sediment leading to an adjustment in the character of the barrier island. Geomorphological changes will ensue and sequences of landscape development will be generated on the basis of the negative sediment budget.

Sea-Level Rise

The geomorphological evolution of Fire Island is tied to the general rise of sea level that followed the melting of the large continental ice masses in the world. It is estimated that at the time of the most recent maximum accumulation of ice on the continents, about 20,000 years ago, the world sea level was on the order of 120-140 m lower than at present (IPCC, 2001) and the shoreline was about 130-145 km off of Fire Island. As the glaciers melted, the world’s ocean received the water and the oceans encroached upon the margins of the existing land masses. The initial sea-level-rise rates were rapid and it is unlikely that sizeable shoreline features were able to develop. However, around 7,000-9,000 years ago, the rate of sea-level rise decreased and there is evidence of bay-type sedimentation about one mile offshore in about 13-15 m. water depth (Sanders and Kumar, 1975; Leatherman and Allen, 1985). As sea level continued to rise at a slow pace, it is likely that newly-formed barrier island formations migrated inland through processes of overwash and alongshore extension. Another decrease in the rate of sea-level rise occurred around 3,000-3,500 years ago when sea level was about 2 m lower than at present (Psuty, 1986). At this time, many of the barrier islands along the East Coast shifted from transgressing landward to enlarging, both vertically and seaward (Kelley, 1995: Kraft, et al., 1987). Fire Island probably participated in this transition from a narrow, low, barrier with frequent episodes of overwash to a more stable island that widened as sediment was accumulated and increased in elevation as coastal dunes developed to enlarge the mass of sand in the subaerial environment. It is thought that the previous rise of sea level had submerged great quantities of sand on the continental shelf that had been deposited by the glacial outwash (Schwab, et al., 1999) and that this sediment was being entrained by the wave energies at the ocean margin to nourish the expanding and now downdrift-migrating barrier islands (Kumar and Sanders, 1974, McCormick and Toscano, 1981). Thus, a combination of available sediment and a very slowly-encroaching sea level provided the opportunity to support the development of an enlarging barrier island system.

Sea level has not been static in the past, and it is not static at this time. Evidence derived from tide gauges in the region document the continuing encroachment of the world's ocean onto the continent. Data derived from nearby sites such as The Battery in New York harbor (2.77 mm/yr), Montauk Point (2.58 mm/yr), Sandy Hook (3.88 mm/yr), and Atlantic City (3.98 mm/yr) demonstrate the magnitude of this increase of the relative rise in sea level (Titus and Narayanan, 1995; Zervas, 2001; http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml).

The change measured at the tide gauges is referred to as relative rise because the margin of the continent is sinking tectonically, the recent sediment accumulations are compacting, and the surface of the ocean is elevating. The world's ocean is receiving water through melt of snow fields and small mountain glaciers, and the ocean is also increasing in volume through thermal expansion as the ocean water warms. Together, these several conditions combine to cause the encroachment of the ocean onto the margin of the continent. The magnitude of relative sea-level rise at Fire Island is probably closer to that at Sandy Hook (Fig. 6) (http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml) because the geomorphological setting is similar. Both are on barrier island formations with considerable thicknesses of recent deposits, although Sandy Hook does have greater accumulations of modern sediments in the location of the tide gauge. In the eight decades of record for Sandy Hook, the average rate of rise is nearly 4 mm per year. This is a fairly large number but it is similar to the rates recorded at other barrier island locations on the East Coast (http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml). Importantly, the rate of relative sea-level rise over the past 3,000 years of slow rise was less than 1 mm per year, and the rate during the more rapid displacement of the barrier island up the continental shelf immediately preceding this recent time was on the order of 2.5 mm per year (Psuty and Ofiara, 2002).

We appear to be in a time of increasing instability of the barrier island system as driven by the growing rate of sea-level rise (Pendleton, et al., 2004) and we may also be in a time of depleted sediment supply from the glacial outwash source. An additional factor associated with sea-level rise is the changing base level on which storm surge will operate. Because of sea-level rise, the more recent storm surges can reach farther into the barrier island and into higher locations than their counterparts of previous decades. For example, if the 1938 hurricane conditions occurred in 2004, it would operate on a sea level nearly 21.3 cm (9 inches) higher and thereby have a much more devastating flood effect. Increased vulnerability to storms and storm surges will accompany coastal inundation associated with sea-level rise unevenly along Fire Island (Pendleton, et al., 2004). Areas of low elevation will be experiencing the effects sooner than the higher areas, with a general encroachment of the water along all of the margins causing a narrowing, and thereby lowering the protective capacity of the island. Further, additional analysis of the data from the Sandy Hook and other tide gauges reveals that the rate of rise is

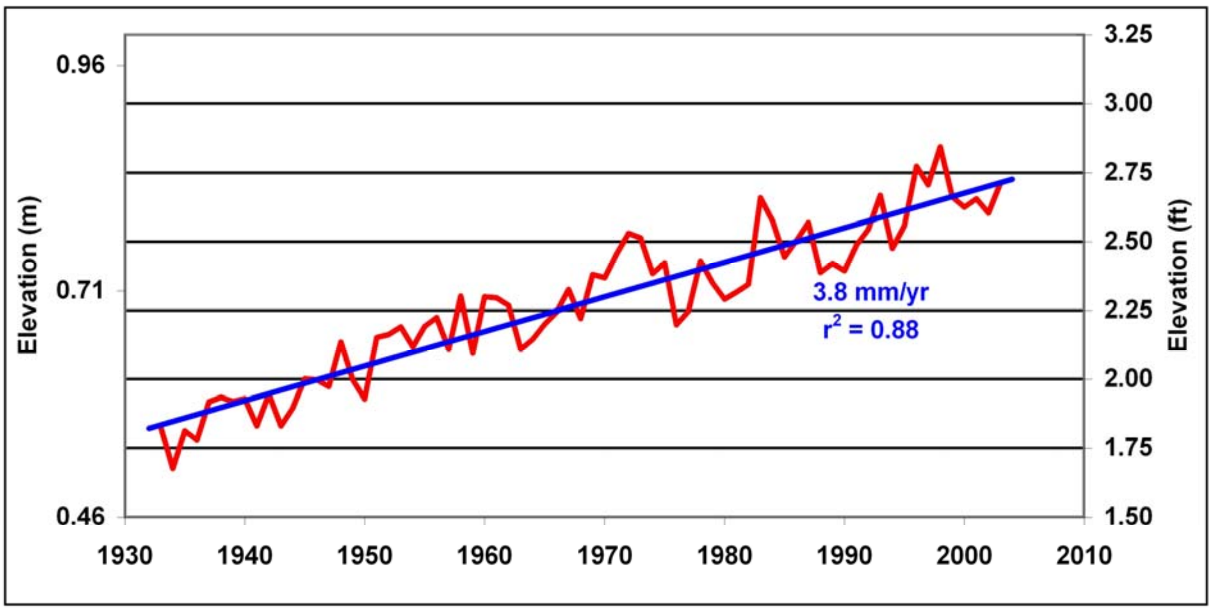

Figure 6. Increase in mean annual water level at Sandy Hook tide gauge, Nov. 1932 - July 2004. The linear trend line portrays a mean increase of relative sea level of 3.8 mm/yr. The mean monthly data that were used to compile this trend line are available at: http://co-ops.nos.noaa.gov/data_retrieve.shtml?input_code=100461111vmm, Station ID 8531680.

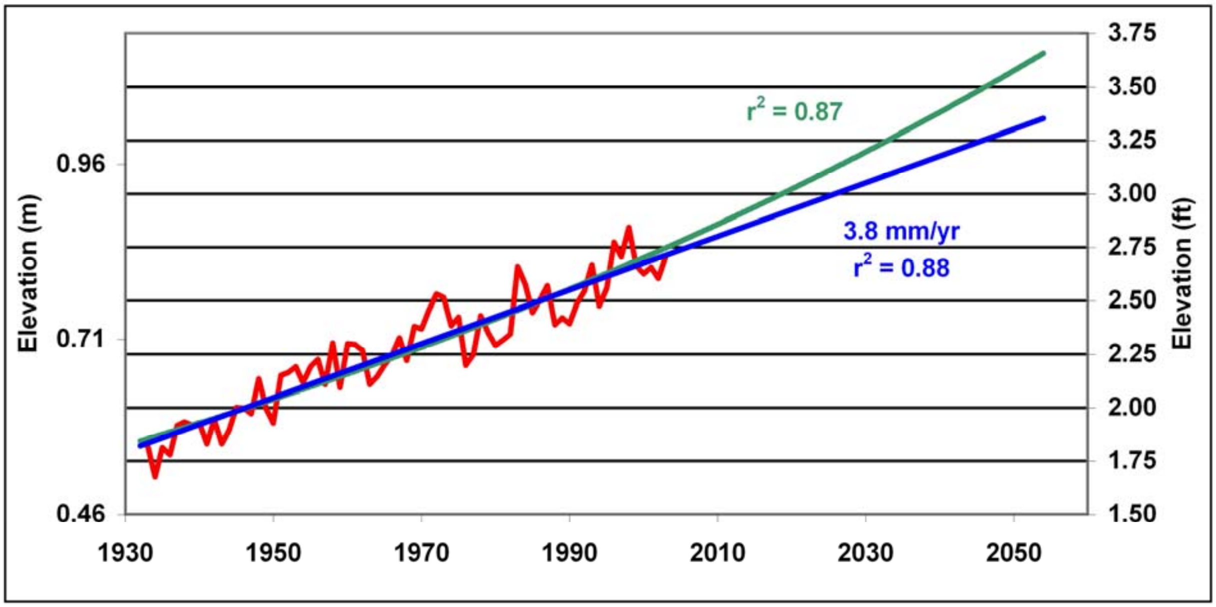

Figure 7. Comparative analysis of the linear rate of relative sea-level rise from the Sandy Hook tide data and an exponential rate from the same data, for the period Nov. 1932 to July 2004. The r^2 value (coefficient of correlation) indicates that the fit of the data to a linear trend line ($r^2 = 0.88$) or an exponential trend line ($r^2 = 0.87$) is about the same, but the net rise is greater with the exponential rate over time. The mean monthly data that were used to compile this trend line are available at: http://co-ops.nos.noaa.gov/data_retrieve.shtml?input_code=100461111vmm Station ID 8531680.

probably increasing (Fig. 7). That is, statistical analysis shows that the data describe a slope, which is curving upward, as well as they describe a linear trending slope. If the increased rate of rise were an accurate forecast of occurrence, future flooding events would be even higher and island instability would increase accordingly (Pendleton, et al., 2004). Thus, instead of a linear increase of 20 cm over the next fifty years, the exponential rise could reach almost 30 cm.

LANDFORMS

Beaches

Certainly, there are many variations in the form and dimensions of a beach profile as conditions change from season to season and with individual storm events. However, there is a basic configuration or assemblage of components of the beach that develop to create the general profile, from which there are sequential changes in the pattern of erosion and accumulation (Cowell and Thom, 1994). This profile (Fig. 8) is common at Fire Island and consists of a broad, flat upper surface that begins at the toe of the dune at about 3-3.5 m elevation and slopes gently seaward to a crest that is at about 2 m elevation. This surface is referred to as the beach berm and it is on the order of 25-50 m wide in a non-erosional situation. This beach berm contracts during storm events that mobilize the sand and scarp the upper beach, often leaving an uneroded segment as a high surface seaward of the dune. Recovery following the storm consists of the building of a lower surface that accumulates sand and expands both seaward and upward to essentially recreate the general berm. Thus, an episodic storm event causes the profile to pass through stages of erosion and recovery.

The sand removed from the berm tends to move offshore and alongshore. The component of the eroded berm that moves offshore will usually be retained in the profile as an offshore bar that will lie 75-150 m off of the beach and in water depths of about 2-5 m (Morang, et al., 1999). With sediment input, the bar builds vertically and may increase in size to occupy about half of the water depth. Storm waves cause the bar to increase in size, shift seaward, and to form a more consistent barrier offshore of the island. During the recovery phase, the bar releases sediment that is transferred to the beach to rebuild the berm. Thus, there is an episodic transfer of sediment between the beach and the bar that is part of the natural exchange accompanying storm events. Large storms cause transfers of sediment into deeper water and the recovery associated with these events is less complete and the net effect is a loss of sand and an inland displacement of the beach profile following the exchange.

Further, because the storm waves usually arrive at some angle to the beach, there is a component of alongshore mobilization with storm events and sediment will be transported along the island. Some sand arrives from the east, across Moriches Inlet, to contribute to the sediment supply of the island (USACOE, 2002). Nearshore currents generated by the wave systems that are dominantly from the southeast quadrant propel the sediment toward the west, and eventually carry the sediment into Fire Island Inlet where it leaves the barrier island and is generally lost to the system.

Fire Island beaches are also affected by circulation cells that develop in association with an arcuate configuration of the offshore bar and the beach face. These are sites of localized sediment mobilization and can produce excessive scouring of the beach profile, to the point of

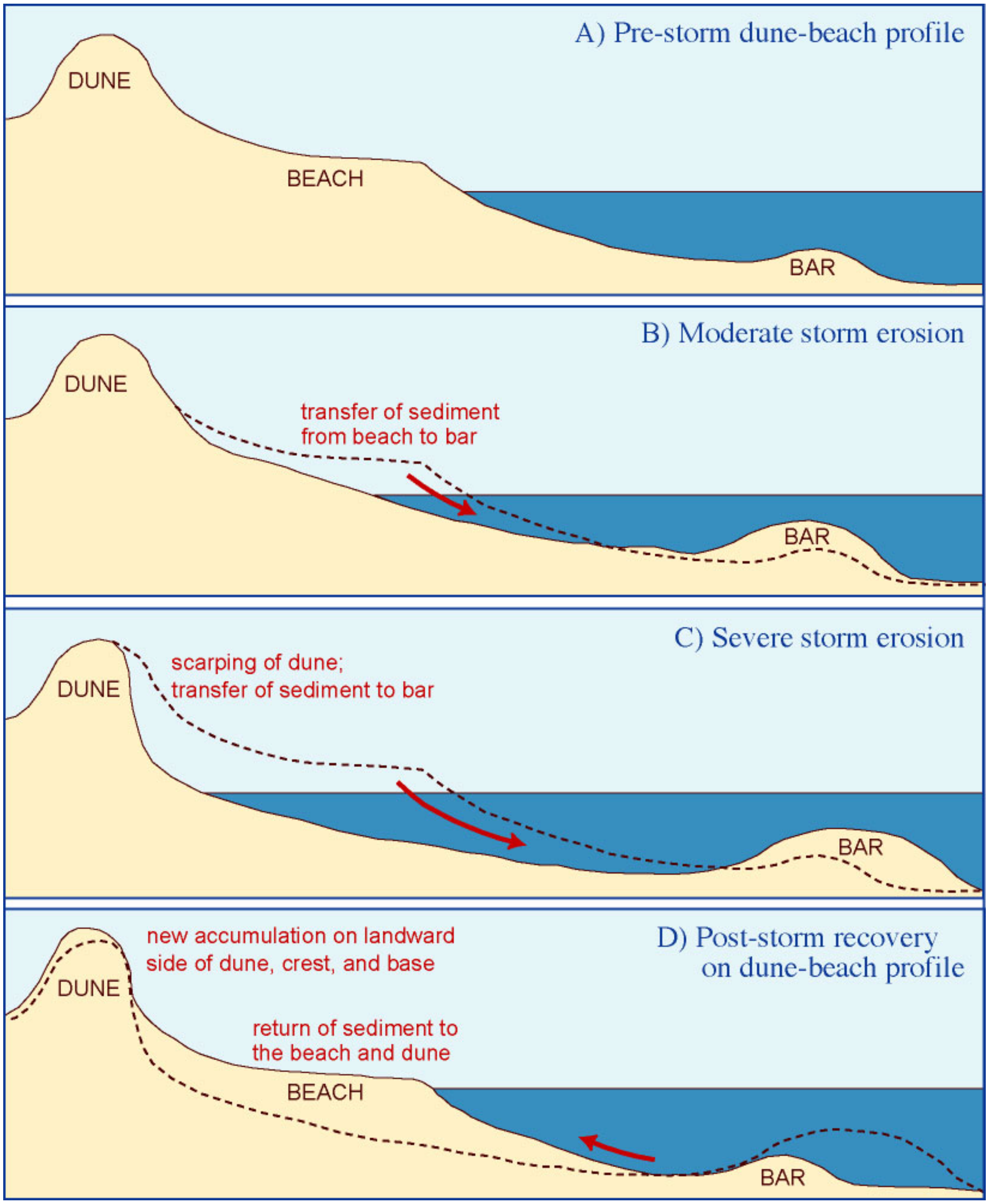

Figure 8. Sand-sharing on an idealized beach/dune profile indicating the episodic exchange of sediment between the dune, beach, and offshore bar morphologies.

Figure 9. Erosion of beach and foredune was associated with a well-developed circulation cell in the beach. The foredune crest was displaced inland approximately 30 m associated with the passage of the circulation cell, Talisman, August 1994. The foredune crest remained in this location following recovery of the beach portion of the profile.

Figure 10. Aerial view of an indentation in the beach associated with a break in the bar in the background, Sailors Haven, The foredune crestline is more irregular in the foreground and more sinuous in the background, indicating the variety of sculpting processes producing the form. J. R. Allen photo.

eroding the berm and scarping the dune face (Fig. 9). The cells are related to breaks in the continuity of the offshore bar and are largely defined by the spacing of the breaks in the bar. Allen and Psuty (1987) installed instruments in one of these circulation cells and measured much greater wave energies reaching the beach inland from the breaks in the bar. They further described the energetics for creating localized displacements, alongshore lengths of 300m -1200 m, in the beach along portions of Fire Island (Fig. 10). This systematic development of beach indentations associated with circulation cells is consistent with the models of beach morphodynamics developed by Wright and Short (1984) that ascribes such beach responses to modal conditions of inshore energetics related to the oncoming incident waves and the periodic oscillations of shore-perpendicular waves (edge waves) trapped between the bar and the beach. Gravens (1999) also identified the occurrence of large undulations in the beach where the backshore berm was severely eroded and the adjacent foredune was scarped. His analysis described these large forms as having dimensions of 1.0-1.8 km alongshore, sometimes progressing downdrift and sometimes remaining stationary. Additionally, the nearshore cell may dissipate and the beach will recover in place, often with a pronounced scarp cut into the berm or base of dune.

Thus, Fire Island beaches pass through a variety of stages of cut and fill that create character to the beach profile in the form of scarps and steps in the berm or base of dune. Some of these cut and fill episodes are related to storm events and the change to and from high energy conditions that mobilize large areas alongshore (Fig. 11). Other cut and fill conditions are associated with breaks in the bar that are in turn part of large alongshore circulation cells. The major cutting into the beach is positioned opposite the break in the bar and is an opportune location for higher wave energy to reach the beach and cause a very localized penetration into the berm. If the fill that follows is equal to the loss that accompanied the cutting into the berm, the beach will essentially return to its former position and with the same sand volume. If, however, the cut and fill results in a net loss of sediment, this is the action of erosion and inland displacement of the beach profile, whether by storm event or passage of a circulation cell.

Coastal Dunes

Coastal dunes are the dominant landform on Fire Island. They exist adjacent to the active beach. They occur as remnant forms along the spine of the island, and as large masses of sand forming low cliffs on the bayside of the island. They can be linear, they can be irregular, they can be sites of blowouts and mobile sand, they can be stabilized with vegetation, they can be isolated hummocks, they can be large continuous features extending for kilometers. They are the essence of the surface morphology of most of Fire Island.

As part of the sand-sharing system, sediment is intermittently transferred from the beach into the area near the toe of the dune where it collects in the zone of pioneer vegetation (Psuty, 2004). This pioneer plant life is uniquely equipped to survive in this ecological niche of heat, aridity, low nutrient supply, and saline conditions. Inland transport of sand is effectively reduced by the configuration of leaves and stems of the plants to cause accumulation on the dune face or dune toe in the upper reaches of the dune/beach profile (Fig. 12). The coastal dune is a vital component of the sand-sharing system because it keeps sand in a location where storm waves can scarp the dune and mobilize sand that will buffer the losses from the beach. It is an example of a form of sand storage that both contributes to the alongshore sediment supply and provides a barrier to storm surge and overwash.

Figure 11. Hurricane waves eroding beach and scarping foredune, August 1995. Davis Park.

Figure 12. Pioneer vegetation extending into the upper beach and trapping sand in transport. Sailor's Haven, September 2003..

The coastal dune feature that is in active exchange of sediment with the beach is referred to as the 'foredune' because it is the seawardmost component of the dune forms. There are other dunes that may be inland of the foredune that are no longer in active exchange with the beach. They are referred to as secondary dunes because their function has been altered. They once were in active exchange but conditions changed to cause them to be displaced from the active beach. There are many examples of secondary dunes on Fire Island and their historical evolution helps to explain the variable dynamics and sediment supply that have resulted in the juxtaposition of landforms on the island.

The coastal foredune is not a single simple ridge of sand. It exists in a multitude of dimensions and configurations at the inland margin of the beach along most of Fire Island. The form ranges from a linear ridge with almost perfect symmetry to a feature that is very convoluted (Fig. 10). It is a high, sharply-crested ridge in one location, and a low hummocky feature in another. In other portions of Fire Island, the dune form has been greatly modified, such as in the communities and the county and state parks at either end of the island (Figs. 13 and 14). There is not one single form because the foredune is in various stages of waxing and waning in its development as a product of sediment budget, exposure to wind and waves, modification by humans, and long-term sea-level rise (Psuty and Allen, 1993).

The secondary dunes likewise share in the variable developmental history of the island and are inland of the foredune because of changes in the sediment supply and alterations of the island configuration. Importantly, although the active foredune occupies a small portion of the present-day island's surface, dunal topography exists across most of the island and dunes are the most dominant component of the landscape on the barrier. Some of the secondary dunes create a recognizable linear ridge that is inland of the active foredune. This linear feature is a former foredune that is now stranded inland and separated from the beach by a modern foredune. Such a situation occurs when sufficient sand is brought to the beach to cause accretion or widening (Psuty, 1988). With sufficient widening, a new foredune develops and strands the former linear ridge inland (Fig. 15).

Often the secondary dune has an irregular crest and is composed of small hills and hollows. This is common when the primary foredune is partially dissected and transgressing inland as it occupies the upper portion of the beach in the sand-sharing and blowouts, which transfer sediment inland. The gaps in the foredune ridge are zones of foredune dissection and the gaps shift from one zone of weakness in the integrity of the foredune ridge to another. In portions of Fire Island, the irregular hummocky topography of blowouts and hillocks extends across the island, indicating a long history of inland transfers and general instability. In other portions of the island, the irregular hummocky surface is succeeded seaward by a linear foredune, indicating that an active foredune was created that became stable in the sand-sharing system and the shoreline probably built seaward to strand the transgressing and dissected former foredune. In yet other areas on the island, there is a very large broadly-linear dunal feature that has considerable alongshore extent. It tends to be located at the bayside margin of the island and is separated from the active foredune by a swale. In these locations, the island is characterized by the large inactive dunal ridge to the north, the active foredune to the south and a well-developed swale separating the two dunal features (Fig. 16). This situation is caused by the creation of an older component of the barrier island that was well-developed and had a long history of sand accumulation and slow inland migration, which was succeeded by a sediment accumulation phase that broadened the island and shifted the shoreline seaward, stranding the ancestral core of the island. Subsequently, the sediment accumulation phase ended and the

Figure 13. Artificial foredune ridge, bulldozed into place and planted with dune grass. New plantings on remolded face of artificial foredune. Fair Harbor, June 2004.

Figure 14. Bulldozed sediment on seaward side of foredune, Smith Point County Park, October 2002.

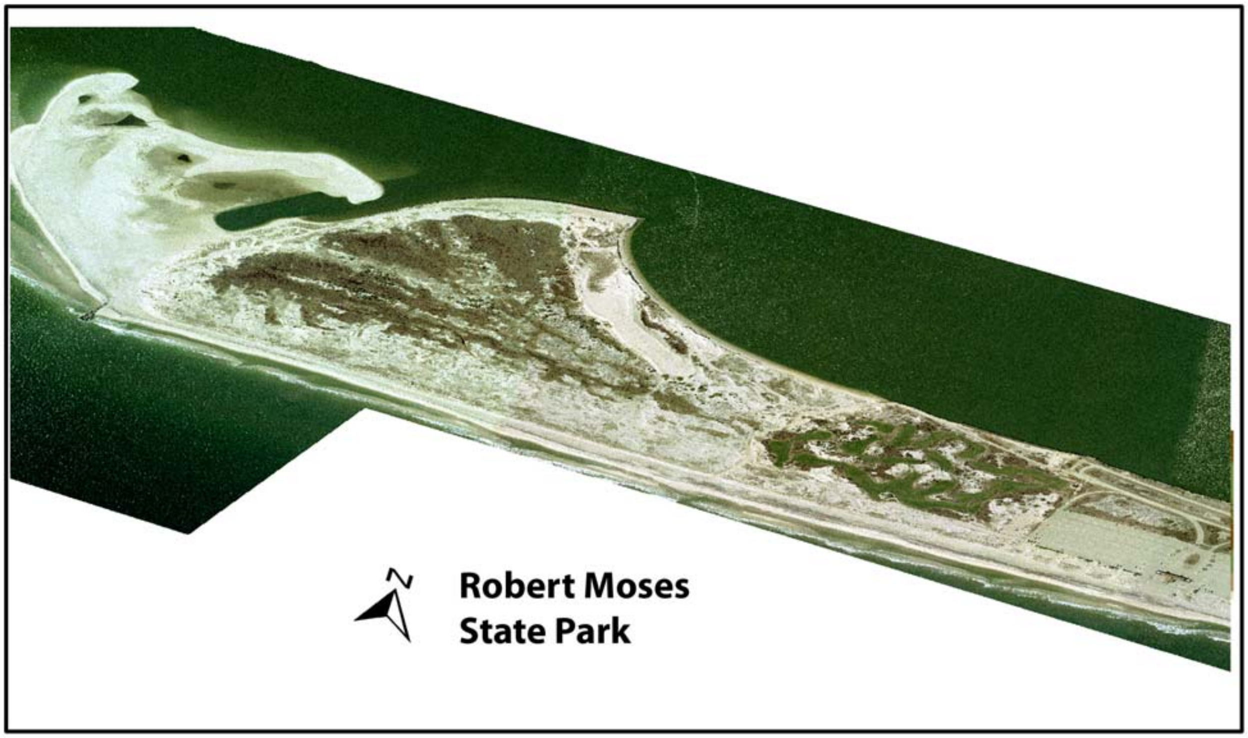

Figure 15. Perspective view of series of stranded coastal foredune ridges at accreting end of Fire Island, Democrat Point. 2001 aerial photography, Source: NY State Office of Technology, 0.5 foot pixel color imagery, western portion of tileset, I_12930204_06_07200_col_2001 through I_13260222_06_07200_col_201.

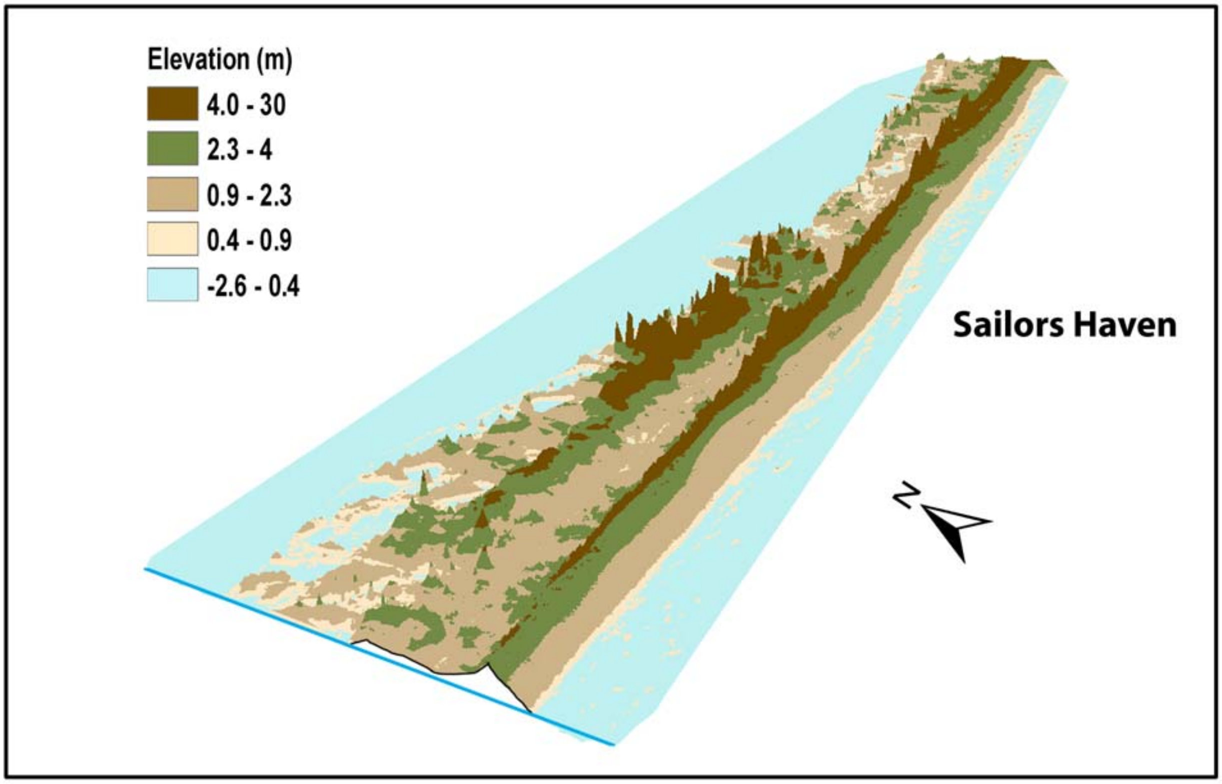

Figure 16. Topographic portrayal of the broad swale that is separating the large stranded former foredune ridge from the modern foredune ridge. The modern ridge is actively transgressing inland across the swale, Sailors Haven. Topography derived from 2002 LIDAR data (Source: FIIS 2002 Bare Earth EAARL Lidar, Center for Coastal and Watershed Studies, U.S. Geological Survey, St. Petersburg, Florida).

foredune is currently shifting inland and transgressing the intervening topography. The sequence is related to the availability of sediment entering the system (Psuty, 1988; Sherman and Bauer, 1993; Psuty, 2004).

The growth of large foredune features with irregular topography suggests a sediment budget that is slightly negative for the shoreline but positive for the foredune (Psuty, 1990; Psuty and Piccola, 1994). That is, there are opportunities for sand to be transferred inland and accumulate in the dune portion of the sand-sharing system while the beach is in a near-equilibrium or slightly negative condition. The quantity of sand accumulated is a function of the time available for the continuous transfer inland and stabilization. Longer durations provide for larger dunes. Later, if the local sediment budget becomes positive because of inputs from the offshore or from updrift, the beach will expand and only small hummocky incipient foredunes will be created (Fig. 17). Still later, if the sediment budget shifts to slightly negative, there will be an opportunity for sand to be transferred into the foredune as it is being displaced inland. Slow rates of inland displacement would result in a positive accumulation in the foredune and creation of a large dune (Fig. 18). Faster rates of inland displacement will either produce a smaller foredune, or if the displacement is faster than the inland transfer of sand, the foredune will become very attenuated and may be very dissected by blowouts and loss of sand inland, further depleting the sand-sharing system.

Thus, dune ridge-lines at inland locations indicate positions of former shorelines because of their function in the sand-sharing system. They may be stranded by widening of the island in the case of large amounts of sand becoming available, or they may be stranded by the progressive alongshore lengthening of the island, causing older margins of the island to be stranded by the active shoreline (Psuty, 1990). The more linear ridge lines are indicative of relative stability of the foredune and are likely during periods of near equilibrium sediment budget. The very dissected ridge lines are indicative of a more negative sediment budget and more episodes of erosion and mobilization of the ridge form, more indicative of destabilization and inland transgression of the foredune portion of the sand-sharing system (Psuty, 1990). A further complication to the complex geomorphological history of Fire Island is that the secondary dunes may be destabilized after they have been stranded and isolated from the active beach. Storms, fires, clearing by humans, disease in the covering vegetation, etc., can remove the stabilizing vegetation and blowouts can develop in the sand hills at any time (Nordstrom and McCluskey, 1985). And, the direction of sand transfers will be dictated by the local topography, the remaining vegetative cover, the dominant winds, etc. There are some dune forms on the island, in the Wilderness Area, the Lighthouse area, and others, that are currently transgressing toward the south-southeast. This seems to be related to destabilization of the secondary dune forms while they are isolated from the beach, although storm and overwash events may be responsible for the loss of vegetation cover.

The history of the sequence of coastal dune development is complex on Fire Island and there is a paucity of dates on the evolutionary development of the geomorphology, so the interpretations are derived from juxtaposition of forms augmented by knowledge gained by sequences more completely studied in nearby areas.

Figure 17. Low, hummocky incipient foredune development in association with positive sediment budget since the 1980s. Inland transport of sand accumulating near toe of incipient foredune, in process of being stabilized by pioneer vegetation. Beach survey team in action. Cherry Grove, May 1997.

Figure 18. Transfer of sand inland of the coherent foredune crest and slow displacement of the foredune landward. East of Davis Park, May 1997.

INLETS / GAPS

Fire Island Inlet

Since the early 1700's, Fire Island Inlet has existed continuously, although the inlet has migrated dramatically over time (Kassner and Black, 1983). Since 1825, the inlet has migrated approximately 8 kilometers to the west. The inlet's migration was halted in 1941 by the construction of the Federal jetty on the eastern shoulder of the inlet at Democrat Point (USACOE, 2002). The jetty, 1525 m in length, was successful in arresting inlet movement for more than a decade, but it did not provide a stable navigation channel. In 1948, modification of the Federal project to provide an inlet channel 3 meters deep and 75 meters wide was recommended (Smith, et al., 1999).

The shoaling that occurred resulted in a tendency for the inlet channel to relocate to the north; causing erosion to Oak Beach and Gilgo Beach, located to the west of the inlet (USACOE, 2002). These conditions led to the modification of the Federal project at Fire Island Inlet to include shore stabilization of the area extending from Fire Island Inlet to Jones Inlet. The area within the inlet to produce a southward shift of the navigation channel and to provide fill material for the feeder beach located about 3.2 kilometers west of Democrat Point/Oak Beach (the area was dredged to a mean low water depth of 5.5 meters for a length of 2,100 meters with a width varying from 180 to 365 meters); and 3) construction of an 800-meter sand dike across the inlet gorge extending southeast from Oak Beach (USACOE, 2002). This attempt to stabilize the navigation channel and to reduce erosion on the north and west shores of the inlet, was completed in 1959.

The sand dike was successful in maintaining channel position and minimizing erosion on the northwestern shore. However, the inlet continues to experience shoaling, in high enough amounts that require frequent dredging. As a result, modification of the Federal project to incorporate sand bypassing at Fire Island Inlet was authorized in 1971.

Since 1971, the maintenance of Fire Island Inlet has consisted of periodic dredging of the navigation channel, sporadic dredging of the littoral reservoir immediately adjacent to the jetty, land reclamation, and feeder beach nourishment (Smith., 1999). Dredging of the inlet has been performed almost annually since 1954, totaling nearly 16 million cubic meters from 1954 to 1994 or about 400,000 m^3/year (USACOE, 2002). The present cost of dredging at Fire Island Inlet is about $5 million per year. Most of the dredged materials have been placed west of the inlet between Fire Island and Jones Inlet (the sand was bypassed to the down-drift side) (USACOE, 1993, 2002).

Moriches Inlet

Moriches Inlet was formed during a storm on March 4, 1931. For the period of 1931 to 1947, the inlet migrated approximately 1,070 meters west (Kassner and Black, 1982). Between 1933 and 1938, the inlet widened and deepened as tidal currents deposited large sand delta on both the ocean and bay side of the inlet. The Great Hurricane of 1938 further widened the inlet to over 1,200 m and caused severe erosion on the banks of Moriches Inlet. Subsequently two breaches formed directly west of the inlet. In May 1939, these breaches were artificially closed. In the years 1947 to 1948, a rubble-mound revetment was constructed on the western inlet bank to reduce any further westerly migration of the inlet (Smith, et al., 1999).

The inlet channel continued to narrow as a result of the ongoing growth of the Cupsogue Spit (located to the east), while the revetment proved to be somewhat successful in maintaining the inlet's position. A storm in November of 1950 resulted in large amounts of sand that washed over the barrier island to the east of the inlet depositing sediments in the bay-connected inlet channel. During another storm in May of 1951, Moriches Inlet experienced a closure because of the reduced flow through the inlet. Jetty construction took place from 1952 to 1953; during a storm in September 1953, the inlet was reopened. The width of the inlet (240 meters) was essentially fixed after completion of the jetty construction. The original channel was oriented slightly east of north entering the inlet. The main channel bifurcated to connect the east and west basins of Moriches Bay with the inlet from a point 240 to 300 meters from the inlet entrance (Smith, et al., 1999).

Moriches Inlet is dredged only when major issues of navigation become apparent. From 1953 to the present, dredging quantities for the inlet are approximately 2.5 million cubic meters, an annual average of 60,000 cubic meters (Smith, et al., 1999). The dredged material was typically placed along the beaches adjacent to the inlet or within nearshore areas east and west of Moriches. In the past, most of the known placement of dredge spoil resulted in disposal to the east of the inlet. However, in an effort to promote the east-west alongshore transport, dredged material is distributed both east and west of the Moriches Inlet (Smith, et al., 1999; USACOE, 2002).

The U.S. Army Corps of Engineers (1993, 2002) describes improvements made to the inlet since 1982 as: 1) a deep inner channel 30 meters wide by 2 meters deep to Moriches Inlet; 2) an outer channel extending from the ocean to the inner channel with a width of 60 meters, a low water depth of 3 meters and an advanced maintenance deposition basin; 3) rehabilitation of the outer end of the west jetty; 4) scour blanket fronting the west jetty and repairs to both jetties; and 5) a stone revetment along the bay side of the beach directly east of the east jetty. Construction activities were completed in 1986.

There is a current proposition that the ebb-tidal delta is approaching an equilibrium size and would no longer collect and retain littoral drift that arrives from east of Moriches Inlet to Fire Island (USACOE, 2002; Allen, et al., 2002). This is supported by observations of major accretion of the shoreline at Great Gun Beach, about two kilometers west of Moriches Inlet, that occurred between 1986 and 1994 (Allen and LaBash, 1997). This major accretion suggests that substantial natural bypassing of the inlet, which was stabilized by jetties in the early 1950's, is now taking place. Once the jetty was constructed and the inlet deepened, the system shifted from flood-tidal dominance to ebb-tidal dominance, which caused shifts in sand distribution. After placement of the jetty, the inlet created an offshore sand buildup, which normally would have been transported to Fire Island. Inlet surveys for the 1981 to 1996 period show that ebb shoal growth was significant with deposition ranging to 4 m in thickness (Allen, et al., 2002). Total accumulated ebb-tidal shoal volumes are about 1.5 – 2.2 million cubic meters (Allen, et al., 2002; USACOE, 2002).

The predominance of littoral transport to the west is indicated by the western offset of the ebb shoal. The formation of an offshore bar extending west from the ebb shoal suggests inlet sand bypassing for this period (Fig. 19). The large amount of shoreline accretion extending west from the point where the ebb tidal delta meets the shoreline (approximately 1,100 meters west of the inlet) also supports the natural sand bypassing process. Shoreline erosion is prevalent immediately west of the inlet. This erosion is primarily related to sediment trapping in the inlet and ebb shoal. Moriches bathymetric changes for the 1933 to 1996 period included ebb shoal deposition totaling 4.7 million cubic meters, extending west from the inlet for a distance of approximately 2.5 kilometers (Smith, et al., 1999; USACOE, 2002). During this period, erosion

Figure 19. Moriches Inlet, April 1992. The offset in the shoreline is related to erosion downdrift of jetties. The seaward projection of the beach is where sediment is being transferred from the offshore delta to the shoreline. Old washover features on the bayside of the barrier give geomorphic evidence of former inlets in the area. Foredune ridge is very segmented along Smith Point County Park, a further indication of past inlets and washovers. Photo by J. R. Allen.

immediately west of the inlet is evident, as is the dramatic growth of the ebb-tidal delta. A tendency for the channel to assume a southwest-northeast alignment is indicated by scouring at the offshore end of the western jetty (exceeding depths of 10 meters). This tendency results from the predominance of western alongshore sediment transport, and combined with sediment trapping in the inlet, is responsible for erosion that appears immediately west of the western jetty (Smith, et al., 1999). The system stabilized forty years after installation of the jetties, and sand resumed movement downdrift once again. The issue regarding the scale of bypassing is important on many levels, but most notably because it affects the management responses that may be implemented by agencies seeking to promote and maintain alongshore sediment entrainment.

Those who support engineered bypassing suggest that there is a continuing linear rate of interception (Spencer and Terchunian, 1997). They imply that the erosion occurring throughout Fire Island is being directly caused by the Westhampton Beach groin field, to the east and updrift of Moriches Inlet, and by the sediment that is accumulating in the Moriches tidal deltas. This concept, attributing the island-wide continuing erosion on Fire Island largely to updrift sediment transport interruptions, is not well substantiated and goes against the scientific appreciation of the localized impacts of inlets and structures on the regional sediment budget (Allen, et al., 2002). Theory further suggests that the ebb-tidal delta cannot grow forever at the same rate due to eventual limits imposed by natural feedback (Boothroyd, 1985). Additional hydrographic studies at the inlet will shed additional light on the topic.

Gaps

The continuity of the linear dune ridges is interrupted several times along the barrier island as a result of past events that have either produced washovers that extended across the width of the island, or are at sites of former inlets that have since been filled in, or some combination of the two conditions (U.S. Army Corps of Engineers, 1995). The inland band of dune ridges is especially disjunct and represents a large number of conditions of washover or inlet development. In the general area of the present Moriches Inlet, there is morphological and stratigraphical evidence for at least 19 inlet positions (Leatherman and Allen, 1985). One example of a previous inlet is the aptly-named “Old Inlet” in the Wilderness Area (Fig. 1). Historical records indicate that the inlet was open from 1763 to 1825 (URS Consultants, 1999; Tanski, et al., 2001), thereby segmenting the present Fire Island. Geomorphological evidence supports the existence of an inlet by presence of former foredunes that once lined the margins of the inlet beach (Fig. 20). The dune feature to the west of the old inlet is quite large, indicative of positive sediment budget in the dune at the time of formation, as is befitting of a shoreline that was being displaced slowly landward. The dune features to the east of the inlet display the morphology of an accreting spit that was building westerly and had a succession of low foredune ridges closing off the inlet. The forms show the inlet channel being lengthened westerly as the spit grew, eventually sealing off the connection between the ocean and bay.

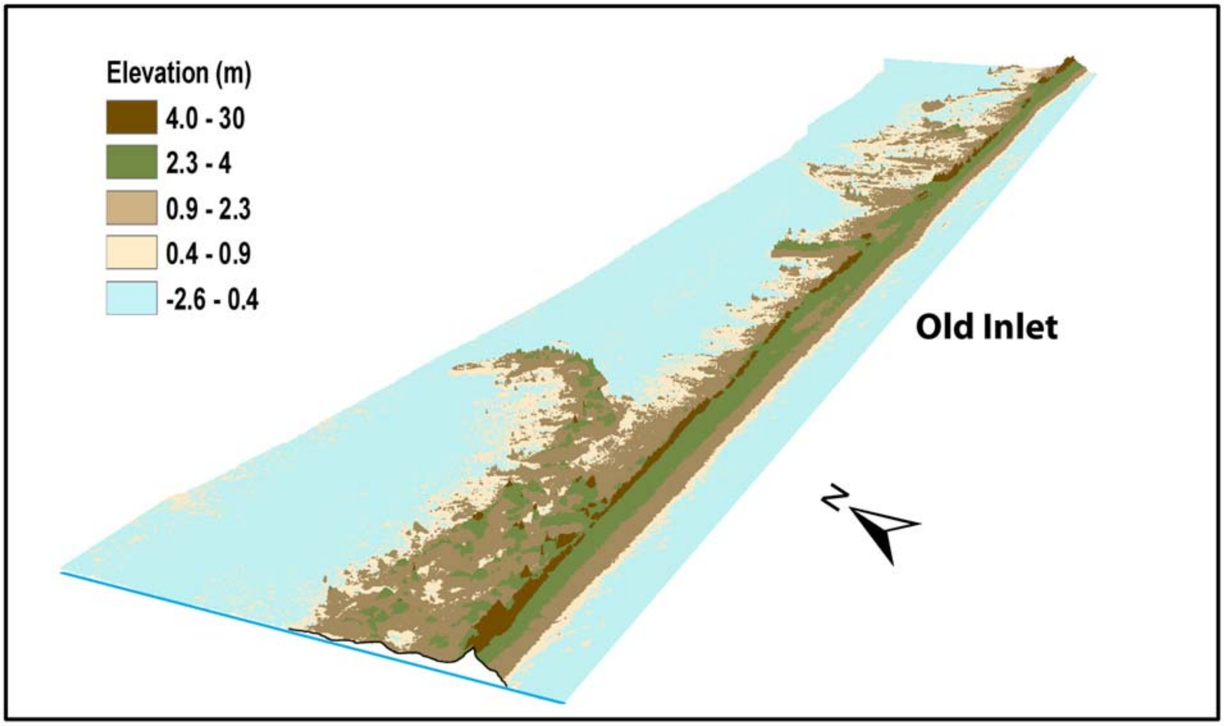

Figure 20. Perspective view of topography at Old Inlet, derived from 2002 LIDAR data (Source: FIIS 2002 Bare Earth EAARL Lidar, Center for Coastal and Watershed Studies, U.S. Geological Survey, St. Petersburg, Florida). The inlet is bounded by former foredunes curving into the channel. The seaward, modern foredune ridge forms a barrier to the inlet throat and continues to the west (foreground) where it served to displace the inlet to the west before sealing it off from the bay. Several recurving foredunes currently located east of the inlet indicate the continuing westerly displacement of the inlet during its active history. Elevations are relative and there is no water/land contact in the data set; the blue color is symbolic, not absolute.

SHORELINE CHANGE

The shoreline is an extremely dynamic portion of the island. Gains and losses occur through a variety of temporal spans that vary from short duration storm events, through seasonal cycles at the annual time scale, and into decadal, century-long, and multi-century trends. The data available to discern and understand these variations are somewhat uneven. The recent decades of ground surveys and aerial photography provide very good and detailed coverage of the short-term changes, but they also illustrate the very large variation in shoreline position accompanying specific events. Incorporation of longer-term data sets such as older charts and maps provide a somewhat different perspective on shoreline change because these sources are less precise in representing a specific condition. However, they do provide a basis for evaluating changes on the broader scale and can be compared to establish the more general island configurations.

Allen, et al. (2002) make the case for tracking shoreline changes back to 1870 because of the high quality shoreline survey conducted at that time. They suggest that an interpretation of mean high water can be reasonably derived from the 1870 survey and subsequently compared to more recent surveys to generate measurements of the changes. Further, in addition to the determination of the displacement over this entire time span, they separate the surveys before and after 1933 to represent possible changing conditions associated with the opening of Moriches Inlet in 1931. Their analysis of shoreline position for the entire ocean shoreline of Fire Island shows an average shoreline landward displacement of 0.4 m/yr for the 1870-1998 period. They determined that in the 1870-1933 period, the mean inland displacement was 0.47 m/yr, whereas the 1933-1998 period had a mean inland displacement of 0.34 m/yr. Spatially, the earlier period (Fig. 21) has an erosional trend in the vicinity of Moriches Inlet, a sequence that shows decreasing loss and increasing accumulation into the Wilderness area, general loss from Watch Hill toward the Fire Island Light, and a very large inland displacement to Fire Island Inlet. The effects of the creation of Moriches Inlet are shown for the period 1933–1979 (Allen, et al. 2002) (Fig. 22) because the position of the shoreline immediately downdrift of the new inlet had shifted inland substantially, with a decreasing effect farther downdrift to the vicinity of Watch Hill. From there, the net change is a slowing rate of increase, eventually becoming erosional near Sailor’s Haven, and reaching a maximum erosional rate at the Fire Island Lighthouse. At the western extremity, the effects of the Fire Island jetty cause the very large positive displacement of the shoreline. It is probably the effect of the jetty that is largely responsible for the differences between the average rates of displacement in the two periods of shoreline change measurements.

The annual erosion of the ocean shoreline represents a removal of sand from the shoreface and a downdrift transfer that is reflected in the westerly buildup of Democrat Point, the site of more than 8 km of new barrier creation since the initial construction of a Fire Island Lighthouse in 1826 (rebuilt in 1858) (Kassner and Black, 1983). Further, the multi-decadal shoreline positions seem to represent a passage of pulses of sand alongshore as represented by the numerous oscillations in the shoreline position at the scale of several kilometers and the broad sloping trends of loss and gain at the scale of tens of kilometers.

Allen, et al. (2002) provide further insight to the shoreline trends of the recent decades because a great number of alongshore beach surveys were collected at short time intervals and related to a common reference line. They describe a general pattern of sine waves in the

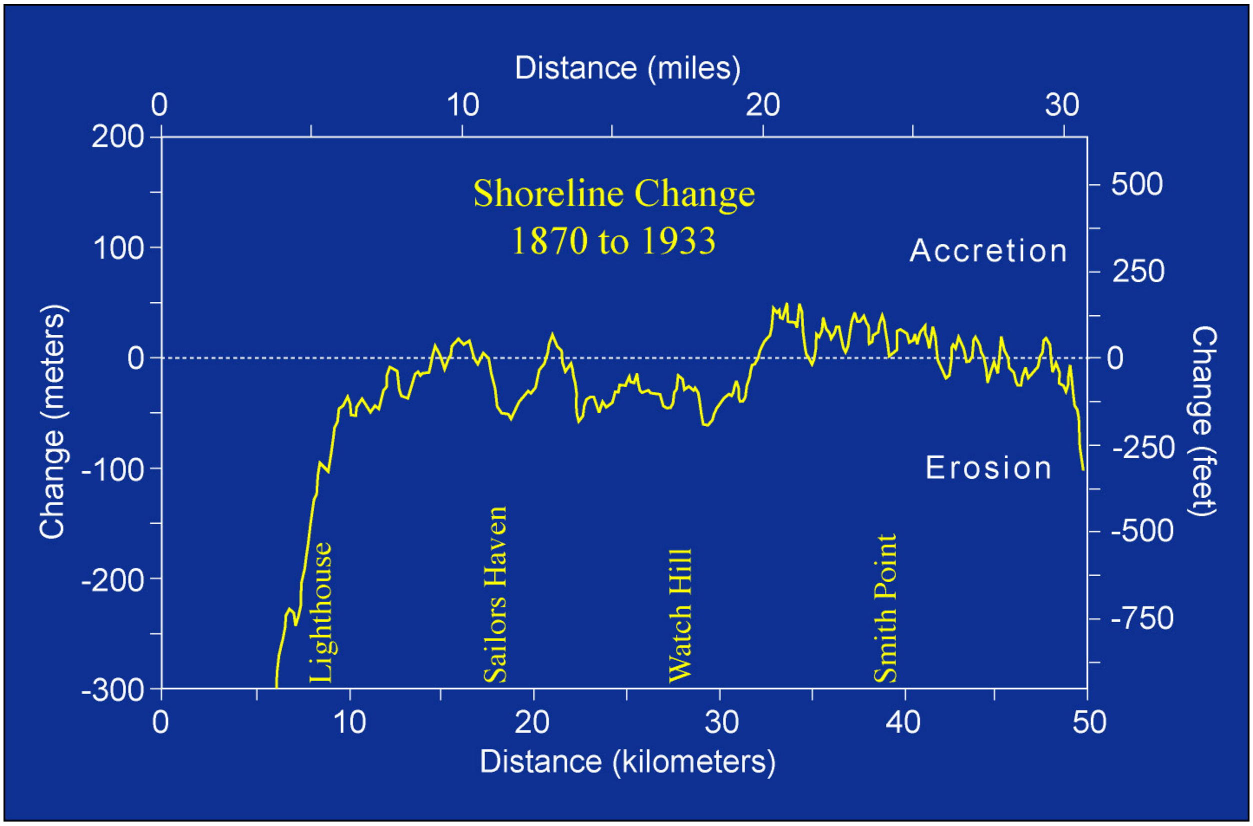

Figure 21. Net shoreline displacement at Fire Island, 1870-1933 (Allen, et al., 2002).

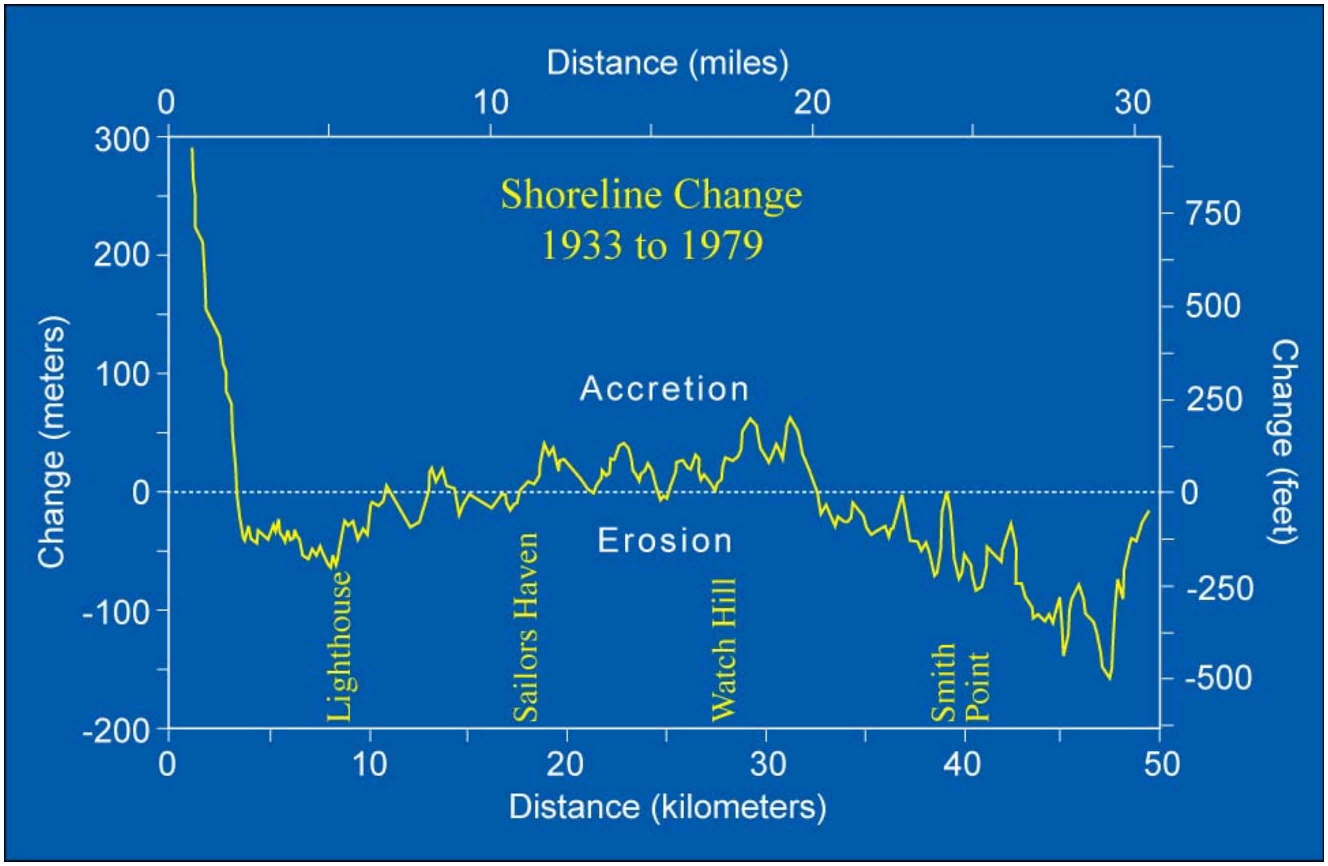

Figure 22. Net shoreline displacement at Fire Island, 1933-1979 (Allen, et al, 2002).

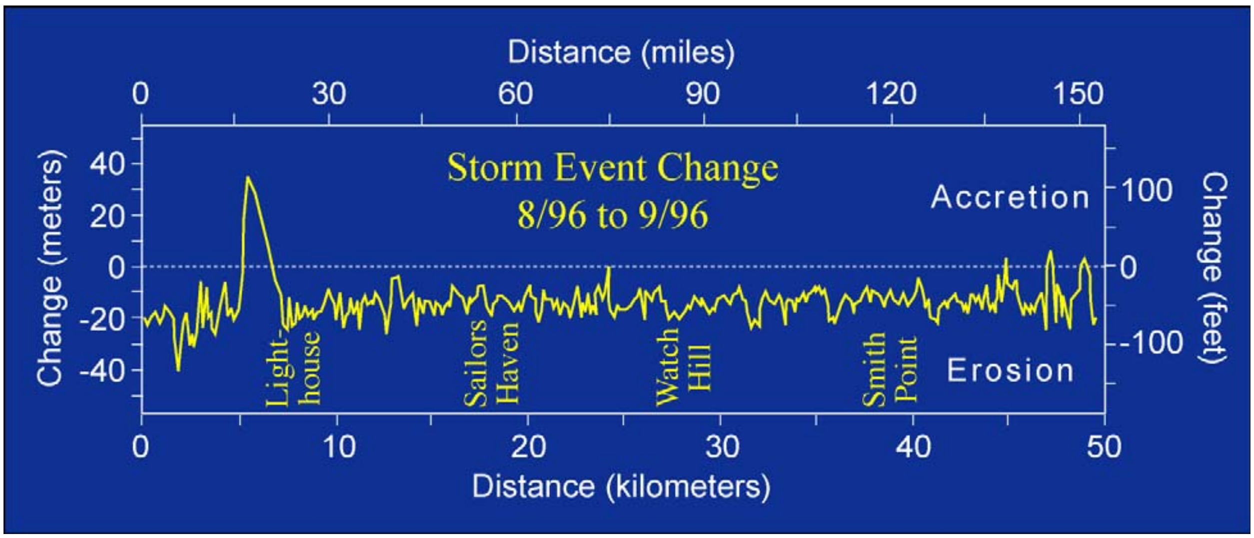

Figure 23. The shoreline change signature associated with a major storm is a nearly linear displacement of the shoreline along the length of the island (Allen, et al., 2002).

shoreline that widen and narrow the beach in a rhythm that is more regular and more persistent in the western portion of the island. The oscillatory pattern seen in the multi-year to decadal scale above (Figs. 21 and 22) is contrasted with shoreline changes associated with a 1996 storm event (Fig. 23) that produced a more linear response to the advent of higher energy and storm surge (the positive peak to the west of the lighthouse is produced by emergency beach fill).

The history of shoreline change during the recent 135 years gives us a perspective on the conditions that have characterized Fire Island for most of its history. The shoreline has been very mobile and there has been an alongshore transport of sediment to extend the island westerly. However, the island has at times been segmented and the delivery of sediment has augmented various portions of what we collectively call Fire Island. The pulses of sand propelled westward may represent storage and release of sediment temporarily captured in inlet tidal deltas to be subsequently released upon changes in the inlet condition. The pulse of positive sediment accumulation appears to be shifting westward in the post Old Inlet time. This may be related to the sedimentation that closed Old Inlet and the inlet to the east of Old Inlet. It may be part of a sediment pulse that originated farther to the east because of other inlet systems that were releasing sediment as they underwent morphological change.

The history of shoreline displacement landward is supported by the geomorphological evidence that shows the coastal foredune as a single large zone of accumulation that is transgressing inland by wind and wave processes (Psuty and Allen, 1986; Psuty, et al., 1988;Psuty, 1989; Psuty and Allen, 1993). Exceptions to the single foredune occur in the vicinity of abandoned inlets and the current Fire Island Inlet. In these locations, the geomorphology indicates an evolutionary development of accretionary foredune ridges on the eastern margin of the inlet, a single larger foredune ridge to the west, and a gradual westerly elongation of the inlet channel. Eventually, the inlet channel was sealed and is presently the site of a foredune ridge in various stages of growth that extends across the entire inlet location, such as at Old Inlet.

Thus, the information derived from early shoreline surveys integrated with the modern surveys, augmented by the primary and secondary foredune evolutionary history, point to a landward displacement of the shoreline in the current time. The process is not linear but very complex because of instances of sediment accumulations and releases associated with the long-term sediment sources as well as the storage and transfers related to inlets and foredune sequences (Psuty, 2004).

REGIONAL CHARACTERIZATION

The foregoing discussion of the geomorphological development of Fire Island incorporates the general history of barrier island formation related to the rise of sea level over the past several thousand years. It is the history of shoreline creation and displacement during the uneven rate of transgression of the ocean. It is the working and re-working of sediments available on the continental shelf either as a result of glaciation and glacio-fluvial deposition during the Quaternary or older sediment sources derived from Cretaceous-aged sandy deposits near the present coast. It is the history of a westerly transport of sediment to support an elongation of the barrier island system that developed along the southern margin of Long Island. It is the segmentation of that barrier to form a variable number of islands in the sequence as inlets opened and closed. The islands initially transgressed inland during a period that may have spanned a time from 8,000 years ago to 3,500 years ago (Walker and Coleman, 1987). About 3,500 to 3,000 years ago, a combination of a marked reduction in the rate of sea-level rise and the availability of recently-submerged quantities of sand supported the growth and expansion of the ancestral Fire Island barrier island. The oldest portions of the Fire Island barrier are the large high dunes on the bayside of the areas near Sailor's Haven and Watch Hill. They may be the core of the island. Extending from these areas are smaller former foredune ridges that represent the westward accretion that added to the mass of the island. Also, expansion occurred seaward of the core as sediment was widening the barrier and probably merging several of the barrier island segments (McCormick and Toscano, 1981).

It is likely that inlets and/or breaches continued to characterize parts of the Fire Island barrier because there are gaps in the ancestral foredune ridge and there are stranded accretionary foredunes that mark locations of former inlets. Following the expansion and elevation of the barrier island, it is likely that much of the available sediment was mobilized and transferred landward and the local supply became essentially exhausted, although re-working of the barrier island accumulation could provide local and temporary sources of sediment (Dubois, 1995; Pendleton, et al., 2004). With the reduction and possible exhaustion of the source of sediment to maintain the dimensions of the barrier island within the past thousand years, there was an onset of erosion or inland displacement of the ocean shoreline, leading to the development of a large coastal foredune that slowly migrated inland as the shoreline retreated. The foredune was a part of the morphology created by the inland transgression and it was present in various configurations, ranging from a coherent linear ridge where the displacement was slow to a very irregular and broken ridge with deflation hollows where the displacement was faster. The latter portion is characterized by paths of sand transfer inland as amorphous sheets and parabolic dune forms, obscuring the pre-existing topography. More recently, the process of sediment loss and morphological displacement is being exacerbated by the accelerated rate of sea-level rise. This increased rate of change is part of the barrier island response to a limited supply of sediment and an induced destabilization associated with a transgressing sea.

Not all parts of Fire Island are responding in like manner to the processes acting upon it. Some of the processes are being applied unevenly and thus there are differences in the natural response. Some of the natural processes are being affected by human actions and the responses are being conditioned by the magnitude and continuity of the human activities. It is said that Fire Island is divided into three parts, each with a somewhat different geomorphological character. The following discussion amalgamates the scientific data that have been collected to date to provide a regional description of the geomorphological characteristics of Fire Island on the basis of three zones, with transitions between them.

Eastern Zone

Extending from Moriches Inlet to the vicinity of Watch Hill, this portion of Fire Island has a long history of inlet creation and island segmentation. The historic charts and the coastal geomorphology document changes in shoreline position as inlet development and closure affected sand availability in downdrift locations. Many of the secondary dune ridges (stranded foredunes) located inland of the present coast are curved inland, indicating they were formed at inlet margins. Leatherman and Allen (1985) describe evidence for at least 19 breach events (inlets/washover) in the vicinity of the present Moriches Inlet, suggesting a recurring condition favoring inlet development in this area. The presence of other former inlet locations, Old Inlet and the un-named inlet to its east, suggest that this portion of the barrier was intermittently segmented and connected in the past. With the closure of the historic inlets in the early 19th century (Tanski, et al., 2001), the geomorphological forms show that a continuous coastal foredune evolved in conjunction with a shoreline displacement that varied from slow retreat in the vicinity of Moriches Inlet to slow advance east of Watch Hill.

Following the creation of Moriches Inlet in 1931, the interruption of alongshore transport and the accumulation of sediment in the tidal deltas caused the eastern portion of the island to retreat at a high rate immediately in the vicinity of the inlet, with a decreasing rate of retreat toward the west, reaching an equilibrium to the east of Watch Hill. Evidence from the bathymetric surveys and the shoreline surveys (Allen and LaBash, 1997; Allen, et al., 2002; USACOE, 2002) indicate that the ebb tidal delta at Moriches Inlet has reached its storage capacity and that natural bypassing has resumed (except for the material collecting in the navigation channel). If so, the dredging and downdrift disposal of the sediment from the navigation channel should return the rates of change to their background levels (slow erosion). Suggestions that the collection of sediment in the ebb tidal delta is responsible for downdrift erosion into the central and western portions of Fire Island (Spencer and Terchunian, 1997) are not supported by the survey evidence. There is, however, a much higher rate of erosion along the eastern portion of Fire Island and a continuing inland displacement of this segment of the barrier island relative to the remainder of the island. Erosion from the eastern area and its downdrift transport is part of the sediment supply to the rest of the island.

Central Zone

The central zone extends from the vicinity of Watch Hill to the vicinity of Sailor’s Haven and is characterized by a general uniformity of shoreline response during nearly all of the survey periods. Topographically, the two ends of the section have a very wide and high secondary dune system at the bayside, a well-developed foredune ridge at the oceanside, and a lower area with hummocky, low dune features between the two ridges. The shoreline has a general curving trend, convex seaward. The middle portion of this section of the island, Talisman – Barrett Beach, is the narrowest part of Fire Island, only 80 m from the foredune crest to the bay. In 1994, a localized erosion cell in the beach removed most of the foredune in this location and there was a serious threat of overwash and potential breaching. Subsequent foredune development has restored much of the dune elevation. However, the new foredune was displaced inland about 30 m, further narrowing the elevated topography in this section to its present dimension (Psuty, et al, in press).

The historical beach surveys depict a change in the east-to-west trend occurring at the Watch Hill area and continuing to about the Sailor’s Haven area. This is true whether the trend in the middle section is accretional or erosional. Part of the change in response is likely related to the change in island curvature and the changing distribution in alongshore energies for transport. There may also be some structural control from the offshore geology exercising an influence in the displacement of the barrier island (Saunders and Kumar, 1975; Williams, 1976; Schwab, et al. 2000). And, according to Schwab, et al. (2000) there is an offshore source of sediment adding to the alongshore supply in this general area. That is, an additional input of sand is contributing to the sediment budget from about Watch Hill and westward and it is slowing the rate of erosion and inland displacement relative to the eastern portion of the island. This source is also responsible for the creation of a set of sand ridges located offshore in at least 8 m of water and inclined to the shoreline. They have a spacing of about 6 km from crest to crest. Shoreline change maps show a similar 6 km spacing in higher and lower rates of displacement, and it is thought that the ridges are altering the nearshore distribution of wave energy to cause this spatial pattern (Allen, et al., 2002). In further support of this influence, the pattern of displacement of the coastal foredune also displays the 6 km spacing in rates of inland transfers. But, because the foredune is more conservative in its response to erosional events and displacement, the dimensions of change are only about half of those dimensions describing the beach changes (Allen, et al., 2002).

Western Zone

The western zone begins in Point O'Woods and extends to the western limit of Fire Island. This area is largely dominated by coastal features related to the westerly migration of the end of the island and the creation of a series of curving dune ridges in sub-parallel alignment. The pattern was altered by the construction of the Fire Island Inlet jetty in 1941, but the post-1941 changes are in keeping with the sediment budget and island's developmental history.

The historical shoreline surveys represent the western area as eroding, with an increase in the rate of erosion from east to west. At first, this seems to be contradictory to the claim that the island is extending to the west. Closer analysis indicates that the some of the erosion is related to the change in the curvature of the island as it is extending westerly. Prior to the construction of the Fire Island Inlet jetty, the curving foredune ridges depicted a westerly offset of ridge development that is partially supported by erosion and inland displacement of the beach and foredune to the east. That is, erosion at the base of these recurving ridges was supplying sediment to accumulate at the distal end of the island. Thus, the oceanward foredune was eroding and migrating inland along the eastern portion of this section while it was accreting and shifting into the channel at the western portion of the section. Construction of the jetty changed the conditions at the inlet but did not alter the sediment balance farther updrift, which remains erosional and with a coastal foredune that would be displaced inland slowly under natural conditions. However, this section of Fire Island is highly manipulated by human action. The beach as well as the foredune have been sites of sediment placement and re-shaping. Two tetrapod-type groins (76 m in length) were constructed in Ocean Beach in 1976 by the village and State to protect the water tower in Ocean Beach(USACOE, 2002). Whereas the updrift beach has been the site of sediment accumulation and improved stability, the downdrift portion has seen considerable cutback and displacement of the beach and the former foredune ridge.

Further, foredune creation and enhancement in the towns and villages in this zone has created a dune feature that is often located seaward of its natural position and this "sand ridge" is extremely vulnerable to both storm erosion and passage of the migrating erosion cells. Maintaining this artificial foredune feature is proving to be difficult under the constraints of a negative sediment budget and a rising sea level. As a result, some of the communities are providing for a temporary adjustment in the sediment budget by bringing new sand by truck or pipeline into the system to widen the beaches. This process, beach nourishment, has been practiced more frequently on Fire Island during the past few decades. Beach nourishment is defined as the introduction of new sand, placed on the beach by mechanical means, which has the immediate effect of increasing the dry beach width. Some of the 17 communities on Fire Island have initiated their own nourishment projects whereas other projects are associated with Federal / State / County efforts at sediment management (Table 2).

Since the 1940s, the beaches on Fire Island have been nourished with almost 5.4 million m^3 of sand (Kana, 1999; Valverde, et al, 1999). Through the 1960s, most of the projects (totaling

Table 2. History of Beach Nourishment on Fire Island (gaps likely).

Placement Site	**Date**	**Volume** (cubic meters)	**Length** (meters)	**Cost/Source** (actual cost that year)
ROBERT MOSES STATE PARK (dredged from Fire Island Inlet channel and shoal)	1993 1994 1997 1999-00 2001-02	458,730 153,000 277,000 103,500 126,000		Federal Federal Federal Federal Federal
GREAT SOUTH BEACH (general Fire Island)	1962 1960s 1967 1973 1983 1991	760,000 203,300 103,250 133,100 7,650 2,300	9,335	$844,100 (Fed Emergency) Local/private Local/private Local/private Local/private Local/private
Brookhaven and Islip Townships	1962	546,650	11,280	$528,600 (Fed. Emergency)
Fire Island Pines	1994 1997 2003-04	115,000 1,100,000 575,000	1,900 1,950 2,250	$900,000 Local/private Local/private $3,710,000 Local/private
Great Gun Beach	1969 1995	47,700 30,600		Local/private Local/private
Seaview, Ocean Bay Park, Point O'Woods	1994	206,400	3,000	$1,580,000 Local/private
Saltaire/Fairharbor/ Dunewood/Lonelyville	1994 2003-04	420,000 995,000	2,500 2,700	$3,000,000 Local/private $5,200,000 Local/private
Smith Point County Park (unable to verify other quantities dredged from Moriches Inlet to beach)	1996	458,700		Local/private
Water Island	1996	58,000	300	$470,000 Local/private

Sources: Valverde, et al., 1999; USACOE, 2002;
http://www.fireislandassn.org/news04_1.htm#Beach%20Fill%20Projects
http://www.fiyrra.com/fiyrra/0204asbpa.pdf

~2.5 million m^3) were beach disposal of dredged bay and inlet sediments under the direction of Suffolk County. Dredging by the County virtually ceased in the 1970s. In the 1970s and 1980s, a total of less than 180,000 m^3 were placed on the beach. During the 1990s, and especially after the significant storms in 1992, more aggressive beach nourishment efforts were resumed and a total sand volume of 1.9 million m^3 was emplaced during this decade (Kana, 1999; Valverde, et al., 1999). In 2003/04, an additional 1.2 million m^3 of sand was pumped onto the beaches of many of the communities (Fire Island Renourishment Projects Fact Sheet, 11/6/2003; http://www.fiyrra.com/FRenourishment03.html).

MANAGEMENT AND ITS IMPACTS

The dynamic geomorphological system of Fire Island is the site of private and public ownership, as well as a hierarchy of management authorities. The primary administrative body is the National Park Service (NPS), Department of the Interior, which has jurisdiction pursuant to Public Law 88-587 of 1964. The enabling law authorized the Secretary of the Interior to establish an area to be known as the Fire Island National Seashore (FINS) for the purpose of conserving and preserving certain undeveloped beaches, dunes, and other natural features within Suffolk County. Seventeen communities lie within the FINS jurisdiction. In March 1978, the NPS adopted a General Management Plan (GMP) for FINS to deal with the management and protection of the natural resources (an updated GMP is to be initiated within the next year). The FINS statue directs the agency to adopt standards for local zoning authorities to enact consistent with local ordinances. Once local ordinances consistent with the standards in Title 36 Code of Federal Regulations are approved, certain private property within FINS is exempt from federal condemnation. The standards also apply to the use and development of public property. From time to time, these standards may be reviewed and revised (36 CFR 28.1).

There are three zoning districts that lie within FINS that have to adhere to the above regulations: Community Development; Seashore; and Dune. The standards for the Community Development District are intended to provide that private property within this district may be retained and developed by its owner in accordance with approved local ordinances and the Federal standards. For the Seashore District, the standards provide that private "improved property" may be retained by its owner but additional development is strictly limited. Within the Dune District, the standards provide that private undeveloped property may be retained by its owner as long as it is maintained in its natural state (36 CFR 28.7).

Many of these districts overlap each other, but it is the Dune District, specifically, that is of concern because no new development is allowed. The Dune District extends from the mean high water line to 40 feet landward of the primary natural high dune crest (foredune), as designated on the Fire Island National Seashore Map OGP-0004 and on Suffolk County Property Maps, as mapped in November 1976 or as subsequently remapped (to date, the Dune District has not been officially remapped). The Dune District overlaps portions of the Community Development District and the Seashore District and contains the towns of Islip and Brookhaven and the villages of Ocean Beach and Saltaire.

There is other federal legislation that affects the coastal area of Fire Island. The National Environmental Policy Act (NEPA) of 1969 established a national policy for the environment, one that will encourage productive and enjoyable harmony between humans and their environment to promote efforts which will prevent or eliminate damage to the environment and stimulate the health and wealth of the inhabitants, to enrich the understanding of the ecological systems and natural resources important to the Nation, and to establish a Council on Environmental Quality (CEQ). (Pub. L. 91-190, 42 U.S.C., 4321, Sec. 2). Any construction or maintenance project being undertaken or funded by a federal agency is subject to NEPA review, either obtaining clearance under a Categorical Exclusion (CE), a Finding of No Significant Impact (FONSI) after review using the Environmental Assessment (EA) process, or a Record of Decision (ROD) subsequent to an Environmental Impact Statement (EIS), if a FONSI cannot be reached (Diane Abell, Pers. Comm. 2004).

Under the umbrella of NEPA, several regulations were established to protect the coastal area. The Federal Coastal Zone Management Act of 1972 (CZMA) requires that each Federal agency activity within or outside the coastal zone that affects any land or water use or natural resource of the coastal zone shall be carried out in a manner which is consistent to the maximum extent practicable with the enforceable policies of approved State management programs. It supports states through financial assistance, mediation, technical services and information, and participation in priority state, regional, and local forums. The Coastal Zone Management Program (established under CZMA) is administered by the Department of State of New York (DOS).

The DOS created the New York State Coastal Management Program in 1982, which is administered through the DOS Division of Coastal Resources. With their Program, the DOS uses a set of enforceable coastal policies to guide the state's efforts to create and maintain clean, accessible, and prosperous coastal areas and inland waterways for present and future generations. The DOS is also responsible for conducting a consistency review to ensure the policies formed for the coastal area are being followed. With regard to FINS and coastal consistency, only projects below the mean high water mark (requiring federal funds) would require a review, anything upland of the mean high water mark would not.

The Coastal Barrier Resources Act (CBRA), Public Law 97-348 enacted in October 1982, addresses problems caused by coastal barrier development. It has designated various undeveloped coastal barrier islands, depicted by specific maps, for inclusion in the Coastal Barrier Resources System. These designated areas were made ineligible for direct or indirect federal financial assistance that might support development, including flood insurance, except for life-saving activities. In 1990, the Coastal Barrier Improvement Act was passed which added a category of 274 otherwise protected areas of coastal barriers within lands reserved for conservation purposes. Parts of Fire Island are included in this category.

Whereas the DOS creates the coastal policies and determines consistency, it is the New York Department of Environmental Conservation (DEC) Bureau of Flood Protection, Coastal Section: Erosion Management and Flooding that administers these policies. They are also responsible for administering the Coastal Erosion Hazard Area (CEHA) management program as enabled by Environmental Conservation Law Article 34 Coastal Erosion Hazard Areas. Regulation of these areas is delegated to local zoning authorities or the county if these authorities agree to assume such responsibility. If not, regulation remains with the DEC. The CEHA is defined as all of the beach and dune between mean high water and a line drawn parallel with the shoreline 25 feet (7.6 m) landward of the landward toe of the primary dune (6 NYCRR 505.2; NY State DEC: http://www.dec.state.ny.us/website/regs/part505.html). The CEHA boundaries were based on: 1) location of mean high water; 2) location of the crest of the primary dune, or identifiable remnant and; 3) adding 25 feet for a buffer area. The 25-foot "buffer area" considers the need for dunes to be able to respond to wind and waves, and, in some cases, to migrate to a location more landward than previous to the storm. Over the past 25 years, erosion has occurred and much of the foredune has receded to just in front of, or in some cases, under or behind the row of houses that front the Fire Island beach, meaning that some houses are located within the CEHA. Not withstanding the other federal legislation, the State's CEHA is perhaps the most important regulation for Fire Island. The coastal environment is dynamic and the shoreline and dunes move in response to natural forces, especially storms. CEHA declares that activities, development, or other actions in such areas should be undertaken in such a manner as to minimize damage to property, and to prevent the exacerbation of erosion hazards. Such actions may be restricted or prohibited if necessary to protect natural protective features or to prevent or reduce erosion impacts. Both publicly and privately financed erosion protective structures should be designed to minimize damage to other man-made property or to natural protective features or to other natural resources; long-term costs of such structures should be carefully weighed against public benefits before construction is undertaken (NYS ECL, Article 34, Section 34-0102, 2, 5).

Some of the communities within FINS have undertaken beach scraping projects that mechanically remold the beach and redistribute sand within the existing dune-beach sand-sharing system. Dune construction or enhancement is accomplished through beach scraping in which bulldozers are used to push sand from the beach towards the front line of beach homes. The goal of this construction to reconstruct foredunes that have eroded during storms. Under New York State law, beach scraping is considered as routine beach maintenance or regrading activities; however, routine beach regrading is also considered by NY DEC as a "presumably incompatible use" under their Tidal Wetland Land Use Regulations 6 NYCRR Part 661, and for which a permit is required. The criteria required for beach scraping include 100 ft. of dry beach (i.e., above mean high water), with an elevation of plus 7 ft. NGVD29. A 60 ft. swath of the 100 ft. may be scraped to a depth of not more than 12 inches, with the sand moved to the dune area.

Beach scraping is a commonly-used foredune creation technique practiced by Fire Island communities (Fig. 24) and has occurred since 1993. This manipulation of the beach sand does not change the general sediment budget but it does augment the volume of sand in the foredune and thereby increases the buffering capacity of the foredune while reducing the buffering capability of the beach. However, there are ecological impacts associated with the emplacement, both in the dunes and the beach. And there are questions remaining about the reduction of beach elevation, the actual effects on buffering, and the impacts of the equipment.

Together with the natural processes and the effects of cultural development, the several levels of management authority combine to limit and guide the geomorphological character of Fire Island. They are a continuing constraint functioning within the system.

SUMMARY

The Fire Island barrier island is the product of sediment accumulation in the past several thousand years. The geomorphological evolution has progressed through periods of sea level rise and changing sediment supply to maintain the island. There has been a long history of opening and closing of inlets as well as elongation of the island unit to the west. As the island

Figure 24. Beach scraping has transferred sediment from the berm (foreground) to the face of the foredune (background). Water Island,1995.

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has progressed through periods of sediment accumulation and sediment loss, the shoreline has shifted seaward as well as landward. Opening and closing of inlets have caused interruptions in the alongshore transport of sediment for extensive periods before some sort of equilibrium returned and many of these effects are recorded in the landforms on the island.

The present situation is that there is insufficient sediment coming to Fire Island from all of the potential sources to maintain the entire system. There is evidence of erosion on all parts of the island, except at the artificially-created Democrat Point. The sediment deficits are greatest along the eastern portion of the island, but are buffered in the central and western area because of the contributions from an offshore source. The recent acceleration in sea-level rise coupled with the general negative sediment budget will result in continued beach erosion and dune displacement, with greater effects occurring in the eastern portion of the island. The barrier island system is constantly undergoing dynamic changes and human occupation is being increasingly exposed to damage and risks. There are a variety of administrative programs that are in place to decrease, or mitigate damage to the coastal features, and to encourage the retention and enhancement of the characteristics of the Fire Island National Seashore.

AREAS FOR FUTURE INVESTIGATION (NOT IN PRIORITY ORDER)

1. Data gathering toward the objective of piecing together the sediment budget calculation is a worthwhile goal and needs to be undertaken at the variety of scales appropriate to the barrier island. Sediment budget is a very difficult measurement to attain because it involves so many variables and operates at a number of scales. However, it is important to measure the amount of sediment that is entering and leaving the system. It has importance in describing the entire barrier island, any segment of the island, each of the adjoining inlets, and the subaerial dune forms. It is complicated because of the submarine component that is difficult to measure and to discern differences between shortterm and longer-term changes. It is problematic because of the inherent variation in the beach configuration.
2. Inlet dynamics and sediment transfers are important at both termini of Fire Island. Moriches Inlet bathymetry needs to be conducted at a fine scale and over a number of years to ascertain the sediment-bypassing scenario proposed by previous studies. Fire Island Inlet is growing increasingly inefficient and will require more effort to maintain. More detailed information on the bathymetry and likely channelized alternatives should be undertaken at this inlet.
3. It would be very helpful to have a better understanding of the temporal development of the surface geomorphology of Fire Island during the past 3-4,000 years. There are very few isotopic dates that apply to the sequential development of the island. With techniques of luminescent dating, it would be possible to establish the ages of the several components of the island and generate an appreciation of the temporal dynamism of the barrier system. Together with C^{14} dating of locations near the inlets, dating of the dune features would create a foundation for understanding the mobility and stability of Fire Island.
4. Nearly all of the surface topography of Fire Island consists of some sort of dunal morphology. The many decades of aerial photography and the recent LIDAR data could

be investigated to provide a better understanding of the dimensional changes that have occurred and are occurring on the island. Combined with dating techniques, the sequential development of the surface geomorphology would be of great value in determining the geotemporal scale of landform development.

5. Monitoring of the ambient conditions is of great value. Periodic beach surveys, whether by field teams, LIDAR data, or some combination is a general need to establish the dimensions of change and to maintain current knowledge of the conditions present in the system.
6. The rising sea level is a very important driver of geomorphological change throughout much of Fire Island. Data gathering in the form of a recording tide gauge is needed to document the scale and rate of this process.
7. In conjunction with item 6, there should be a program of continuing observations of the geomorphological responses to sea-level rise as they relate to vertical and horizontal displacements of topography and sediment balances in the subaerial features.

ACKNOWLEDGEMENTS

Pulling together a vast array of information is always the product of a wide range of people and agencies that contribute information and support to the process. This White Paper has had a long gestation period. Not just the months since the contract was awarded to produce the written version, but the many years of debate and discussion regarding observations, measurements, professional publications, gray literature, professional presentations, and camaraderie associated with the many members of the team that journeyed often to Fire Island to add yet another chapter to the Fire Island saga. Special mention is offered to Jim Allen, our friend and fellow coastal geomorphologist, for the intellectual stimulation and lengthy discussions regarding our joint efforts at Fire Island. The superintendents of FINS, past and present, have given generously in support of this product through the years, and the staff has been very helpful in pulling the final pieces together. We especially thank Diane Abell, Patti Rafferty, and Mike Bilecki for their assistance in identifying resources and helping to move the process ahead. Members of the New York District of the U.S. Army Corps of Engineers provided assistance with project information, aerial photos, and reports. Steve Couch was an invaluable resource, as were Jen Irish, Lynn Bocamazo, and Chris Rasmussen. Mark Duffy of the National Park Service and John Brock of the United States Geological Survey provided the 2002 LIDAR data of Fire Island. Ken Keene, now of the National Marine Fisheries Service, was an able assistant at the beginning of the project when many of the publications were researched and collected. Michael Siegel, Director of the Cartography Lab, Rutgers University, produced the maps for the paper. A special note of appreciation is due to Dr. Charles T. Roman, National Park Service, for suggesting this project and having the patience to oversee it to completion. And, thanks are extended to three anonymous reviewers of the draft manuscript for their constructive comments and sharp eyes.

LITERATURE CITED

Abell, D., Fire Island National Seashore, National Park Service, 2004. Personal communication.

Allen, J.R. and N.P. Psuty, 1987. Morphodynamics of a single-barred beach with a rip channel, Fire Island, NY. Coastal Sediments '87, ASCE: 1964-1975.

Allen, J.R., and C. LaBash, 1997. Measuring shoreline change on Fire Island, NY. Maritimes, 39: 13-16.

Allen, J.R., C. LaBash, P. August, and N. Psuty, 2002. Historical and Recent Shoreline Changes, Impacts of Moriches Inlet, and Relevance to Long Island Breaching at Fire Island National Seashore, NY, Technical Report NPS/BSO-RNR/NRTR/2002-7, Dept. of the Interior, National Park Service.

Boothroyd, J. C., 1985. Tidal inlets and tidal deltas. In: R. A. Davis, Jr., editor, Coastal Sedimentary Environments, Second Edition, Springer-Verlag, Berlin, pp. 445-532.

Cowell, P. J., and B. G. Thom, 1994. Morphodynamics of coastal evolution. In: R.W. G. Carter and C. D. Woodroffe, editors. Coastal Evolution: Late Quaternary shoreline morphodynamics, Cambridge University Press, Cambridge UK, pp. 33-86.

Dolan R. and R.E. Davis, 1992. Rating Northeasters. Mariners Weather Log, 36: 4-11.

DuBois, R.N., 1995. The transgressive barrier model: an alternative to two-dimensional volume balanced models. Journal of Coastal Research, 11: 1272-1286.

Gravens, M.B., 1999. Periodic shoreline morphology, Fire Island, New York. Coastal Sediments '99, ASCE: 1613-1626.

Headland, J.R., C. Rasmussen, L. Bocamazo, W.G. Smith, and M. Herrman, 1999. Tidal inlet stability at Fire Island, Moriches and Shinnecock Inlets, Long Island, New York. Coastal Sediments '99, ASCE: 2249-2264.

Intergovernmental Panel on Climatic Change, 2001. IPCC Third Assessment Report: Climatic Change 2001. Cambridge University Press, UK.

Kana, T.W., 1995. A mesoscale sediment budget for Long Island, New York. Marine Geology, 126: 87-110.

Kana, T.W., 1999. Long Island's South Shore beaches: A century of dynamic sediment management. Coastal Sediments '99, ASCE: 1584-1596.

Kassner, J. and J.A. Black, 1982. Efforts to stabilize a coastal Inlet: A case study of Moriches Inlet, New York. Shore and Beach, 50: 21-29.

Kassner, J. and J.A. Black, 1983. Fire Island Inlet, New York: Management of a complex inlet. Shore and Beach, 51: 3-8.

Kelley, J. T., W. R. Gehrels, and D. F. Belknap, 1995. Late Holocene relative sea-level rise and the geological development of tidal marshes at Wells, Maine. Journal of Coastal Research, 11: 136-153.

Kraft, J. C., M. J., Chrzastowski, D. F. Belknap, M. A. Toscano, and C. H. Fletcher, 1987. The transgressive barrier-lagoon coast of Delaware: Morphostratigraphy, sedimentary sequences and responses to relative rise in sea level. In: Nummedal, D., O. H. Pilkey, and J. D. Howard, (eds), Sea-Level, Fluctuation and Coastal Evolution. Society of Economic Paleontologists, Tulsa, Oklahoma, pp. 129-143.

Kumar, N. and J.E. Sanders, 1974. Inlet sequence: A vertical succession of sedimentary structures and textures created by the lateral migration of tidal inlets. Sedimentology, 21: 491-532.

Leatherman, S.P. and J.R. Allen, editors, 1985. Geomorphic Analysis, Fire Island Inlet to Montauk Point Long Island, New York, Reformulation Study, Final Report from National Park Service for U.S. Army Corps of Engineers.

Morang, A., D.S. Rahoy, and W.G. Grosskopf, 1999. Regional geologic characteristics along the South Shore of Long Island, New York. Coastal Sediments '99, ASCE: 1568-1583.

McCormick, L., and M. Toscano, 1981. Origin of the barrier system of Long Island, N.Y. Northeastern Geology, 3: 230-234.

McCormick, L. R., O. H. Pilkey, Jr., W. J. Neal, and O. H. Pilkey, Sr., 1984. Living with Long Island's south shore. Duke University Press, Durham, North Carolina,

McGinty, T. 2004. Hurricane preparations: Taking LI by storm, scientists say this season could be more active than usual and predict island will be hit – eventually. Newsday, July 12, 2004, p. 6.

National Weather Service, Eastern Region, 1994. The Great Nor'easter of December 1992, Bohemia, NY.

Nordstrom, K.F., and J.M. McCluskey, 1985. The effects of houses and sand fences on the eolian sediment budget at Fire Island, NY. Journal of Coastal Research, 1: 38-46.

Pendleton, E.A., S.J. Williams, and E.R. Thieler, 2004. Coastal Vulnerability Assessment of Fire Island National Seashore to Sea Level Rise. U.S. Geological Survey Open-File Report 03-439.

Psuty, N.P., 1986. Holocene sea level in New Jersey. Physical Geography. 7: l56-l67.

Psuty, N.P, 1989. An application of science to the management of coastal dunes along the Atlantic Coast of the USA. In: C.H.Gimingham, W. Ritchie, B.B. Willetts, and A.J. Willis, editors, Coastal Sand Dunes, Proceedings. Royal Society of Edinburgh, Scotland, Section B (Biological Sciences), 96B: 289-307.

Psuty, N.P. 1990. Foredune mobility and stability, Fire Island, New York. In: K.F. Nordstrom, N.P. Psuty, and R.W.G. Carter, editors, Coastal Dunes: Form and Process, John Wiley Interscience, London, UK, pp.159-176.

Psuty, N. P., 2004. The coastal foredune: A morphological basis for regional coastal dune development. In: M. L. Martínez, and N. P. Psuty, editors, Coastal Dunes, Ecology and Conservation. Springer-Verlag, Berlin, pp. 11-27.

Psuty, N.P. and J.R. Allen, 1986. Analysis of dune crestline changes, Fire Island, New York, U.S.A. Proceedings, First International Conference on Geomorphology, Part 1, John Wiley & Sons, New York, NY, pp.1169-1183.

Psuty, N.P. and J.R. Allen, 1993. Foredune migration and large scale coastal processes. In List, J.H., editor, Large Scale Coastal Behavior '93. U.S. Geological Survey Open-File Report 93-381.

Psuty, N.P., J.R. Allen, and R. Starcher, 1988. Spatial analysis of dune crest mobility, Fire Island National Seashore, New York. In: N. P. Psuty, editor, Dune/Beach Interaction, The Journal of Coastal Research, Special Issue No. 3, pp. 115-120.

Psuty, N.P. and D.D. Ofiara, 2002. Sea-level rise. Coastal Hazard Management, Lessons and Future Directions from New Jersey. Rutgers University Press, New Brunswick, NJ, pp. 133-156.

Psuty, N. P., J. P. Pace, and J. R. Allen, in press. Coastal foredune displacement and recovery, Barrett Beach-Talisman, Fire Island, New York, USA, Zeitschrift fur Geomorphologie Supplementband, Coasts Under Stress II, 26 ms pp.

Psuty, N. P., and T. Piccola, 1994. Foredune sediment budgets, Fire Island, New York, USA, 1982-1991. In: A. Miossec, editor, Defense des cotes ou protection del'espace littoral, quelles perspectives, Proceedings, Universite de Nantes, pp. 186-196.

Rosati, J.D., M.B. Gravens, and W.G. Smith, 1999. Regional sediment budget for Fire Island to Montauk Point, New York, USA. Coastal Sediments '99, ASCE: 802-817.

Sanders, J.E. and N. Kumar, 1975. Evidence of shoreface retreat and in-place drowning during Holocene submergence of barriers: Continental shelf of Fire Island, NY. Geological Society of America Bulletin, 86: 65-76.

Schubert, C. E, and R. Busciolano, 1994. Peak storm-tide elevations produced by the December 1992 storm along the coast of Long Island, New York, with historical peak storm-tide elevations. Geology of Long Island and Metropolitan New York. State University of New York, Stony Brook, pp. 130-136.

Schwab, W.C., E.R. Thieler, J.R. Allen, D.S. Foster, B.A. Swift, J.F. Denny, and W.W. Danforth, 1999. Geologic mapping of the nearshore area offshore Fire Island, New York. Coastal Sediments '99, ASCE: 1552-1567.

Schwab, W.C., E.R. Thieler, J.R. Allen, D.S. Foster, B.A. Swift, and J.F. Denny, 2000. Influence of inner-continental shelf geologic framework on the evolution and behavior of the barrier-island system between Fire Inland Inlet and Shinnecock Inlet, Long Island, New York. Journal of Coastal Research, 16: 408-422.

Sherman, D. J., and B. O. Bauer, 1993. Dynamics of beach-dune systems. Progress in Physical Geography. 17: 413-447.

Smith, W.G., K. Watson, D. Rahoy, C. Rasmussen, and J.R. Headland, 1999. Historic geomorphology and dynamics of Fire Island, Moriches and Shinnecock Inlets, New York. Coastal Sediments '99, ASCE: 1597-1612.

Spencer, B. and A.V. Terchunian, 1997. The sand thieves of Long Island's South Shore. Shore and Beach, 65: 4-12.

Taney, N.E., 1961. Geomorphology of the south shore of Long Island, New York. Beach Erosion Board, Technical Memorandum No. 128. U.S. Army Corps of Engineers, Fort Belvoir, VA.

Tanski, J., H. Bokuniewicz, and C. Schlenk, 2001. Impacts of Barrier Island Breaches on Selected Biological Resources of Great South Bay, New York, Final Report. New York Sea Grant, Stony Brook, NY.

Titus, J. G., and V. K. Narayanan, 1995. The Probability of Sea Level Rise. U.S. Environmental Protection Agency, Washington, D. C.

URS Consultants/Moffatt & Nichol Engineers, 1999. Barrier Island Breach and Overwash Impacts: Atlantic Coast of Long Island, Fire Island to Montauk Point, New York. Position paper prepared as part of Storm Damage Reduction Reformulation Study, New York, NY.

U.S. Army Corps of Engineers, 1983. Atlantic Coast of Long Island, Fire Island Inlet and Shore Westerly to Jones Inlet, New York, Beach Erosion Control and Navigation Project, General Design Memorandum, New York District, NY.

U.S. Army Corps of Engineers, 1993. Fire Island to Montauk Point, Long Island, New York, Project Reformulation: Initial Management Plan, New York District, NY.

U.S. Army Corps of Engineers, 1995. Fire Island to Montauk Point Long Island, New York, Breach Contingency Plan, Executive Summary and Environmental Assessment, New York District, NY.

U.S. Army Corps of Engineers, 2002. Fire Island to Montauk Point Reformulation Study, Draft Interim Report, New York District, NY.

Valverde, H.R., A.C. Trembanis, and O.H. Pilkey, 1999. Summary of beach nourishment episodes on the U.S. East Coast barrier islands. Journal of Coastal Research, 15: 1100-1118.

Vogel, M. J., and T. W. Kana, 1985. Sedimentation patterns in a tidal inlet system, Moriches Inlet, New York. Proceedings, 19th International Coastal Engineering Conference, American Society of Civil Engineers, pp. 3017-3033.

Walker, H. J., and J. M. Coleman, 1987. Atlantic and Gulf Coastal Province. In: W. L. Graf, ed., Geomorphic Systems of North America. Geological Society of America: Boulder, Colorado, pp. 51-110.

Williams, A.T., 1985. Genesis of Fire Island foredunes, New York. Sedimentary Geology, 42: 201-216.

Williams, A.T., and P. Morgan, 1993. Scanning electron microscope evidence for offshore-onshore sand transport at Fire Island, New York, USA. Sedimentology, 40: 63-77.

Williams, S. J., and E. P. Meisburger, 1987. Sand sources for the transgressive barrier coast of Long Island, New York: Evidence for landward transport of shelf sediments. Coastal Sediments '87, ASCE: 1517-1532.

Williams, S.J., 1976. Geomorphology, shallow subbottom structure, and sediments of the Atlantic inner continental shelf off the Long Island, New York. Technical Paper No. 76-2, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA.

Wright, L.D., and A. Short, 1984. Morphodynamic variability of surf zones and beaches: A synthesis. Marine Geology, 56: 93-118.

WEB SITES

http://assembly.state.ny.us/leg/?cl=37&a=151 – New York State Assembly, NY State Consolidated Laws: Environmental Conservation, Article 34: Coastal Erosion Hazard Areas (CEHA).

http://cirp.wes.army.mil/cirp/ - Coastal Inlets Research Program of the U.S. Army Corps of Engineers; tide and inlet information, journal publications.

http://co-ops.nos.noaa.gov/tides04/tab2ec2a.html#20 - NOAA/NOS site for tide information.

http://frf.usace.army.mil/wis/ - site for hindcast wave data for offshore sites, Wave Information Studies program of the U.S. Army Corps of Engineers.

http://nyswaterfronts.com/index.asp - NY Department of State, Division of Coastal Resources.

http://pubs.usgs.gov/of/2003/of03-439/ - United States Geological Survey site; Coastal Vulnerability Assessment of Fire Island, USGS Open File Report 03-349.

http://fwie.fw.vt.edu/www/cmigis/FIISfiles/FIIS_report.pdf - Final Report of the NPS Vegetation Mapping Project at Fire Island National Seashore, CMI-GRS – 02-03.

http://www.dec.state.ny.us/website/regs/part505.html - NY State Department of Environmental Conservation site, rules and regulations, 6 NYCRR Part 505, Coastal Erosion Management. Also Part 661, Tidal Wetland Land Use.

http://www.fireislandassn.org/fia_home.htm - site for Fire Island Association; beach erosion issues, news, etc.

http://www.fireislandcc.org/ - Facts and resources about Fire Island.

http://www.fiyrra.com ; http://www.fiyrra.com/fiyrra/0204asbpa.pdf – Fire Island Year Round Residents Association; contains local tide information; newsletter for American Shore Beach Preservation Association.

http://www.nan.usace.army.mil/fimp/problem.htm - US> Army Corps of Engineers site for Fire Island to Montauk Point (FIMP) Reformulation Study.

http://www.ndbc.noaa.gov/Maps/Northeast.shtml - NOAA site for offshore buoys, waves and climate data. Two buoys have data records that pertain to Fire Island offshore area; Station #44025 has been collecting wave data since1996, and Station #44017 since 2002.

http://www.nicholas.duke.edu/psds/nourishment.htm - Program for the Study of Developed Coastlines, Duke University; beach nourishment database.

http://www.nps.gov/fiis/; http://www.nps.gov/fiis/BeachEA6-3-03.pdf - site for the National Park Service and Fire Island National Seashore; Fire Island National Seashore Short Term Community Storm Surge Protection Plan, Environmental Assessment, June 2003.

NPS D-114 September 2005

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