Geologic Resources Inventory Scoping Summary
Gateway National Recreation Area

Prepared by Trista L. Thornberry-Ehrlich
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Geologic Resources Division
National Park Service
US Department of the Interior

The Geologic Resources Inventory (GRI) provides each of 270 identified natural area National Park System units with a geologic scoping meeting and summary (this document), a digital geologic map, and a geologic resources inventory report. The purpose of scoping is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and monitoring and research needs. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity to discuss park-specific geologic management issues, and if possible include a site visit with local experts.

The National Park Service held a GRI scoping meeting for Gateway National Recreation Area on June 21, 2010 at the park's headquarters building in Staten Island, New York. A site visit at the recreation area occurred the following day. Heather Stanton (Colorado State University [CSU]) facilitated the discussion of map coverage and Bruce Heise (NPS-GRD) led the discussion regarding geologic processes and features at the park. After an introduction by park Chief of Resource Management, Dave Avrin, Norbert Psuty from Rutgers University presented a brief geologic overview of the park and surrounding area. Participants at the meeting included NPS staff from the park and Geologic Resources Division, geologists from Rutgers University (Dr. Psuty) and the New Jersey Geological Survey (Scott Sanford), and cooperators from Colorado State University (see table 2). This scoping summary highlights the GRI scoping meeting for Gateway National Recreation Area including the geologic setting, the plan for providing a digital geologic map, a prioritized list of geologic resource management issues, a description of significant geologic features and processes, lists of recommendations and action items, and a record of meeting participants.

Park and Geologic Setting

Established on October 27, 1972, Gateway National Recreation Area was the first National Park Service (NPS) unit having the national recreation area designation and contains the only national wildlife refuge in the NPS. The park is the third most visited NPS unit in the NPS system (nearly 9,000,000 visitors in 2010) spread out over more than 10,760 ha (26,600 ac). Gateway National Recreation Area is located in the Staten Island and Brooklyn boroughs of New York City as well as Monmouth County, New Jersey. The park consists of several units throughout the New York Harbor area including Great Kills, Miller Field, Fort Wadsworth, Sandy Hook, Breezy Point, Fort Tilden, Jacob Riis, Plumb Beach, and Jamaica Bay. Features at the park include saltwater and freshwater wetlands, maritime forests, freshwater ponds, beaches, dunes, barrier spits/islands, and waters in and around New York Harbor. The park includes Jamaica Bay, the largest natural open space in New York City, providing vital habitat for over 300 species of migratory birds.

The park is located near the maximum extent of Pleistocene glacial advance in New York, and glacial moraine and outwash unconsolidated deposits mantle the underlying bedrock in portions of the park. The bedrock throughout the area includes Cretaceous and Tertiary sedimentary units. The coastal areas of the park contain very young, Holocene sands derived from the glacial deposits, continental formations, and offshore shoals.

Geologic Mapping for Gateway National Recreation Area

During the scoping meeting, Heather Stanton (CSU) presented some of the main features of the GRI's digital geologic maps, which reproduce all aspects of paper maps, including notes, legends, and cross sections, with the added benefit of being GIS compatible. The NPS GRI Geology-GIS Geodatabase Data Model incorporates the standards of digital map creation for the GRI Program and allows for rigorous quality control. Staff members digitize maps or convert digital data to the GRI digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase and shapefile format, layer files complete with feature symbology, FGDC-compliant metadata, an Adobe Acrobat PDF help document that captures ancillary map data, and a map document that displays the map and provides a tool to access the PDF help document directly from the map document. Final data products are posted at NEW LINK. The data model is available at http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm.

When possible, the GRI Program provides large scale (1:24,000) digital geologic map coverage for each park's area of interest, which is often composed of the 7.5-minute quadrangles that contain park lands (fig. 1). Maps of this scale (and larger) are useful to resource managers because they capture most geologic features of interest and are spatially accurate within 12 m (40 ft). The process of selecting maps for management begins with the identification of existing geologic maps (table 1) and mapping needs in the vicinity of the park unit boundary. Scoping session participants then select appropriate source maps for the digital geologic data or develop a plan to obtain new mapping, if necessary.

Table 1. GRI Mapping Plan for Gateway National Recreation Area

Covered Quadrangles	Relationship to the park	Citation	Format	Assessment	GRI Action
Jersey City	Intersects several non I&M units managed by GATE	Stanford, Scott D., 1995, Surficial Geology of the Jersey City Quadrangle, Hudson and Essex Counties, New Jersey, New Jersey Geological Survey, Open-file Map OFM 20, 1:24000 scale	Digital	No	Convert NJGS data
Arthur Kill	Intersects part of GATE units on Staten Island	Stanford, Scott D, 1999, Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles, Middlesex and Union Counties, New Jersey, New Jersey Geological Survey, Open-file Map OFM 28, 1:24000 scale	Digital	No	Convert NJGS data within the Arthur Kill quad
Sandy Hook West and East	Intersects Sandy Hook Unit of GATE	Stanford, Scott D, 2000, Surficial Geology of the Sandy Hook Quadrangle, Monmouth County, New Jersey, New Jersey Geological Survey, Open-file Map OFM 39, 1:24000 scale	Digital	No	Convert NJGS data
Long Branch West and East	South of Sandy Hook Unit	Stanford, Scott D., 2000, Surficial Geology of the Long Branch Quadrangle, Monmouth County, New Jersey: New Jersey Geological Survey, Open-file Map OFM 38, scale 1:24000	Digital	No	Convert NJGS data

Covered Quadrangles	Relationship to the park	Citation	Format	Assessment	GRI Action
Sandy Hook West and East	Intersects Sandy Hook Unit of GATE	Minard, J.P., 1969, Geology of the Sandy Hook quadrangle in Monmouth County, New Jersey, U.S. Geological Survey, Bulletin 1276, 1:24000 scale	Paper/ DJVU	No	Digitize entire map
NJ parts of Jersey City, Arthur Kill, Sandy Hook (W and E) and Long Branch (W and E)	Intersects NJ units of GATE	Pristas, R. P., 2004, Bedrock geology of New Jersey, New Jersey Geological Survey, Digital Geodata Series DGS 04-6, 1:100000 scale	Digital	No	Convert portions of NJGS data that intersect quadrangles of interest
NJ parts of Jersey City and Arthur Kill	Intersects northern NJ units of GATE	Drake, A.A., Volkert, R.A., Monteverde, D.H., Herman, G.C., Houghton, H.F., Parker, R.A., and Dalton, R.F., 1996, Bedrock geologic map of northern New Jersey, U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-2540-A, 1:100000 scale	Paper	No	Digitize symbology and features not present in digital data for quadrangles of interest
Sandy Hook (W and E) and Long Branch (W and E)	Intersects Sandy Hook Unit of GATE	Owens, J.P., Sugarman, P.J., Sohl, N.F., Parker, R.A., Houghton, H.F., Volkert, R.A., Drake, A.A., Jr., and Orndorff, R.C., 1999, Bedrock geologic map of central and southern New Jersey, U.S. Geological Survey, Miscellaneous Investigations Series Map I-2540-B, 1:100000 scale	Paper	No	Digitize symbology and features not present in digital data for quadrangles of interest
Sea Cliff, Lynbrook, Lawrence	East of GATE units	Fuller, M.L., 1914, The geology of Long Island, New York, U.S. Geological Survey, Professional Paper 82, 1:125000 scale	Paper	No	Digitize parts of map in quadrangles of interest
Jersey City, Arthur Kill, The Narrows	Intersects western GATE units	Merrill, F.J.H., Darton, N.H., Hollick, Arthur, Salisbury, R.D., Dodge, R.E., Willis, Bailey, and Pressey, H.A., 1902, New York City folio, Paterson, Harlem, Staten Island and Brooklyn quadrangles, New York-New Jersey; Staten Island 15' Quadrangle (page 26), U.S. Geological Survey, Geologic Atlas of the United States Folio GF-83, 1:62500 scale	Paper	No	Digitize NY portions of map, update geologic unit names to match modern conventions
Brooklyn, Jamaica, Coney Island, Far Rockaway	Intersects Jamaica Bay and Breezy Point units of GATE	Merrill, F.J.H., Darton, N.H., Hollick, Arthur, Salisbury, R.D., Dodge, R.E., Willis, Bailey, and Pressey, H.A., 1902, New York City folio, Paterson, Harlem, Staten Island and Brooklyn quadrangles, New York-New Jersey; Brooklyn 15' Quadrangle (page 27), U.S. Geological Survey, Geologic Atlas of the United States Folio GF-83, 1:62500 scale	Paper	No	Digitize map, update geologic unit names to match modern conventions
Jersey City, Arthur Kill, The Narrows	Intersects western GATE units	Merrill, F.J.H., Darton, N.H., Hollick, Arthur, Salisbury, R.D., Dodge, R.E., Willis, Bailey, and Pressey, H.A., 1902, New York City folio, Paterson, Harlem, Staten Island and Brooklyn quadrangles, New York-New Jersey; Staten Island 15' Surficial Quadrangle (page 30), U.S. Geological Survey, Geologic Atlas of the United States Folio GF-83, 1:62500 scale	Paper	No	Digitize NY portions of map, update geologic unit names to match modern conventions

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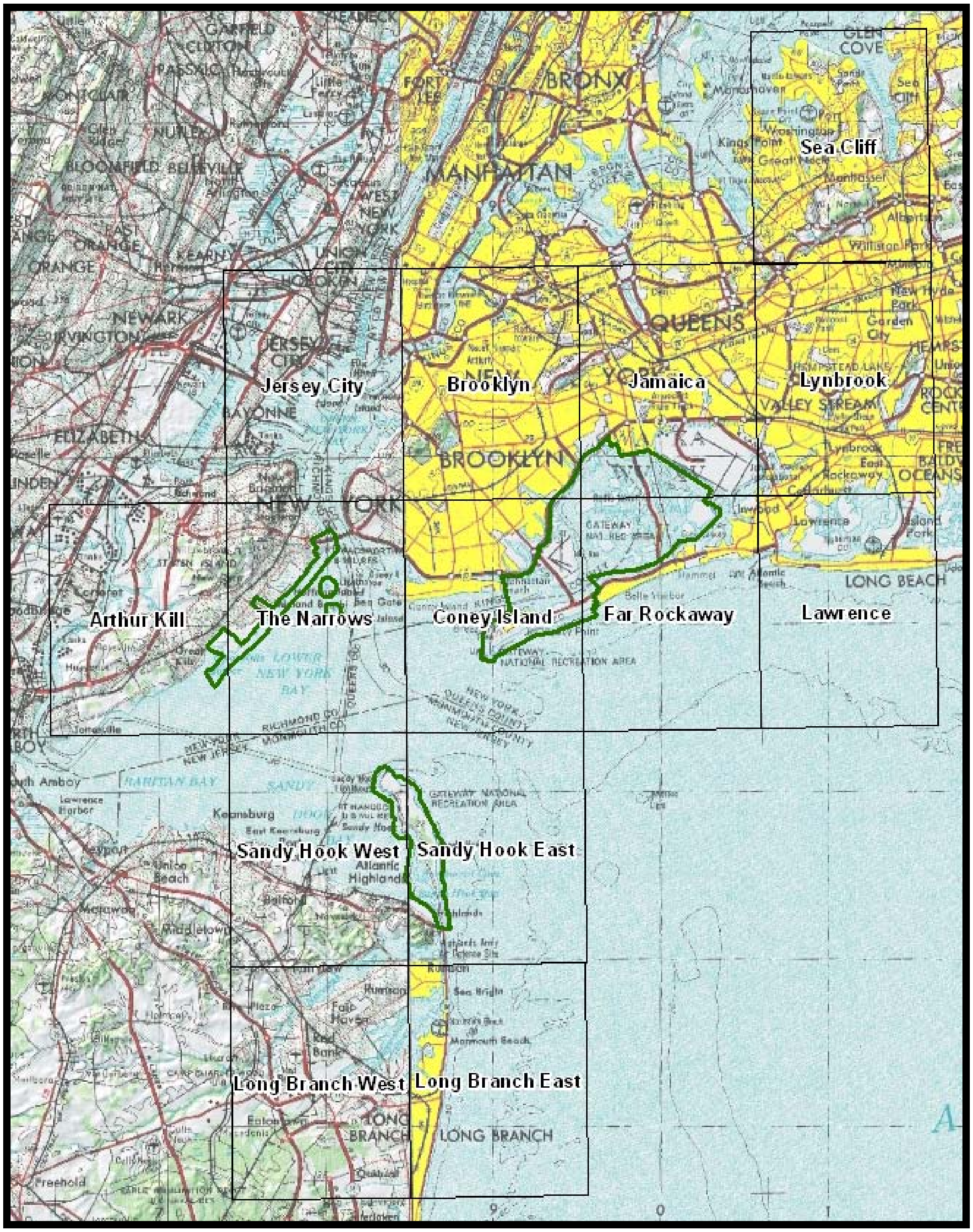

Figure 1. Area of interest for Gateway National Recreation Area, New York and New Jersey. The 7.5-minute quadrangles are labeled in black. Green outlines indicate national recreation area boundaries.

Map data from different sources, displaying different themes and at different scales, are available for discrete areas within Gateway National Recreation Area. Surficial data for Staten Island exist in a U.S. Geological Survey (USGS) water resources information report (WRI 87-4048) at 1:41,700 scale by Soren (1988). Surficial and bedrock mapping are available, including some buried contacts and subaqueous geology, from the New Jersey Geological Survey (NJGS). The NJGS also provides glacial sediment mapping at 1:100,000 scale, and maintain a mine features database that may have pertinent information for the park concerning disturbed lands. There is bedrock map coverage for New York at 1:250,000 scale. The New York museum may also have some geologic map information. Problems with New York data may arise with different projections. Certain mapping entities used their own projections based on features such as water towers. Using road networks between new and old maps may help alleviate georeferencing issues caused by odd projections.

To properly manage the coastal resources in the park, there is a great need to know where sediment is accumulating or eroding and in what direction. Bathymetric data and some benthic habitat maps for Jamaica Bay should be available in 2011. Sidescan sonar surveys exist, acquired by an Acoustic Doppler Current Profiler (ADCP), that have some information on the bathymetry, current direction, and bedrock bottom of some areas. The park is interested in knowing the exact location of jetties, groins, anthropogenic modifications throughout the park, but especially south of Sandy Hook, New Jersey. The park also would like to obtain well date, especially for Jamaica Bay and Brooklyn. The park would like to see a wetland layer on the geomorphic map.

During the scoping meeting the following quadrangles were determined to be of interest for park resource management needs: Sea Cliff, Jersey City, Brooklyn, Jamaica, Lynbrook, Arthur Kill, The Narrows, Coney Island, Far Rockaway, Lawrence, Sandy Hook (West and East) and Long Branch (West and East). The GRI will digitize or convert maps listed in Table 1. Old, circa 1902 folio maps have good detail and are the basis for newer mapping including plant surveys by the Staten Island Research Institute. However, the shoreline has changed dramatically since 1902 and some of the geological terminology may be out of date. The park decided this bedrock and surficial coverage was adequate for their needs. In addition to the bedrock and surficial data, it was determined that more detailed coastal geomorphological mapping is needed in coastal areas of the park and that the Geologic Resources Division will enter into an agreement with Norb Psuty and the Rutgers University group to conduct this work. This group has access to an underwater vehicle (AUV) that can go offshore to gather data in the submarine environment. NPS coastal mapping protocols will serve as guidelines for any potential future mapping. In addition to the data listed in Table 1, data that could be consulted include wells and natural fissures in Brooklyn and seismic susceptibility maps in New Jersey mentioned by Scott Stanford. An additional resource that could be consulted for data covering Gateway National Recreation Area is the New York State GIS Clearinghouse (http://www.nysgis.state.ny.us/); Mark Christiano has contacts within the New York City government that could help with some GIS data.

Geologic Resource Management Issues

The scoping session for Gateway National Recreation Area provided the opportunity to develop a list of geologic features and processes, which will be further explained in the final GRI report. During the meeting, participants identified the most significant issue as:

Coastal development/evolution and management

Other geologic resource management concerns discussed include coastal erosion processes, fluvial and lacustrine features and processes (including wetlands), seismicity, disturbed lands, submerged features, and impacts from climate change. The park is currently working on its general management plan with an estimated time to completion of 1–2 years. Knowledge of the geology of the area would aid in this endeavor.

Coastal development/evolution and management

The coastline at Gateway National Recreation Area is constantly changing. Two of the major factors influencing the shoreline geomorphological evolution at the park are sea level change and sediment supply. Sea level change plus other components such as wave energy (dimension and direction) control the transport of sediment in the system. In the New York Harbor area, waves are coming from the southeast resulting in a north and east sediment transport direction. Coastal features are being driven and elongated into New York Harbor. There is not a great source of sediment for Sandy Hook as opposed to Long Island, which has glacial sediments in the form of till, moraine, and outwash. At Breezy Point there is evidence of inlets all along the island showing sediment accumulating into the backbay including 2006 LiDAR data showing detailed topography including dune features and relict inlets. In Jamaica Bay, the system has lost access to the major source of sediment that once entered through an adjacent coastal inlet. The westward extending Breezy Point barrier as substantially isolated the Bay from the coastal source of sediment. At Sandy Hook, the coast of New Jersey immediately to the south is continental bedrock rather than Holocene dandy barrier island and thus provides a limited supply of sediment to Sandy Hook. Mapped old shorelines and dunes are preserved at Sandy Hook because extensive residential and commercial development did not occur there as at Breezy Point.

NOAA maintains two tidal gauges in the area, one on Sandy Hook and one at The Battery at the northwest corner of Long Island. The latter is sited on bedrock, whereas the former sits on a foundation of thick Holocene sands. The Sandy Hook gauge shows a 4 mm/year (0.2 in./yr) inundation due in part to a global rate of 2 mm/yr (0.01 in./yr) and the island subsiding at 2 mm/yr (0.01 in./yr) (sand compaction and subsidence are the primary processes as the island consists of 800 ft of unconsolidated sediment). Rutgers has contracts with the NPS to monitor shorelines within the park.

With current levels of sea level rise, instability is causing shoreline erosion, wetland loss and continual displacement of shoreline features. These result in a morphology manifested as scarps, bluffs, dunes, and beaches. A portion of Plumb Beach is moving inland 2 to 3 m/yr (6 to 9 ft/yr) and a portion of Great Kills is eroding about 5 m/yr (16 ft/yr) (figs. 2 and 3). At Sandy Hook, 2005 LiDAR data show shorelines migrating north and west, with between 306,000 and 382,000 cu m/yr (400,000 and 500,000 cu yd) of sediment moving along the migrating zone. Sandy Hook is accumulating about 30 m/yr (100 ft/yr) on the northern end (fig. 4). Jamaica Bay historically received adequate amounts of sediment to maintain the system balance and had more wetlands.

However, the wetlands are currently disappearing due to sea level rise, boat wakes, and dredging. There exist many questions about the restoration of wetlands in the bay. The NPS and Army Corps of Engineers (USACOE) are “building” wetlands in Jamaica Bay. Here, the USACOE dredges sediment and pumps it to remnants of a large flood tidal delta. Sediment has also been placed at Plumb Beach, an artificial ridge of sand that forms the road base for part of the Belt Parkway (built in the 1930s). Plumb Beach is part of the Jamaica Bay Unit of Gateway and it incorporates a very active beach/dune system as well as an important wetland habitat.

The dynamic coastal system at Gateway National Recreation Area has been the site of extensive anthropogenic impacts for many generations. The “cultural” versus “natural” features throughout much of the park are a continuum. Most of the area is not strictly natural, but modified by humans in some way. These modifications are in turn altered by natural processes and the sequence continues. Coastal modifications include jetties, groins, riprap, sea walls, hardened shorelines, and dikes. At Breezy Point, construction of a large jetty in 1938 caused massive sediment accumulation and seaward shoreline displacement with associated beach and dune topography. There are timber, stone, and concrete bulkheads in this part of the park. Sedimentation is extending westward and creating flood-tide delta topography. However, there is near constant dredging of channels into the bay and redistribution of the sediment. According to an 1891 map of Great Kills on Staten Island, there was a barrier island and associated backbay wetlands at the site of park component; it was subsequently eroded. Development has since altered much of the original topography with landfill, marina dredging, and an artificial barrier. The central portion of Plumb Beach is currently stabilized with an extensive barrier of sand bags. Erosion is extending in both directions from the central locations and impacting the beach/dune topography. The Fort Wadsworth and Miller Field “beaches” are artificial, composed of fill to create a type of sandy barrier at the shoreline.

At Sandy Hook in 1982(?), severe erosion cut the beach and damaged the single shore road in the park. This so-called critical zone of erosion location is near where a seawall ends (within NPS boundaries) on Sandy Hook (fig. 5). Approximately 300,000 to 400,000 cu m/yr (392,000 to 523,000 cu yd/yr) of sand is moving to the north. Net alongshore transport direction is from north to south, then to the west around the hook, where the waves refract. Some of the sand is accumulating at the northern tip and extending the Hook. Right now, there is a newly-constructed buried pipeline that is intended to transport a sand slurry southward. 30,000 cu m/yr (40,000 cu yd/yr) from the northern area to the Critical Zone, a recycling of the longshore transport This is working within the scale of dynamics and the natural system, rather than dumping millions of yards of dredged sediment all at once. The unusually cold winter of 2009–2010 froze water in the pipes and curtailed operation of the system. As of this meeting date (June 2010), plans call for operation of the slurry pipeline in November, 2011.

Other geologic resource management issues

Coastal erosion processes

Management issues at Gateway National Recreation Area include pervasive erosion. Artificial fill material at Great Kills overlies wetlands and landfills, connecting a remnant of the former barrier island to the mainland. This material is interlayered, and contains anthropogenic signatures including brick clasts and other debris (fig. 6). Now, erosion is creating small cliffs into that fill. Scarps at Great Kills can reach 4 m (13 to 14 ft), above the beach below. This is threatening infrastructure such as trails and parking areas. A bike path at Plumb Beach is constantly threatened by erosion, and mitigation efforts are not stemming the threats to the bike path that runs adjacent to the beltway. There are steep drop-offs up to 2 m (6 ft) high at the Fort Tilden bulkhead where erosion is also removing sediment inland of the structure. Fort Wadsworth is vegetated and relatively free from slope process issues. Walkways over dune areas along the shore are often shifted and inundated with sand. Winter storms (i.e. March 2010) can scour out 2.5 m (8 ft) drops at almost any shore. These can be a hazard to visitors before the summer beach reestablishes itself below. Identifying specific erosional zones would be a useful dataset for park resource managers.

Fluvial and lacustrine features and processes

Along the northern margin of Jamaica Bay, there are channels with fluvial deposits and adjacent wetlands. On Staten Island there is an amalgamation of streams at Great Kills. Moravian Creek used to flow through the northeastern section of Miller Field. It is now buried after complaints of flooding by local residents forced the city's hand. This was one of the last trout streams in New York City. Nearby is a rare swamp white oak forest. Due to water management practices, this environment is no longer a swamp, and is currently rather unhealthy. The park is interested in preserving it. Oakwood Creek flows along the northeast boundary of Great Kills. This open area is prone to flooding. A concrete walkway ends and the boundary is unclear over a wetland that was channelized pre-1930s. The National Hydrologic Database group has nothing on file for Gateway National Recreation Area. There is some desire at the park to restore some freshwater wetlands. There are already turtles and frogs present in riparian areas within the park.

There are several freshwater ponds on Sandy Hook with numerous smaller freshwater features (wetlands) (fig. 7). Big Johns Pond is in a valley of the wildlife refuge. After a fire there, a tractor excavated the area for reptile habitat. There are lots of pond features in Jamaica Bay. Return-a-gift Pond was funded by tax money. "Rift Valley" ponds are in the northern area of Jamaica Bay. Exclamation Point Pond, North Pond, and Coast Guard Pond are all at Sandy Hook. These often form in swale areas that remain after additional accretion to the hook of the barrier. The Hook serves as a freshwater conduit. Griese Point has wetland and coalescing pools. Hidden Pond at Fort Tilden was excavated as a dump area for the army. Ponds form a critical habitat because freshwater at the surface is relatively rare within the NPS areas at Gateway National Recreation Area.

Seismicity and tsunamis

The passive eastern continental margin of the United States is not a hotspot for seismicity. Nevertheless, seismic events occur all along the coast as buried ancient structures accommodate stresses within Earth's crust. Historically, there were two magnitude ≈5 earthquakes in the New York City area. One was on Coney Island in 1884 and another occurred locally in the 1730s. There are low-magnitude events occurring on a constant basis. It is possible that evidence of seismic deformation could be discovered in the sediments at Gateway National Recreation Area, such as blowouts and liquefaction features. Historical slump blocks flank the bluffs below Sandy Hook at the Highlands. The NJGS website has an epicenter map. If seismicity of significant magnitude did occur, bluffs along the Atlantic Highlands have failed before and could be triggered to fail again. These are outside of the park, but could impact the sediment budget at Sandy Hook. The NJGS has seismic susceptibility maps for the counties in New Jersey. Each report has landslide, seismic soil class, and liquefaction susceptibility maps at the following website http://www.njgeology.org/enviroed/hazus.htm. Seismic epicenters are catalogued at http://www.njegology.org/geodata/dgs04-1.htm. The New York City Metro area consortium has data for New York.

Tsunamis may occur if the bluffs on Highlands near Sandy Hook were to fail and slough into the sea, causing a large wave (see Menard professional paper). The USGS published a document about landslides in the New Jersey Highlands available at http://pubs.er.usgs.gov/djvu/PP/pp_898.djvu. Similar to the effects of major storms, a tsunami type event would funnel into New York Harbor affecting Staten Island and Jamaica Bay. Nicholas Koch (Queen's College) did a study on old islands off of the Rockaways.

Disturbed lands and boundary issues

Gateway National Recreation Area is nearly synonymous with disturbed lands. Some of the earliest impacts included grazing along salt marshes in colonial times. Great Kills was a dump area and contains radioactive waste. This is the reason for a proposed restoration soils project. There are numerous salt water marsh restoration projects ongoing. The sand supply pipeline at Sandy Hook is restoring the budget of sediments by anthropogenic manipulation. There are borrow pits in Jamaica Bay, with Grassy Bay being the largest. Developers dredged Jamaica Bay to provide fill material for adjacent John F. Kennedy airport. A portion of this area was formerly salt marsh. Many landfills are within park areas. Some sand mining may have occurred locally. The park boundary is at mean low tide (this datum is always changing and legislation is vague on that point). In theory, the park has 0.4 km (0.25 mi) of offshore area; however, at Sandy Hook, the land is moving so quickly that the boundaries are constantly changing too. The Beltway boundary was clearly defined at Plumb Beach. The NPS owns all of Jamaica Bay, but in general, the boundary issues of the park are difficult.

Submerged features

Park boundaries extend some 0.4 km (0.25 mi) offshore, thus a large area within the park is submarine. In general, the substrate offshore is much the same as that onshore, namely sand and unconsolidated, mixed sediments Because of the shifting, dynamic nature of the coastline within the park, this boundary is also changing and there is some confusion as to where the boundary is at a particular area at a specific time. There is some speculation that natural fissures in bay sediments are acting as sources of upwelling freshwater driven by hydraulic gradient. Researchers at Rutgers University have access to a submarine research vessel (AUV) that could be a useful mapping tool for the offshore areas of the park given funding support.

Impacts from climate change

The park is very interested in management for climate change. Even a small change in sea level will have dramatic effects on the coastal landforms within the park. Increasing sea level will severely impact the park causing significant dune movement. In November 2009, a severe winter storm caused coastal landform changes, and then on March 14, 2010, an extended cyclonic nor'easter storm lasted over six high tides and caused drastic damage and erosion. The NPS lost $3,000,000 of assets, 1.5 to 4.5 m (5 to 15 ft) of cliffside area was lost at Great Kills, and unexploded ordinance were exposed in park dunes. This erosion threatened cultural resources and infrastructure. If climate change causes increased storm frequency and intensity, the park resources are in danger of severe degradation and change. According to topographic models, as long as the sediment supply is adequate, dunes will maintain their elevations. Whether the dune continuity will remain intact is unknown. Dimensions and features of the dune/beach system will remain the same, but shift location (typically landward). If sediment supply is inadequate, the continuity of coastal features will likely degrade and irregularities will be the norm. Recreational resources will be impacted at Gateway National Recreation Area. Sandy Hook may become Sandy Island and pose an access issue for resource managers.

Figure 2. Erosion and sandbags attempting to stabilize the shore at Plumb Beach. Note the proximity to the Belt Parkway and the washed out remnant of the bike path adjacent to the chainlink fence to the right of the image. View is to the west. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 3. Erosional scarp at Great Kills. Note the trees being undercut and washing into the water. Pilings were once beneath a bathhouse at the site. View is to the southwest. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 4. Active accretion of the northern end of Sandy Hook as marked by the fresh, unvegetated sand. Note the New York City metro area in the distance. View is to the north. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 5. View of Sandy Hook sand spit at the southern margin of the park boundary. Note the location of the shore road and portions of the seawall. View is to the east from Twin Lights State Park. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 6. Layered fill at the Great Kills erosional scarp. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 7. Freshwater marshes in interdune swales on the accretionary end of Sandy Hook. View is to the east. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Features and Processes

Coastal features and processes

Gateway National Recreation Area hosts myriad coastal features including beaches, dune ridges, barrier spits, foredunes, stranded foredunes, washover fans, inlets, tidal deltas, berms, marshes, and backbay lagoons. Beaches are a land feature, a transitory strip of sand often mapped as beach. This ever shifting coastal system is controlled by many factors including the rate of sea level change, the amount of relative sea level rise, sediment supply, longshore drift, storms (these may tap sediments that are usually immune to coastal processes), wave direction, and anthropogenic impacts. Sediment supply is from the glacial deposits as well as sediments eroded from the continent by fluvial, coastal, and colluvial processes. Most of the sand and sediment along the coastal areas of Gateway National Recreation Area accumulated approximately 2,000 years ago when sea level was several meters lower than its current level. At that time, the rate of sea level change slowed to approximately 1 mm/yr (0.04 in./yr). At this time, the sand "organized" into a series of barrier islands, with accompanying marshes and estuaries. This relative slow rate of sea level change persisted until about 500 years ago, when the rate increased again—possibly the result of the agricultural revolution followed by the industrial revolution (i.e., human impacts). Now, the Late Holocene sediments are greatly affected by humans and are now mostly the product of manipulation. In the local area, tide gauge records and C^{14} dates give overall trends of climate change and sea level fluctuation. Local rise is a function of passive margin subsidence, self-compaction, and global sea level rise.

Features at the park such as Great Kills and Miller Field are the result of recent anthropogenic processes interacting with local wave and currents and sea level changes. Rockaway Peninsula is not directly formed of glacially derived sediments, but is the result of westward drift of re-mobilized glacial outwash sediments. At Jamaica Bay, a brackish water estuary exists with much of the freshwater input derived from groundwater, not surface water. Terraziano (USGS) produced a publication studying fissures in the bay as freshwater sources. There is some concern about waste water treatment plants that may impact Jamaica Bay.

Geomorphological features are divisible as formed via accumulation or erosion. Features formed by accumulation include beaches, dunes, sand-inundated marshes, barrier spits, and accreted headlands. Features formed by erosion include bluffs, cliffs, channels, scours, and scarps. However formed, the topography, habitat, and ecosystem at Gateway National Recreation Area are worthy of careful management, but reactions to changes are hard to predict due to the pervasive anthropogenic development.

History and geology connections

Poised at the entrance to New York City's valuable harbor area, the Hudson River Valley, and northern coastal New Jersy, Gateway National Recreation Area has long been a settlement site, important transportation corridor, and strategic landform. Archaeological remains attest to early American Indian inhabitants. A paleo-Indian site known as "area K" is the proposed site for a Veteran's Center behind Navy Lodge at Fort Wadsworth. There are archaeological remains at Barren Island and Fort Tilden, such as charcoal deposits. Floyd Bennett Field also has features of archeological interest. During the American Revolutionary War, Gateway forts played important roles in the defense of New York City. Many of the coastal defenses are from the American Civil War era, including the Weed Battery on Staten Island (fig. 8). Other historic features that have a connection to geology include Floyd Bennett field. This flat open space was the cradle of early aviation and New York City's first municipal airport. The oldest continually operating lighthouse in the country is at Sandy Hook, shining a light to warn passing ships of shallow waters off the end of the ever-changing sand spit.

The history at Gateway National Recreation Area includes a long and ongoing progression of land-use changes and human attempts to manipulate the natural system. Many historic maps covering the area show the progressive filling of marshes dating back to before the 1800s. Early USGS maps show prolific tidal marshes prior to infilling.

Paleontological resources

According to the paleontological resource inventory and monitoring report prepared by the Geologic Resources Division for Gateway National Recreation Area, there is potential to find fossils in glacial deposits in Staten Island. There are Pleistocene through Cretaceous rocks at depth. Fossils often wash up on beaches. People trawling for clams have found mastodon teeth in the marine sediments. C^{14} dates are available from Sandy Hook, Staten Island, and Jamaica Bay. The oldest date from the Menard map/report is 9,000 years old. These were dates from marsh deposits and other inland sources which indicate that Sandy Hook was formerly in a bay environment and that the Hook environment has migrated inland and northerly during the Late Holocene.

Glacial features

During the Pleistocene, episodic cooler climates led to global glaciation events. Of these, the Illinoian and later Wisconsinan events strongly influenced the development of the landscape in the Gateway National Recreation area. The park sits at or near the glacial terminus of the Wisconsinan event and the surrounding area exhibits a glaciated landscape to the north and an unglaciated landscape to the south. Terminal moraines and glacial outwash underlie much of the park area in New York whereas unglaciated bedrock exists in New Jersey. The glacial terminus was across Staten Island and the Narrows at Fort Wadsworth. The terminal moraine formed here approximately 14,000–16,000 years ago with a seaward apron of glacial outwash spreading southward including the northern area of Jamaica Bay. The Narrows is the result of the terminal moraine which was once continuous across here and impounded the Hudson Valley drainage forming a series of glacial lakes. Finally, the moraine was breached at the narrows forming a "natural gateway" slot through the moraine deposits (fig. 9). Some drainage even came from the Great Lakes area and this flux of freshwater may have caused a cooling trend, providing a link between geology and paleoclimate.

Aeolian features

There are no isolated dune features except those associated with the beach profile (coastal processes). Older shorelines have dune lines associated with them. In the Merrill report (available online), there is a thin veneer of aeolian silt atop the glacial sediments in the soil profile at Staten Island. There is regionally a few feet of loess atop till and moraine deposits. These are often important marker beds for archaeological studies indicating a lack of anthropogenic disturbance.

Unique features

Winter beaches turn red and dark due to the winnowing away of quartz grains from garnet and other heavy mineral sands that originate in glacial outwash supplying the local alongshore sediment supply. New Jersey is a source for dark minerals out of Cretaceous and Tertiary units. McMaster published a New Jersey beach sands publication indicating source areas and processes.

Two manmade islands exist at GATE: Hoffman Island (former sanitarium), and Swinburne Island (Ellis Island rejects and crematorium) (fig. 10). Developers constructed these islands in the late 1800s with deposits excavated during the subway system development in New York City. There are no maintained boat landing sites at these islands. Their shorelines are rocky and slippery. Populations of seals and birds use the islands for habitat.

Figure 8. Weed Battery, a Civil War era fortification on the northeastern edge of Staten Island. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 9. Verrazano Narrows Bridge from Staten Island to Brooklyn, located at the breach across the terminal moraine. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 10. Hoffman Island (foreground) and Swinburne Island (background) in New York Harbor. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Field Trip Notes

Stop 1: Twin Lights overlook (New Jersey State Park). At the base of Sandy Hook, the spit began to erode in the 1950s. In 1976, some water breached the area in a storm. At least four former inlets are recorded on historical charts discharging through Sandy Hook (once intermittently "Sandy Island"). There is a Miocene-age veneer of sediments on the Highlands of New Jersey. The Critical Zone occurs at the end of the seawall made of large angular rocks. The Navesink-Shrewsbury river system drains through here into Sandy Hook Bay from south to north at the base of the bridge. This confluence is an important habitat for mercenaria clams in the inner bay. Without the seawall, a natural system of breaches and closures would occur with sediment accumulating from the Navesink-Shrewsbury river system. The neck is very narrow and the access road to the park is threatened by erosion and overwash. Sand occasionally must be plowed from the road and waves during storms, such as the March 2010 storm, threaten access. Freshwater ponds sit between salt marsh zones south of the end of the hook as progressive accretion forms prograding shorelines. At Spermiceti Cove, there is shellfish habitat and salt marsh. These are rather rare here due to pervasive filling. Holly and western red cedar form the forest cover on the older parts of the hook. Between 1976 and 1980, the park attempted beach nourishment at the Critical Zone on the Hook. In 1983–84, dredging of the Federal navigation channel off of the north end of the Hook transferred sand from the channel to a barge on the bayside and then via a pipeline to the Critical Zone. Similar efforts saw some 1,529,000 cu m (2,000,000 cu yd) of sand transported in 1990, 1998, 2002, and 2007. Current plans call for sediment to be moved via a slurry pipeline that extends from Gunnison Beach, buried along the road shoulder, to the Critical Zone. The pipeline consists of an 28-cm (11-in.) pipe buried 0.5 m (1.5 ft) below the surface and three booster stations, with three potential discharge points south, middle, and north at the Critical Zone. There is a pipeline spur to the Kingman-Mills Battery sites on the bayside. The pipeline only ran three days before freezing in the winter 2009–2010. Beach nourishment threatens surf breakpoints at one end of the sea wall where waves peak at a sand bar and riders can surf 460 m (500 yd) inland in one run. The Highlands are an erosional upland remnant from 5.2 Ma. Until the Pliocene, there was a connected highland between Twin Lights and Long Island. The pre-Illinoisan Hudson River drained southwest and exited at Delaware Bay, at approximately 2 Ma. There were three glaciations here since the New York Bight formed at Raritan Bay, the Hudson River breached the upland to carve its current course. Fluvial deposits regionally record this change. Hudson River canyon is now flooded, but during two more glaciations, the channel deepened and eroded farther into the upland area. After the glacial retreat, a bay area filled the lowlands approximately 9,000–10,000 years ago with 45 to 60 m (150 to 200 ft) of Holocene sediments. The glacier here was part of the Laurentide ice sheet (Hudson-Champlain lobe). It melted back out of the area by approximately 18,000 years ago, as dated by the terminal moraine at Staten Island. Nearshore shelf deposits make up the Highlands and include glauconite deposits.

Stop 2: Lot C. The bike path is five or six years old and is a multi use path (MUP). The sea wall originally followed the shoreline at the time it was built in 1900–1926. The shoreline has now visibly retreated north of the wall's terminus. 172,000 cu m/yr (225,000 cu yd/yr) of sediment loss was estimated over the period 1982–1990. Available surveys include a NGDB 29 vertical datum to monitor subaerial changes and contains a great record of where, how, and when material moves. There is a 400 m (1,300 ft) offshore bar that is visible during storms that forms a wave break off of the northern portion of the seawall. This bar bends inland and connects to the shoreline north of the terminus of the seawall. There is a shoal at the bend beyond the seawall to the north that is fed by artificial beach nourishment occurring to the south. Inland dunes here are not moving. The south dune joins the seawall then crosses it farther south. Dunes were created at the Critical Zone by the NPS inland of the recreational beach. Species such as piping plovers, black skimmers, oyster catchers, and terns nest at the beach and the park restricts access to these sensitive areas. There are seven groins in the NPS property at Sandy Hook that are tied to the seawall. They are within the low, intertidal zone. In general, a jetty at an inlet creates a jet to flush the inlet whereas a groin reduces alongshore sediment movement (by 50% in theory). In New Jersey all these types of features are often “jetties”. There are several shore-parallel lines of artificial dunes.

Stop 3: Fishing Beach. On the way to the beach the road passes Nike missile silos. In the 1960s, there was a stand-down at Fort Hancock. This could be a future interpretive target. Magnetic surveys show Sandy Hook as being “metallic” due to the presence of ordinance and metal structures everywhere. The beach has a dissected foredune at its inner margin that is migrating inland and shows erosional scarps and inland transfer of sediment. The 2010 March storm exposed a WWII dance floor adjacent to the parking area. It is now reburied by shifting sands. Unexploded ordinance is exposed often. Beach nourishment sand must be screened for ordinance, 90% will still detonate and is dangerous. People who find such ordinance are advised to turn them into the park ranger station. This is an area of persistent erosion, but there are some natural dunes present. Here, waves are orthogonal to the coastline with a north-south facet; farther northward, the waves are progressively less orthogonal to the beach face. The USGS did LiDAR surveys here in 2009, but they were returned due to large holes in the data. The 2007 data are acceptable. There are 2005 data for Jamaica Bay and that survey is rescheduled for 2011. LiDAR surveys there are very difficult because of the air traffic and policies of JFK airport.

Stop 4: North Beach. Prior to extensive beach nourishment in 1983–84, the foredune was far inland. The beach has now accumulated vast amounts of sediment since 1983–84 because of beach nourishment in the park and updrift of the park, nearly 382,000 cu m/yr (500,000 cu yd/yr) due to net longshore transport. The Sandy Hook navigational channel is not filling up very quickly and there is little need to regularly dredge. The park owns ¼ mi seaward of the shoreline, so technically, the park “owns” the shipping channel because of vast sediment accumulation there. The lighthouse used to be at the shore, but is now far inland. LiDAR shows many former shorelines and dunes here that are inland now due to sediment accretion. The False Hook shoal offshore here is part of an ebb tide delta. It extends far to the south in 3 to 4 m (9 to 12 ft) depth of water. There is a good connection between that shoal and Sandy Hook. Sediment may be propelled along the shoal instead of filling the navigational channel. In 1994 there was a major beach nourishment project in the communities south of the park boundary. 15,000,000 to 19,000,000 cu m (20,000,000 to 25,000,000 cu yd) of sand have accreted here since 1994. At North Beach, the slurry pipeline will extend to the shoreline during its operation. It sucks up a sand slurry that is pumped downsystem to the south. There are freshwater pond and marsh areas behind sequential accumulated and stranded former dunes.

There is a nice view of Staten Island and Manhattan from this point. There is 380 ft of serpentinite (bedrock) exposed on a roadcut on Staten Island. Geologists estimate a 91 m/km (300 ft/mi) ice profile (slope rise of ice surface) behind the terminal moraine, thus the ice was 460 m (1,500 ft) thick in Manhattan (Empire State building is ≈ 350 m [1,150 ft] tall). The terminal moraine crosses the Narrows into Brooklyn. Long Island is Cretaceous bedrock and mantled by moraine, outwash, and Holocene fill at the coast. The two tails of Long Island at the eastern end are moraine over bedrock. Harbor Hill is late Wisconsinan. The ice may have retreated earlier on Long Island than Staten Island. Work in New York for glacial history and deposits has stalled this century, but there is a big hydrologic interest for New York City that may spur further work.

Stop 5: Nine Gun proving grounds. The military used to test ammunition here by shooting down the beach. This explains the vast amount of buried ordinance that exists at Sandy Hook. The battery here dates from 1890–1910 and featured disappearing guns that recoiled downward to be reloaded. In 1924–25, there was a dune here with ponds trapped behind. The recurves of the island have freshwater wetlands in the interdune swales. All the bare sand off the north shore is very young, only a few years old, since ca. 2006 surveys. Two navigation channels go into New York Harbor: the northern Ambrose channel to New Jersey and Manhattan, and the southern Sandy Hook channel to New Jersey ports. The north maintenance area near the green water tower floods from the bayside. Battery Potter was a command center that looks like a vegetated dune on the seaward side, as do many of the abandoned military features at Gateway National Recreation Area.

Stop 6: Lighthouse and Fort Hancock. This is the oldest continuously-operating lighthouse in the US. Menard mapped slumps at the base of the New Jersey Highlands bluffs. The slumps may have originated at seeps above an aquitard clay layer. Atop the Highlands is an apartment building that was constructed just prior to regulations prohibiting such construction. It appears very out of place on the landscape. Officer's Row is visible here with older houses in need of refurbishing. These could be leased out or used as possible park housing if the remodeling projects could proceed.

Stop 7: Chapel. The NPS wants a permanent dock here one for ferries and NPS boats including a 7 m (23 ft) boat. There are old breakwaters and pillars (pilings) of wood here. There is a need to know how to stabilize the eroding shoreline here first before the dock construction. The engineering structures currently do not allow for a dock or for shallow-water research vessels. Perhaps a wave absorbing surface (stone bulkhead) parallel to the existing bulkhead? There is also a problem with the state of New Jersey regarding clam resources. The NPS is not finding clams here, but the state has habitat maps indicating a clam habitat. The state finds clams offshore from here, but the sand in the nearshore area is different and many predators seem to preclude the inhabitation of clams. The dock would be sheltered by the accreting hook and not much dredging would be required at first.

Stop 8: Kingman Mills. This site is next to a holly forest, with old battery housing guns (like the ones featured in the film "Guns of Navarone" with a 30 km [20 mi] range, 35 cm [14 in.] guns) along the eroding shoreline. The slurry pipeline may bring sand here. Offshore AUV data exist for this location.

Stop 9: Great Kills. There is radioactive fill here (not considered very dangerous to visitors). An old beach club (bathhouse) existed here. The park removed it, but pilings are visible indicators of erosion along the shore. More than 15 years later, there has been 5 m/yr (16 ft/yr) of shoreline retreat at the former bathhouse location. Trees are falling in to the harbor, particularly during storms. The erosive bank has a scarp several meters high. There is some relict marsh where there used to be a barrier island. The eroded material is now transported southwest along the beach and will close the access to the harbor soon if left alone to proceed naturally. There are monthly water quality measurements available for this location. Trails, roads, marina, and other infrastructure are threatened here by the ongoing erosion. The scarp shows layering of sediments, but Norb Psuty is fairly certain that this is fill with brick clasts, shells (not outwash). Layering could be due to adding via truck and dredging when the marina was created.

Stop 10: Great Kills, Crookes Point. This area and trail accreted since the installation of the post-WWII jetty. Crookes Point used to be an island, but the neck was artificially filled in.

Stop 11: Plumb Beach. This vantage point looks out toward Breezy Point to the south. Rockaway Inlet is open to the ocean there. This is an inlet to Jamaica Bay. Waves come directly onshore here that are refracted at West Sheepshead Bay and East Jamaica Bay. This is an artificial sand ridge atop marsh deposits that are inland of the location of an original barrier island. The community use is very high here. Erosion at the west end toward the beltway is causing accumulation at the east end and inundation of the marsh there that hosts bird and crab habitats. The ACOE dredges 100,000–200,000 cu m (131,000–262,000 cu yd) of channel fill from Rockaway Inlet every few years and could nourish the beach here, but that would be too much influx all at once and would overwhelm the system and completely bury the marsh. Norb Psuty suggests bio-log groins at the end to protect the marsh and keep sand more at the beach. There is a sandbag and construction debris foundation here to attempt to mitigate erosion toward the Beltway. Many thousands of sand bags are here to attempt to keep the beach and protect the Beltway. Permit issues restrict what the park can do. For instance, there can be no bulkhead and no asphalt. This system was created in the 1930s with the construction of the Beltway. A large fill operation created a wide beach, an artificial dune line, with vegetation in 1992. This area needs sediment management. In 1992, the ACOE moved some 112,000 cu m (146,000 cu yd) of sand that started shifting east. Now, the new dune line is expanding over the wetlands and towards the navigation channel at the eastern end of the beach.

Stop 12: Driving around Jamaica Bay. The Riis Park area of the Jamaica Bay Unit is very low and has been inundated many times. All of the islands visible in Jamaica Bay today are brackish marshes. In the early 1920s, squatters claimed tracts of land under what is now the Cross Bay Boulevard. Eventually, they were granted property rights in exchange for paying taxes. The town of Broad Channel now occupies this area. This town has a dispute with the NPS because the NPS wants to keep a natural state of erosion in place, but natural processes will eventually flood the town. A rise in sea level of 1 m (3 ft) will effectively destroy the town, even if sea level does not rise this much, periodic storms will cause significant damage. There is an erosion issue on nearby West Pond where a dike was constructed to create a fresh water pond. The dike is now subject to erosion. There is debate as to whether the dike should be repaired in the face of continual sea level rise. There are concerns about needing to balance what is going to happen naturally with maintaining the pond and the town. The NPS is cooperating with the ACOE on a plan to continue dredging the Rockaway Inlet with the dredge spoil to serve as a base to restore the Jamaica Bay wetland areas. The Rutgers University group (Norb Psuty) performed surveys to determine what level of sand was necessary for this restoration. Experiments are underway along the northern edge of Jamaica Bay on rebuilding the marshlands.

Recommendations

1. Consult the NJGS website regarding geologic concerns for Sandy Hook and the Highlands area http://www.njgeology.org.
2. Consult the New York City administrations GIS clearinghouse for additional map data.

Action Items

1. GRI report author will consult the parks website on climate change http://www.nature.nps.gov/geology/parks/gate/index.cfm.
2. GRI staff will obtain a copy of the USGS WRI 87-4048 by Soren (1988).
3. GRI report author will obtain a copy of the Merrill report (available online) regarding the soil profile at Staten Island.
4. GRI report author will obtain the New Jersey beach sand publication by McMaster.
5. GRI report author will obtain a copy of Terraziano's USGS publication on fissures in the bay as freshwater sources.
6. GRI report author will obtain copies of the Menard professional paper and study by Nicholas Koch from Queens College on tsunamis and Rockaways.

References

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Table 2. Scoping Meeting Participants

Name	Affiliation	Position	Phone	E-Mail
Doug Adamo	NPS, GATE	Chief of Natural Resources	718.354.4510	doug_adamo@nps.gov
Dave Avrin	NPS, GATE	Resource Management Chief	718.354.4625	dave_avrin@nps.gov
Mark Christiano	NPS, GATE	GIS Specialist	718.354.4225	mark_christiano@nps.gov
Brian Feeney	NPS, GATE	Staten Island Unit coordinator	718.351.8426	brian_feeney@nps.gov
Bruce Heise	NPS, Geologic Resources Division	Geologist	303.969.2017	Bruce_Heise@nps.gov
Pete McCarthy	NPS, GATE	Sandy Hook Unit coordinator	732.872.5513	pete_mccarthy@nps.gov
Suzanne McCarthy	NPS, GATE	Deputy Superintendent	718.354.4663	suzanne_mccarthy@nps.gov
Bill Parker	NPS, GATE	Biologic Technician		william_s_parker@nps.gov
Norb Psuty	Rutgers University	Coastal geomorphologist	732.708.1462	psuty@marine.rutgers.edu
Amanda Rollizo	NPS, GATE	Biologic Technician		
Scott Stanford	NJGS	Research scientist	609.292.2576	scott.sanford@dep.state.nj.us
Heather Stanton	Colorado State University	Geologist	970.491.5147	heather_stanton@partner.nps.gov

Dave Taft	NPS, GATE	Unit coordinator	718.338.3358, ext 238	dave_taft@nps.gov
Trista Thornberry-Ehrlich	Colorado State University	Geologist	406.837.2274	tthorn@warner.cnr.colostate.edu