National Park Service
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Natural Resource Stewardship and Science

Inventory of Coastal Engineering Projects in Gateway National Recreation Area

Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/738



ON THE COVER
Fort Hancock's Officers' Row, Sandy Hook unit, Highlands, New Jersey.
Photograph by: Kate Dallas

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Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/738

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Abstract

A reconnaissance-level investigation, analysis and inventory of coastal engineering projects in eight coastal national parks were completed by Oregon State University with funding provided by the National Park Service Geologic Resources Division. The coastal national parks inventoried in this study include:

1. Cape Hatteras National Seashore
2. Colonial National Historical Park
3. Fort Matanzas National Monument
4. Fort Raleigh National Historic Site
5. Gateway National Recreation Area
6. Golden Gate National Recreation Area
7. Olympic National Park
8. San Francisco Maritime National Historical Park

This report includes information on coastal engineering projects identified in, or immediately adjacent to, Gateway National Recreation Area (GATE). The report serves as a supplement to a Geographic Information Systems (GIS) database (the GIS data are available online at http://irma.nps.gov).

The natural processes of sediment transport and coastal evolution within GATE have been extensively altered by coastal engineering projects. Two hundred and fifty-four coastal structures were identified within and adjacent to the park. Together these structures span over 58 km (36 mi) and armor or stabilize 36% of the park's shoreline. Nine beach nourishment projects (with 31 episodes) placed a minimum of 10.2 million m^3 (13.3 million yd^3) of sand within the park from 1915–2012, while four additional projects (with 29 episodes) placed over 36 million m^3 (47 million yd^3) of sand updrift of park shorelines between 1926 and 2009.

Three dredging projects (with 44 episodes) removed over 5 million m^3 (6.5 million yd^3) of sediment from navigation channels adjacent to the Staten Island and Sandy Hook units of GATE between 1934 and 2011. Three filling projects (with 6 episodes) in the Staten Island unit placed a minimum of 12.6 million m^3 (16.5 million yd^3) of material from 1860–1948. Dredge and fill projects within the Jamaica Bay unit have dramatically altered the landscape. Very conservative estimates of dredging cite the removal of 71 million m^3 (93 million yd^3) of material from 1900–1992 (Swanson et al. 1992).

Historic dredge and fill activities within Jamaica Bay have decreased the bay's surface area and increased mean water depths. These changes have modified the bay's hydrodynamics, negatively impacted water quality, and contributed to a large loss of wetland habitat.

Dredge, fill, and stabilization efforts at Staten Island's Great Kills Park have significantly altered the natural landscape. These projects altered longshore sediment transport pathways and filled historic wetlands, degrading natural ecosystem services.

Sandy Hook's Sea Bright seawall has stopped the natural processes of overwash and inlet formation. The seawall, coupled with groin construction, has artificially stabilized the southern

end of the spit. While spit stabilization has promoted recreational access and development, it has also contributed to erosion at the northern end of the seawall.

The feasibility of protecting all of the threatened buildings and roads within GATE will decrease in the future as sea level rises and the existing coastal engineering structures degrade. Understanding the implications associated with allowing some developed sites within GATE to revert to natural processes is critical.

Acknowledgments

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We would like to specifically thank Mark Christiano, a GIS specialist at Gateway, for spending multiple days in the field with us during our site visit to Gateway. Mark's local knowledge was incredibly useful while visiting coastal structures and he helped arrange informative meetings with other park staff and local experts. Mark also provided all of the imagery used in the study.

Park staff at Gateway were extremely helpful and provided assistance throughout the project. Tom Hoffman, Ricky O'Neill, Linc Hallowell, and Dave Avrin were especially helpful. Brian Forseth, Chief of Maintenance at the Sandy Hook Unit, provided information about the Sandy Hook sand slurry pipeline and Bruce Lane, Chief Ranger, supplied beach nourishment data for Sandy Hook's Critical Zone.

Karl Nordstorm, Nancy Jackson, and Norb Psuty of Rutgers University supplied local expertise and references. Their collective wisdom, experience in the area, and assistance with our project was invaluable to our research.

Steve Couch, Erin Nagel, and others at the U.S Army Corps of Engineers New York office met with us during our site visit to discuss dredging operations in the region. In the months following, they generously shared data and answered our many questions. Annette Baden, the Corps' Assistant to the Freedom of Information Act Officer, provided additional historic dredging records.

Background information for structures at the Sandy Hook Coast Guard Station was provided by Brian McCabe, a U.S. Coast Guard Chief Warrant Officer.

Introduction

The Coastal Engineering Inventory (CEI) project aims to inventory, catalog and map coastal engineering projects in and adjacent to coastal units of the National Park Service (NPS). The primary projects that were inventoried include coastal structures, dredge and fill projects, and beach nourishment and dune construction projects. In this phase of the inventory coastal engineering projects were identified in eight coastal national parks. Prior to this study another report (Coburn et al. 2010) documented coastal engineering projects in ten additional coastal national parks. The report and GIS data are available online at http://irma.nps.gov.

In this phase of the NPS CEI project, a qualitative impacts analysis was also performed to help better understand the extent of human-altered coastal areas within each respective park. This section describes the impacts of coastal engineering projects and their influence on natural sediment transport processes. In addition to highlighting major engineering projects that are impacting local and regional sediment transport, we have also included related information pertaining to current park management concerns as expressed during the site visit.

Coastal engineering projects are usually motivated by a desire to stabilize the coastline from erosion or alter the coastal zone for a particular purpose (i.e. maintain a navigation channel, develop roadways, or restore wetlands). In order to fulfill project objectives, a suite of engineering solutions are available that are typically categorized into hard and soft engineering projects. Coastal engineering solutions often combine both hard and soft engineering approaches, such as when beaches are nourished following breakwater construction.

Hard engineering solutions include the construction of seawalls, revetments, breakwaters, sills, and bulkheads to stabilize the shoreline and sometimes protect against coastal flooding (see the Glossary in Appendix A for definitions). Jetties and groins are also classified as hard engineering projects and are used to alter the sediment transport regime by trapping sediment. Impacts from hard structures are highly site dependent, but may include the loss of sediment supplied to downdrift areas, localized scour in front of and at the downdrift end of structures, visual impacts, placement losses, reduction in beach access, and the alteration or reduction of habitat.

Soft engineering solutions include non-structural means of stabilizing the backshore or changing coastal environments through beach nourishment, dune construction, dredging, or filling. These methods add or redistribute sediment within the system and are used to widen sediment-starved beaches, maintain navigable waterways, protect coastal infrastructure, and restore wetlands. As with hard solutions, impacts vary significantly by project and location. Soft engineering projects may impact hydrodynamic and sediment transport processes, beach morphology, aquatic ecosystems, and/or beach habitats.

The overall goal of this study is to develop a greater understanding of the coastal engineering modifications in the National Park System. Along coastlines expected to be impacted by climate change, structurally modified shorelines will likely respond differently than natural coastlines, which may have a more dynamic response to coastal erosion and sea level rise. An inventory of coastal engineering modifications will provide information to allow resource managers to make better decisions about how to preserve NPS resources, establish baselines, develop desired future conditions, and balance the protection of historic resources and infrastructure with the

preservation of natural systems. All of these actions will improve the ability of the NPS to manage coastal park units in accordance with NPS policies. The main NPS policies relevant to coastal engineering projects are summarized below (see NPS *Management Policies 2006* for more detail).

Maintenance of Natural Processes

Generally, NPS policy requires that natural coastal processes in parks, such as erosion, shoreline migration, deposition, overwash, and inlet formation, be allowed to continue without interference (NPS *Management Policies* § 4.8.1.1 2006). The NPS may intervene in these processes only in limited circumstances, such as when there is no other feasible way to protect natural resources, park facilities, or historic properties (NPS *Management Policies* § 4.8.1 2006).

Restoration of Natural Processes

In parks where pre-existing or new activities or structures have altered and/or are currently altering coastal dynamics, ecosystems, tidal regimes, and sediment transport rates, the NPS policy is to investigate, in consultation with appropriate state and federal agencies, alternatives for mitigating the effects of such projects and for restoring natural conditions (NPS *Management Policies* § 4.8.1.1 2006). NPS restoration actions in human-disturbed areas seek to return the area to the natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated, as called for by park management plans (NPS *Management Policies* § 4.1.5 and § 4.4.2.4 2006). An example would be the restoration of shoreline processes.

Park landscapes disturbed by natural events, such as hurricanes, are allowed to recover naturally unless manipulation is necessary to 1) mitigate for excessive disturbance caused by past human effects, 2) preserve cultural and historic resources as appropriate based on park planning documents, or 3) protect park developments or the safety of people. (NPS *Management Policies* § 4.1.5 and § 4.4.2.4 2006).

Construction of Facilities

Generally, the NPS must avoid the construction of buildings, roads, and other development that will cause unacceptable impacts on park resources and values (NPS *Management Policies* § 9.1 2006). Development will not compete with or dominate park features or interfere with natural processes (NPS *Management Policies* § 9.1.1.2 2006). In shoreline areas, this means that new developments will not be placed in areas subject to wave erosion or active shoreline processes unless 1) the development is required by law; or 2) the development is essential to meet the park's purposes, as defined by its establishing act or proclamation, and

- no practicable alternative locations are available;
- the development will be reasonably assured of surviving during its planned life span without the need for shoreline control measures; and
- steps will be taken to minimize safety hazards and harm to property and natural resources (NPS *Management Policies* § 4.8.1.1 2006).

Replacement of Facilities

Park development that is damaged or destroyed by a hazardous or catastrophic natural event will be thoroughly evaluated for relocation or replacement by new construction at a different location. If a decision is made to relocate or replace a severely damaged or destroyed facility, it will be

placed, if practicable, in an area that is believed to be free from natural hazards (NPS *Management Policies* § 9.1.1.5 and § 4.1.5 2006).

Cooperative Conservation

Under NPS policy, park superintendents are required to monitor state government programs for managing state-owned submerged lands and resources within NPS units. When there is potential for such programs to adversely impact park resources or values, superintendents will make their concerns known to appropriate state government officials and encourage compatible land uses that avoid or mitigate potential adverse impacts. When federal acquisition of state-owned submerged lands and resources within NPS units is not feasible, NPS will seek to enter into cooperative agreements with state governments to ensure the adequate protection of park resources and values (NPS *Management Policies* §3.4 2006).

In addition, the NPS has the authority under 36 C.F.R. §1.2(a)(3) to apply general NPS regulations, such as special use permit requirements, on or in waters that are subject to the jurisdiction of the United States, or in areas within their ordinary reach up to the mean or ordinary high water line, even if the submerged lands are non-federally-owned and regardless of whether the park has exclusive, concurrent, or proprietary jurisdiction. Waters subject to the jurisdiction of the United States refers to three types of waters: (1) navigable (as defined in 33 C.F.R. § 2.36(a), (2) non-navigable but located on lands for which the U.S. has acquired title or control and has accepted or retained exclusive or concurrent jurisdiction, and (3) waters made subject to U.S. jurisdiction by certain international agreements and statutes (33 C.F.R. § 2.38).

Methods

Coastal engineering terminology was adapted from the NPS Coastal Engineering Inventory pilot project (Coburn et al. 2010) and through discussion with the NPS Geologic Resources Division. The NPS selected eight coastal national parks in which coastal engineering projects were identified, inventoried and mapped. Projects in the inventory include engineered coastal structures, dredging, filling, beach nourishment, and dune construction.

A digital park boundary shapefile for all of the inventoried parks was downloaded from the NPS Integrated Resources Management Applications Portal (https://irma.nps.gov). Georeferenced digital orthophoto imagery was obtained and added to ArcMap 10.0 to create a basemap.

A visual inspection of the orthophoto imagery was completed and locations of all discernible coastal structures were digitized using ArcMap. A site visit to the park in December 2011, along with staff correspondence, was used to complement and confirm initial findings based on examination of the imagery and to identify other coastal engineering projects not evident from imagery alone. A comprehensive online and hardcopy literature search was undertaken to obtain attribute data for each project (year of construction, material, year of maintenance, cost, lead construction agency, and volume). Unless otherwise specified, costs presented in the report are in project-year dollars.

A project was considered distinct if there was any discernible, physical separation between it and an adjacent coastal engineering project. A series of bulkheads constructed by individual interests, for example, would be classified as one structure as long as no identifiable gaps were observed between them. Some projects, such as dredge projects that place dredge spoil on the beach, serve multiple purposes (i.e., dredging and beach nourishment). In these cases, the primary reason for the project was ascertained and the project was classified accordingly. Projects that occurred repeatedly in one place (e.g. inlet dredging) were counted as one project.

Overview statistics were calculated to summarize the coastal engineering projects within each park. The percentage of shore stabilized or impacted by coastal structures was found by totaling the length of bulkheads, breakwaters, groins, revetments, seawalls, and sills and dividing it by the total length of shoreline. Structure length and shoreline length were determined using ArcMap. The structure length used in calculating the percentage of shoreline armored for individual shore parallel structures was merely the length of the structure. For groin fields (defined here as three or more groins) the length of stabilized shore was set as the length of the groin field, while for jetties the width of the mouth of the inlet was used.

An ArcGIS 10.0 file geodatabase for each park was compiled using ArcMap. Each geodatabase includes a park boundary feature class and identified coastal engineering projects separated into three feature classes: 1) coastal structures 2) dredge and fill projects and 3) beach nourishment and dune construction projects. The GIS projects also contain an ArcMap document for data viewing (.mxd), data layer files (.lyr), FGDC-compliant metadata (.xml and.txt), FAQ metadata (.html), a table attribute file (.pdf), and a README file (.pdf). Location information for dredge, fill, beach nourishment, and dune construction projects was often non-existent or vague. Therefore, not all of these projects are included in the GIS data, and those that are included have only approximate locations.

Results

A total of 254 coastal structures, 9 beach nourishment projects (31 episodes), and 6 dredge and fill projects (50 episodes) were identified in, and adjacent to, Gateway National Recreation Area (GATE) (Table 1). In addition, an unknown, large number of dredge and fill projects have occurred within Jamaica Bay. Four beach nourishment projects (29 episodes) also placed large volumes of sand on beaches updrift (i.e., outside) of the park. We include, in our analysis beach nourishment projects from as much as 12 km (7.5 mi) updrift of the park if they influence sediment dynamics within the park.

GATE is broken into three units: Jamaica Bay, Staten Island, and Sandy Hook (Figure 1). This report is organized by park unit with GATE summary statistics and background presented first, followed by descriptions of engineering projects within each unit. Summaries of the coastal engineering projects identified within each park unit are presented in Appendices B–J.



Figure 1. Map of Gateway National Recreation Area showing the three major park units: Jamaica Bay, Staten Island and Sandy Hook (NPS 2013).

Coastal structures within and adjacent to the park extend for over 58 km (36 mi) (Table 2 & Figure 2). Excluding the Jamaica Bay Marsh Islands, structures stabilize roughly 36% of the shoreline within GATE (Figure 3). Individually, the Jamaica Bay, Staten Island, and Sandy Hook unit shorelines are 36%, 45%, and 31% stabilized, respectively (Jamaica Bay percentage includes bay and ocean shorelines and excludes the marsh islands).

Table 1. Coastal engineering projects in each unit of Gateway National Recreation Area. The number of episodes for each beach nourishment or dredge/fill project is shown in parentheses. Beach nourishment and dredge/fill projects include only those projects where a year and an approximate location could be determined, and not all of the projects had volume information. Therefore, the number of projects and total volumes should be considered minimum values and represent only a fraction of the total projects that have occurred within the park.

Park Unit	[1]# Structures	# Beach Nourishment Projects	[2]Beach Nourishment Volume (million m^3)	Beach Nourishment Year	# Dredge/Fill Projects	Dredge/Fill Volume (million m^3)	Dredge/Fill Year
Jamaica Bay	143	[2]4 (32)	25.80	1915–2012	?	[3]71	1900–1992
Staten Island	47	4 (13)	2.38	1936–1983	4 (15)	13.88	1860–2003
Sandy Hook	64	[2]5 (15)	18.67	1963–2009	2 (35)	3.77	1960–2011
Total	**254**	**13 (60)**	**46.85**		**?**	**88.65**	

[1]Includes structures in and adjacent to GATE.

[2]A majority of the beach nourishment projects occurred updrift (i.e. outside) of the park in the Jamaica Bay and Sandy Hook units,.

[3]Swanson et al. (1992) reports a conservative estimate of 71 million m^3 of sediment dredged from Jamaica Bay from 1900–1970.

Table 2. Coastal structures in Gateway National Recreation Area (note, some of the structures overlap).

[1]Structures	GATE Total	GATE Total Length (m)	Jamaica Bay	Jamaica Bay Length (m)	Staten Island	Staten Island Length (m)	Sandy Hook	Sandy Hook Length (m)
Breakwater	**5**	**580**	3	265	1	195	1	120
Bulkhead	**25**	**16,070**	14	10,425	5	2,215	6	3,430
Groin	**126**	**7,630**	79	4,430	17	1,560	30	1,640
Jetty	**2**	**2,700**	1	2,550	1	150	0	0
Levee	**1**	**195**	0	0	1	195	0	0
Pier	**33**	**8,110**	19	4,925	8	2,785	6	400
Revetment	**54**	**17,350**	26	9,020	10	3,560	18	4,770
Seawall	**8**	**5,870**	1	1,365	4	1,435	3	3,070
TOTAL	**254**	**58,505**	**143**	**32,980**	**47**	**12,095**	**64**	**13,430**

[1]See Appendix A for structure definitions.

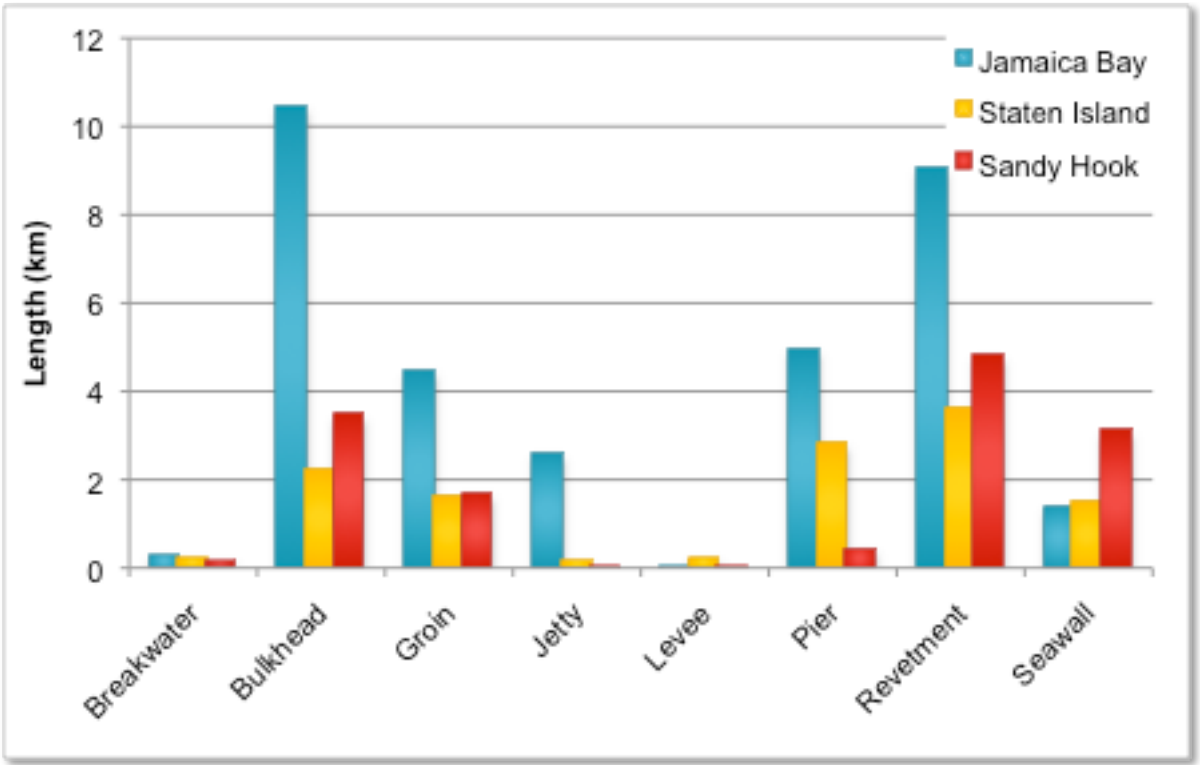


Figure 2. Total length of each structure type in the three units of GATE.

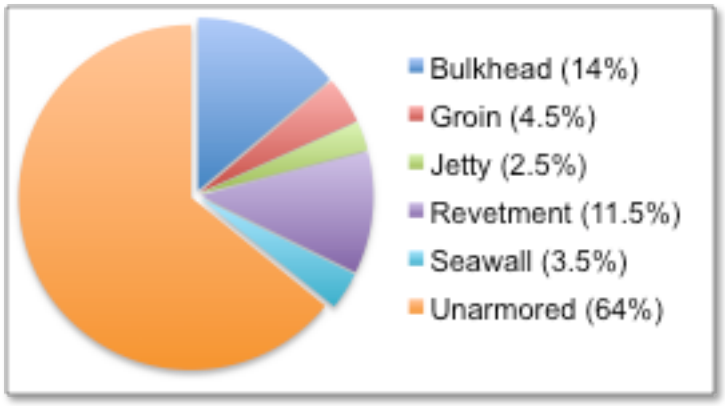


Figure 3. Percentage of shoreline stabilized (by structure type) and unarmored in GATE (excludes Jamaica Bay Marsh Islands).

The shoreline within GATE has experienced many beach nourishment, dredge, and fill projects, a majority of which occurred before the park was established in 1972. Due to the sheer number of projects, it was beyond the scope of this project to research each individual nourishment, dredge, and fill project that has occurred within the park boundary. In addition, many projects that were identified within the literature did not have robust documentation and often lacked volume and/or location information. Therefore, nourishment, dredge, and fill data presented in this report are not a complete representation of what has actually occurred within the park, and quantitative results should be considered minimum values.

Nine beach nourishment projects (with 31 episodes of nourishment) were identified within GATE that together placed 10.2 million m^3 (13.3 million yd^3) of sand on park beaches from 1915–2012. Four additional projects (with 29 episodes of nourishment) placed 36.6 million m^3 (47.9 million yd^3) of sand on beaches updrift of the park between 1926 and 2009 (combined results in Table 1).

Three dredging projects in the Staten Island and Sandy Hook units removed a total of 5.1 million m^3 (6.7 million yd^3) of sediment from 1934–2011 during 44 dredging operations. Fill projects in the Staten Island unit placed a minimum of 12.6 million m^3 (16.5 million yd^3) of material between 1860 and 1948 (minimum because not all projects had volume information) (dredge and fill results combined in Table 1).

Jamaica Bay has been extensively altered by dredge and fill projects since 1900. Swanson et al. (1992) reports a conservative estimate of sediment dredged in Jamaica Bay as 71 million m^3 (93 million yd^3) from 1900 to 1992. Channel dredging in the first half of the 20th century increased the volume of the bay by 350%, while filling of the bay margins reduced the surface area of the bay by nearly 50% (New York City Department of Environmental Protection (NYCDEP) 2007).

Background

Gateway National Recreation Area (GATE) includes more than 100 km^2 (26,600 ac) of parkland in New Jersey and New York (Figure 1). The park was established on October 27, 1972 and was the first site selected as part of a proposed nationwide program intended to bring the National Park System closer to the cities of the United States (NPS 1979). GATE is the third most visited unit in the NPS system and is in one of the most highly developed regions in the world. GATE consists of over 45 km (28 mi) of open to near open ocean shoreline and over 100 km^2 (25,000 ac) of salt marsh estuary in Jamaica Bay.

The shoreline of GATE is composed of ocean beach, barrier peninsula, and estuarine tidal marsh. The bedrock throughout the area includes Cretaceous and Tertiary sedimentary units (Thornberry-Ehrlich 2011). The park is located near the maximum extent of Pleistocene glacial advance in New York, and glacial moraine and outwash sediments overlie bedrock in some sections of the park. Coastal areas within the park are comprised of Holocene sands derived from glacial deposits, continental formations, and offshore shoals (Thornberry-Ehrlich 2011).

Winter storm waves, driven by strong northeasterly winds, refract around New England and arrive from the east-southeast locally (Psuty et al. 2010). This pattern of winds and waves results in northward sediment transport along the New Jersey shore and westward transport along the Rockaway Peninsula. The dominant longshore transport along Staten Island is from northeast to

southwest, but there is a reversal in direction (toward inner New York harbor) at the northeast end of the island.

The coast of GATE experiences semi-diurnal tides (two highs and two lows per day) with an average spring tidal range of 1.59 m (5.22 ft) at the Sandy Hook tide gauge (Psuty et al. 2010). The Sandy Hook tide gauge shows a relative sea level rise of 3.90 $\pm$ 0.25 mm/yr (0.15 $\pm$ 0.01 in/yr) from 1932 to 2006 (NOAA 2012a), due in part to global sea level rise and to the island subsiding at 2 mm/yr (0.01 in/yr) (Thornberry-Ehrlich 2011). The Battery tide gauge, at the southern tip of Manhattan, records a lower rise of 2.77 $\pm$ 0.09 mm/yr (0.11 $\pm$ 0.004 in/yr) from 1856 to 2006 (NOAA 2012a) because sediment compaction at this location is lower (Psuty et al. 2010). These rates of relative sea level rise are considerably larger than the 20th century global average of 1.7 mm/yr (0.07 in/yr) (Church and White 2006).

GATE was affected by Hurricane Sandy, which came ashore in the Mid-Atlantic United States on October 29, 2012. Impacts along the coast included significant beach and dune erosion, widespread flooding, overwash and sediment deposition, and catastrophic damage to oceanfront homes and infrastructure. At Fire Island National Seashore (roughly 50 km [31 mi] east of the Jamaica Bay unit of GATE), the dunes lost as much as 3 m (10 ft) of elevation and eroded back an average of 21 m (70 ft), the equivalent of 30-years of chronic coastal change (USGS 2012a). Specific impacts within GATE included significant beach erosion at Fort Tilden that exposed a previously buried section of bulkhead, breaching of West Pond, damage to a coastal path at Great Kills Park, and inland sediment deposition from overwash throughout the park (Rebecca Beavers, NPS, email, 12/23/12). Overwash also helped to build elevation in low-lying areas within the park, such as at Crookes Point in Great Kills Park. Fieldwork for this study was conducted before Hurricane Sandy; therefore, GIS attributes regarding structure condition and function reflect observations made before this event.

Jamaica Bay Unit

The Jamaica Bay unit of GATE covers a large area encompassing Jamaica Bay and the western end of the Rockaway Peninsula (Figure 4). Jamaica Bay is a saline to brackish estuary and one of the most heavily urbanized bays in the country. The Bay covers roughly 108 km^2 (26,640 ac) and is surrounded by salt marshes, parks, landfills, residential communities, major roadways and the John F. Kennedy International Airport (JFK). Jamaica Bay provides important habitat that supports populations of 214 species of special concern, including state and federally endangered and threatened species (NYCDP 2007). The Jamaica Bay unit contains many cultural and recreation destinations, including Floyd Bennett Field, Plumb Beach, Jamaica Bay Marsh Islands, Fort Tilden, and Jacob Riis Park (Figure 4).

One hundred and forty-three coastal structures were identified in, and adjacent to, the Jamaica Bay unit of GATE, spanning a total of nearly 33 km (20.5 mi) (Table 3 & Appendix B). Excluding the marsh islands, coastal structures stabilize roughly 36% (Figure 5), or 15 km (9.3 mi), of the approximately 42-kilometer (26 mi) long shoreline within the Jamaica Bay unit (this includes the north and west shoreline of Jamaica Bay, Plumb Beach, all of Floyd Bennett Field, and the bay and ocean shoreline of the Rockaway Peninsula, see Figure 4).

Table 3. Coastal structures in and adjacent to the Jamaica Bay unit of GATE.

[1]Structure	Count	Length (m)
Breakwater	3	265
Bulkhead	14	10,425
Groin	79	4,430
Jetty	1	2,550
Pier	19	4,925
Revetment	26	9,020
Seawall	1	1,365
TOTAL	**143**	**32,980**

[1]See Appendix A for structure definitions.

Beach nourishment projects have placed huge volumes of sand on area beaches since the early 1900s. Nourishment projects found in this research show that over 25.8 million m^3 (33.7 million yd^3) of sediment was added to beaches within, and (primarily) updrift of, the park from 1915 to 2012 (Table 6 & Appendix C). However, this total is certainly a minimum value, since we were unable to find background information for all of the nourishment projects and there were likely additional projects for which we were unable to find any documentation.

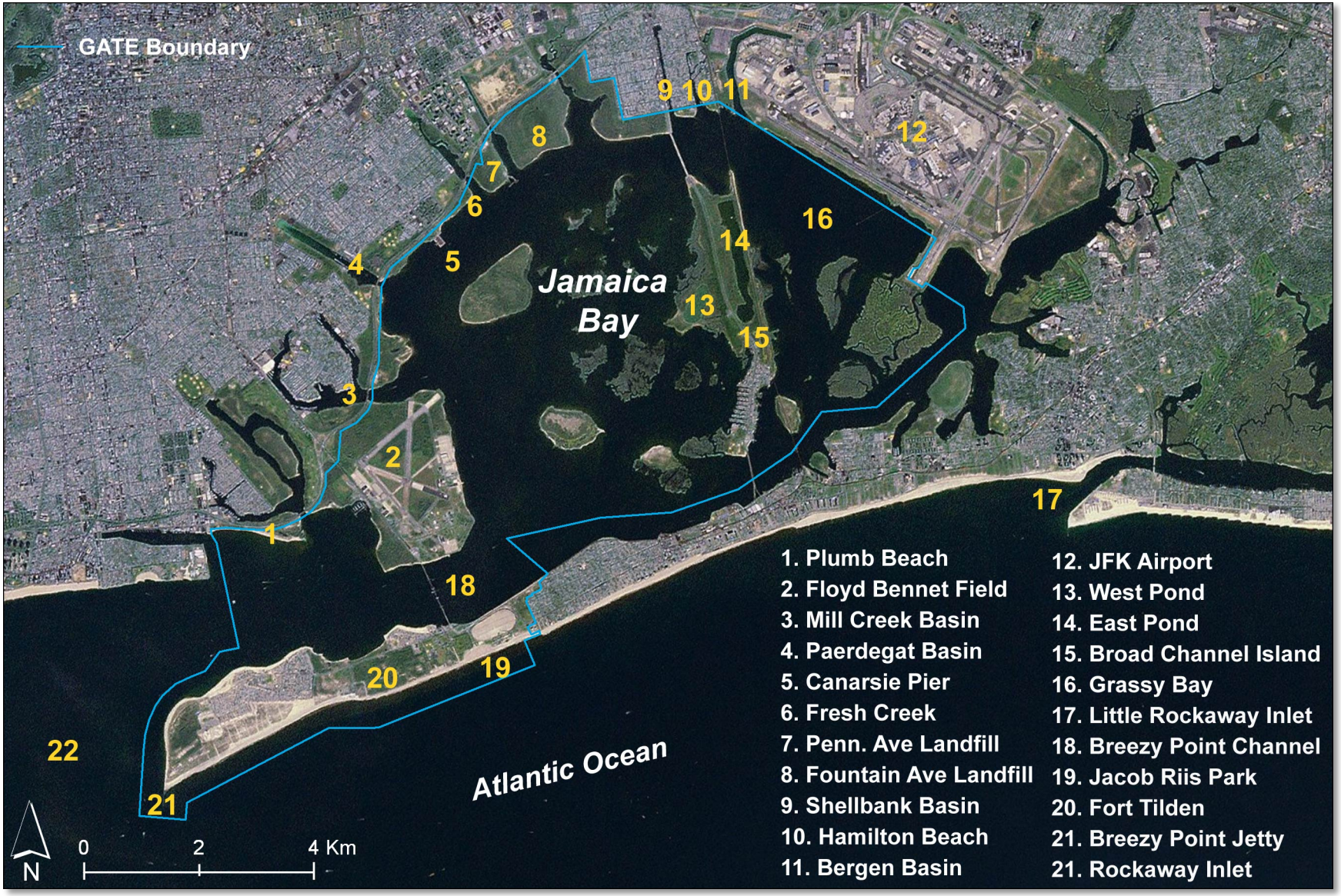


Figure 4. Jamaica Bay unit of Gateway National Recreation Area and places mentioned in the report (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

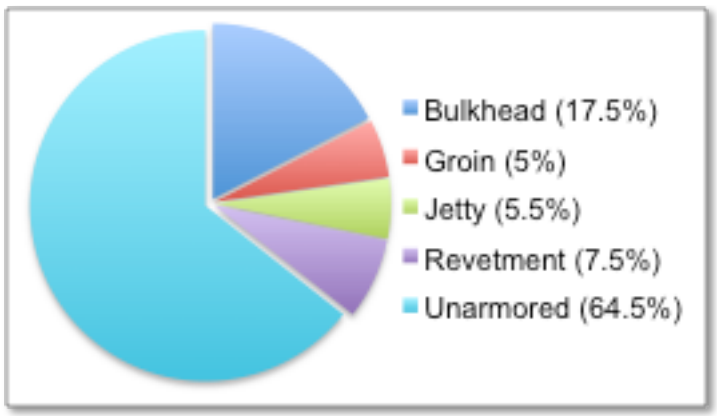


Figure 5. Percentage of shoreline stabilized (by structure type) and unarmored in the Jamaica Bay unit. Does not include marsh islands.

Jamaica Bay has been extensively altered by dredge and fill projects since the early 1900s. By 1950 channel dredging had increased the volume of the bay by 350%, while filling of the bay margins had reduced the surface area of the bay by nearly 50% (NYCDEP 2007). Figures 6 and 7 show nautical charts of Jamaica Bay in 1889, 1926, 1954, and 2011 that together depict the development and alteration of Jamaica Bay through time.

It was beyond the scope of this project to investigate every dredge and fill project within Jamaica Bay. Dredge and fill results presented here are therefore incomplete. A timeline of dredge and fill projects assembled from observations of historic nautical charts and a literature review is presented in the "Dredge and Fill in Jamaica Bay" section. Appendix D contains an overview of the dredge and fill projects where location information could be ascertained.

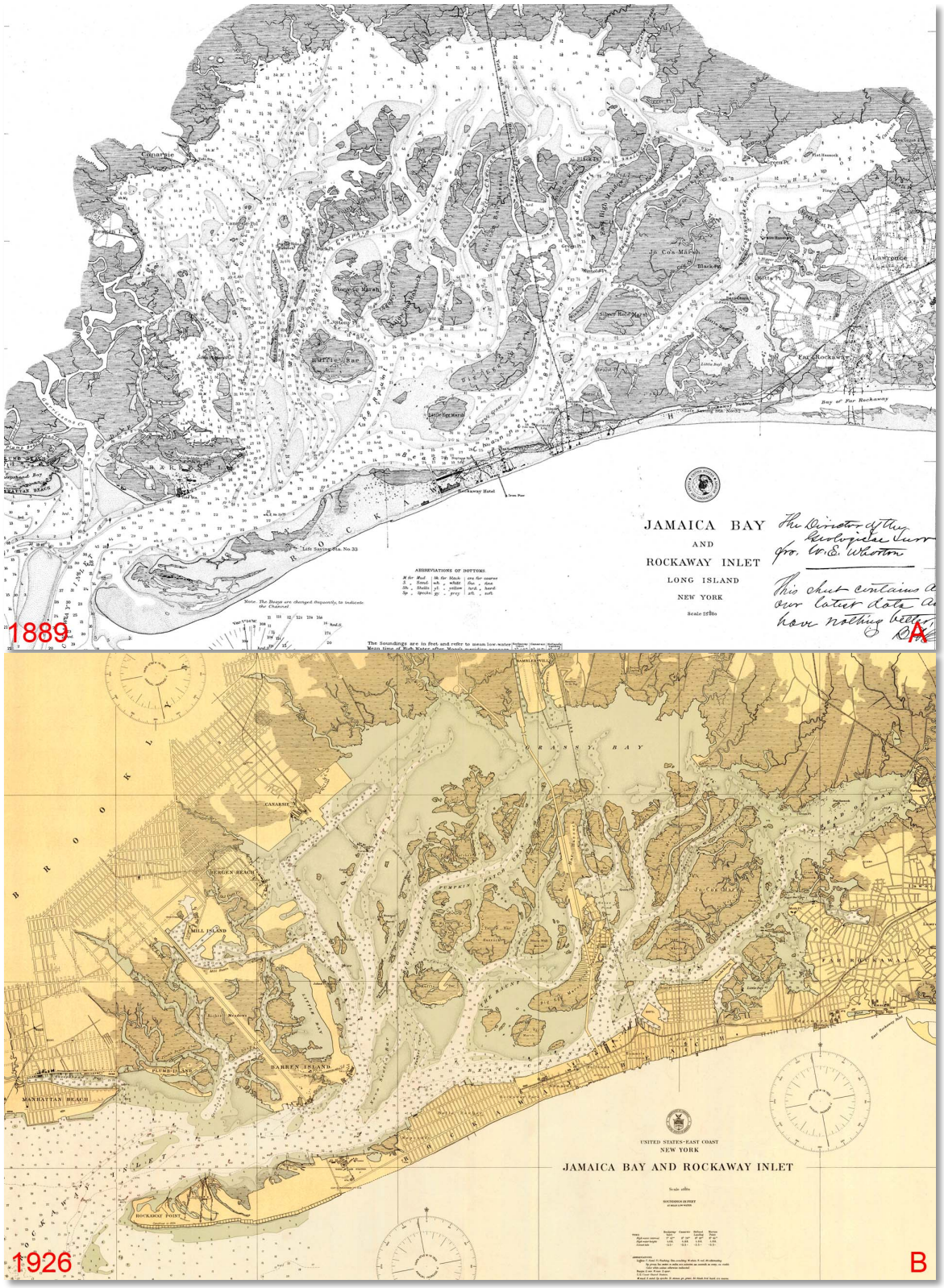


Figure 6. Historic nautical charts of Jamaica Bay in A) 1889 and B) 1926 (from NOAA 2012b). Note the significant Bay filling and westward spit extension of Rockaway Peninsula.

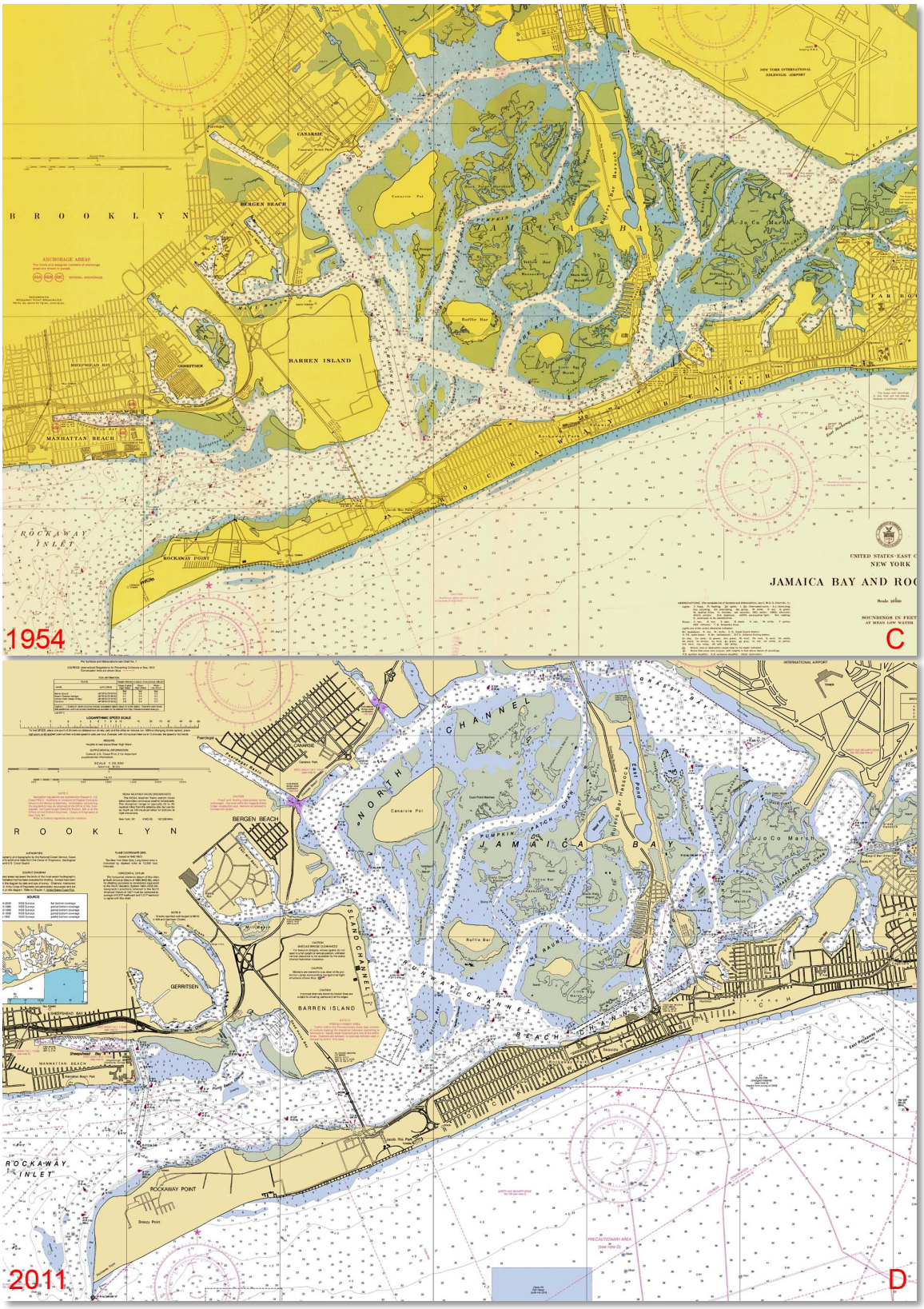


Figure 7. Historic nautical charts of Jamaica Bay in C) 1954 and D) 2011 (from NOAA 2012b). Note the growth of the western end of Rockaway Peninsula.

Floyd Bennett Field

Floyd Bennett Field (FBF) was dedicated in 1931 as New York's first municipal airport. FBF was the site of many record-breaking flights and it served a major role in World War II (Cody and Auwaerter 1982). In 1972 the Navy transferred most of FBF to the NPS. Today FBF is the largest area of open land in New York City, encompassing over 5 km^2 (1,300 ac).

FBF was created by connecting Barren Island and a number of other smaller islands to the mainland by filling channels and marshes (Figure 8). One of the oldest coastal structures in Jamaica Bay is a timber bulkhead on the southwest corner of FBF (Figure 9 & #10 Figure 10). The bulkhead is currently submerged and pilings are likely all that remain of the structure. The Coast and Geodetic Survey chart of 1903 (NOAA 2012b) illustrates that the original bulkhead was built prior to 1903, while modern aerial images show that rock (also currently submerged) was added to the eastern end of the bulkhead sometime before 2003 (#11 Figure 10).

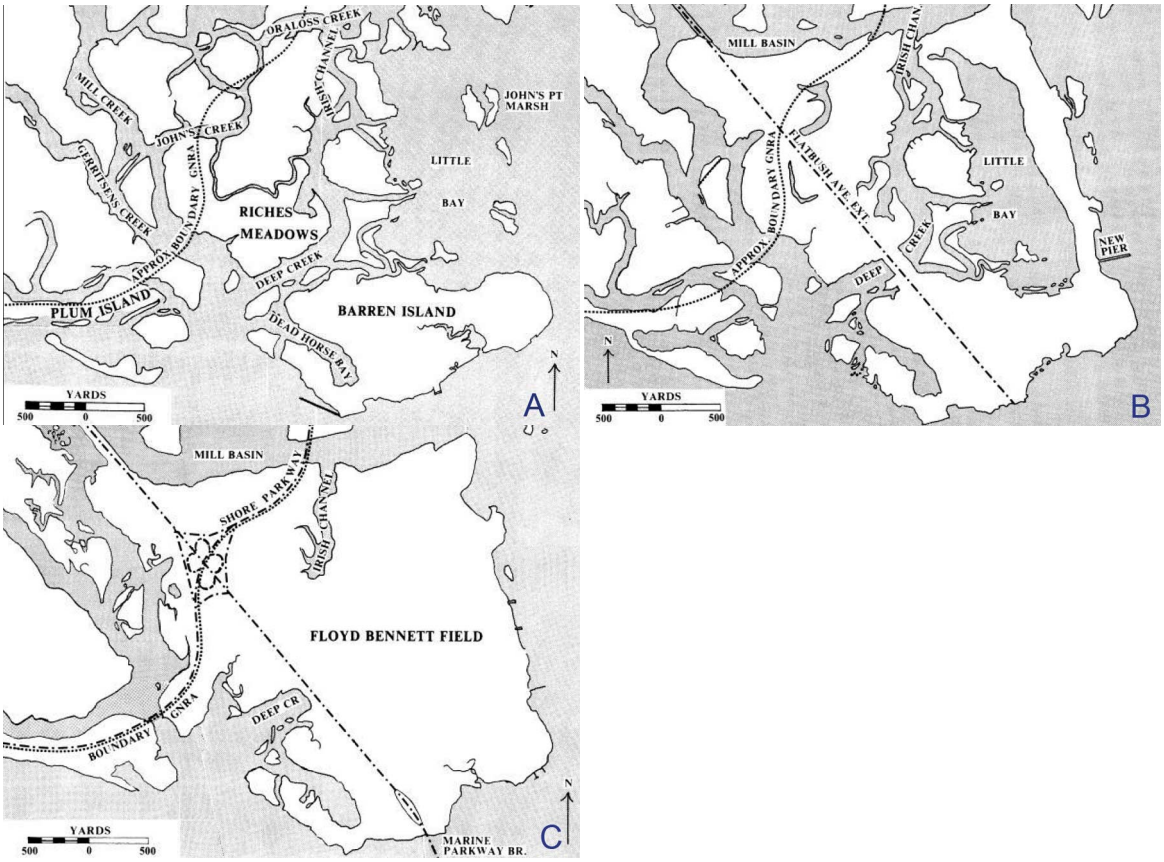


Figure 8. Development of Floyd Bennett Field in A) 1911, B) 1926, and C) 1940 (from Black 1981).

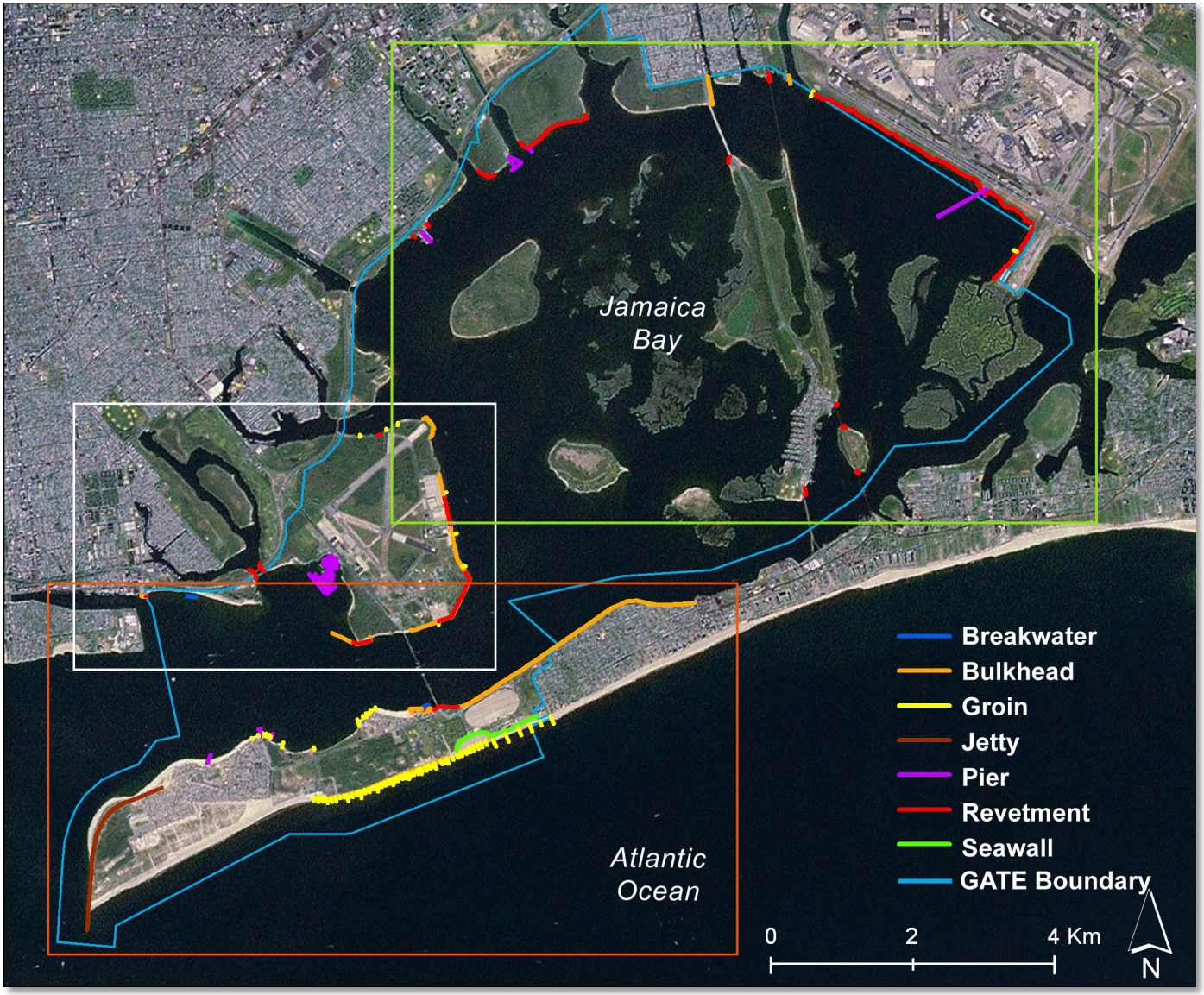


Figure 9. Structure map for Jamaica Bay. Area in white box is shown in Figure 10, green box in Figure 14, and orange box in Figure 18 (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

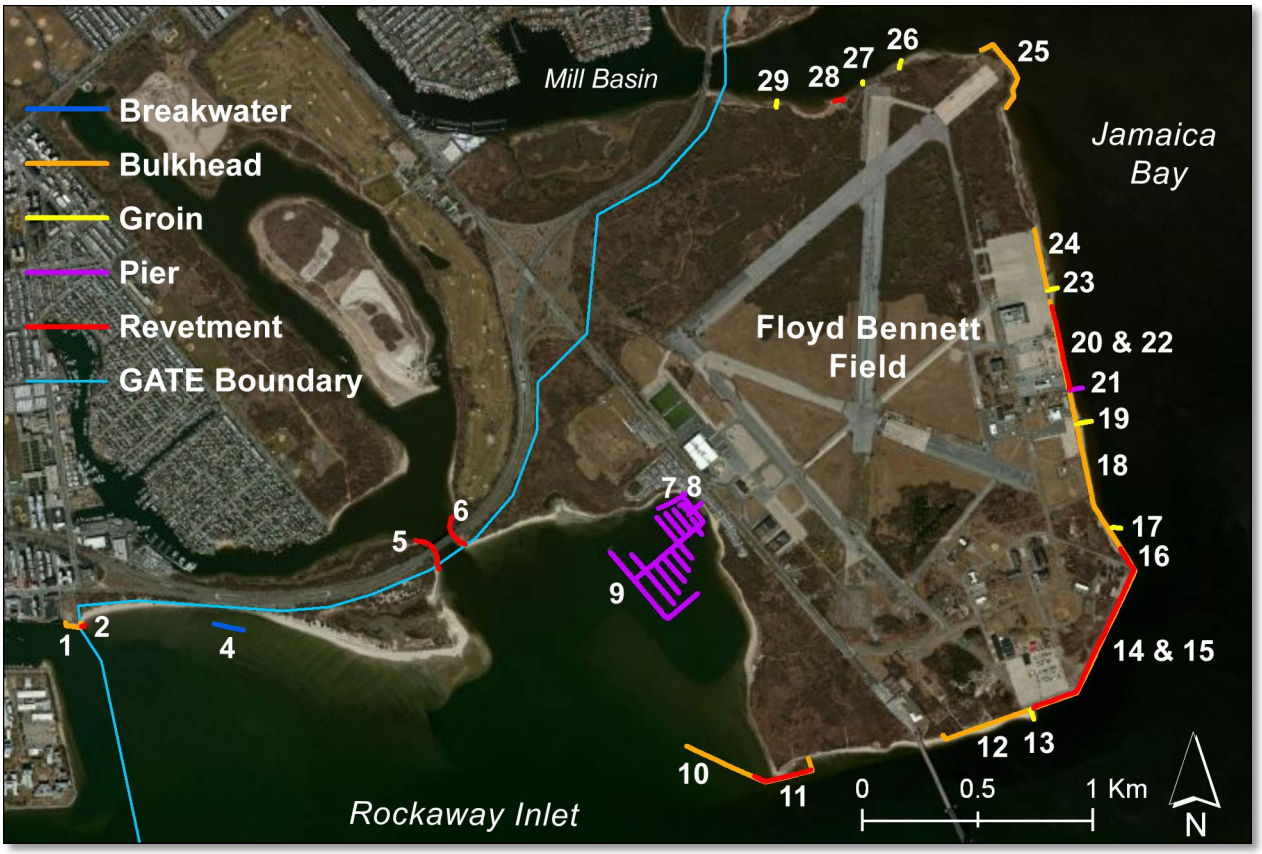


Figure 10. Structure map for the Floyd Bennett Field area (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

The New York Department of Docks began filling marshes along eastern FBF in 1911 for development of a harbor that never materialized (Cody and Auwaerter 1982). Filling continued with construction of the airport in 1928–1938. Over 4 million m^3 (5.2 million yd^3) of sediment dredged from the Rockaway Inlet Shoal, Mill Basin Channel, and Jamaica Bay Main Channel (Wrenn 1975) was used to fill 1.6 km^2 (387 ac) north of Barren Island in 1929 (Figure 11) (Cody and Auwaerter 1982). This fill was supported by steel bulkheading along the eastern edge of the airfield (#18 Figure 10).

In 1937 the U.S. Coast Guard built a timber seaplane ramp on the eastern shore of FBF, which was rebuilt with concrete in 1955 (#19 Figure 10). To complete the construction of the Naval Aviation Patrol Base in 1940, the Navy built a timber bulkhead (#20 & 24 Figure 10) and filled the area with material dredged from Jamaica Bay (Cody and Auwaerter 1982). The bulkhead was extended to the north in 1952 and a revetment was placed on the bay side of the bulkhead in 1972 to protect the aging bulkhead (#22 Figure 10) (Cody and Auwaerter 1982).



Figure 11. Historic aerial image looking north over Barren Island in 1929. White area in the middle of the image shows the extensive area of fill placed at Floyd Bennett Field (from Cody and Auwaerter 1982).

In 1942 the Navy began an extensive expansion of FBF related to World War II that ultimately increased FBF from 1.6 km^2 (387 ac) to more than 5.2 km^2 (1,280 ac) (Cody and Auwaerter 1982). During this period the estuary to the north of the airport was filled and the southern shoreline was expanded with fill between 15 and 122 m (50 and 400 ft) out into Rockaway Inlet and Jamaica Bay (Cody and Auwaerter 1982).

To retain the new fill, a steel sheet pile bulkhead was constructed along the southern shore in 1942 (#12 Figures 10 & 12). At the same time, a 1.1 km (0.7 mi) shore-parallel wharf and steel bulkhead were also built on the southeast corner of FBF (#14 Figures 10 & 12). The slope behind the bulkhead was covered with riprap in 2007 (labeled as revetment, #15 Figure 10). Other construction in 1942 included seaplane ramp A (#13 Figure 10), seaplane ramp B (#23 Figure 10), and three piers along FBF's eastern shore that are no longer present (Cody and Auwaerter 1982).



Figure 12. Steel sheet pile bulkheads built in 1942 at southern Floyd Bennett Field (left image: #12 Figure 10, right image: #14–15 Figure 10) (images by Kate Dallas).

In 1960 the U.S. Coast Guard built a pier on the eastern shore of FBF (#21 Figure 10). In the same year a 380-meter (1,250 ft) long wooden bulkhead was built on the northeast corner of FBF to contain fill placed for expansion of a runway (#25 Figure 10) (Cody and Auwaerter 1982). Three wooden groins and a revetment made of concrete blocks exist along the northern FBF shoreline (#26–29 Figure 10), but no information could be found on these structures.

Gateway Marina is a private marina located on the western side of Floyd Bennett Field in Dead Horse Bay (#7–9 Figure 10). The marina has 500 slips and comprises over 2,500 m (8,200 ft) of piers and floating docks.

Plumb Beach

Plumb Beach has been eroding since the 1930s when the area was filled during construction of the Belt Parkway (USACE 2012a). Waves from a nor'easter storm in the fall of 2009 eroded the beach and came within 8 m (25 ft) of the Parkway (USACE 2012a). Thornberry-Ehrlich (2011) reports that the central section of Plumb Beach is moving inland at roughly 2 to 3 m/yr (6 to 9 ft/yr).

In 1992, the U.S. Army Corps of Engineers (USACE) placed 147,000 m^3 (192,000 yd^3) of sand dredged from the Rockaway navigation channel onto Plumb Beach (Psuty et al. 2010). Additional shoreline protection strategies have been used in central Plumb Beach, including a submerged, offshore breakwater made of tires built in 1980–1983 (#4 Figure 10) (Psuty et al. 2010) and the placement of sand bags in 2009 (Figure 13). Sand bags are not included in the overall project statistics because they are generally temporary features. However, during our December 2011 site visit the sand bags were still in place. On the far western end of the beach, at the boundary of GATE, there is a cement bulkhead and a short section of revetment (#1–2 Figure 10). No background information could be found on these structures.



Figure 13. Sand bags at Plumb Beach in December 2011. View is to the west (image by Kate Dallas).

The USACE, working with the NYCDP and the NPS, is currently managing a $6.5 million (project year cost) restoration project at Plumb Beach. The project began in October 2012 and includes beach nourishment of 97,100 m^3 (127,00 yd^3) of sand dredged from the Ambrose Channel (located roughly 4 km [2.5 mi] northeast of Sandy Hook, not shown), construction of two groins, and installation of an offshore, stone breakwater (Dredging Today 2012).

Canarsie Pier

The northern shoreline around Canarsie Pier (#31 Figure 14) underwent significant changes after 1900. Over 1.6 km (1 mi) of shoreline from Paerdegat Basin to just west of Fresh Creek (Figure 4) was filled and bulkheaded in the mid 1920s (Figure 6) (Black 1981). The City of New York built Canarsie Pier (#31 Figure 14) as a commercial dock in 1926–1927 at a cost of $487,889 (Wrenn 1975). The pier is 180 m (590 ft) long and 120 m (395 ft) wide and has small rock revetments on both sides (#30, 32 Figure 14).

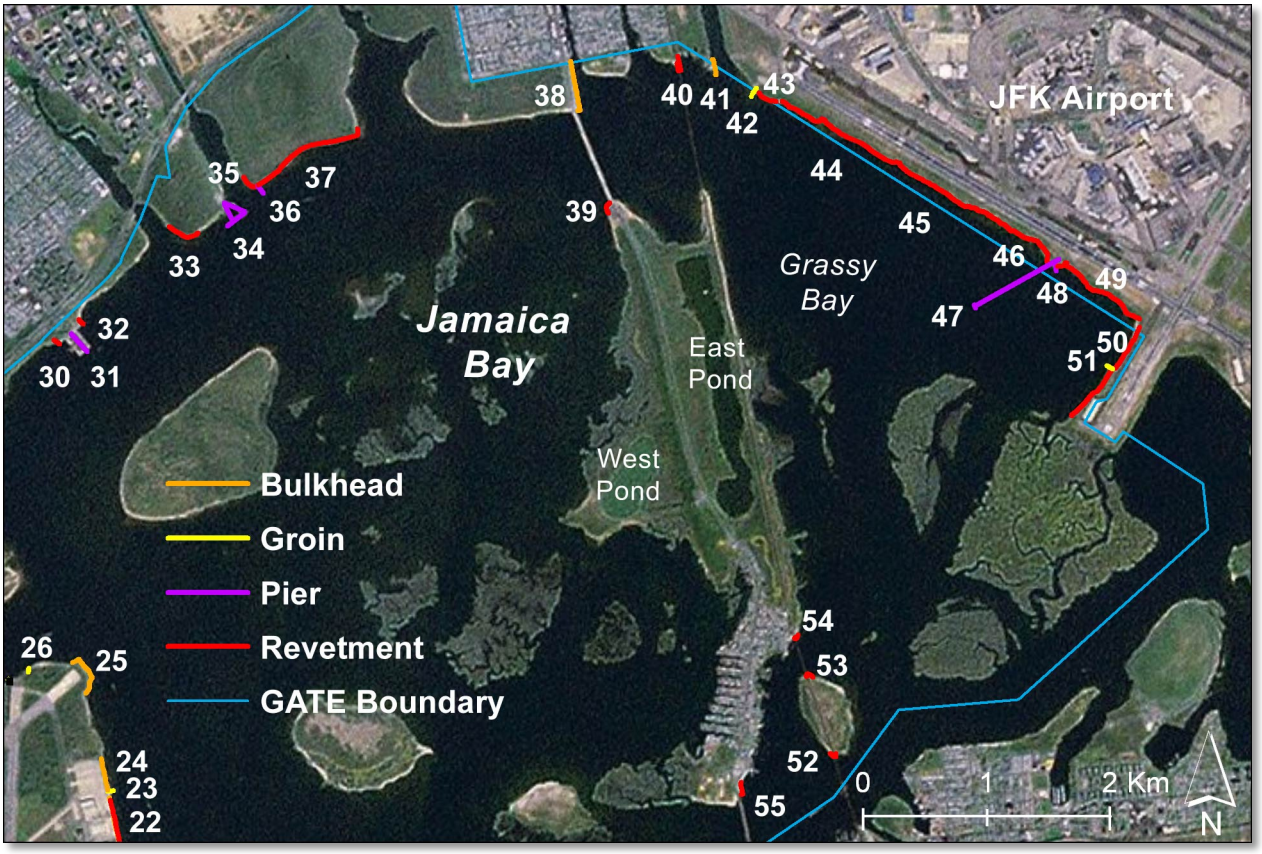


Figure 14. Structure map for Jamaica Bay's northern shoreline and marsh islands (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

Landfills

Two large, historic landfills exist along the northern Jamaica Bay shoreline, Fountain Avenue Landfill and Pennsylvania Avenue Landfill. Pennsylvania Avenue Landfill was built on fill placed in the mid 1950s and was open from 1956–1980 (Chang 2009). The landfill includes a revetment and a 515-meter (1,690 ft) long triangular shaped pier (#33–34 Figure 14). Nautical charts show the pier was originally built in the 1970s and modified in the mid 2000s (NOAA 2012b).

Fountain Avenue Landfill was built on fill placed in the late 1950s and early 1970s and operated from 1961–1985 (Chang 2009). The landfill has a pier and two rock revetments that armor 1,120 m (3,675 ft) of shoreline (#35–37 Figure 14). Nautical charts show the pier was built in the mid 2000s (NOAA 2012b). In 2004 the City of New York started a $200 million project to restore both landfills (Chang 2009).

Northeastern Jamaica Bay

The northeastern shoreline of Jamaica Bay, which includes JFK airport, is built on filled wetlands (Figures 6 & 7). By 1948 approximately 37 million m^3 (48 million yd^3) of sand had been dredged from Grassy Bay to fill 18 km^2 (4,500 ac) of marshland to create the airport (Swanson et al. 1992, JFK 2012). The pit caused by dredging is the now the deepest part of Jamaica Bay (Swanson and Wilson 2008).

The airport is protected by 4.6 km (2.9 mi) of rock revetments (#43–46, 49–50 Figure 14) and has two groins and two piers along its shoreline. One groin, located at the northern end of the airport (#42 Figure 14), was built in the mid 1970s (NOAA 2012b). The other rock groin, also installed in the 1970s, is located on the western shore of one of the airport's runways (#51 Figure 14). The timber piers are located adjacent to each other and vary significantly in length. The northern pier (#47 Figure 14) is over 800 m (2,625 ft) long and was built in the late 1940s (NOAA 2012b). The second pier is only 40 m (131 ft) long and is of unknown origin (#48 Figure 14).

Other coastal structures are present at the mouths of Shellbank and Bergen basins and at Hamilton Beach (Figure 4). At Shellbank Basin there is a timber bulkhead (#38 Figure 14). A review of historic nautical charts shows the existence of a bulkhead in this location since the late 1930s (NOAA 2012b). A timber bulkhead is also present at the mouth of Bergen Basin and is of unknown origin (#41 Figure 14). The northern end of the railroad trestle bridge at Hamilton Beach is protected by a revetment that is roughly 200 m (660 ft) long (#40 Figure 14).

Jamaica Bay Marsh Islands

The Jamaica Bay Marsh Islands provide rich habitat for a variety of fish and wildlife species. Over the last century anthropogenic activities such as dredging, filling, construction, and pollution, coupled with long-term sea level rise and insufficient sediment supply, have altered the natural environment and led to massive losses of salt marsh (Rafferty et al. 2011). Based on aerial photographs, NYCDEP (2007) reports that 5.7 km^2 (1,400 ac) of salt marsh were lost from 1924 to 1999. Prior to 1974, the majority of salt marsh loss was the result of dredging, filling, and draining projects along the margins of the Bay (NYCDEP 2007). Since 1974, salt marsh loss has occurred primarily due to the loss of salt marsh islands (NYCDEP 2007).

Broad Channel (Figure 15) is the only inhabited island in Jamaica Bay. Broad Channel was created by connecting the previously separated islands of Goose Creek, Black Bank Marsh, Bar Hassock, Goose Pond Marsh, and Big Egg Marsh with fill from 1924–1926 (NOAA 2012b). Broad Channel is connected to the mainland and the Rockaway peninsula by Cross Bay Boulevard, which was finished in 1926. Short sections of revetment protect the boulevard's bridges on both the northern and southern ends of the island (#39 & 55 Figure 14). There are also numerous small, private docks and piers on southern Broad Channel, but they are not included in this study.

The historic Long Island Railroad trestle runs along the eastern side of Broad Channel Island across Jamaica Bay. A wooden trestle was completed in March 1880 and had carried millions of passengers until a fire in May 1950 (Black 1981). The City of New York purchased the trestle a few years later and replaced it with a dredged embankment. Broad Channel's two freshwater ponds, East and West Pond (Figure 14), were created by the City of New York in 1953 (Lawrence 2008) to mitigate for the loss of bird habitat that occurred after construction of the railroad embankment (Wrenn 1975). In October 2012, both East Pond and West Pond were breached during Hurricane Sandy.

In response to the rapid loss of salt marsh islands in Jamaica Bay, restoration projects began in 2003 (Figure 15 and Table 4). In September 2003, GATE restored 0.01 km^2 (2 ac) of marsh during an experimental restoration project at Big Egg Marsh (Figure 15). From 2006 to 2010 a multiagency effort, led by the USACE, restored 0.16 km^2 (39 ac) of marsh at Elders Point East, 0.13 m^2 (33 ac) at Elders Point West, and 0.18 m^2 (44 ac) at Yellow Bar (Rafferty et al. 2011). Sediment dredged during the New York & New Jersey Harbor Deepening Project was used for the Elders Point West project, while sand dredged from the Ambrose Channel was used at Yellow Bar. Sand from the Ambrose Channel was also used in fall 2012 to restore approximately 0.08 km^2 (20.5 ac) at Black Wall and 0.04 km^2 (9.8 ac) at Rulers Bar Hassock (Patti Rafferty, NPS Coastal Ecologist, email, 11/7/12).

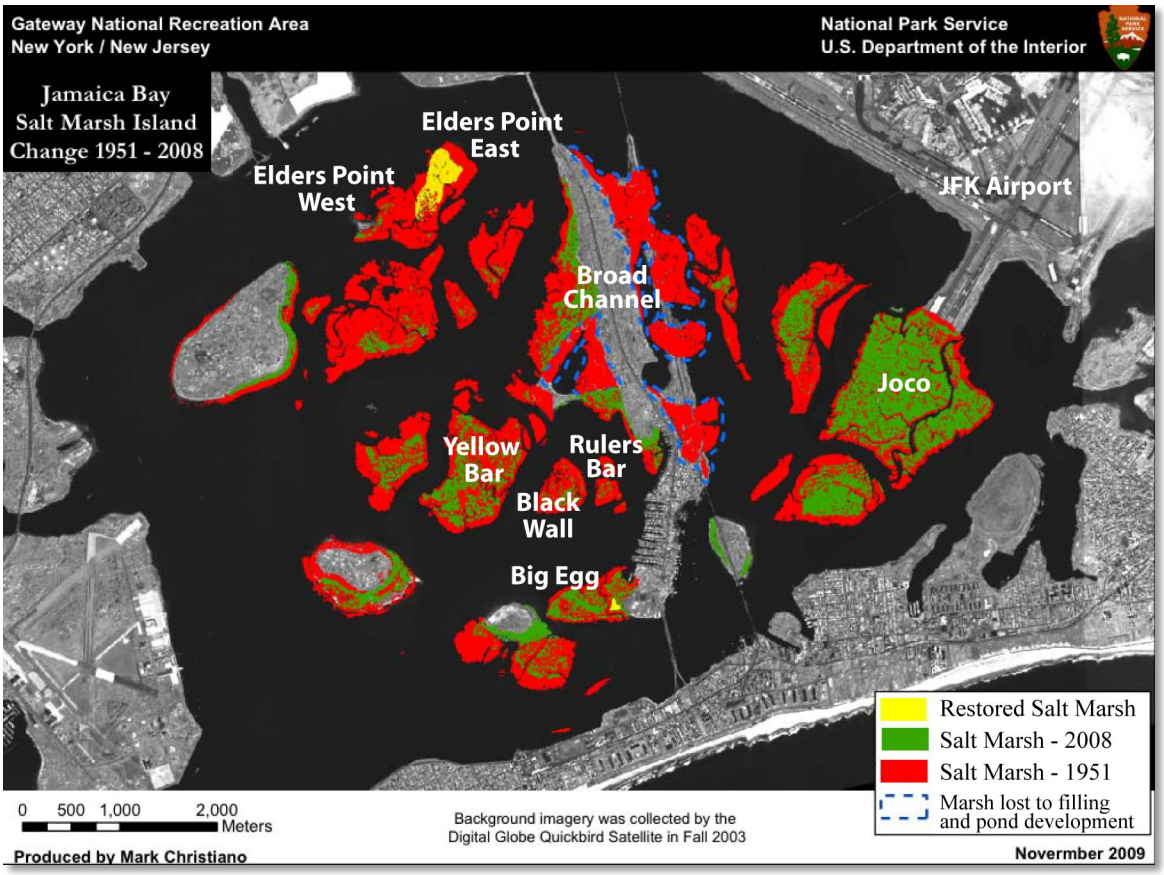


Figure 15. Map of Jamaica Bay Salt Marsh Island Change from 1951–2008. Areas of restored marsh are only those restored through 2011 (adapted from Rafferty 2011).

Table 4. Jamaica Bay Salt Marsh Island restoration data.

Location	Year	Area (km^2)	Volume (m^3)	Project-Year Cost	[1]Source
Big Egg Marsh	2003	0.01		$315,536	1
Elders Point East	2006	0.16	190,000	$13,000,000	1
Elders Point West	2010	0.13	231,000	$17,200,000	1
Yellow Bar	2012	0.18	287,000	$19,642,857	2
Black Wall	2012	0.08	118,510		2
Rulers Bar	2012	0.04	72,630		2

[1]Source: 1: Rafferty et al (2011), 2: USACE (2013).

Dredge and Fill in Jamaica Bay

The topography of Jamaica Bay has experienced significant alterations through dredging and filling. Generally, the changes have consisted of the dredging of channels and filling of marshes along the edges of the bay. Many of the changes made before the 1930s were motivated by the unrealized plan for the development of Jamaica Bay into a major seaport and industrial center (Black 1981). Much of the plan never came to fruition, in part because Jamaica Bay was transferred to the Department of Parks and Recreation in the late 1930s (Black 1981).

Channel dredging in the first half of the 20th century increased the volume of the bay by 350% (NYCDEP 2007) and the mean depth from approximately 1 to 5 meters (3.3 to 16.4 ft) (Swanson et al. 1992). At the same time, the surface area of Jamaica Bay has been reduced by nearly 50%, from 101 km^2 to 53 km^2 (25,000 ac to 13,000 ac) (NYCDEP 2007). Swanson et al. (1992) reports that between 1900 and 1970 the USACE issued an average of three dredging permits per year for Jamaica Bay and lists a conservative estimate of sediment dredged in Jamaica Bay as 71 million m^3 (93 million yd^3) (through 1992).

A timeline of dredge and fill operations in the Jamaica Bay unit of GATE is presented below. The timeline was assembled from a literature review and observations of historic nautical charts from the Office of Coast Survey's historical map and chart collection website (NOAA 2012b). Information in the timeline sourced from the literature is cited, whereas no reference is listed when the information came from historic nautical charts.

The timeline includes only those projects that were easily discernable on nautical charts and is in no way complete. Due to the sheer number of channel dredging projects, many are not included in the timeline. Most of the dredge and fill projects along the Jamaica Bay side of Rockaway are not included because it was impossible to discern if bathymetric changes were natural or anthropogenic due to the rapid natural changes of the peninsula. Quantitative dredging information for the Jamaica Bay/Rockaway navigation channel is presented after the timeline in Table 5. A map of Jamaica Bay with place names mentioned in the timeline is shown in Figure 16.

Timeline of Dredge and Fill Projects in Jamaica Bay

1889–1911: Mill Creek area filled in 1900 (Black 1981), Rockaway Inlet dredged in 1910 (Black 1981), Broad Channel dredged up into Grassy Bay prior to 1911 (Swanson and Wilson 2008), Bergen Beach area filled, and Canarsie Pier area filled.

1911–1922: Portions of Beach Channel dredged by 1911, channel dredged from Rockaway Inlet to Mill Basin from 1912 to 1913 with dredged sediment placement on the eastern side of Floyd Bennett Field (Black 1981), Mill Basin Channel dredged to roughly 5 m (16 ft) deep in January 1916, Shellbank Basin dredged by 1916, Hawtree Basin dredged by 1916, Old Howard Beach area filled (between Shellbank and Hawtree basins).

1922–1932: Channel dredged from Mill Basin to Fresh Creek in the early 1920s with dredged sediment placed on central Floyd Bennett Field (Black 1981), Deep Creek dredged circa 1923, water between marsh islands filled to create Broad Channel Island in the mid 1920s for the construction of Cross Bay Boulevard, Plumb Beach Channel dredged circa 1929, Fresh Creek dredged in the late 1920s, Jamaica Bay Channel inner entrance dredged in 1929, Bergen Basin

dredged circa 1930, Paerdegat Basin dredged to roughly 5 m (16 ft) deep in Feb 1932, Mill Basin Channel dredged and widened, shoreline from Paerdegat Basin to Fresh Creek filled, Spring Creek Park area filled, Broad Channel dredged into Grassy Bay, Island Channel dredged and widened adjacent to Floyd Bennett Field.

1932–1940: Gerristen Creek dredged in May 1933, Beach Channel dredged, northeast corner of Floyd Bennett Field filled, channel dredged from Canarsie Pier to Spring Creek Park.

1940–1954: Northern and southern areas of Floyd Bennett Field filled by 1944, East and West Pond dredged, fill placed around East and West Pond, railway embankment on eastern Broad Channel Island created with dredged material, Head of Bay dredged in mid 1940s, JFK airport area filled by 1948, Hendrix Creek dredged in the early 1950s, Spring Creek Park area filled in the early 1950s.

1954–1965: Grass Hassock Channel dredged June 1960 to May 1961, JFK runway that extends into the bay created with fill in 1962, eastern half of Fountain Ave. Landfill area filled, Pennsylvania Landfill area filled.

1965–1975: Beach Channel dredged in April–July 1972, western half of Fountain Ave. Landfill area filled circa 1973.

Table 5. Dredging data for the Rockaway Channel (Annette Baden, Assistant to the Freedom of Information Act Officer, USACE, email, 7/27/12).

Location	Month	Year	Volume (m^3)
Inner entrance channel	Jul–Dec	1929	1,026,816
20 ft Channel	Oct–Dec	1976	68,578
Entrance channel	Oct–Dec	1976	166,701
20 ft Channel	May–Jul	1979	47,195
Sea leg of channel	Jan–Jun	1981	121,771
Entrance channel	July	1985	138,908
Entrance channel	Dec–Feb	1987–1988	176,056
Entrance		1991	308,988
Entrance	Mar–Apr	1992	111,472
Entrance	Feb–Apr	1994	152,101
Entrance	Sep–Nov	1996	172,665
Entrance	Sep–Nov	2000	174,785
Entrance	Oct–Apr	2004	139,870
Entrance	Mar–Oct	2009	292,593
TOTAL			**3,098,498**



Figure 16. Jamaica Bay with place names mentioned in the dredging timeline (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

Rockaway Peninsula

The Rockaway component of GATE encompasses the western end of the Rockaway barrier peninsula, which includes Jacob Riis Park, Fort Tilden, and Breezy Point (Figure 4). Historically, the peninsula built westward in response to alongshore sediment transport (Figures 6 & 7). Much of the land west of Fort Tilden has formed since 1866 due to natural sediment transport processes and beach nourishment in updrift communities. The westerly expansion of the island halted in 1933 with construction of the 2,550-meter (8,370 ft) long Breezy Point jetty (Figure 17).

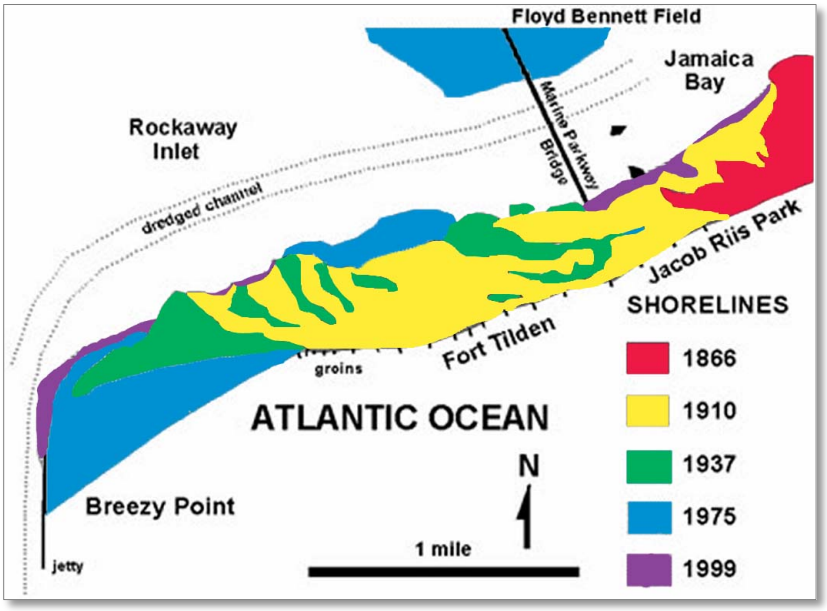


Figure 17. Map showing the westward expansion of the Rockaway Peninsula (adapted from USGS 2012b).

Groins have been built along most of the Rockaway ocean shoreline in an attempt to trap sand as it moves naturally westward with the alongshore sediment transport. Groin construction on the peninsula was completed primarily from 1922–1927 and was accompanied with placement of more than 3.8 million m^3 (5 million yd^3) of sediment (Psuty et al. 2010). Sherman et al. (1990) report that 198 groins were built since the mid-1920s along the Rockaway Peninsula. Fifty-five groins were identified in the Jacob Riis and Fort Tilden area (Figure 18), however, there are likely additional groins buried in the sand.

Beach nourishment has occurred regularly along the Rockaway beaches since the 1920s. From 1977 to 2004 the U.S. Army Corps of Engineers designed, constructed, and maintained a 30–61 m (100–200 ft) wide beach updrift of the park at an elevation of 3 m (10 ft) above Mean Low Water from Little Rockaway Inlet (Figure 4) to the eastern end of Jacob Riis Park, a distance of 10 km (6.2 mi) (USACE 2012b). Due to the high cost of continued nourishment, a new plan is being developed to find a long-term, cost-effective solution to continued erosion along the peninsula.

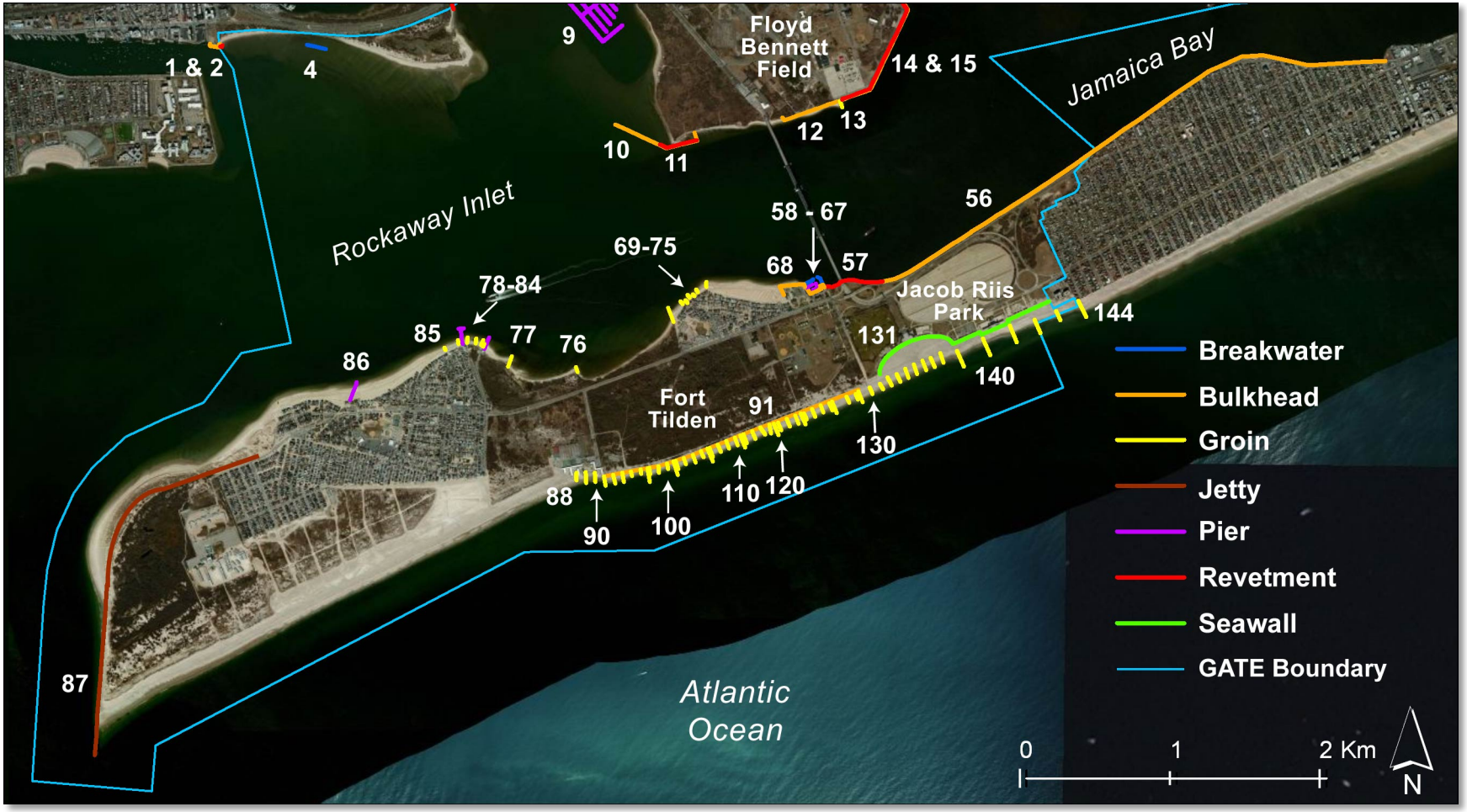


Figure 18. Structure map for the Rockaway area of GATE (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

Summaries of beach nourishment activities compiled by Unrau (1981), Valverde et al. (1999), and the Program for the Study of Developed Shorelines at Western Carolina University (WCU 2012) report that over 25.8 million m^3 (33.7 million yd^3) of sediment was placed along the Rockaway ocean shoreline between 1915 and 2005 at a cost of over $89 million (project-year costs, Table 6). This total includes placement on beaches within and updrift (east) of the park, with a majority of the nourishment having occurred updrift. Since sediment transport is to the west, beach nourishment on updrift beaches likely impacts beaches within GATE. Approximately 153,000 m^3 (200,000 yd^3) of dredged material from the Little Rockaway Inlet is also placed on the very eastern end of the Rockaway barrier every two years (Psuty et al. 2010).

Table 6. Beach nourishment along Rockaway's ocean shore (includes areas within and updrift of GATE).

Year	Volume (m^3)	Length (m)	Project-Year Cost	[1]Source
1915	765			1
1916 & 1920	4,740			1
1926–1930	3,975,685		[2]$1,044,596	2
1930–1936	3,975,685		$858,369	2
1939	305,822	1,448	$60,000	2
1940	191,139			1
1958	955,694		$911,079	2
1962	133,797	644	$135,500	2
1967	229,366	1,127	$307,377	2
1975	2,804,922	4,828	$9,420,556	2
1976	1,138,881	6,759	$2,204,467	2
1977	764,555	3,219	$2,500,000	2
1978	513,246	2,414	$1,200,000	2
1980	356,283	1,127	$1,724,000	2
1982	815,321	1,931	$2,716,750	2
1982	124,622	457	$965,776	2
1984	1,275,201	1,770	$9,732,204	2
1986	1,028,326	1,931	$6,972,540	2
1988	891,471	1,931	$3,406,906	2
1994	116,977	914	$1,373,000	2
1996	259,949	1,219	$2,400,000	2
1995–1996	2,052,886			3
2000	1,146,832			3
2001	956,273		$5,698,348	4
2001	764,555	9,978	$24,100,000	4
2002	108,490		$1,568,703	4
2004	766,258	9,978	$10,000,000	4
2005	168,202			4
TOTAL	**25,825,943**	**51,675**	**$89,300,171**	

[1]Source: 1: Unrau 1981, 2: Valverde et al. 1999, 3: USACE 2012c, 4: WCU 2012.

Jacob Riis Park

Jacob Riis Park was established in 1912 and used by the United States Navy from 1917 to 1928 (Unrau 1981). Stabilization of the shoreline began in 1914 with construction of five timber groins at the eastern end of the park (exact location unknown) (Unrau 1981). In 1915 the existing groins were strengthened and an additional 100 m (340 ft) of timber groins were added along

with 180 m (580 ft) of timber bulkheading and 765 m^3 (1,000 yd^3) of backfill (exact location unknown) (Unrau 1981).

Beach stabilization continued in 1916 with construction of 610 m (2,000 ft) of timber bulkhead, ten timber groins, and 3,820 m^3 (5,000 yd^3) of beach nourishment (exact location unknown) (Unrau 1981). A storm in December 1918 caused significant damage to the groins and bulkhead. Work began in October 1920 to repair the structures, which included 920 m^3 (1,200 yd^3) of sand placement (Unrau 1981).

Shoreline protection structures were extended to the western portion of the park in 1926–1927. Additional timber groins, 40 to 61 m (130 to 200 ft) in length spaced 61 m (200 ft) apart, were built (#130–138 Figure 18 & Figure 19) and attached to a newly constructed bulkhead (Unrau 1981). In the winter of 1932–33 laborers from the Works Progress Administration built a concrete seawall along the length of the park, which was later removed (Unrau 1981).

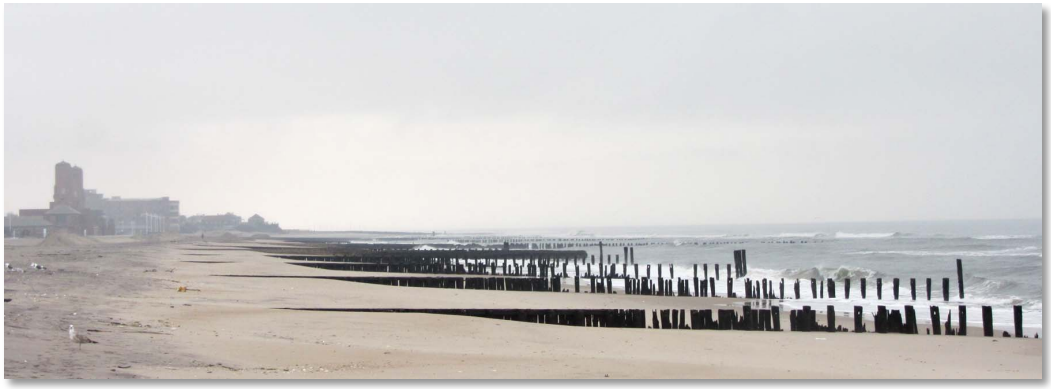


Figure 19. Timber groins at Jacob Riis Park (#130–135 Figure 18). View is to the northeast (image by Kate Dallas).

The Jacob Riis bathhouse (Figure 20) was built in 1932 and is listed on the National Register of Historic Places. On April 1, 1936 the Atlantic Gulf and Pacific Dredging Company started a beach nourishment project to triple the size of the beach in front of the bathhouse from 32,375 to 97,125 m^2 (8 to 24 ac) (Unrau 1981). In total, over 1.5 million m^3 (2 million yd^3) of sand dredged from the Rockaway Inlet, east of the present day Marine Parkway Bridge, was placed on the beach (Unrau 1981).

During late 1936 and early 1937 the existing seawall was removed and a new 1,420-meter (4,660 ft) long curved, concrete seawall was built further inland to accommodate the larger beach (Unrau 1981) (#131 Figure 18). Improvements were also made to the groins, including reconstruction of thirteen groins. Beach nourishment occurred again in 1939 east of the bathhouse (16,820 m^3 [22,000 yd^3]) and in 1940 in front of the bathhouse (191,140 m^3 [250,000 yd^3]) (Unrau 1981).

Groin construction has continued over time, including enlargement of several groins on the eastern end of the beach in 1939, relocation of a few groins to the center of the new elliptical beach area in 1939, and construction of five new groins in front of the bathhouse in 1940 (#139–143 Figure 18) (NYCDP 1940a). A plan drawing by the New York City Department of Parks

shows 30 groins (longer groins referred to as jetties in the drawing) fronting the bathhouse in 1940 (Figure 20). However, only 15 groins were visible in December 2011. It is unknown if there are more groins buried in the sand, or if they were removed. Unrau (1981) reports that some groins were removed in 1957 and 1958 along the eastern end of the park.

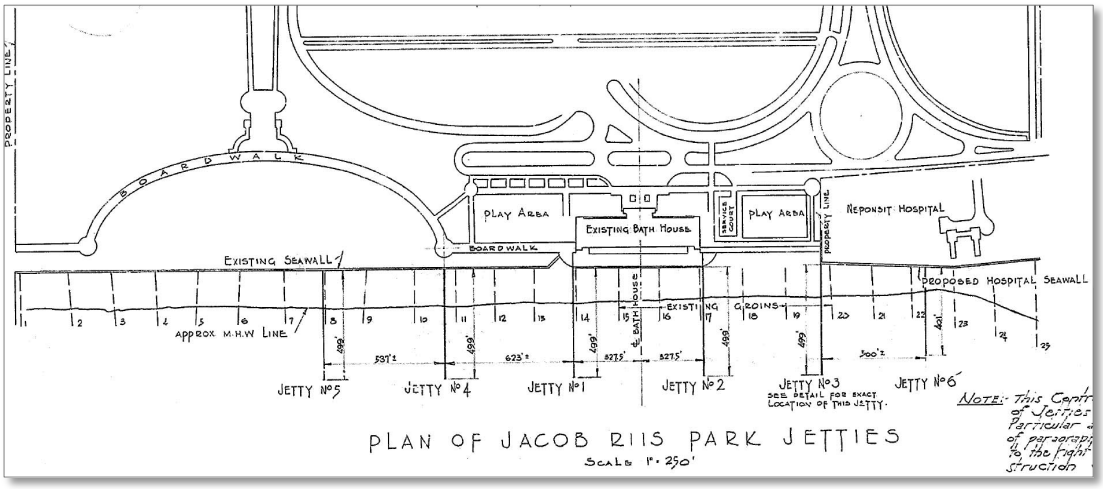


Figure 20. Plan drawing of Jacob Riis Park from 1940 showing the location of the bath house, seawall and groins (larger groins are labeled as jetties) (from NYCDP 1940a).

The terminal groin on the eastern end of the beach (#144 Figure 18 and Figure 21) was built by the USACE in 1980, on the site of a smaller existing groin, and included placement of 356,283 m^3 (466,000 yd^3) of sand (USACE 1979, Valverde et al. 1999). The terminal groin was enlarged in 1982 (Psuty et al. 2010) and maintained in 1986 (NPS 1986a).



Figure 21. Terminal groin on the eastern end of Jacob Riis Park (#144 Figure 18). View is to the southeast (image by Kate Dallas).

The Jamaica Bay side of Jacob Riis Park was filled in 1936–1937 for the creation of a new road network following construction of the Marine Parkway Bridge (Unrau 1981). To maintain the new fill, a timber and steel bulkhead was installed in April 1937 (#56 Figure 18) (Unrau 1981). In 1945 a concrete cap was added to the bulkhead and a rock revetment was added between the western end of the bulkhead and the Marine Parkway Bridge (#57 Figure 18) (NYCDP 1945, Unrau 1981). A plan drawing from 1945 (NYCDP 1945) shows the bulkhead extending to the

eastern end of Jacob Riis Park, but it is unknown how far east it stretched. Today the bulkhead runs for 3.8 km (2.4 mi) along the Jamaica Bay shoreline (#56 Figure 18).

Fort Tilden

At the time that Fort Tilden was established in 1917 the area was largely tidal marsh (Toress 1980). The marsh was filled by the USACE with an unknown volume of sediment dredged from Jamaica Bay (Toress 1980). From August 1918 to August 1919 the United States Engineers Office built 1,830 m (6,000 ft) of timber bulkhead and 1,990 m (6,518 ft) of timber groins at a cost of $49,444 (exact location unknown) (War Dept. 1919). A separate project in 1918 built an additional 400 m (1,300 ft) of groins. High surf damaged the bulkhead and groins during construction in March and May of 1919, requiring reconstruction (War Dept. 1919). The groins were effective at trapping sand from the very beginning and significant accretion was noted in July 1919 (War Dept. 1919).

In 1920 the War Department strengthened the bulkheads and groins at a cost of $5,644 (Toress 1980). The U.S. Coast and Geodetic Survey chart of 1922 (NOAA 2012b) shows a bulkhead with 15 groins on the eastern end of Fort Tilden. By 1932 the bulkhead and groin field had been extended westward, almost to the Breezy Point jetty, with 70 groins present from Fort Tilden to the jetty (1932 Chart, NOAA 2012b). Forty-one groins were visually identified in front of Fort Tilden in 2011, but no groins could be seen west of the fort (Figure 18). The western groins are likely still present, but presumably have been buried in the sand that has accumulated updrift of the jetty.

A cross section of the bulkhead on a 1943 plan drawing by the United States Engineers Office shows two timber bulkheads in front of Fort Tilden (USACE 1943a). It is unknown when the second bulkhead was added. The 1943 plan also shows the addition of a revetment between the two bulkheads and seaward of bulkheads, as well as construction of eight large rock groins in front of the fort (USACE 1943a). The rock groins were built to roughly twice the length of the existing timber groins and are still visible today (Figure 18). During a site visit to the park in December 2011, a bulkhead with fronting riprap was observed on western and central sections of Fort Tilden (#91–92 Figure 18 & Figure 22). The eastern third of the bulkhead fronting the fort was buried in sand and not visible. However, erosion from Hurricane Sandy in October 2012 exposed the full length of the bulkhead and this structure may now be impacting natural sediment transport processes.



Figure 22. Timber bulkhead, riprap, and groins at Ft. Tilden (#91–93 Figure 18). View is to the west (image by Kate Dallas).

On the bayside of Fort Tilden, pilings remain from the original wharf and associated bulkhead that were used to ship materials to the fort beginning in 1917 (#68 Figure 18). Extensive repairs were made to the wharf in 1937–1938 at a cost of $35,043 and further repairs were made in 1944 and 1951 (Torres 1980).

To the east of the historic wharf pilings is Riis Landing. The boat basin was previously known as Station Rockaway and was managed by the U.S. Coast Guard. Today it is used for fishing and occasional ferry service. The basin has continuous bulkheading along its shore and two timber breakwaters that protect the basin's four piers. The bulkhead on the western side of the basin is made of steel and was constructed in 1943 by the USACE (USACE 1943b). A plan drawing for the 1943 bulkhead (USACE 1943b) shows an existing bulkhead on the south side of the basin. No further information could be found on the history of the other structures in the basin. The boat basin has likely been dredged periodically over time, with one known episode of dredging occurring in 1987 by the U.S. Coast Guard (USCG 1987).

The private community of Roxbury lies to the west of the U.S. Coast Guard Boat Basin. The beach fronting Roxbury was nourished in 1994 with 152,150 m^3 (199,000 yd^3) of sediment at a cost of $1,288,000 (Valverde et al. 1999). Seven groins are currently visible on the west end of Roxbury Beach (#69–75 Figure 18). Observations of nautical charts reveal that groins #72 and #69 were built in the 1930s, followed by #70, 74, and 75 in the 1950s and 1960s, and #71 and 73 in the mid 1970s (NOAA 2012b). Three additional groins on the eastern half of the beach are present on nautical charts beginning in the 1940s (NOAA 2012b), but are currently not visible and are likely buried in the beach.

The community of Breezy Point lies to the west of Roxbury. The bay shoreline of Breezy Point has eight groins and three piers (#76–86 Figure 18). The piers (#78, 83, 86 Figure 18) were installed in the late 1910s and early 1920s (NOAA 2012b). Groin construction occurred primarily in the early 1940s, with only one groin (#77 Figure 18) built later in the late 1950s or early 1960s (NOAA 2012b). Eight additional groins were identified along the Breezy Point bay shoreline on nautical charts starting in the 1940s, but are not visible today.

Staten Island Unit

The Staten Island unit of GATE extends along the southeastern shore of Staten Island, and includes Great Kills Park, Miller Field, Fort Wadsworth, and two man-made islands, Hoffman and Swinburne Islands (Figure 23). The shoreline within this unit has been modified by a myriad of coastal structures, beach nourishment, and fill at Great Kills Park. The dominant longshore transport along the island is from the northeast to southwest, with a reversal in direction (i.e. towards inner New York Harbor) at the northeast end of the island. Erosion has been persistent along the Lower New York Bay Staten Island shoreline, with the shoreline eroding an average of 38 m (125 ft) from 1836 to 1961 (Okulewicz and DiGuardia 1984).

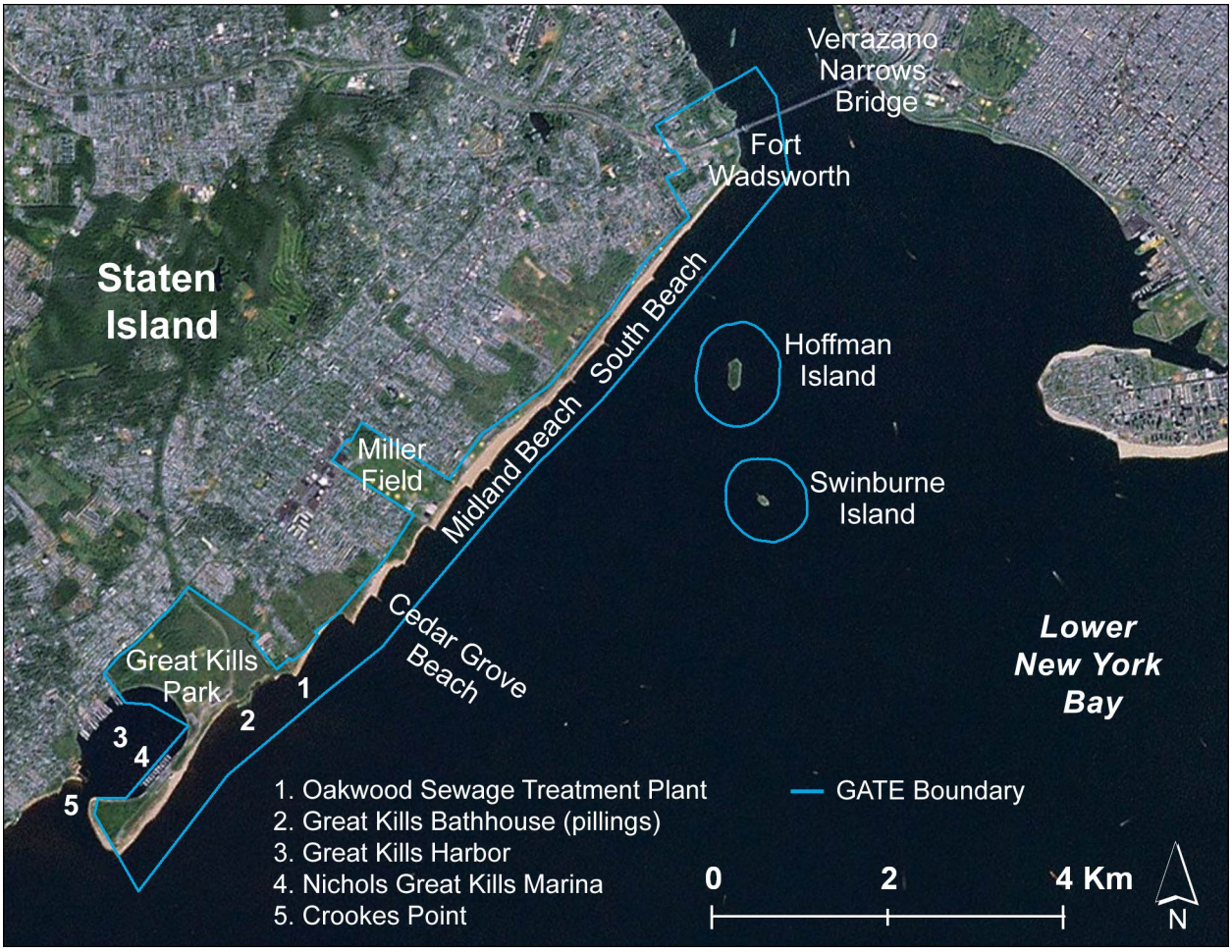


Figure 23, Location map for the Staten Island unit of GATE (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

Fifty-five coastal engineering structures and projects were identified in the Staten Island unit of GATE. The total is comprised of 47 coastal structures (Table 7), 4 beach nourishment projects, and 4 dredge and fill projects. Coastal structures stabilize 7.8 km (4.8 mi) of the Staten Island unit, or 45% of the roughly 17.4-kilometer (10.8 mi) long shoreline (Figure 24). If Hoffman and Swinburne Islands are excluded, structures stabilize 39%, or 6.5 km (4 mi), of the approximately 16.5-kilometer (10.3 mi) long Staten Island shoreline within GATE. See Appendix E for an overview of all of the structures identified within the Staten Island unit.

Table 7. Coastal structures in the Staten Island unit of GATE.

Structures	Count	Length (m)
Breakwater	1	195
Bulkhead	5	2,215
Groin	17	1,560
Jetty	1	150
Levee	1	195
Pier	8	2,785
Revetment	10	3,560
Seawall	4	1,435
TOTAL	**47**	**12,095**

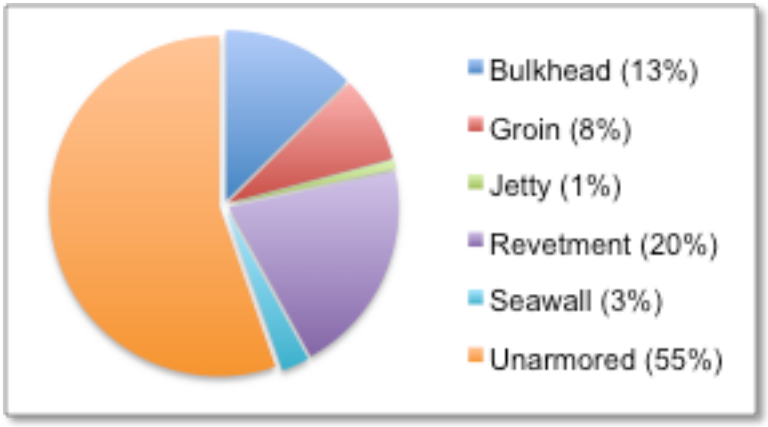


Figure 24. Percent of shoreline stabilized (by coastal structure type) and unarmored in the Staten Island unit of GATE (includes Hoffman and Swinburne islands).

Beach nourishment projects placed a minimum of 2.3 million m^3 (3.1 million yd^3) of sand along the GATE Staten Island shore from 1936 to 1983 (minimum because volume information could not be found for all projects) (Appendix F). Dredging removed over 1.2 million m^3 (1.6 million yd^3) of sediment from the Great Kills area between 1934 and 2003 and a minimum of 12.5 million m^3 (16.3 million yd^3) of fill was placed within the Staten Island unit from 1873 to 1948 (minimum because volume data could be found for all projects). See Appendix G for an overview of dredge and fill projects identified within the Staten Island unit.

Fort Wadsworth

Fort Wadsworth includes Battery Weed, a Civil War era fortification that is on the National Register of Historic Places. Battery Weed was built between 1847 and 1864 and is protected by a 268 m (879 ft) long granite seawall built from 1855–1871 (#146 Figures 25 & 26, Figure 27) (Gleisner and Auwaerter 2008).

The seawall was originally constructed to create a moat around the battery and ranges in height from 1.2 to 2.9 m (4 to 9.5 ft) and in depth from 1 to 2 m (3.5 to 6.5 ft) (Langan Eng. 1995). Sections of the seawall have collapsed over time, including a section south of the Fort's pier circa 1970 (Figure 27) and a section north of the pier circa 1980 (Gleisner and Auwaerter 2008). A portion of the seawall along the eastern side of the battery was rebuilt in 2006 (Gleisner and Auwaerter 2008).



Figure 25. Structure map for the Staten Island unit of GATE. Area in orange box is enlarged in Figure 26 and area in white box is shown in Figure 31 (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

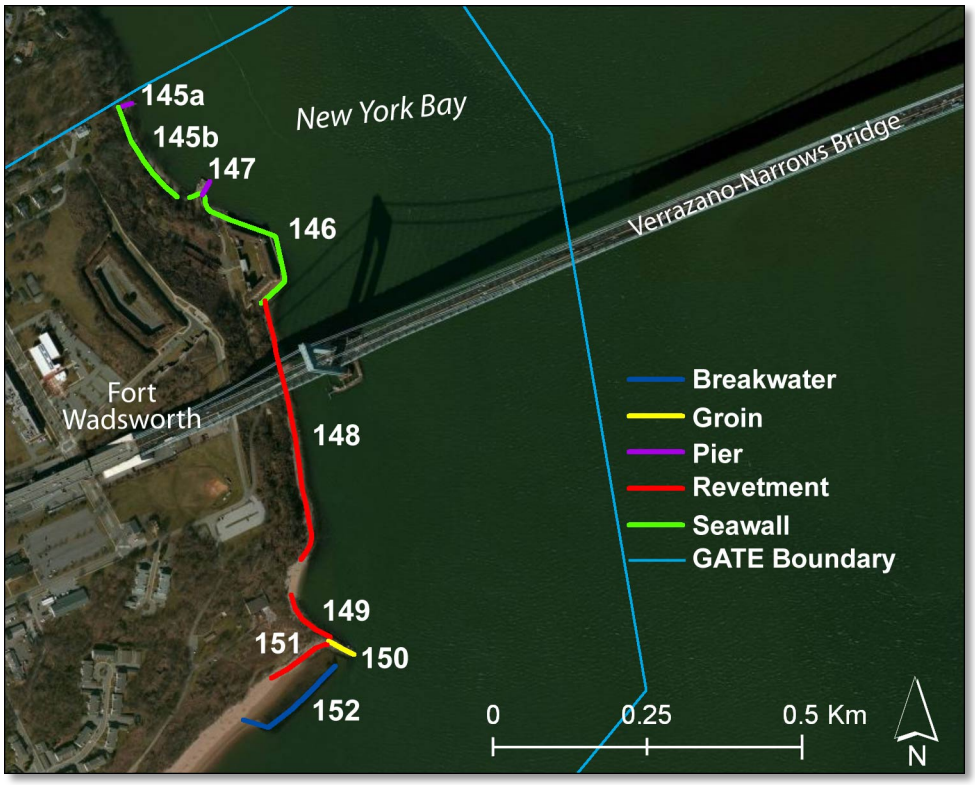


Figure 26. Structure map for the Fort Wadsworth area (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).



Figure 27. Battery Weed and its partially collapsed granite seawall (#146 Figure 26). View is to the southeast with the Verrazano-Narrows Bridge in the background (image by Kate Dallas).

North of the battery is a granite and concrete pier built by the U.S. Army by 1858 (#147 Figure 26 & Figure 28) (Gleisner and Auwaerter 2008). The pier was used for unloading cargo and later, during World War I, as a deployment area for torpedo mines (Langan Eng. 1995). Further additions to the pier included a granite L-shaped section completed prior to 1871 and a 47 m (154 ft) long timber addition in roughly 1907 (Langan Eng. 1995). The timber extension, along with a mine boathouse, dock house, and quartermaster warehouse, were removed circa 1960

(Gleisner and Auwaerter 2008). North of the pier is a roughly 180 m (590 ft) long concrete seawall constructed by Works Progress Administration-funded laborers circa 1938 (#145b Figure 26) (Gleisner and Auwaerter 2008) and a pier built before 1974 (#145a Figure 26).



Figure 28. Granite and concrete pier at Battery Weed (#147 Figure 26). View is to the northeast with the Verrazano Narrows Bridge in the background (image by Kate Dallas).

South of Battery Weed is a 435 m (1,430 ft) long revetment that runs underneath the Verrazano Narrows Bridge (#148 Figure 26). At the southeast corner of Ft. Wadsworth there is a detached, submerged breakwater, a rock groin, and two short rock revetments flanking the groin (#149–152 Figure 26). No background information could be found on these structures.

The beach on the ocean-facing side of Fort Wadsworth was nourished in the mid 1950s with an unknown volume of sediment (Psuty et al. 2010). The northern 75 m (245 ft) of beach is covered with a revetment (#151 Figure 26) and is located inshore of a submerged breakwater (#152 Figure 26). The remaining stretch of beach within Fort Wadsworth (southwest to #153 Figure 25) has an artificial sand dike along the back beach that acts as a barrier to storm surge (Psuty et al. 2010).

Franklin D. Roosevelt Boardwalk to Cedar Grove Beach

The Franklin D. Roosevelt Boardwalk stretches for 4 km (2.5 mi) from Fort Wadsworth to Miller Field (#155 Figure 25). From Fort Wadsworth to just south of the Ocean Breeze Pier (#158 Figure 25), the boardwalk is elevated and made of wood, while the remaining section to Miller Field is a low-lying paved path. The timber boardwalk was built in 1935 by the Works Progress Administration and rehabilitated by the New York City Department of Parks (NYCDP) in 1960–1961 (Wrenn 1975).

The original boardwalk construction was accompanied by 764,550 m^3 (1,000,000 yd^3) of beach nourishment, which created a beach 76 m (250 ft) wide along the full length of the boardwalk (Wrenn 1975, USACE 2002). Six timber and rock groins, and a timber bulkhead were also built at the same time to protect South Beach. The total project in 1935 was reported to have cost more than $2 million (Wrenn 1975).

In 1995 New York State and New York City agencies placed about 1,437,360 m^3 (1,880,000 yd^3) of medium-grained sand on Midland Beach at a cost of $745,000 (USACE 2002). The

newest addition to the shoreline is the steel and concrete Ocean Breeze Pier that opened in 2003 at a cost of $9 million (#158 Figure 25 & Figure 29) (NYC 2003).

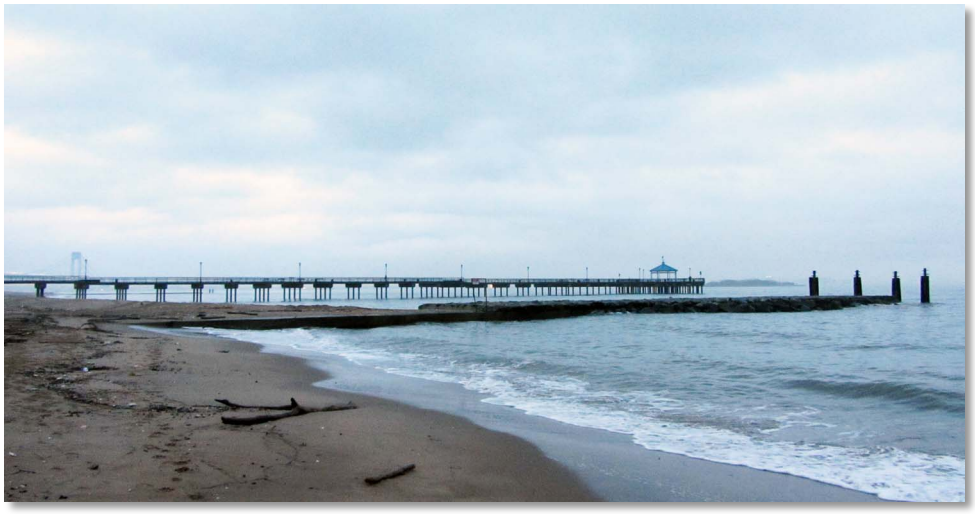


Figure 29. Ocean Breeze Pier and a groin at Midland Beach (#158–159 Figure 25). View is to the northeast (image by Kate Dallas).

Similar to the beach at Fort Wadsworth, an artificial sand dike is present in the back beach at Miller Field (Psuty et al. 2010). Psuty et al. (2010) describe the shoreline fronting Miller Field as completely artificial and a product of filling and groin construction. No information, however, could be found on the volume of sand placed.

From Fort Wadsworth to Great Kills Park there are 16 groins present along the shoreline (Figures 25 & 30). All of the groins were built before 1991 and eight of them are made of rock topped with a flat concrete cap. The remaining groins are made of wood, rock, concrete, or wood and rock (Figure 30).

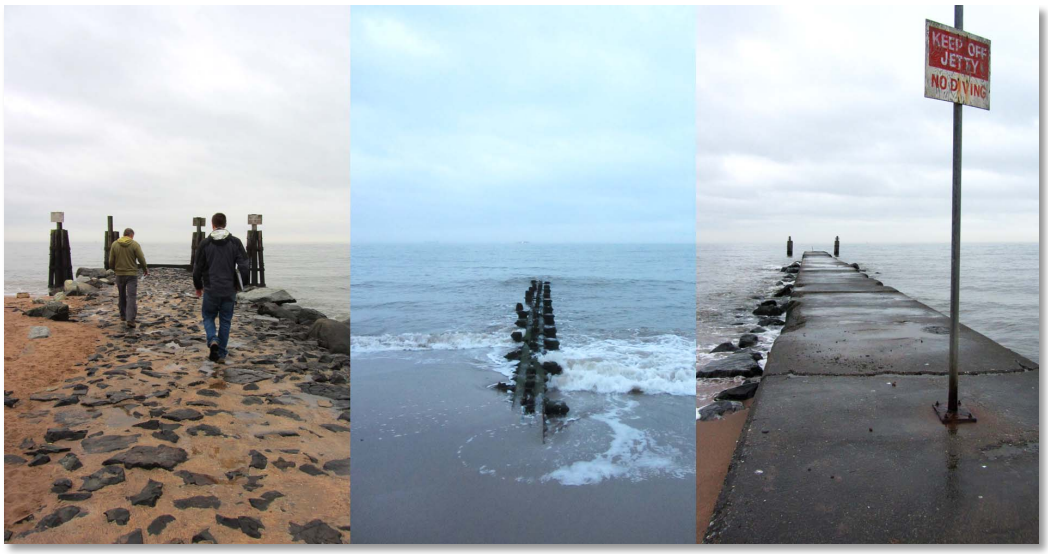


Figure 30. Groins along the Staten Island shoreline (from left to right #167, 163, 160 Figure 25) (images by Kate Dallas).

Oakwood Beach

The Oakwood Beach Wastewater Treatment Plant is at the northern end of Great Kills Park (Figure 31). The wood and concrete outfall flume, built in 1941 and repaired in 1957 by the NYCDP (NYCDP 1957), acts as a groin and limits littoral transport to the southwest (#172 Figures 31 & 32). The adjacent wooden bulkhead was built in 1957 by the NYCDP (#173 Figures 31 & 32) (NYCDP 1957). The NYCDP also installed a revetment west of the bulkhead in 1960 (#174 Figure 31) (NYCDP 1960). In 1975 an outfall pipe, partially buried in the seafloor, was constructed that extended almost 1.6 km (1 mi) offshore (Okulewicz and DiGuardia 1984). Okulewicz and DiGuardia (1984) report the pipe may act as a submerged groin impeding bottom littoral flow.



Figure 31. Structure map for the Great Kills Park area (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).



Figure 32. Outfall flume and timber bulkhead at the Oakwood Beach Wastewater Treatment Plant (#173, 174 Figure 31). View is to the northwest (image by Kate Dallas).

In 1999, the U.S. Army Corps of Engineers (USACE) constructed two earthen levees to protect the Oakwood Beach area from flooding. One levee was built south of the treatment plant along the eastern side of Oakwood Creek with a crest elevation of 3 m (10 ft) (#171 Figure 31) (USACE 2002). The second levee is an inland road running north and west of the treatment plant (not included in this inventory) (USACE 2002). In 2002, the NYCDP installed a 730-meter (2,400 ft) long revetment on the northern end of Oakwood Beach (#170 Figure 25) (Michael Browne, New York City Parks, email, 6-20-2012).

Great Kills Park

Great Kills Park was constructed through extensive dredging and filling. The total land area of the park is 1.6 km^2 (488 ac), of which 0.9 km^2 (223 ac) are composed of filled wetlands (NPS 2012a). The Works Progress Administration, USACE, and City of New York carried out the park's construction. The park was established by the NYCDP in 1934, but did not open to the public until 1949.

In preparation for filling, a 122-meter (400 ft) long steel bulkhead was constructed in 1933 near the present day Nichols Great Kills Marina (Figure 31) by the NYCDP (NYCDP 1933). The bulkhead was extended in both directions in 1935, with the southern end extending around the tip of Crookes Point (NYCDP 1935a) (#183 Figure 31). Filling started in 1935 and ultimately connected Crookes Point to the mainland (NYCDP 1935b, Baker and Honig 1982). In 1939, over 1.1 million m^3 (1.5 million yd^3) of sand was dredged out of Great Kills Harbor and put on Great Kills Park, accomplishing the dual purpose of creating a harbor and new land for the park (NYCDP 1940b, Baker and Honig 1982).

Additional bulkheading was required for fill placed in the 1940s. In 1943, a timber bulkhead was built on the northern shore of the boat basin (#175 Figures 31 & 33) (NYCDP 1943), bringing the total length of bulkhead to approximately 3,050 m (10,000 ft). Filling continued from November 1944 to July 1948 when over 11 million m^3 (15 million yd^3) of sanitary landfill material was used to raise the elevation of the park (Baker and Honig 1982).

The original steel bulkhead deteriorated and the section at the boat basin was removed and replaced in the late 1980s with a 549 m (1,800 ft) long timber bulkhead (#181 Figure 31) and two sections of revetment (#180, 182 Figure 31) (Baker and Honig 1982). At the same time, 866 m (2,840 ft) of the northern timber bulkhead was also rehabilitated (NPS 1986b).

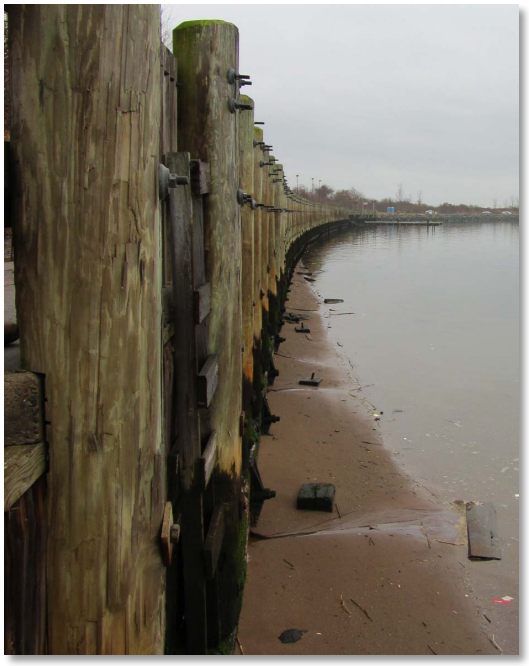


Figure 33. Bulkhead at Great Kills Harbor (#175 Figure 31). View is to the southeast (image by Kate Dallas).

The 160-meter (525 ft) long rock jetty at Crookes Point was built around 1957 by the NYCDP (#184 Figure 31, 34) (NYCDP 1956). Except for the very southern end, the jetty is now completely buried in sand. The purpose of the jetty is to prevent sand from entering the Great Kills Harbor navigation channel. The jetty has been effective at trapping sand, as evidenced by the difference in beach elevation on either side of the jetty, but sand has also traveled around the jetty and formed a beach on the downdrift, channel side (Figure 31).



Figure 34. Rock jetty at Crookes Point, Great Kills Park (#184 Figure 31). View is to the southeast (image by Kate Dallas).

The northeastern section of Great Kills Park has experienced chronic erosion over time (Figure 35). Likely drivers of erosion include wave focusing due to a projecting headland near Oakwood Beach and interruption of alongshore sediment transport by updrift groins (Psuty et al. 2010). Okulewicz and DiGuardia (1984) report the rate of erosion at Great Kills more than doubled after construction of the Oakwood Beach Wastewater Treatment outfall pipe (#172, Figure 32) in 1975.



Figure 35. Northeastern Great Kills Park on 3/8/1991 (left) and 6/17/2010 (right). The bathhouse was demolished by 1997 (images from Google Earth 2012).

Beach nourishment was the primary coastal protection method employed in the Great Kills Bathhouse area from 1949 to 1983. The beach between the bathhouse and Oakwood Beach Wastewater Treatment Plant was nourished in 1949 (NYCDP 1949), and again in 1954 with an unknown volume of sediment (NYCDP 1954). The beach fronting the bathhouse was nourished from 1966 to 1983 with roughly 183,000 m^3 (240,000 yd^3) (Table 8) (NYCDP 1966, Niedoroda et al. 1975, Okulewicz 2011). Erosion continued, leading to the loss of the nourished beach and eventually necessitating removal of the bathhouse.

Table 8. Beach nourishment projects at the Great Kills Bathhouse (NYCDP 1966, Niedoroda et al. 1975, Okulewicz 2011).

Year	Volume (m^3)
1966	
1972	~15,290
1973	~15,290
1974	~15,290
1975	~15,290
1979	30,580
1982	64,990
1983	26,760
TOTAL	**~183,490**

The federal navigation channel into Great Kills Harbor was constructed in 1927 and modified in 1938 (USACE 2012d). The project provides for a channel 3 m (10 ft) deep and 46 m (150 ft) wide from deep water in Lower New York Bay to the entrance of the harbor, a distance of approximately 3 km (1.9 mi) (USACE 2012d). Records from the USACE show that over 1.2 million m^3 (1.6 million yd^3) of material has been dredged from the Great Kills navigation

channel and anchorage area (Table 9) (Annette Baden, Assistant to the Freedom of Information Act Officer, USACE, email, 7/27/12).

Table 9. Dredging information for Great Kills navigation channel and anchorage area (data from Annette Baden, Assistant to the Freedom of Information Act Officer, USACE, email, 7/27/12).

Location	Month	Year	Volume (m^3)
Entrance channel	Dec–Aug	1934–1935	207,506
Entrance channel	Dec	1939	38,695
Channel & anchorage area	Jul–Feb	1941–1942	713,712
Channel & anchorage area		1943	21,313
Entrance channel	Jan–Feb	1945	47,797
Anchorage area	Jun	1948	58,183
Anchorage area	Jul	1948	71,648
Entrance channel	May–Jun	1962	20,643
Whole channel	Sep–May	2002–2003	104,307
TOTAL			**1,283,804**

Hoffman and Swinburne Islands

Hoffman and Swinburne Islands are two man-made islands off the southeastern coast of Staten Island in Lower New York Bay (Figure 23). The islands were constructed in the mid-1860s with sand dredged from New York Harbor (Stalter and Munir 2002). Swinburne Island is 10,000 m^2 (2.5 ac), while Hoffman Island, initially a 10,000 m^2 (2.5 ac) island, was enlarged to 40,000 m^2 (9.9 ac) in 1896 (Stalter and Munir 2002).

Hoffman and Swinburne Islands were used as a quarantine station and crematorium, respectively, for immigrants until the 1920s. From 1938 to 1947 the United States Merchant Marine used Hoffman Island as a training school (Wrenn 1975). Both islands were purchased by the NYCDP in 1965 and became part of GATE in 1972. The islands are now nesting sites for cormorants and gulls and are closed to the public. Both islands are surrounded by low seawalls and revetments and Hoffman Island also has two dilapidated piers on its western shore (#185–190 Figure 25). No information could be found on the history of these structures.

Sandy Hook Unit

The Sandy Hook unit occupies the northern 10 km (6 mi) of the Sandy Hook spit and contains mostly undeveloped lands (Figure 36). The spit receives sediment from northerly transport along the New Jersey shoreline and has grown northwestward over time. When the Sandy Hook lighthouse was built in 1974 it was 150 m (500 ft) from the spit's tip, but today it is 2.4 km (1.5 mi) from the tip due to spit accretion (Hoffman no date) (Figure 36). The spit has accreted through the northern extent of the GATE administrative boundary. The narrow, southern end of Sandy Hook is very susceptible to storm overwash and Sandy Hook has breached at times in the past. Plum Island represents the remnants of a washover fan at southern Sandy Hook (Figure 36).



Figure 36. Map of the Sandy Hook unit. The green-hatched areas are sections of federal channels included in this study (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

A total of 71 coastal engineering projects were identified in the Sandy Hook unit, including 64 coastal structures (Table 10), 5 beach nourishment projects, and 2 dredging projects. Coastal structures armor over 9.5 km (5.9 mi), or 31% of the approximately 31 kilometer-long (19 mi) shoreline in the Sandy Hook unit (Figure 37); if the two submerged bulkheads (#243 Figure 44 and 248 Figure 47) are removed from consideration, shore parallel structures armor 25%, or roughly 7.5 km (4.5 mi), of the shoreline.

Beach nourishment projects within Sandy Hook placed 5.7 million m^3 (7.4 million yd^3) of sand from 1975 to 2002, while adjacent communities updrift (south) of Sandy Hook placed 13 million m^3 (17 million yd^3) of sand from 1994 to 2009. Dredging in the Sandy Hook Channel and Shrewsbury River Channel near Sandy Hook has removed over 5.6 million m^3 (7.3 million yd^3) of sediment during 35 dredging episodes from 1960 to 2011. Appendices H–J provide overviews of all of the engineering projects identified in and adjacent to the Sandy Hook unit. For clarity in the report, the Sandy Hook unit is broken into four sections; northern, central, southern and south of the park (Figure 36).

Table 10. Coastal structures located within the Sandy Hook unit.

[1]Structures	Count	Length (m)
Breakwater	1	120
Bulkhead	6	3,430
Groin	30	1,640
Pier	6	400
Revetment	18	4,770
Seawall	3	3,070 [2]
TOTAL	**64**	**13,430**

[1]See Appendix A for structure definitions.
[2]Length represents the length of seawalls within the park. The southern seawall extends for roughly an additional 9 km (5.6 mi) south of the park.

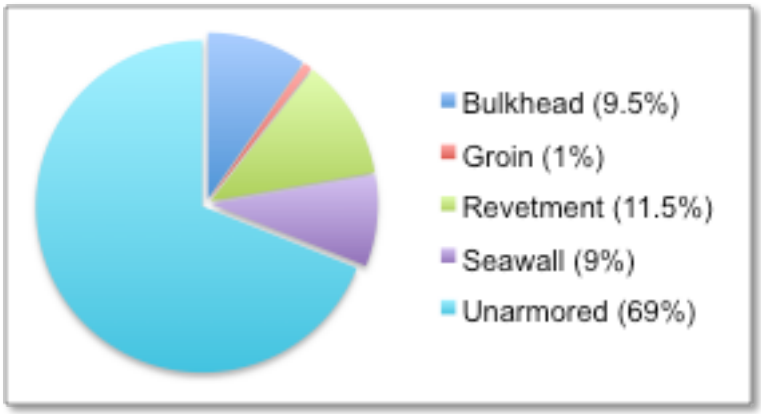


Figure 37. Percent of shoreline stabilized (by structure type) and unarmored in the Sandy Hook unit (includes submerged bulkheads).

Northern Sandy Hook

The northeast shore of Sandy Hook has accreted significantly over the last 30 years (Figure 38). Beach nourishment projects on southern Sandy Hook, and more notably, south (updrift) of the

park, have contributed great quantities of sand to the local sediment budget. From 1977–2002 beach nourishment projects placed over 28 million m^3 (37 million yd^3) of sediment (see the Southern Sandy Hook and South of the Park sections). Coastal erosion structures built in the past to protect the northeast shoreline are now buried in the back beach, far inland from the current shoreline. For example, at Gunnison Beach there is a timber groin that is completely buried by sand in the back beach (Figure 39 & #204 Figures 40 & 41). There are also rock groins at North Beach buried in the sand. Psuty et al. (2010) notes two rock groins at North Beach, while close inspection of Figure 38 shows possibly 3 groins. One rock groin at North Beach was positively identified in this study (#205 Figure 41).

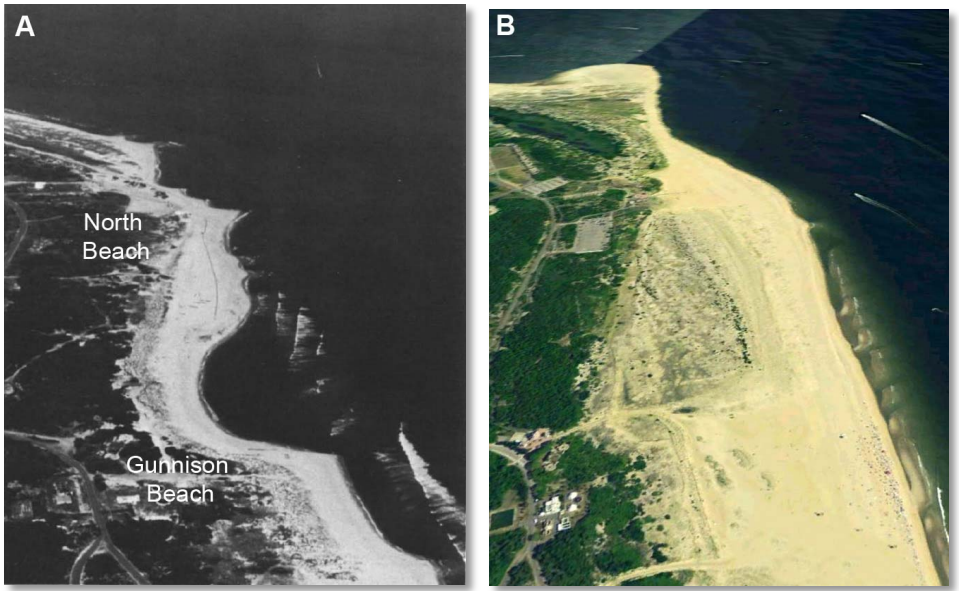


Figure 38. Comparison of the North Beach and Gunnison Beach areas in A) 1975 and B) 2009 shows significant beach accretion at northern Sandy Hook. The 1975 image was taken during a beach nourishment project – notice the pipeline on the beach and accretion fillet. View is to the north (1975 image from Nordstrom 1979, 2009 image from Google Earth 2012).



Figure 39. Buried groin in the back beach at Gunnison Beach (#204 Figure 41) (image by Kate Dallas).

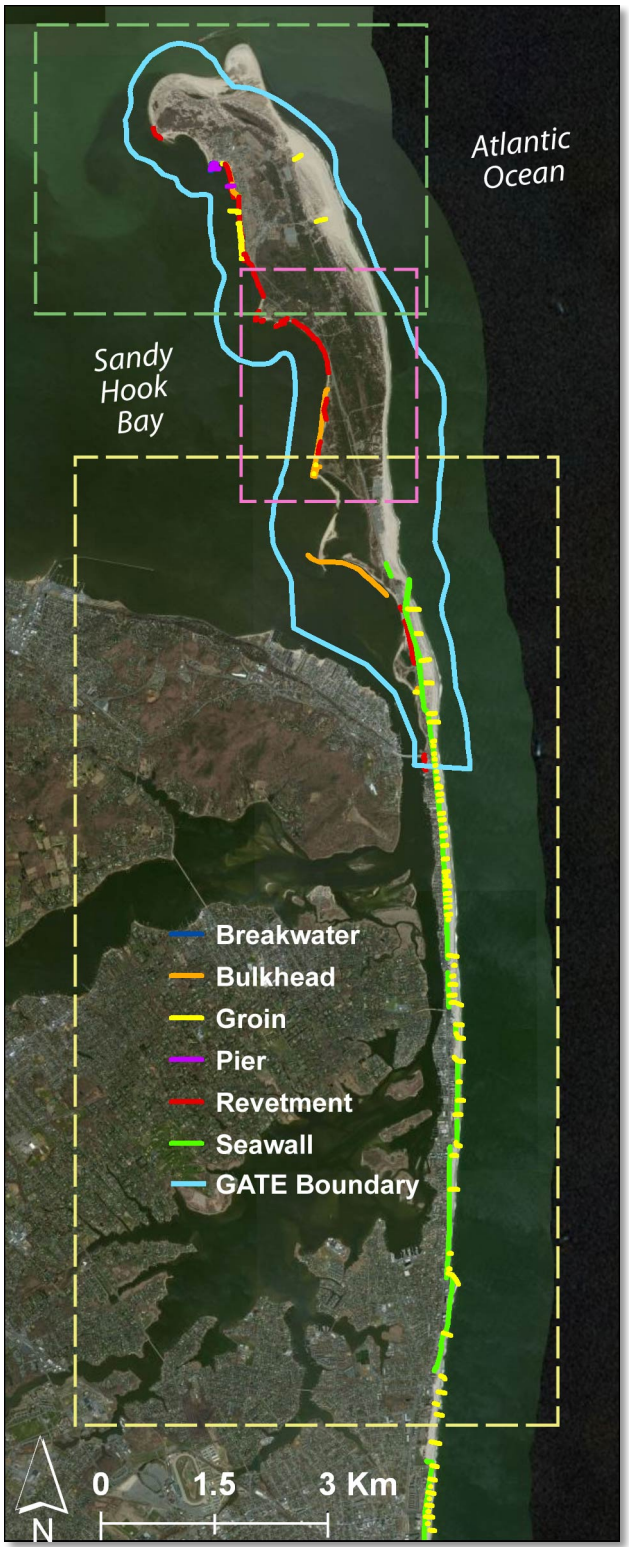


Figure 40. Structure overview map for the Sandy Hook unit. Green box, pink box, and yellow box are enlarged in Figures 41, 44, and 47, respectively (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

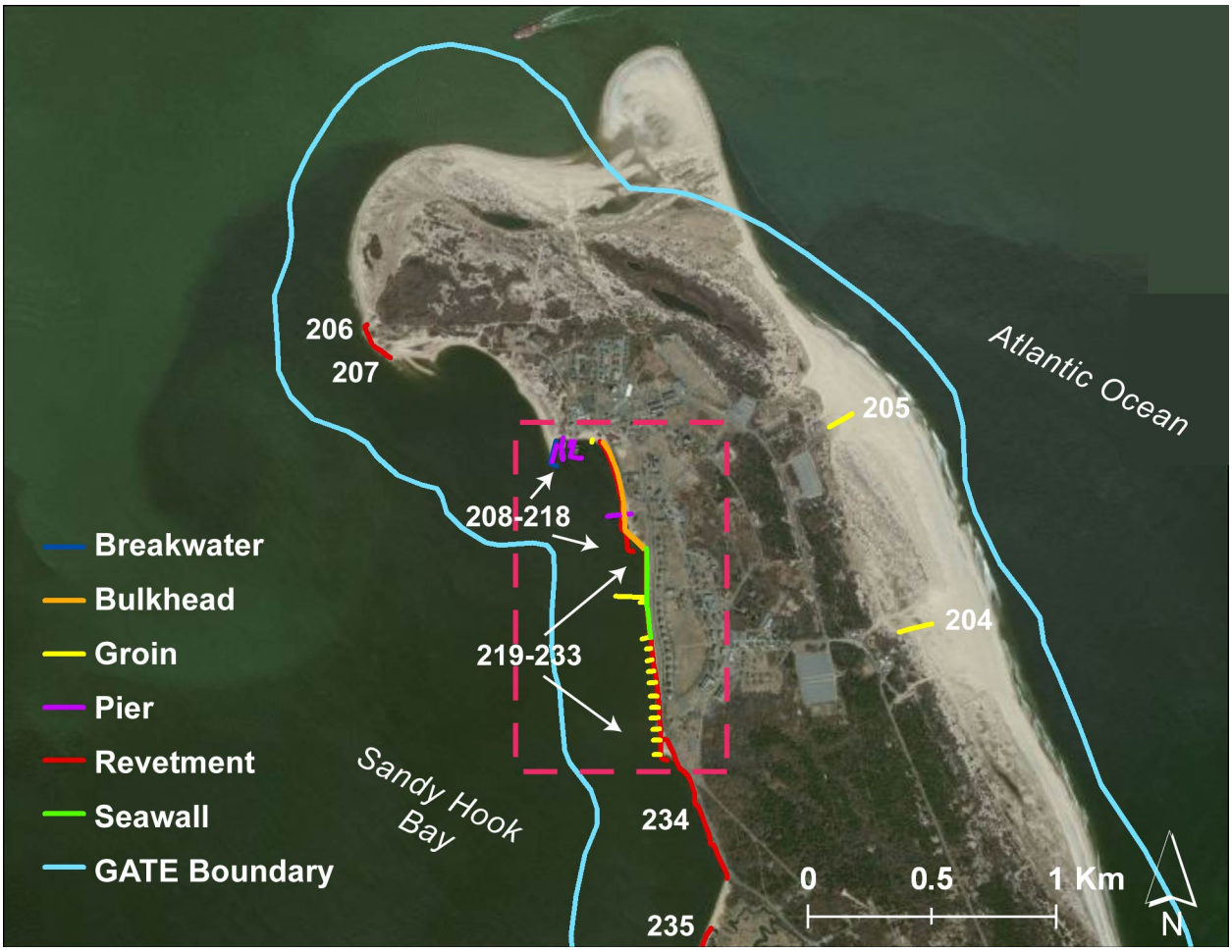


Figure 41. Structure map for Northern Sandy Hook. Area in pink box is enlarged in Figure 42 (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

In addition to accretion at North Beach and Gunnison Beach, sediment is also transported past the tip of Sandy Hook into the adjacent Sandy Hook Channel (Figure 36) increasing dredging requirements. The Sandy Hook Channel is one of the main entrance channels into the Port of New York is dredged periodically by the USACE. Since 1960, dredging has removed over 3.2 million m^3 (4.2 million yd^3) of sediment (Table 11) (USACE 2012e, Annette Baden, Assistant to the Freedom of Information Act Officer, USACE, email, 7/27/12). Material dredged from the channel has been placed at offshore disposal sites, on the beach at South Beach, and at other beneficial reuse locations including at Gunnison Beach.

Table 11. Dredging records for the Sandy Hook Bayside (SHB) Channel (data from USACE 2012e and Annette Baden, Assistant to the Freedom of Information Act Officer, USACE, email, 7/27/12).

Location	Month	Year	Volume (m^3)
SHB Channel–Gedney	Jan–Mar	1960	182,499
SHB Channel–Gedney	May–Jun	1962	27,830
SHB Channel Bayside	Jul–Aug	1965	165,450
SHB Channel–Sandy Hook Point	Jan–Mar	1966	42,586
SHB Channel–Sandy Hook Point	Jul–Aug	1969	345,571
SHB Channel	Apr–May	1971	309,133
SHB Channel	Jul–Aug	1972	255,192
SHB Channel	Oct–Nov	1973	24,939
SHB Channel	Dec–Jan	1974	105,174
Sandy Hook Point	Mar–Jun	1976	220,881
Sandy Hook Point	Apr	1978	237,776
Sandy Hook Point		1978	77,327
SHB Channel & cutoff between Bayside/Main	Apr–May	1965	236,859
Ocean to SHB Channel	Mar–Apr	1968	381,819
Junction Main Ship and SHB Channel	Jul–Aug	1979	225,663
Sandy Hook Point	Jul–Aug	1979	29,084
South side of SHB Channel	Aug–Sep	1984	82,396
SHB Channel		1997	71,868
SHB Channel	Sep–Nov	2008	18,024
SHB Channel	Sep	2009	99,392
SHB Channel	Dec–Mar	2011	134,726
TOTAL			**3,274,189**

Dredging, combined with waves, currents, and the construction of numerous structures has led to the interruption of sediment transport and caused severe erosion along the bayside beaches of Sandy Hook (Hoffman no date). In response to shoreline retreat, much of the bayside shore has been stabilized by coastal structures.

Since 1848 the U.S. Coast Guard has operated a life-saving station on the northwestern part of Sandy Hook. The land was formally transferred from the Army to the Coast Guard on October 25, 1950 (USCG no date). The station currently occupies 0.4 km^2 (95 ac) and has five boat piers and one attached breakwater (#208–213 Figure 42). Coastal structures at the Coast Guard station are included in this report because they are adjacent to park property. According to Brian McCabe, a Chief Warrant Officer with the U.S. Coast Guard, the original piers were built by the Army and have been updated by the Coast Guard over time (phone, 8/29/12). The small floating concrete and timber boat piers on the east side of the basin (#211–214 Figure 42) were built in the 1970s by the Coast Guard and updated in 2007. The Coast Guard also updated the large concrete and timber boat pier (#210 Figure 42) in the 1990s (Brian McCabe, U.S. Coast Guard, phone, 8/29/12). No additional background information could be found for the other structures at the station.

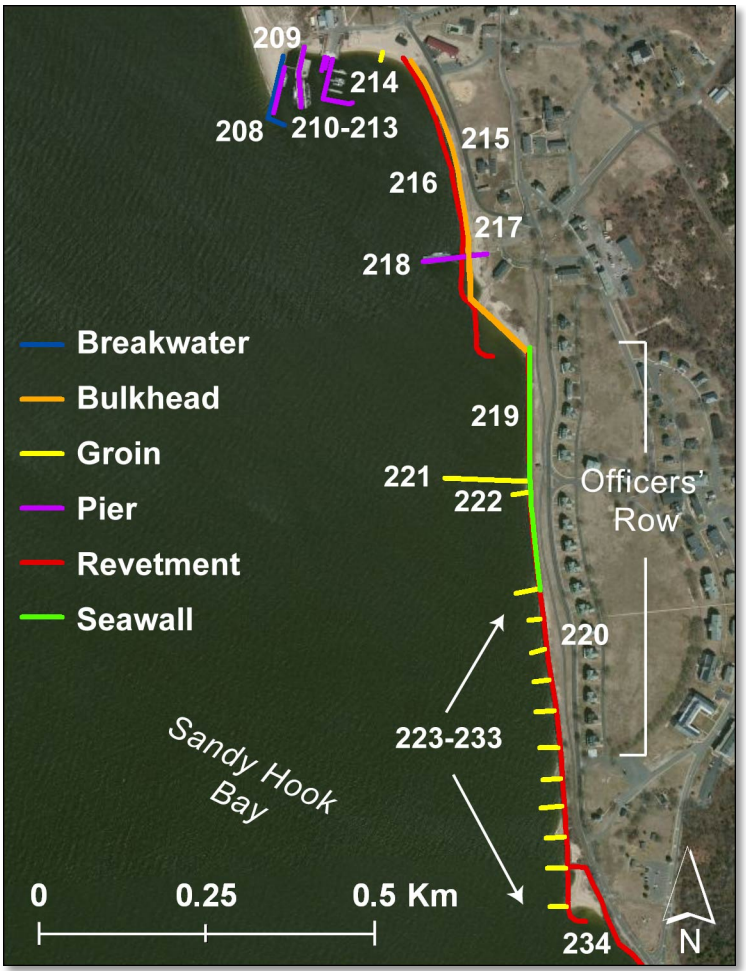


Figure 42. Structure map of the Fort Hancock area. Layers of structures are present at Fort Hancock and are not well represented in this figure. For example, the revetment in front of Officers' Row (#220) extends to the northern end of the seawall (#219), but the northern extent is not visible in the figure due to the overlapping seawall (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).

Fort Hancock is a historic army town on the bayside of Sandy Hook that defended New York Harbor from 1898 to 1974. The shoreline of the Fort has layers of structures built over time in attempts to stabilize the shoreline (Figure 42). One of the first coastal structures installed was a 400-meter (1,300 ft) long wooden bulkhead built by the U.S. Engineers in 1878 (#215 Figure 42) (the bulkhead is currently 490-meters [1,610 ft] long) (Bearss 1988). Another wooden bulkhead extending over 1,000 m in length (3,500 ft) was built in front of the previous bulkhead in 1897 and extended to the southern end of Officers' Row at a cost of $11,640 (#217 Figure 42) (Bearss 1981). Remains of the 1897 bulkhead are visible throughout the modern revetment (#220 Figure 42) along Officers' Row. The 1897 bulkhead performed poorly and was maintained every few years in the early 1900s. Bulkhead maintenance has continued over time, including a $32,000 emergency repair to the northern section in 1965 by the USACE (Bearss 1982).

In September 1899 a 300-meter (1,000 ft) long section of the bulkhead was shielded with a rock revetment, and in 1901 the revetment was extended south another 150 m (500 ft) (#220 Figure 42) (Bearss 1981). Today the revetment stretches for 866 m (2,841 ft). Rock groins in front of Officers' Row were added over time in 1902, 1903 (Bearss 1982), and in later years (#221–233

Figure 42). A concrete seawall also protects northern Officers' Row (#219 Figure 42). The 362 m (1,187 ft) long seawall was built in 1897 at a cost of $11,070 (Tom Hoffman, NPS Park Historian, email, 7/25/12), and repaired in 1965 by the USACE at cost of $8,000 (Bearss 1982). In 1954 the USACE expended $40,000 for construction of a groin near Pennington Street at the southern end of Officers' Row, although the exact location is unknown (Bearss 1982).



Figure 43. Layers of bulkheads and a revetment at Fort Hancock (#215–217 Figure 42). The ferry pier and dock can also be seen in the background (#218 Figure 42). View is to the northwest (image by Kate Dallas).

Ferryboat service to Sandy Hook started in the summer of 1997, with passengers unloading onto a temporary floating barge at Fort Hancock. In 2011 GATE installed a permanent floating dock and pier at the fort (#218 Figure 42). South of Fort Hancock the main road, Hartshorne Drive, runs next to the bay and the shoreline is armored with a rock revetment for 651 m (2,136 ft) (#234 Figure 41).

Central Sandy Hook

Along the central Sandy Hook Bay shoreline there are three historic gun batteries (Figure 36), all of which are stabilized by coastal erosion structures. Battery Arrowsmith, on northern Horseshoe Cove, was built in 1908 (NPS 1982) and is threatened by severe beach erosion. In the early 1990s two revetments composed of broken concrete were built to protect the battery (#235–236 Figures 44 & 45). A wooden bulkhead and a short rock revetment are also present to the east of the battery, on the southeast corner of Horseshoe Cove Marsh, but no information could be found on the history of these structures (#237–238 Figure 44).

Inland from Battery Arrowsmith is the Nike missile tracking area. Bearss (1982) reports that in 1954 the USACE constructed 107 m (350 ft) of bayside groins to shield the tracking area against beach erosion. However, no groins could be identified in this location during our study. South of Horseshoe Cove, Hartshorne Drive runs very close to Sandy Hook Bay and the shoreline is armored with a 887-meter (2,910 ft) long rock revetment (#242 Figure 44). The northern 107 m (350 ft) of the revetment was built in 1954 at an estimated cost of $35,000 (Tom Hoffman, NPS Park Historian, email, 7/25/12). Olko Engineering (1988) reports that the revetment was lengthened to the south in 1988.

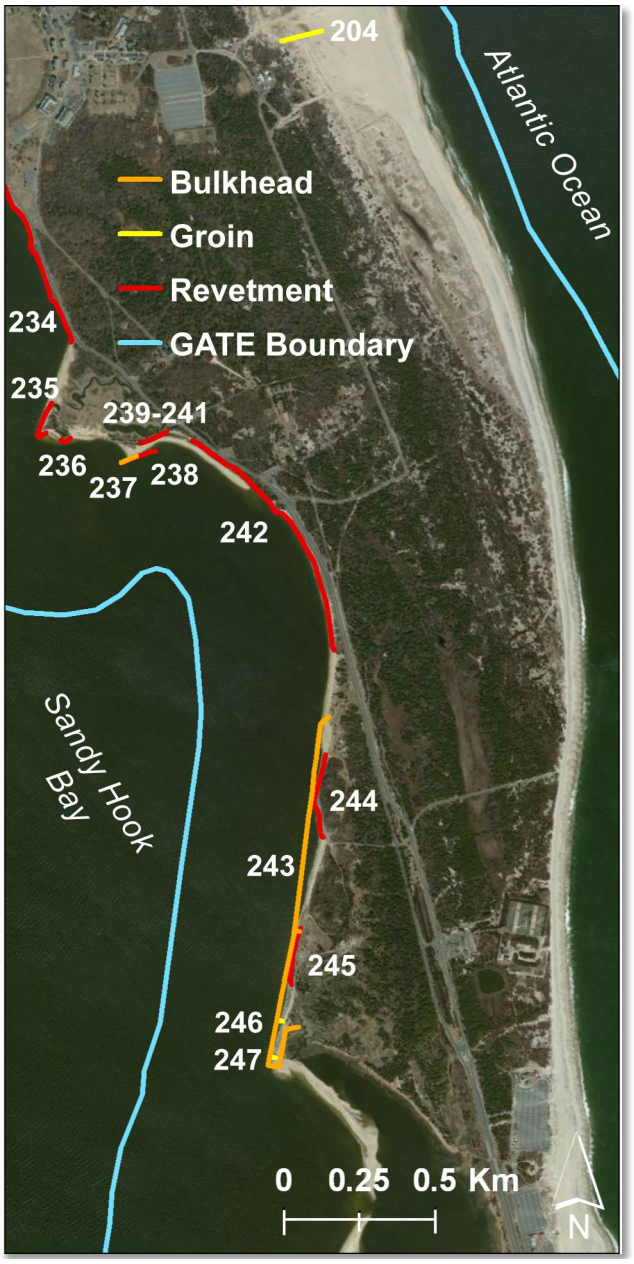


Figure 44. Structure map of central Sandy Hook (image from ESRI ArcGIS basemap, 2011 Bing Maps layer).



Figure 45. A concrete revetment at Battery Arrowsmith (#236 Figure 44). View is to the Northwest (image by Kate Dallas).

Batteries Mills and Kingman were built in late 1917 (NPS 1982) and are protected by revetments (#244–245 Figure 44). The revetment fronting Battery Kingman was installed sometime between 1995 and 2002, while the revetment at Battery Mills was built before 1995. Prior to the revetment, a 1.4 km (4,590 ft) long timber bulkhead provided shoreline protection from Battery Kingman, south past Battery Mills, and around the southern end of two explosive storage bunkers. Pilings are all that remain of the bulkhead, which was built in 1961 at a cost of $25,000 (Bearss, 1982) (#243 Figures 44 & 46). Extensive erosion has carved the shoreline back behind the bulkhead, leaving the pilings standing offshore and water lapping up to the storage bunkers (Figure 46). The cement bunkers are now acting as groins and trap sand (#246–247 Figure 44).



Figure 46. Pilings from a historic timber bulkhead and a cement bunker that acts as a groin in central Sandy Hook (#243 & 246 Figure 44) (image by Kate Dallas).

Southern Sandy Hook

A desire for coastal stability led to the construction of a 12-kilometer (7.5 mi) long rock seawall from 1900–1926 (Psuty et al. 2010). The massive seawall spans from Monmouth Beach, south of the park, to 2.5 km (1.6 mi) within the Sandy Hook unit (Figure 47A). In its current state, the seawall has a general elevation of 5.1 m (17 ft) (NAVD88) and a width of 3.7 m (12 ft) (Psuty et al. 2010). Fifty-two groins extend out from the seawall and were built in the early 1900s in an effort to trap and maintain sand. Eleven of these groins are located within the park (#192–202 Figure 47B), but are not currently visible because they are buried in accreted sand.

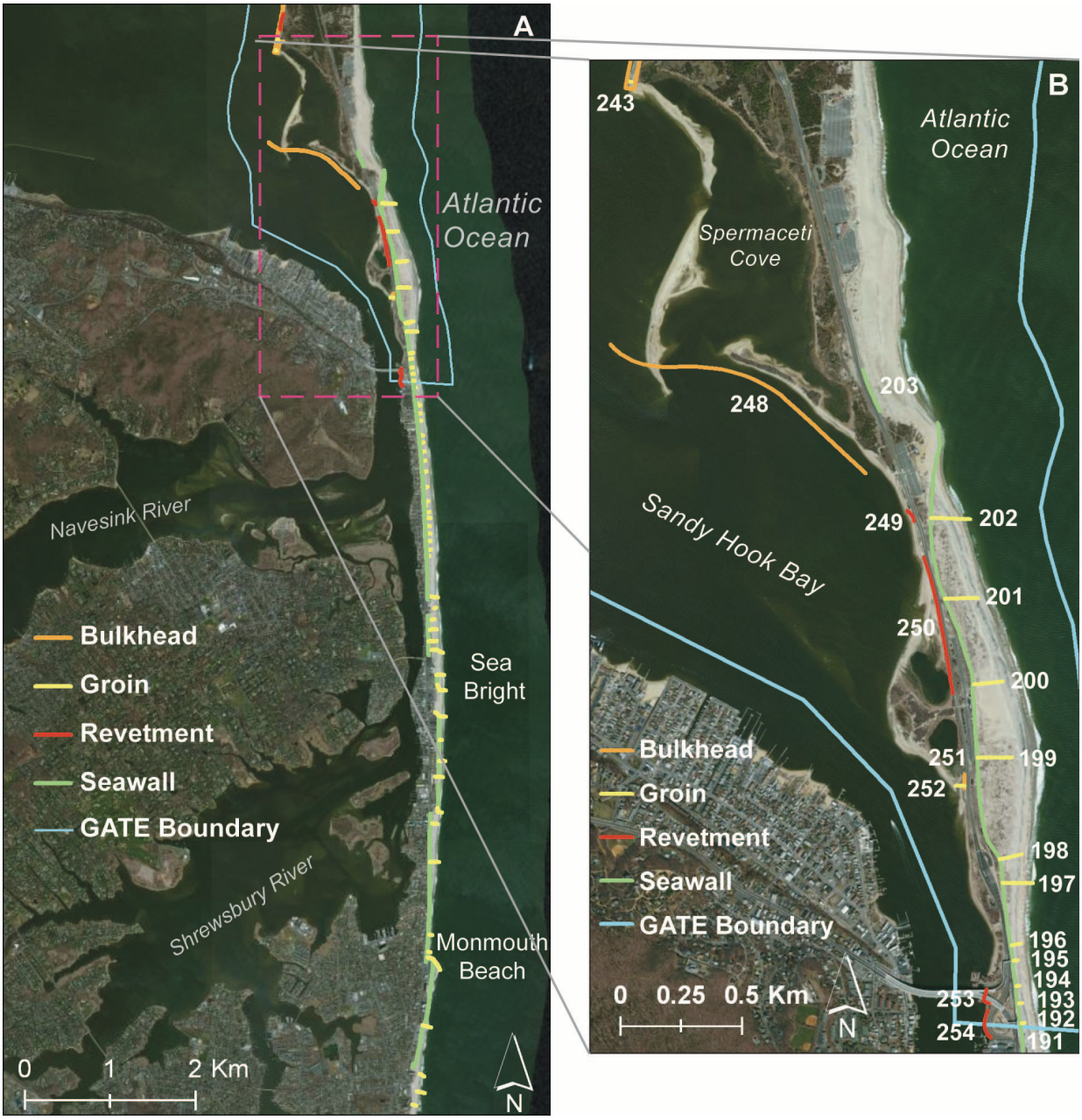


Figure 47. A) Map of the seawall and groins south of Sandy Hook. Area in pink box is enlarged in B. B) Structure map of southern Sandy Hook (images from ESRI ArcGIS basemap, 2011 Bing Maps layer).

Since the mid-1970s persistent erosion has occurred at the northern end of the seawall (Figure 48), impacting South Beach and park facilities (Psuty and Namikas 1991). This area is known as the Critical Zone. Storms in 1974, 1977, 1981, 1982, 1988, 1991, 1992, 1996, 1997, and 1998 caused overwash and flooding in the Critical Zone (Psuty and Namikas, 1991; NPS 2004; Bruce Lane, GATE Chief Ranger, email, 6/5/12) and at times, severed the main park access road. In the spring and summer of 1978 a sand bag dike was constructed along the road at the Critical Zone. The dike was capped with an artificial sand dune that was renourished in 1980 with 15,300 m^3 (20,000 yd^3) (Bruce Lane, NPS Chief Ranger, email, 6/5/12). The dike was repaired and enlarged in summer 1981, but a storm in October 1981 severely damaged the dike and eroded the northbound lanes of Hartshorne Drive (Bruce Lane, NPS Chief Ranger, email, 6/5/12).

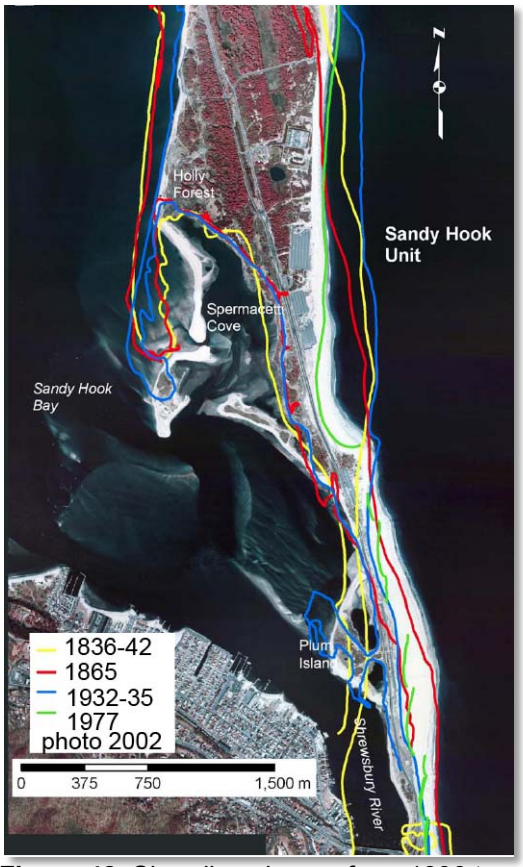


Figure 48. Shoreline change from 1836 to 2002 at southern Sandy Hook (from Pendleton et al. 2005).

Beach nourishment has been the primary protection measure employed at the Critical Zone, with placement of over 5.4 million m^3 (7 million yd^3) of sand from 1977–2002 (Table 12) (Figure 49). Additionally, 76,500 m^3 (100,000 yd^3) was placed offshore just south of the Critical Zone in summer 1978 by the USACE at no cost to the NPS (Bruce Lane, NPS Chief Ranger, email, 6/5/12). In the fall of 1988 a steel bulkhead was installed next to the road at a cost of $600,000 to provide protection until the next nourishment project was conducted (#203 Figure 47B).

Through 2004 the NPS has spent roughly $32 million to maintain the shoreline and vehicle access to Sandy Hook (NPS 2004). Recognizing the need for a long-term beach maintenance program, the park built a sand slurry pipeline to pump sand from Gunnison Beach to the Critical Zone (Figure 50) and from Gunnison Beach to Kingman Battery area. The operating period for the pipeline is November 1 to February 28 and pumping is expected to be conducted semiannually, but as of June 2012 the pipeline had not been productive in moving sand yet (Brian Forseth, NPS Chief of Maintenance Sandy Hook Unit, email, 6/4/12).

Table 12. Beach nourishment projects in the Critical Zone (South Beach).

Location	Year	Volume (m^3)	Project-Year Cost	Sediment Source	Source[1]
Critical Zone	Sept – Dec 1977	152,900	$770, 500	Trucked from North Beach	1, 2
Critical Zone	Jan – Feb 1980	15,300		Trucked from North Beach	2, 3
Critical Zone	Nov 1982 – Jun 1984	2,300,000	$14,500,000	Pipeline from Kingman & Mills Batteries	4, 5
Critical Zone	Aug 1989 – Jan 1990	2,500,000	$5,300,000	Beneficial dredge reuse from Sandy Hook Channel	4, 5
Critical Zone	Jan – Mar 1997	45,900		Trucked from Gunnison Beach	4
Critical Zone	Dec 1997 – Mar 1998	219,800	$3,000,000	Offshore borrow site	4, 5
Critical Zone	Nov 2002	193,400	$1,900,000	Offshore borrow site	4, 5
TOTAL		**5,427,300**			

[1]Source: 1: Nordstrom et al. 1979, 2: Valverde et al. 1999, 3: Psuty and Namikas 1991, 4: NPS 2004, 5: Bruce Lane, NPS Chief Ranger, email, 6/5/12.



Figure 49. Southern Sandy Hook was artificially wide following beach nourishment. View is to the southwest (from Psuty et al. 2010).



Figure 50. Sand slurry pipeline at Gunnison Beach (image by Kate Dallas).

At low tide pilings from a historic wooden bulkhead are visible offshore of southern Spermaceti Cove (#248 Figure 47B). The submerged bulkhead was built sometime before 1870 to mark a historic steamboat channel (Tom Hoffman, NPS Park Historian, email, 5/23/12). Along the southern Sandy Hook Bay shoreline there are also two revetments, another bulkhead, and a groin (#249–252 Figure 47B). Park records show that the USACE installed a 357 m (1,170 ft) long revetment in 1959 at a cost of $46,200 (Tom Hoffman, NPS Park Historian, email, 5/23/12). This may refer to revetment #250 in Figure 47B. No additional information could be found on the other structures along the southern Sandy Hook Bay shoreline, but historic aerial imagery from Google Earth shows that all of them were constructed before 1995. At the very southern edge of the park there are two short revetments near the bridge (#253–254 Figure 47B). Aerial imagery reveals that the northern revetment was built sometime between 2008 and 2010 and the southern revetment before 1995.

The Shrewsbury/Navesink River Channel (Figure 36) is dredged periodically by the USACE. The channel adjacent to southern Sandy Hook is roughly 3.5 km long (2.2 mi), 4 m deep (12 ft), and 90 m wide (300 ft), and runs from deep water in Sandy Hook Bay to the Route 36 bridge (USACE 2012f). Dredging in the Shrewsbury/Navesink River Channel near Sandy Hook removed nearly 500,000 m^3 (650,000 yd^3) from 1927 to 2011 (Table 13) (Annette Baden, Assistant to the Freedom of Information Act Officer, USACE, email, 7/27/12). Olko Engineering (1988) reports that considerable dredge disposal has occurred offshore of Plum Island from dredging operations in the Shrewsbury River.

Table 13. Dredging information for the section of the Shrewsbury/Navesink Channel that is near Sandy Hook (see Figure 36 for location) (data from Annette Baden, Assistant to the Freedom of Information Act Officer, USACE, email, 7/27/12).

Location	Month	Year	Volume (m^3)
Mouth & South of Highlands Bridge	Jul–Sep	1927	42,815
Mouth & South of Highlands Bridge	Apr	1929	15,744
Highlands Bridge & Oceanic Bridge	May–Jun	1930	8,516
Highlands Bridge & Oceanic Bridge	Jul	1931	17,668
Highlands Bridge & Oceanic Bridge	Aug–Sep	1932	29,636
Highlands Bridge vicinity	Jun–Jul	1940	29,478
Highlands Bridge vicinity & N. Branch via Upper Rocky Pt	Apr	1947	29,142
SH Bay to Highlands Bridge vicinity	Aug–Sep	1950	86,562
Highlands Bridge vicinity	Aug–Sep	1950	15,669
South of Highlands Bridge	Jun	1955	3,211
SH Bay to Highland Bridge & N. Branch to Oceanic Bridge	Nov	1985	131,665
SH Bay to Highland Bridge & N. Branch to Oceanic Bridge	Nov–Jan	2009	39,076
SH Bay to Highland Bridge & N. Branch to Oceanic Bridge	Aug–Oct	2010	20,234
SH Bay to Highland Bridge & N. Branch to Oceanic Bridge	Nov–Dec	2011	29,095
TOTAL			**498,510**

South of the Sandy Hook unit

The shoreline south of the park is one of the most heavily engineered coasts within New England and the Mid-Atlantic (Hapke et al. 2010). Data from the USACE (2012d) shows that there are 145 groins from the southern Sandy Hook boundary to Manasquan Inlet (a distance of roughly 33 km [20.5 mi]), which together extend for 13.2 km (8.2 mi). In addition, seawalls are present along 17.3 km (10.7 mi) of the shoreline within the same area.

Large beach nourishment projects south of the park have also impacted the park shoreline. Valverde et al. (1999) document that over 1 million m^3 (1.4 million yd^3) of sand was placed along 8.2 km (5.1 mi) of beach between Sea Bright and Monmouth Beach (Figure 47) in 1963 at a project cost of $1,418,400. From 1994–2009 the USACE placed approximately 13 million m^3 (17 million yd^3) of sediment in the communities of Sea Bright, Monmouth Beach, and Long Branch (Table 14) (USACE no date).

Table 14. Beach nourishment projects to the south of Sandy Hook (data from USACE no date, Valverde et al. 1999).

Location	Year	Renourishment	Volume (m^3)
Sea Bright – Monmouth Beach	1963	1994 – 1996, 2001 – 2002	6,218,130
Sea Bright	1995–1996		2,905,310
Long Branch	1999	2008 – 2009	3,844,950
TOTAL			**12,968,390**

The long-term renourishment plan for Sea Bright to Ocean Township calls for placement of nearly 2.7 million m^3 (3.5 million yd^3) every six years until 2045 (USACE no date). Because sediment transport is to the north in this region, Sandy Hook benefits from the addition of sand to

the system. Psuty and Pace (2009) concluded that the modern erosion rate in the Critical Zone was lower than historical rates because of the nourishment projects to the south.

Impacts

Gateway National Recreation Area is a unique park within the National Park system as it lies within one of the most urbanized centers of the country. Although it was established to preserve and protect the area's outstanding natural and recreational features, most of the coastal topography within the park has been impacted by coastal structures. These structures are changing rates and quantities of sediment transport, as well as areas of sediment accumulation and erosion (Psuty et al. 2010). In addition to traditional hard coastal engineering structures, a host of dredging, beach nourishment, filling, draining, and re-grading activities have transformed the land into commercial and recreational sites (NPCA 2007). This discussion will review some of the major alterations to the natural system and subsequent impacts to sediment transport processes.

The dominant wave energy in the region arrives from the east-southeast, primarily driving longshore currents and sediment transport towards the entrance of the harbor (Figures 51 & 52) (Psuty and Pace 2009). The prevailing wave patterns move sand northward along the beaches of New Jersey, resulting in the formation and extension of Sandy Hook. On Long Island and most of Staten Island, longshore transport moves sand in a southwestward direction, evident in the formation of Breezy Point and Great Kills Spit. Outer coast longshore sediment transport rates along northern New Jersey and southern Long Island are estimated to be between 300,000-400,000 m^3/yr (392,000 -523,000 yd^3/yr) (Van Gaalen 2004).

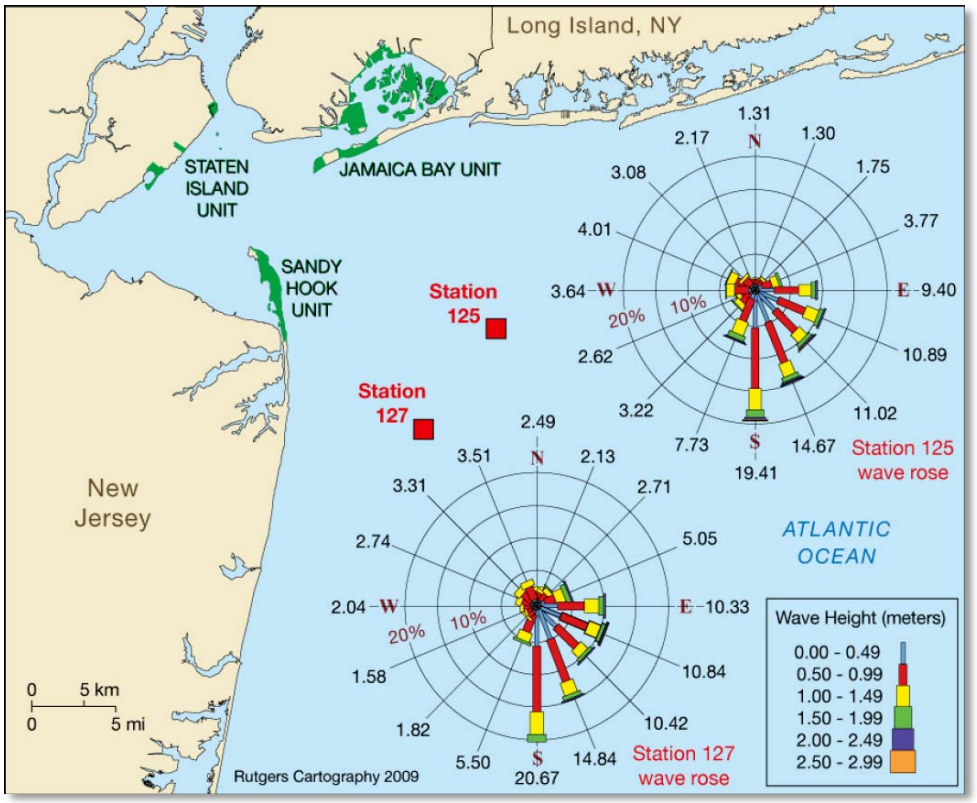


Figure 51. Wave roses showing frequency and magnitude of incident significant wave height at two offshore stations from 1980 to 1999. Values on the perimeter of the roses pertain to annual percentage of waves from that direction (from Psuty et al. 2010 after USACE 2009).

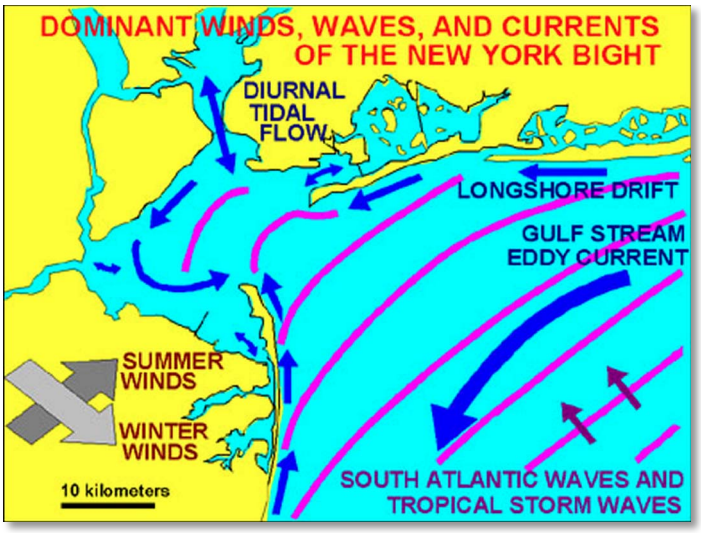


Figure 52. Schematic illustrating dominant winds, waves, and current patterns within the New York Bight (from USGS 2012b).

Jamaica Bay Unit

Jamaica Bay

Jamaica Bay encompasses nearly 107 km^2 (26,640 ac) of land surrounded by a wide array of natural and manmade features (Figure 53), and is one of the most productive coastal ecosystems in the northeastern United States (NPS 2007a). Parklands within Jamaica Bay are considered critical habitat for migrating birds and are home to more than 80 species of fish (NPS 2007a). The bay is known to provide overwinter habitat for brants, mallards, American black ducks, and canvasback ducks, as well as intertidal mudflats for foraging birds such as black skimmers and plovers (Hartig et al. 2002). As noted within the inventory, the bay has long been the site of anthropogenic modifications (such as dredge, fill, bulkheading and stabilization projects) to promote different commercial and recreational interests. The greatest impacts to sediment transport within the bay are the results of the modification of the Rockaway Peninsula and the dredge and fill projects within the interior of the bay.

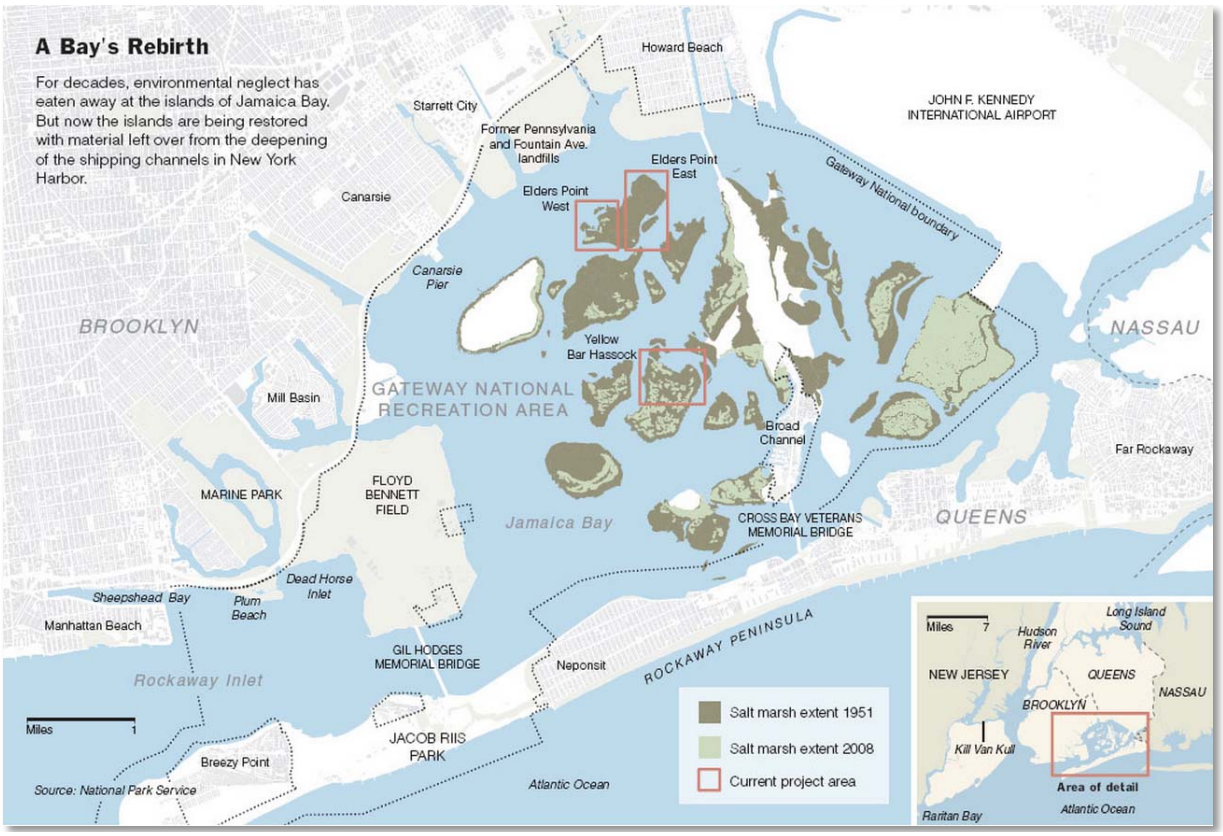


Figure 53. Jamaica Bay map with salt marsh island change from 1951-2008. Red boxes indicate areas of wetland remediation efforts from 2006-2012 (from Roberts 2010).

The Breezy Point jetty, maritime dredging activities, and armoring along the length of the Rockaway Peninsula has altered Jamaica Bay's ability to adapt to natural processes. The impacts of this stabilization and barrier elongation are a marked decrease in natural sediment transport and bay circulation. Lack of sediment input has strained the ecosystem contributing to a continual decrease in available wetland habitat, which is critical for migratory birds along with many other endangered and threatened aquatic and terrestrial species (NPCA 2007).

Saltwater marsh elevations are controlled by sediment deposition and erosion, peat accumulation and decomposition, pore-water storage, and subsidence, and any environmental changes to these processes can affect marshlands. It has been speculated that within Jamaica Bay the current sediment supply may be inadequate to maintain marsh elevations (Rafferty et al. 2011). Nearly 50% of the bay's wetlands have been lost within the last century, with nearly 66% of that loss occurring as a result of dredge and fill activities prior to the formation of GATE (Figures 6 &7) (Gornitz et al. 2001, NYCDEP 2007). Since 1950, filling operations along the bay shoreline have reduced the total surface area of the bay by nearly 50% (NYCDEP 2007).

Dredge and fill operations within Jamaica Bay have not only contributed to wetland loss and ecosystem degradation, but also to changes in hydrodynamics. While the surface area of the bay has been substantially reduced, the volume of the bay has increased by nearly 350% due to channel dredging (NYCDEP 2007). The increase in mean water depths (from 1 to 5 m [3.3 to 16.4 ft]) is thought to increase wave energy and sediment flushing time (Swanson et al. 1992,

USEPA 2001). It has also been hypothesized that borrow pits and navigation channels within the bay act as sediment sinks, removing sediment that otherwise would help to maintain marsh elevation (USEPA 2001). Other anthropogenic influences such as pollutant contamination and changes in runoff patterns and watershed hydrology affect bay salinity and nutrient levels, in turn making the bay unsuitable for native species of flora and fauna (NPS 2007a, Rafferty et al. 2011). Subsequently this further reduces marsh ability to accrete through below ground biomass formation.

While filling activities have been curtailed in recent decades, loss of marsh islands and interior wetlands have continued. A mapping analysis by the New York State Department of Environmental Conservation (NYDEC) in 2001 showed that half of the bay's vegetated marsh islands disappeared between 1924–1999 (NYDEC 2001). The NYDEC study concluded that the rate of marsh loss has stayed high with time, with 0.4 km^2/yr (10 ac/yr) lost from 1924-1974, 0.1 km^2/yr (26 ac/yr) lost from 1974–1994, and 0.2 km^2/yr (44 ac/yr) lost from 1994-1999. With the transformation of wetlands into mudflats and then sand flats, the natural ecosystem services of flood protection and erosion control have been greatly reduced.

Recent projects have begun to rebuild and restore marsh islands with a relatively high level of success. Since 2003, approximately 0.57 km^2 (140 ac) of wetlands has been rebuilt within the bay. Elders Point East and West marsh island restoration projects completed in 2006 and 2010, respectively, included a total placement of 421,000 m^3 (550,650 yd^3) of dredged sand, helping to rebuild 0.29 km^2 (72 ac) of marsh habitat (Figure 54) (USACE 2013b). While restoration and preservation efforts aim to curtail some wetland loss, the underlying trends of wetland bank erosion, marsh deterioration and tidal pool expansion are linked to sea level rise and sediment supply constraints and will likely continue in the future (Gornitz et al. 2001).



Figure 54. Elders Point Island East marsh island restoration in 2003, 2008, and 2010 (from left to right) (images from Google Earth 2012).

Breezy Point Jetty

The Breezy Point area within the Jamaica Bay unit of GATE represents a coastal barrier system that has been extensively altered over the last 150 years. The landscape has been modified to meet various military, commercial and residential interests associated with the development and evolving needs of New York City. While over 50 coastal engineering structures currently exist along the peninsula, the Breezy Point jetty (circa 1934) has had the greatest impact on the landscape (#87 Figure 18 & Figure 55).

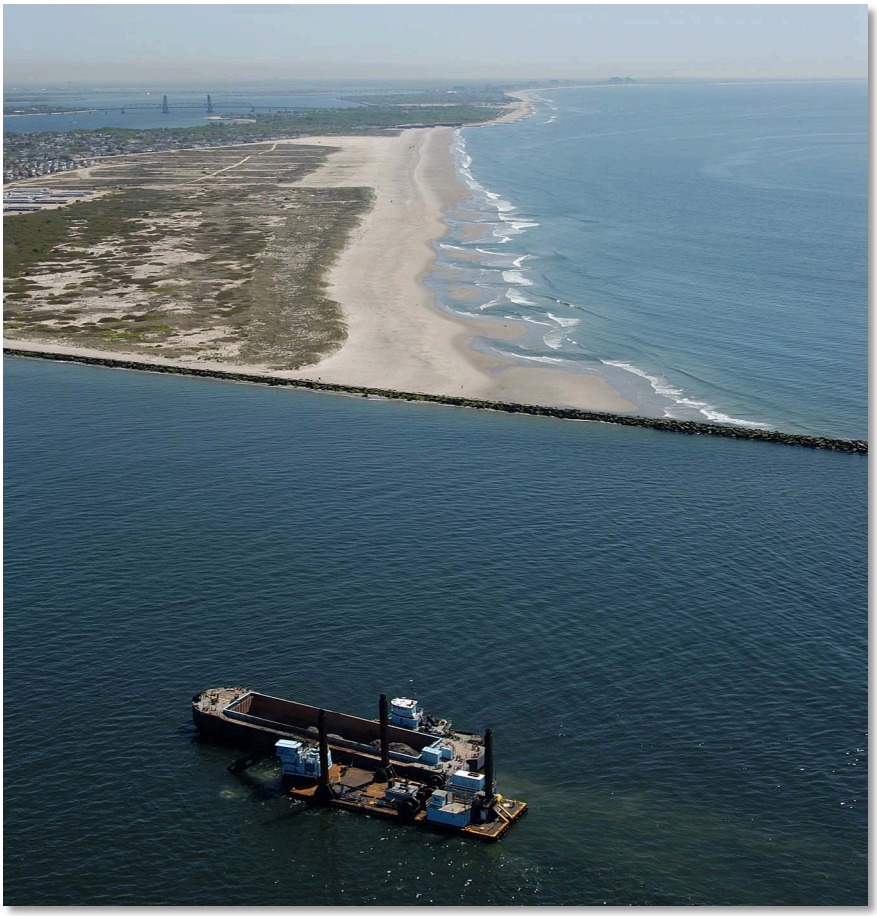


Figure 55. Oblique image of the Rockaway navigation channel, Breezy Point jetty, and accretionary fillet. View is to the northeast (from USGS 2012c).

Natural sediment transport is to the southwest with a transport rate of nearly 344,000 m^3/yr (450,000 yd^3/yr) (Figure 52) (Hess and Harris 1987). Historic imagery and nautical records indicate a clear pattern of southwestern barrier accretion (Figure 56) along the Rockaway Peninsula. There is also a regional trend of landward migration in response to sea level rise along the greater Long Island shoreline (Pendleton et al. 2004).

Construction of the 2,550-meter (8,400 ft) long rock jetty in 1934 terminated the western progradation of the barrier peninsula in an effort to support maintenance of the Rockaway navigation channel (Psuty et al. 2010). The updrift side of the jetty has experienced substantial accretion since the 1930s, with an increase in area of 0.65 km^2 (160 ac) (Figure 56). Presently the area updrift of the jetty is full, and sand is being transported around the jetty and into the

navigation channel (Psuty et al. 2010). As a result, the navigation channel must be actively dredged. Psuty et al. (2010) report that the shoreline along the western end of the accretionary fillet is likely to remain stable as it is constrained by the jetty, while the foredune in this area may continue to increase in height and width due to sediment transfer from the beach. In contrast, the eastern end of the accretionary fillet currently exhibits an erosional trend due to limited sediment supply, likely a consequence of updrift groins trapping sediment (Psuty et al. 2010).

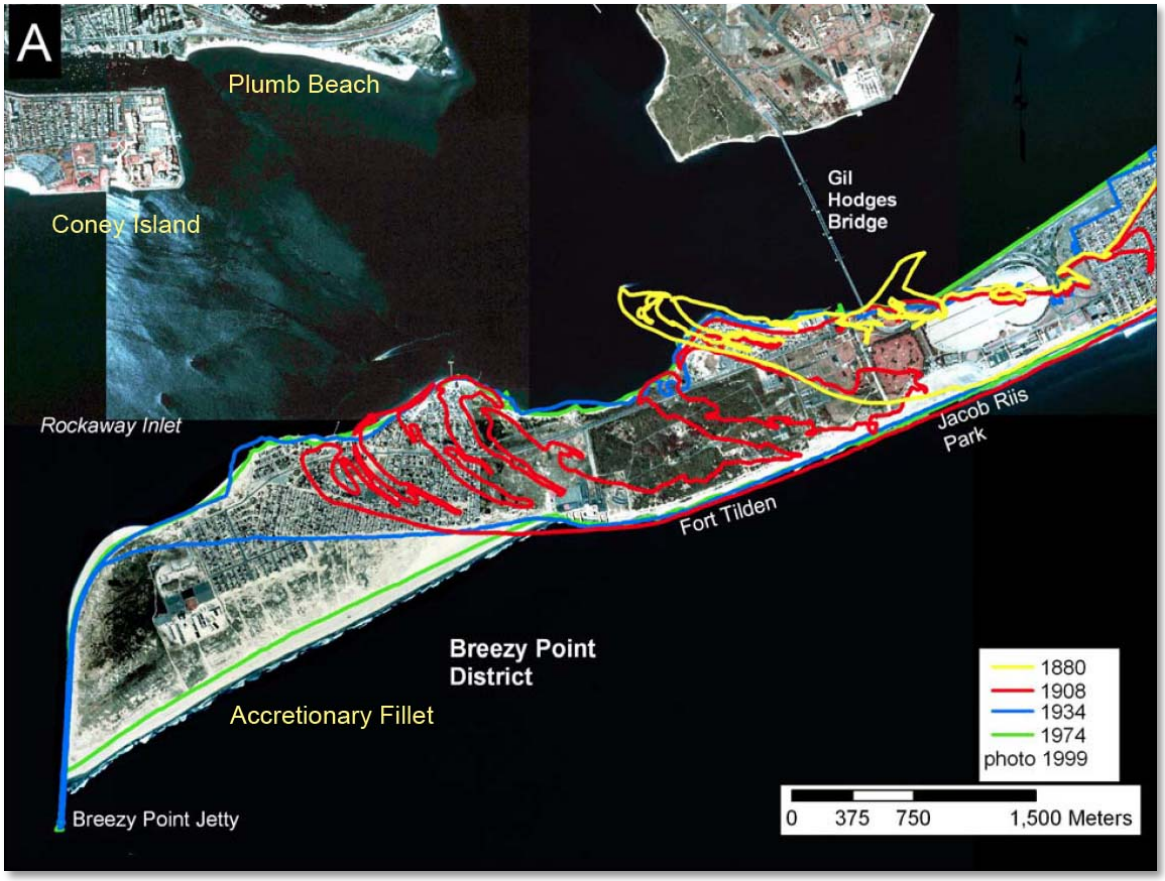


Figure 56. Map showing the westward growth of the Rockaway Peninsula from 1880 to 1999 (modified from Pendleton et al. 2005).

The Breezy Point jetty has also altered historic natural sediment transport pathways. Had natural processes proceeded unimpeded, it has been hypothesized that Rockaway may have eventually connected to Coney Island (Figure 56), with another tidal inlet opening into Jamaica Bay elsewhere (USGS 2012b). Plumb Beach represents the remaining portion of the eastern end of Coney Island, which historically received sediment from the Rockaway Peninsula (Figure 56). The elongation of Rockaway over the past few centuries has effectively isolated Plumb Beach from its sediment source (Psuty et al. 2010). The further elongation of Rockaway in the 1930s combined with localized dredging caused further retreat of Plumb Beach (Psuty et al. 2010). Plumb Beach has recently experienced significant erosion that has necessitated routine beach nourishment and sand bag placement to stabilize the backshore and protect the adjacent Belt Parkway.

Staten Island Unit

Great Kills Park

Great Kills Park, in the Staten Island Unit of GATE, has a storied past in which coastal engineering projects have been utilized to transform the landscape into the harbor and recreation area it is today (Figure 57). While a wide range of shore protection projects including bulkheads, revetments, beach nourishment, and dredging have been employed at Great Kills, this assessment focuses on the artificial fill and jetty construction from the 1930s to the 1950s (#184 Figures 31 & 58).



Figure 57. Aerial image of Great Kills Park. View is to the northeast (from Carse 2011).

The primary development of the park occurred between 1939 and 1951 with over 12.1 million m^3 (16.5 million yd^3) of material placed to fill 0.9 km^2 (223 ac) of wetlands (Wrenn 1975, NPS 2012a). This first stage of filling included placement of nearly 1.1 million m^3 (1.5 million yd^3) of sediment dredged from the Great Kills Harbor. This material was used to fill low areas of Crookes Neck and to attach Crookes Point to the mainland (Figure 58). This phase of the project modified a wide area of habitat, changing the low-lying sand bar and marshlands into a continuous spit landform. Filling also changed the local sediment transport characteristics. Prior to filling, some sediment would have likely been diverted through Crookes Neck towards today's inner harbor, rather than all of the sediment being transported towards the jetty, as is the case today.

The second phase of filling (1944-1948) included placement of nearly 11 million m^3 (15 million yd^3) of refuse material from the boroughs of New York City to elevate the park, making the low-lying areas accessible as a public park (Figure 58) (NPS 2007b). The fill material ranged in thickness from 2.4- 4.6 m (8-15 ft) and was covered by a thin layer of topsoil comprised of clay and sludge from the city's sewage (NPS 2007b).



Figure 58. Aerial image of Great Kills Park with fill and structure overlay (data from NPS 2007a, base image from Bing Maps 2012).

The impacts of fill placement largely stem from environmental consequences. What was once low-lying wetland habitat was covered by a blanket of fill approaching 4.6 m (15 ft) thick in many areas (NPS 2007b). The destruction of wetlands resulted in increased exposure to flooding and the elimination of a natural source of pollution control (USEPA 2006). While the fill created a better environment for upland vegetation and good habitat for migratory and resident birds, insects, small mammals, reptiles, and amphibians, the historic wetlands previously supported abundant wildlife, shellfish, oysters and productive fish nursery grounds (Tiner 2000, NPCA 2007). In addition to ecosystem changes, the sanitary landfill also contained contaminates. Radium deposits have been discovered at a number of sites within the park (likely from discarded medical treatment sources within the initial fill), prompting park closures and an environmental clean-up project (NPS 2012a). The full extent of impacts related to the initial fill repository is unknown, although it has clearly altered the biology and ecosystem of the park.

In 1958 a 160-meter (525 ft) long rock jetty was built at Crookes Point to assist in the maintenance of the navigation channel. Analysis of historic imagery by Pendleton et al. (2005) shows that the jetty has trapped sediment and increased beach width along the southern extent of the spit (Figure 59). Presently, the updrift side of the jetty is full and sediment is being transported around the jetty into the channel and alongshore towards the Great Kills boat basin (Psuty et al. 2010). This has led to the progradation of Crookes Point and the need for additional dredging in the navigation channel. The environmental features of the peninsula have also become degraded through time as invasive plants now dominate the landscape (NPS 2012a).

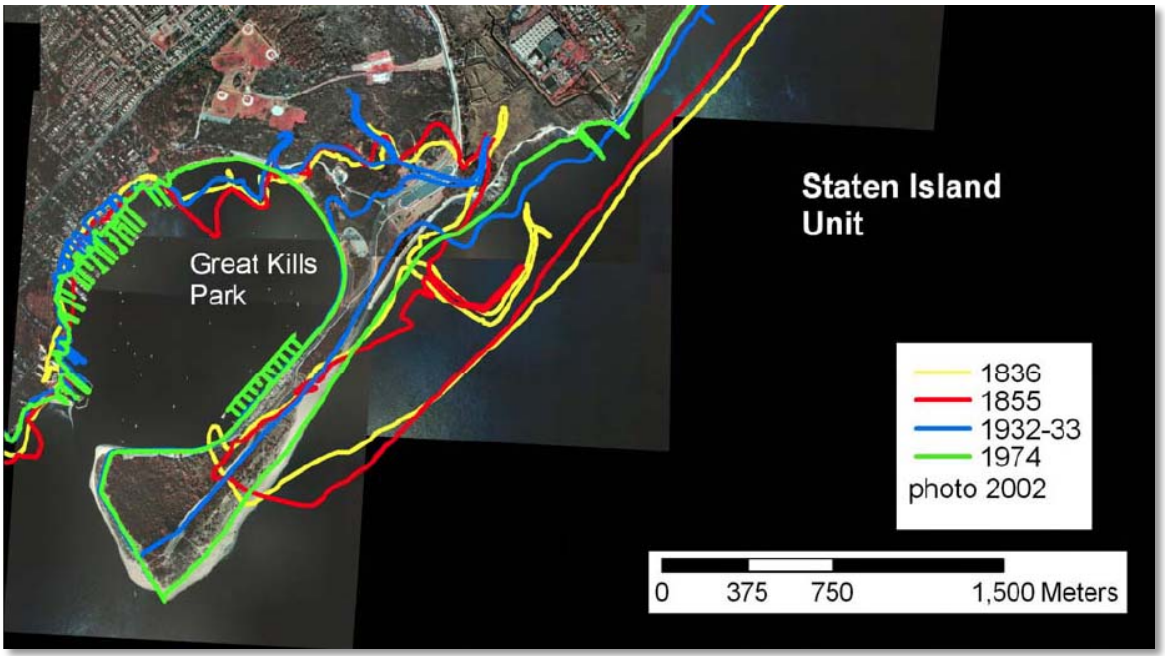


Figure 59. Historic shorelines (1836–2002) in the Great Kills Park area (from Pendleton et al. 2005).

Sandy Hook Unit

Seawall & Critical Zone

The structure with the greatest impact in and adjacent to the Sandy Hook Unit of GATE is the 12-kilometer (7.5 mi) long Sea Bright Seawall. The seawall was constructed from 1900–1926 and extends from Monmouth County, New Jersey to 2.5 km (1.6 mi) within the park (Figures 47 & 60) (Psuty et al. 2010). As illustrated within the inventory, this structure is one of numerous coastal engineering projects that has been completed in the area. These alterations have impacted natural processes, altered sediment availability with beach nourishment, and resulted in focused erosion (Nordstrom et al. 1977, Allen 1981, Psuty and Namikas 1991, Psuty et al. 2010).



Figure 60. Map showing the location of the Sea Bright Seawall along northern New Jersey (from Psuty and Pace 2009).

Within the last 250 years, Sandy Hook has been attached to the mainland at the Highlands, a separated barrier island, and a continuation of the northern New Jersey barrier island system connected at Long Branch (Figure 61) (Moss 1990). Except for short-lived inlets, Sandy Hook has been connected to Long Branch for the last century due primarily to seawall construction, in addition to other engineered solutions (namely groin construction and beach nourishment) (Figure 61) (Nordstrom et al. 1982, USGS 2012b). Previous inlet breaches allowed for sediment transport and hydraulic connectivity between the Shrewsbury and Navesink rivers and the Atlantic Ocean. This historic sequence of inlet formation and subsequent closing was a natural process based on storm frequency and severity, longshore currents and littoral drift magnitudes (Psuty et al. 2010). The presence of the seawall has severed these natural pathways, resulting in landform modification and greater back-bay stability.

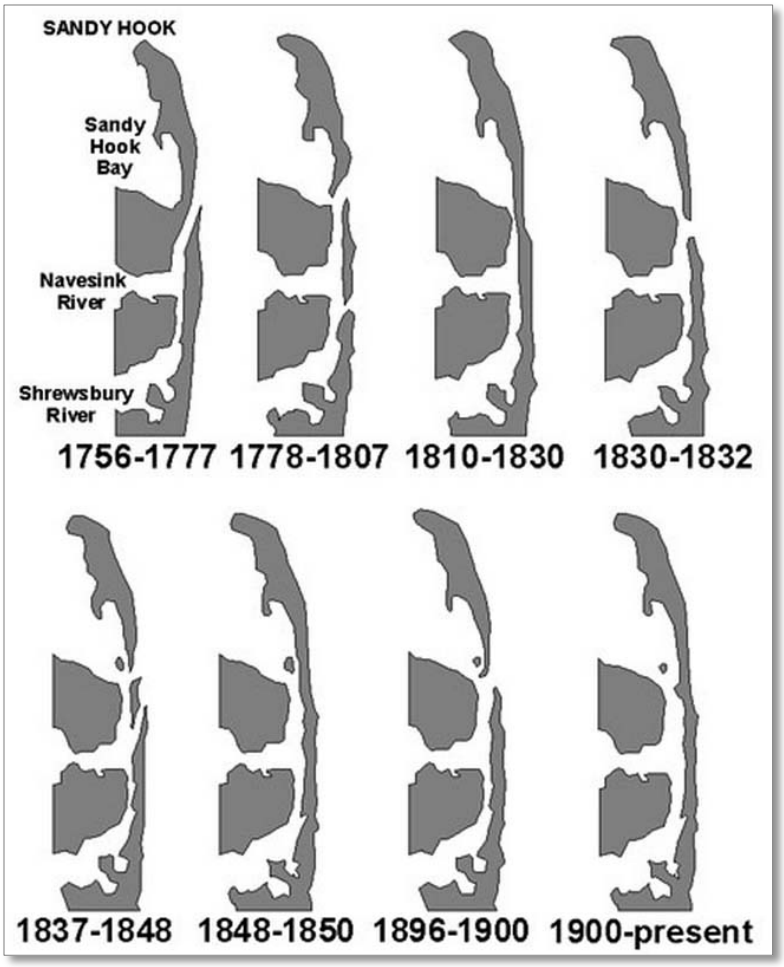


Figure 61. Map showing the progressive shoreline changes at Sandy Hook (from USGS 2012b after NPS Spermaceti Cove Visitor Center Display).

In addition to a distinct landform alteration, the seawall has also contributed to downdrift erosion at the northern end of the seawall. Historically, erosion was so severe that the northern end of the seawall was termed the 'Critical Zone'. Erosion in this location has led to overwash and flooding on numerous occasions and severed access to the spit (Hoffman no date). Estimates of sand transport rates along this section of ocean shoreline are thought to be approximately 382,000 m^3/yr (500,000 yd^3/yr) (Caldwell 1966, Psuty et al. 2010). Psuty and Namikas (1991) measured peak volumetric loss rates of 176,000 m^3/yr (230,000 yd^3/yr) at the Critical Zone in the late 1980s.

It is thought that the persistent erosion problem is a product of limited sand supply and the orientation of the spit in this vicinity (Psuty et al. 2010). Allen (1981) suggested that the fixed north-south orientation of the spit allowed for higher wave energy, causing erosion in this area, compared to the northwesterly facing northern segment of the spit, which experiences a relatively milder wave climate. The long-term erosion problem has persisted since the 1950s, with beach nourishment being the main protective measure. From 1977–2002, 5.4 million m^3 (3.9 million yd^3) of material was placed at the northern end of the seawall (Table 12).

Today a wide sandy beach exists in front of the seawall at the Critical Zone. This is likely due to an abundance of sand originating from updrift beach nourishment projects (Table 14) and beach nourishment projects at the site (Table 12), which have alleviated the natural sediment deficiency. Psuty and Pace (2009) described a relatively low (20,000 m^3/yr [26,000 yd^3/yr]) rate of net sediment loss in recent years (1998–2002), as compared to a high loss rate two decades ago (174,000 m^3/yr [227,600 yd^3/yr] from 1984–1989), which they attributed to updrift beach nourishment projects. While this location will likely continue to be a hotspot for erosion in the future, because the underlying fundamentals contributing to erosion (i.e. natural sediment availability and wave energy) will remain unchanged, the shoreline change rate is highly dependent on the frequency and magnitude of beach nourishment projects. As described within the inventory, long-term renourishment projects are scheduled for updrift coastal communities. If modest negative sediment deficiencies continue to persist, the NPS slurry pipeline (Figure 50) may be able to maintain adequate beach width at the Critical Zone (Psuty and Pace 2009).

Discussion and Recommendations for Further Study

Gateway National Recreation Area is a unique, highly urbanized park, where many coastal engineering projects have been inherited from previous generations. The installation of 254 coastal structures combined with dredge, fill, and beach nourishment projects has severely altered the natural flow of sediment, diminished wetland habitat and, in many locations, created a virtually new coastal environment altogether. Park managers are now managing resources such that a balance between this highly engineered environment and the natural ecosystem may be achieved.

GATE is primarily low-lying (Figure 62), making it vulnerable to increased erosion and flooding in light of the Intergovernmental Panel on Climate Change's sea level rise projections of 0.19 to 0.59 m (0.61 to 1.9 ft) by the year 2100 (IPCC 2007), and the higher projection of many other assessment studies of over 1.0 m (3.3 ft) by 2100 (e.g., Rahmstorf 2010). The devastating effects of Hurricane Sandy highlight the park's vulnerability to elevated water levels during storms (Figure 63). In these events, park holdings are particularly susceptible to overwash, severe erosion and wetland degradation.

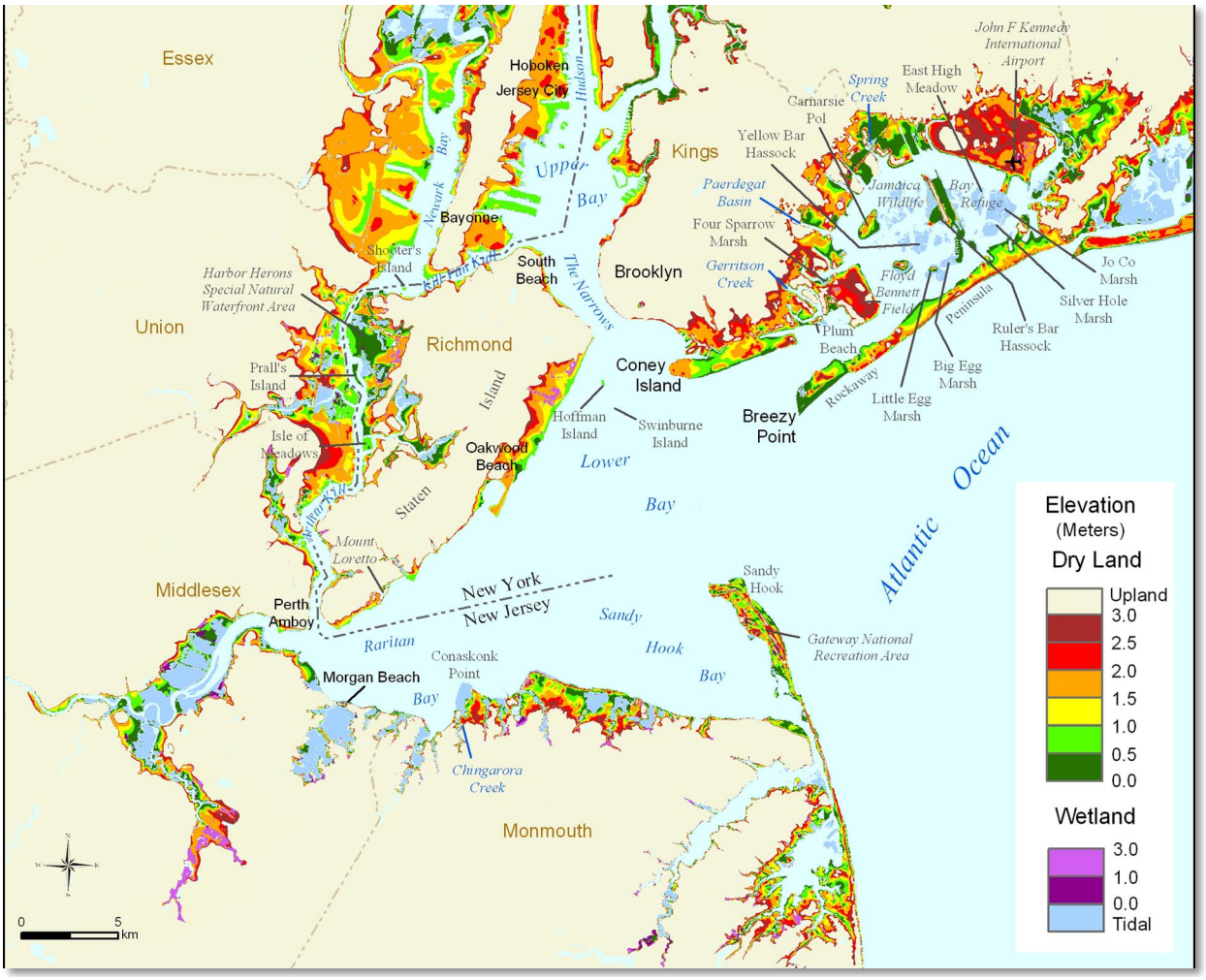


Figure 62. New York regional elevation map, showing that the majority of GATE is less than 3 m (9.6 ft) above the spring high water level (map generated by maps.risingsea.net after Titus and Wang 2008).

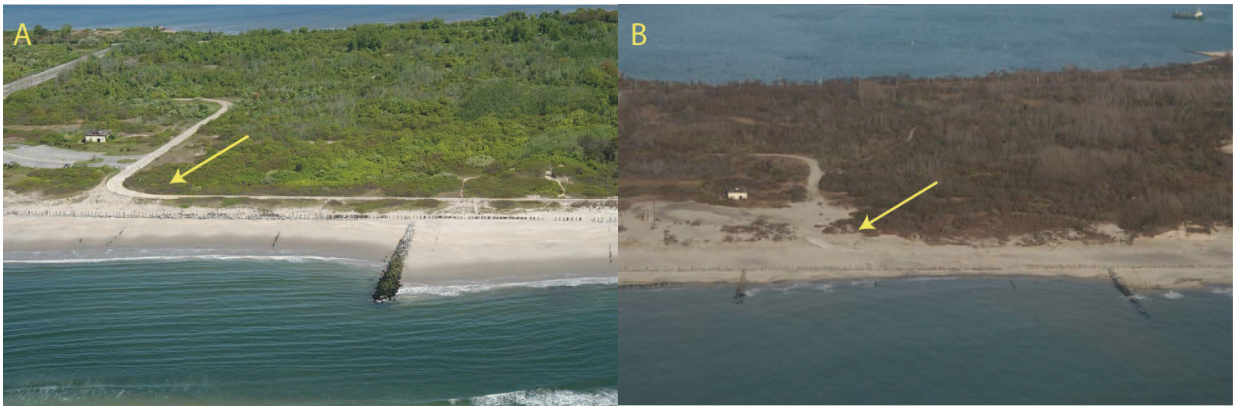


Figure 63. Fort Tilden area on the Rockaway Peninsula A) before (2009) and B) after (2012) Hurricane Sandy. Note the extensive damage to the coastal park road, shoreline retreat and destruction of the artificial dune. Arrows point to same location in both images (from USGS 2012c).

Sediment transport processes and coastal change rates along the outer coastal shorelines of GATE are well documented (e.g., Psuty and Pace 2009, Psuty et al. 2010), while limited research has been completed along the sheltered coastal areas within the park. Resources devoted to sediment dynamics research within the Jamaica Bay unit of the park will be beneficial to continued wetland restoration efforts. Additional resources devoted to assessing park holdings particularly vulnerable to sea level rise and coastal storm hazards will aid park officials in making informed, long-term management decisions regarding flooding and erosion hazards in light of anticipated climate change.

As pointed out by Nordstrom and Jackson (2012), the feasibility of protecting all of the threatened buildings and roads within GATE will decrease in the future as sea level rises and the existing coastal engineering structures degrade. Resources should be devoted to understanding the implications associated with allowing some developed sites within GATE to revert to natural processes. Applying this type of strategy to infrastructure considered marginal at present may help to facilitate more difficult future decisions.

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Appendix A. Glossary

Accretion: The accumulation of sediment, deposited by natural processes.

Beach Nourishment: The introduction of sediment along a shoreline to increase or protect the size of a beach (includes dune and berm construction and nearshore disposal of sediment for the purpose of shoreline stabilization).

Breakwater: Shore-parallel structures that reduce the amount of wave energy reaching a harbor or stretch of shoreline located behind the structure. Breakwaters are similar to natural bars, reefs or nearshore islands and are designed to dissipate wave energy. The reduction in wave energy results in gradients in littoral drift, causing sediment deposition in the sheltered area behind the breakwater. Some longshore sediment transport may continue along the coast behind the breakwater. Structures can be detached, attached or utilized as a headland control feature depending on design and functionality characteristics.

Bulkhead: Vertical structures or partitions, usually running parallel to the shoreline, for the purpose of retaining upland soils while providing protection from wave action and erosion. Bulkheads are either cantilevered or anchored sheet piles or gravity structures such as rock-filled timber cribs and gabions, concrete blocks or armorstone units.

Dike: Earthen structures (dams) that keep elevated water levels from flooding interior lowlands. The protected area is often below sea level. In open coast areas, dikes that separate low-lying areas from open water are often constructed with a revetment or similar armor layer on the open waterside to protect the dike from wave action and erosion.

Dredging: The mechanical removal of sediment, often used to increase or maintain the depth of a navigable waterway.

Erosion: The wearing away of land and the removal of beach or dune sediments by wind and wave action, tidal currents, wave currents, or drainage.

Groin: Structures that extend perpendicular or at nearly right angles from the shore and are relatively short when compared to navigation jetties at tidal inlets. Often constructed in groups called groin fields, their primary purpose is to trap and retain sand. Groins can be constructed from a wide range of materials including armorstone, pre-cast concrete units or blocks, rock-filled timber cribs and gabions, steel sheet pile, timber sheet pile, or grout filled bags and tubes.

Headland Control: The concept of systematically placing structures (typically breakwaters) to create artificial headlands in an effort to promote equilibrium beach formation. Bays are sculptured between these headlands, such that diffraction and refraction cause waves to develop perpendicular to the coast. This is intended to result in a stable shoreline even if sediment is still passing through a system of headlands. This concept is often employed as a regional approach to shore protection.

Jetty: Structures that extend perpendicular or at nearly right angles from the shore commonly used to limit the volume of sediment deposited in inlet channels and prevent inlet migration.

Levee: Flood protection structure that holds back water during flood stage, typically built along a river to protect against flooding.

Pier: A platform extending over water from a shore that is supported by piles or pillars, used to secure, protect, and provide access to ships or boats.

Revetment: A cover or facing of material placed directly on an existing slope, embankment or dike to protect the area from waves and strong currents. Revetments are designed to armor and protect the land behind them and are commonly constructed using armorstone (high wave energy environments) or riprap stone (lower wave energy environments) in combination with smaller stone and geotextile fabrics. Other construction materials include gabions, poured concrete (usually in stepped fashion), pre-cast concrete blocks, and grout filled bags. Structures can be partially detached from the shore (spur) depending on design considerations.

Seawall: Vertical structures used to protect backshore areas from heavy wave action, and in lower wave energy environments, to separate land from water. They can be constructed using a range of materials including poured concrete, steel sheet pile, concrete blocks, gabions, sandbags, or timber cribs.

Sill: Combination of elements from offshore breakwaters and rock revetments, typically built relatively close to shore, continuous and low-lying. Sills are generally built in lower wave energy regimes with the intent of reducing the wave climate and establishing marsh ecosystems or beaches.

Appendix B. Jamaica Bay unit coastal structure data

ID	Location	Structure	Material	Year Built	Year Maint.	Length (m)	[1]Source
1	Plumb Beach	Bulkhead	Concrete			104	
2	Plumb Beach	Revetment	Rock			20	
4	Plumb Beach	Breakwater	Tires	1980–1983		131	1
5	Shell Bank Creek	Revetment	Rock			184	
6	Shell Bank Creek	Revetment	Rock			151	
7	Gateway Marina	Pier		circa 2005		130	2
8	Gateway Marina	Pier		circa 2005		18	2
9	Gateway Marina	Pier		90s and early 2000s	late 2000s	2,513	2
10	Floyd Bennett Field	Bulkhead	Wood	circa 1900		642	2
11	Floyd Bennett Field	Revetment	Rock			255	
12	Floyd Bennett Field	Bulkhead	Steel	1942		398	3
13	Floyd Bennett Field	Groin	Concrete	1942		45	3
14	Floyd Bennett Field	Bulkhead	Steel	1942		1,118	3
15	Floyd Bennett Field	Revetment	Rock	2007		793	
16	Floyd Bennett Field	Revetment	Concrete			96	
17	Floyd Bennett Field	Groin	Rock	early 1940s		40	2
18	Floyd Bennett Field	Bulkhead	Steel	1929		352	3
19	Floyd Bennett Field	Groin	Concrete	1937	1955	68	3
20	Floyd Bennett Field	Bulkhead	Wood	1942		535	3
21	Floyd Bennett Field	Pier	Wood	1960		59	3
22	Floyd Bennett Field	Revetment	Rock	1972		368	3
23	Floyd Bennett Field	Groin	Concrete	1940		47	3
24	Floyd Bennett Field	Bulkhead	Wood	1939–1940	1952	256	3
25	Floyd Bennett Field	Bulkhead	Wood	1960		383	3
26	Floyd Bennett Field	Groin	Wood			33	
27	Floyd Bennett Field	Groin	Wood			11	
28	Floyd Bennett Field	Revetment	Concrete			44	
29	Floyd Bennett Field	Groin	Wood	mid 1940s		28	2
30	Canarsie Pier	Revetment	Rock			52	
31	Canarsie Pier	Pier	Concrete	1926–1927		194	4
32	Canarsie Pier	Revetment	Rock			51	
33	Penn. Ave Landfill	Revetment	Rock			264	
34	Penn. Ave Landfill	Pier		early 1970s	circa 2005	514	2
35	Fountain Ave Landfill	Revetment	Rock			143	
36	Fountain Ave Landfill	Pier		circa 2005		77	2
37	Fountain Ave Landfill	Revetment	Rock			979	
38	Shellbank Basin	Bulkhead	Wood	mid 1930s		426	2
39	Northern Rulers Bar	Revetment				93	
40	Hamilton Beach	Revetment	Rock			197	
41	Bergen Basin	Bulkhead		mid 1940s		138	2
42	JFK Airport	Groin		mid 1970s		81	2
43	JFK Airport	Revetment	Rock			167	
44	JFK Airport	Revetment	Rock			1,095	
45	JFK Airport	Revetment	Rock			1,338	

ID	Location	Structure	Material	Year Built	Year Maint.	Length (m)	[1]Source
46	JFK Airport	Revetment	Rock			212	
47	JFK Airport	Pier		late 1940s		808	2
48	JFK Airport	Pier	Wood	circa 1978		39	2
49	JFK Airport	Revetment	Rock			874	
50	JFK Airport	Revetment	Rock			921	
51	JFK Airport	Groin		mid 1970s		51	2
52	Subway Island	Revetment	Rock			79	
53	Subway Island	Revetment				77	
54	Rulers Bar	Revetment				54	
55	Rulers Bar	Revetment				107	
56	Bay side of Rockaway	Bulkhead	Steel	circa 1940		3,800	2
57	Bay side of Rockaway	Revetment	Rock	1945		405	5
58	Riis Landing	Breakwater		early 1940s		65	2
59	Riis Landing	Pier		early 1940s		47	2
60	Riis Landing	Pier		late 1970s		17	2
61	Riis Landing	Pier				20	
62	Riis Landing	Pier				12	
63	Riis Landing	Pier				45	
64	Riis Landing	Bulkhead	Steel	late 1920s	1943	225	2,6
65	Riis Landing	Pier		circa 2012		55	2
66	Riis Landing	Pier	Wood			25	
67	Riis Landing	Breakwater		early 1940s		69	2
68	Riis Landing	Bulkhead	Wood	early 1920s		247	2
69	Breezy Point	Groin	Rock	1930s		33	2
70	Breezy Point	Groin		before 1954, after 1948		20	2
71	Breezy Point	Groin		mid 1970s		14	2
72	Breezy Point	Groin		1930s		22	2
73	Breezy Point	Groin		mid 1970s		21	2
74	Breezy Point	Groin		before 1965, after 1954		23	2
75	Breezy Point	Groin	Rock	before 1965, after 1954		100	2
76	Breezy Point	Groin	Rock	before 1965, after 1954		33	2
77	Breezy Point	Groin	Rock	before 1965, after 1954		74	2
78	Breezy Point	Pier	Wood	late 1910s		81	2
79	Breezy Point	Groin	Rock	early 1940s		23	2
80	Breezy Point	Groin		early 1940s		35	2
81	Breezy Point	Groin		early 1940s		34	2
82	Breezy Point	Groin		early 1940s		37	2
83	Breezy Point	Pier	Wood	late 1910s		143	2
84	Breezy Point	Groin		early 1940s		24	2
85	Breezy Point	Groin	Rock	early 1940s		17	2

ID	Location	Structure	Material	Year Built	Year Maint.	Length (m)	[1]Source
86	Breezy Point	Pier	Wood	early 1920s		126	2
87	Breezy Point	Jetty	Rock	1931–1933	1953, 1963	2,550	2, 7
88	Fort Tilden	Groin	Wood	circa 1923		53	2
89	Fort Tilden	Groin	Wood	circa 1923		72	2
90	Fort Tilden	Groin	Wood	circa 1923		61	2
91	Fort Tilden	Bulkhead	Wood and rock	circa 1923	1943	1,799	2,8
92	Fort Tilden	Groin	Wood and rock	circa 1923		61	2
93	Fort Tilden	Groin	Wood and rock	circa 1923		59	2
94	Fort Tilden	Groin	Wood and rock	circa 1923		60	2
95	Fort Tilden	Groin	Wood	circa 1923		28	2
96	Fort Tilden	Groin	Wood	circa 1923		29	2
97	Fort Tilden	Groin	Wood and rock	1943		90	1
98	Fort Tilden	Groin	Wood	circa 1923		42	2
99	Fort Tilden	Groin	Wood	circa 1923		43	2
100	Fort Tilden	Groin	Wood	circa 1923		38	2
101	Fort Tilden	Groin	Wood and rock	1943		96	1
102	Fort Tilden	Groin	Wood	circa 1923		57	2
103	Fort Tilden	Groin	Wood	circa 1923		43	2
104	Fort Tilden	Groin	Wood	circa 1923		54	2
105	Fort Tilden	Groin	Wood	circa 1923		41	2
106	Fort Tilden	Groin	Wood and rock	1943		93	1
107	Fort Tilden	Groin	Wood	circa 1923		62	2
108	Fort Tilden	Groin	Wood	circa 1923		53	2
109	Fort Tilden	Groin	Wood	circa 1923		52	2
110	Fort Tilden	Groin	Wood	circa 1923		50	2
111	Fort Tilden	Groin	Wood and rock	1943		85	1
112	Fort Tilden	Groin	Wood	circa 1923		63	2
113	Fort Tilden	Groin	Wood	early 1920s		54	2
114	Fort Tilden	Groin	Wood	early 1920s		58	2
115	Fort Tilden	Groin	Wood	early 1920s		60	2
116	Fort Tilden	Groin	Wood and rock	1943		82	1
117	Fort Tilden	Groin	Wood	early 1920s		55	2
118	Fort Tilden	Groin	Wood	early 1920s		54	2
119	Fort Tilden	Groin	Wood	early 1920s		58	2
120	Fort Tilden	Groin	Wood and rock	1943		78	1
121	Fort Tilden	Groin	Wood	early 1920s		45	2
122	Fort Tilden	Groin	Wood	early 1920s		55	2
123	Fort Tilden	Groin	Wood	early 1920s		52	2
124	Fort Tilden	Groin	Wood	early 1920s		52	2
125	Fort Tilden	Groin	Wood and rock	1943		82	1
126	Fort Tilden	Groin	Wood	early 1920s		44	2
127	Fort Tilden	Groin	Wood	early 1920s		41	2
128	Fort Tilden	Groin	Wood and rock	1943		76	1
129	Jacob Riis Park	Groin	Wood	early 1920s	1936	45	2
130	Jacob Riis Park	Groin	Wood	mid 1920s		43	2, 4
131	Jacob Riis Park	Seawall	Concrete	1936–1937		1,365	9
132	Jacob Riis Park	Groin	Wood	mid 1920s		61	2, 4
133	Jacob Riis Park	Groin	Wood	mid 1920s		56	2, 4
134	Jacob Riis Park	Groin	Wood	mid 1920s		67	2, 4

ID	Location	Structure	Material	Year Built	Year Maint.	Length (m)	[1]Source
135	Jacob Riis Park	Groin	Wood	mid 1920s		68	2, 4
136	Jacob Riis Park	Groin	Wood	mid 1920s		68	2, 4
137	Jacob Riis Park	Groin	Wood	mid 1920s	1940	66	2, 4, 10
138	Jacob Riis Park	Groin	Wood	mid 1920s		67	2, 4
139	Jacob Riis Park	Groin	Wood and rock	1940		112	4, 10
140	Jacob Riis Park	Groin	Wood	1940		123	4, 10
141	Jacob Riis Park	Groin	Wood	1940		119	4, 10
142	Jacob Riis Park	Groin	Wood	1940		98	4, 10
143	Jacob Riis Park	Groin	Wood	1940		67	4, 10
144	Jacob Riis Park	Groin	Rock	1920s	1979, 1982	121	1, 11

[1]Source: Psuty et al. (2010), 2: NOAA (2012b), 3: Cody and Auwaerter (1982), 4: Wrenn (1975), 5: NYCDP 1945, 6: USACE (1943b), 7: Smith (1988), 8: USACE (1943a), 9: Unrau (1981), 10: NYCDP (1940), 11: USACE (1979).

Appendix C. Jamaica Bay unit beach nourishment data

This table contains only those beach nourishment projects where a year and an approximate location could be determined and, therefore, represents only a fraction of the total nourishment projects that have occurred in the area. Refer to Table 6 and the Rockaway Peninsula section in the report for discussion of other nourishment projects within and updrift of the Jamaica Bay unit.

Location	First Year	Renourishment Year	Volume (m^3)	[1]Length (m)	In GATE	[2]Source
Jacob Riis Park	1915		765	118	Yes	1
Jacob Riis Park	1916	1920	4,740	144	Yes	1
Jacob Riis Park	1936		1,529,110	677	Yes	1
Jacob Riis Park	1939		16,820	264	Yes	1
Jacob Riis Park	1940		191,139	193	Yes	1
Eastern Jacob Riis Park	1979		356,282	489	Partial	2,3
Plumb Beach	1992	2012	243,895	241	Yes	4,5,6
Roxbury Community	1994		152,146	773	No	3
Rockaway Beach	Oct 1995	Nov 1996	2,052,886	9,677	No	7
Rockaway Beach	2000		1,146,832	2,368	No	7
Rockaway Beach	2003	March 2004	766,258	6,176	No	7

[1]Length is very approximate.
[2]Source: 1:Unrau (1981), 2: USACE (1979), 3: Valverde et al. (1999), 4: Psuty et al. (2010), 5: WCU (2012), 6: Dredging Today (2012), 7: USACE (2012c).

Appendix D. Jamaica Bay unit dredge and fill data

This table contains only those dredge and fill projects where a year and an approximate location could be determined and therefore, represents only a fraction of the total dredge and fill projects that have occurred in the area. Refer to the Jamaica Bay unit section in the report for a discussion of additional projects.

Location	Type	First Year	Last Year	Volume (m^3)	[1]Area (m^2)	In GATE	[2]Source
Canarsie Pier	Filling	before 1911			54,265	Partial	1
Floyd Bennett Field	Filling	1911	1918		586,201	Yes	2
Mill Basin Channel	Dredging	Jan 1916			133,329	Partial	1
Shellbank Basin	Dredging	mid 1910s			38,069	Partial	1
Hawtree Basin	Dredging	mid 1910s			19,884	Partial	1
Deep Creek Channel	Dredging	circa 1923			87,574	Yes	1
Rulers Bar	Filling	1924–1928			998,190	Yes	1
Bergen Beach	Filling	1920s			591,352	Partial	1
Canarsie Pier	Filling	mid 1920s			319,326	Partial	1
Canarsie Pier	Filling	mid 1920s			171,462	Partial	1
Fresh Creek	Dredging	late 1920s			125,655	Partial	1
Floyd Bennett Field	Filling	1928	mid 1929	4,040,000	1,702,471	Yes	2, 3
Plumb Beach Channel	Dredging	circa 1929			227,307	No	1
Bergen Basin	Dredging	circa 1930			54,363	Partial	1
Paerdegat Basin	Dredging	Feb 1932			213,714	No	1
Gerristen Creek	Dredging	May 1933			155,443	No	1
Floyd Bennett Field	Filling	1940			192,238	Yes	2
Floyd Bennett Field	Filling	1942			741,758	Yes	2
Floyd Bennett Field	Filling	1942			560,603	Yes	2
Gerristen Inlet	Dredging	early 1940s			265,692	Partial	1
JFK Airport	Filling	early 1940s		37,000,000	13,749,668	No	1,4
Hendrix Creek	Dredging	early 1950s			65,681	Yes	1
Spring Creek Park	Filling	early 1950s			291,246	Yes	1
New York Railroad	Filling	early 1950s			265,202	Yes	1
East Pond	Filling	early 1950s			141,492	Yes	1

Location	Type	First Year	Last Year	Volume (m^3)	[1]Area (m^2)	In GATE	[2]Source
Floyd Bennett Field	Filling	1960			15,204	Yes	2
JFK Airport	Filling	1962			409,847	Partial	4
Fountain Ave Landfill	Filling	before 1965, after 1954			492,155	Yes	1
Pennsylvania Landfill	Filling	before 1965, after 1954			352,440	Yes	1
Fountain Ave Landfill	Filling	circa 1973			424,556	Yes	1
Jamaica Bay Channel	Dredging				3,255,162	Partial	5
Big Egg Marsh	Filling	2003			8,172	Yes	6
Elders Point East	Filling	2006		190,000	158,733	Yes	6
Elders Point West	Filling	2010		231,000	134,342	Yes	6
Yellow Bar	Filling	2012		287,000	169,773	Yes	7
Black Wall	Filling	2012		118,510	82,888	Yes	7
Rulers Bar Hassock	Filling	2012		72,630	32,267	Yes	7

[1]Area: Area is very approximate.
[2]Source: 1: NOAA (2012b), 2: Cody and Auwaerter (1982), 3: Blakemore (1981), 4: Swanson et al. (1992), 5: USACE (2012c), 6: Rafferty et al. (2011), 7: USACE (2013a).

Appendix E. Staten Island unit coastal structure data

ID	Location	Structure	Material	Year Built	Year Maint	Length (m)	[1]Source
145a	Fort Wadsworth	Pier		Before 1974		24	3
145b	Fort Wadsworth	Seawall	Cement	circa 1938		178	1
146	Fort Wadsworth	Seawall	Cement	1855–1871	2006	284	1
147	Fort Wadsworth	Pier	Cement	1858	1871, 1907, circa 1960	25	1,2
148	Fort Wadsworth	Revetment	Rock	Before 1994		435	3
149	Fort Wadsworth	Revetment	Rock	Before 1974		98	3
150	Fort Wadsworth	Groin	Rock	Before 1974		48	3
151	Fort Wadsworth	Revetment	Rock	Before 1974		108	3
152	Fort Wadsworth	Breakwater	Rock	Before 1974		193	3
153	South Beach	Groin	Concrete	Before 1991		38	3
154	South Beach	Groin	Wood	Before 1991		79	3
155	FDR Boardwalk	Pier	Wood	1935	1960–1961	2,216	4
156	South Beach	Groin	Rock and concrete	Before 1991		96	3
157	South Beach	Groin	Rock and concrete	Before 1991		103	3
158	Midland Beach Fishing Pier	Pier	Concrete and steel	2003		280	5
159	South Beach	Groin	Rock and concrete	Before 1991		94	3
160	South Beach	Groin	Wood	Before 1991		40	3
161	South Beach	Groin	Wood	Before 1991		61	3
162	Midland Beach	Groin	Rock and concrete	Before 1991		113	3
163	Midland Beach	Groin	Rock and concrete	Before 1991		120	3
164	Midland Beach	Groin	Rock and concrete	Before 1991		107	3
165	Midland Beach	Groin	Rock and concrete	Before 1991		124	3
166	Cedar Grove Beach	Groin	Rock	Before 1991		89	3
167	Cedar Grove Beach	Groin	Rock and concrete	Before 1991		51	3
168	Cedar Grove Beach	Groin	Rock and wood	Before 1991		144	3
169	Cedar Grove Beach	Groin	Wood and rock	Before 1991		156	3
170	Oakwood Beach / Cedar Grove Beach	Revetment	Rock	2000		511	6
171	Oakwood Sewage Treatment Plant	Levee	Earth	Sept 2009		193	7
172	Oakwood Sewage Treatment Plant	Groin	Wood and concrete	1941	1957	97	8
173	Oakwood Sewage Treatment Plant	Bulkhead	Wood	1947		122	9
174	Oakwood Sewage Treatment Plant	Revetment	Rock	1960		123	10
175	Great Kills Marina	Bulkhead	Wood	1943	late 1980s	919	11

ID	Location	Structure	Material	Year Built	Year Maint	Length (m)	[1]Source
176	Great Kills Marina	Revetment	Rock	1980s		25	3
177	Great Kills Marina	Pier	Wood	Before 1991	early 2000s	40	3
178	Great Kills Marina	Pier	Wood	Before 1991	2003–2004	40	3
179	Great Kills Marina	Bulkhead	Wood	Before 2003		13	3
180	Great Kills Marina	Revetment	Rock	late 1980s		418	12
181	Great Kills Marina	Bulkhead	Wood	1935	late 1980s	558	12
182	Great Kills Marina	Revetment	Rock	late 1980s		563	12
183	Great Kills Park	Bulkhead	Steel	1935		600	13
184	Great Kills Park	Jetty	Rock	Before 1956		152	14
185	Hoffman Island	Revetment	Rock	Before 1994		832	3
186	Hoffman Island	Seawall	Cement	Before 1994		761	3
187	Hoffman Island	Pier	Wood	Before 1994		143	3
188	Hoffman Island	Pier	Wood	Before 1994		17	3
189	Swinburne Island	Revetment	Rock	Before 1994		445	3
190	Swinburne Island	Seawall	Cement	Before 1994		211	3

[1]Source: 1: Gleisner and Auwaerter (2008_, 2: Langan Eng. (1995_, 3: Google Earth (2012), 4: Wrenn (1975_, 5: NY (200_3, 6: Pers. Comm. Michael Browne (NYCDP), 7: USACE (2013b), 8: NYCDP (1949), 9: NYCDP (1957), 10: NYCDP (1960), 11: NYCDP (1943), 12: Baker and Honig (1982), 13: NYCDP (1935), 14: NYCDP (1956).

Appendix F. Staten Island unit beach nourishment data

This table contains only those beach nourishment projects where a year and an approximate location could be determined and, therefore, represents only a fraction of the total nourishment projects that have occurred in the area. Refer to the Staten Island unit section in the report for discussion of other nourishment projects.

Location	First Year	Renourishment Year	Volume (m^3)	[1]Length (m)	Source
South Beach	1936–1937		764,550	2,195	USACE (2002)
Great Kills Park bathhouse to sewage plant	1949			988	NYCDP (1949)
Great Kills Park north of bathhouse	1954			544	NYCDP (1954)
Ft. Wadsworth	mid 1950s			708	Psuty et al. (2010)
Midland Beach	1955		1,437,360	2,215	USACE (2002)
Great Kills Park bathhouse	1966	1972, 1973, 1974, 1975, 1979, 1982, 1983	183,490	177	NYCDP (1966), Niedoroda et al. (1975), Okulewicz (2011)

[1]Length is very approximate.

Appendix G. Staten Island unit dredge and fill data

This table contains only those dredge and fill projects where a year and an approximate location could be determined and, therefore, represents only a fraction of the total dredge and fill projects that have occurred in the area. Refer to the Staten Island unit section in the report for a discussion of additional projects.

Location	Type	First Year	Last Year	Episodes	Volume (m^3)	[1]Area (m^2)	Source
Great Kills Park	Filling	1935				242,822	NYCDP (1935)
Great Kills Park	Filling	1939			1,146,830	911,113	NYCDP (1940), Baker and Honig (1982)
Great Kills Park	Filling	Nov. 1944	July 1948		11,468,323	1,586,049	Baker and Honig (1982)
Hoffman Island	Filling	1873				10,825	Wrenn (1975)
Swinburne Island	Filling	1860				44,146	Wrenn (1975)
Great Kills Navigation Channel	Dredging	1934	2003	9	1,283,804	709,291	Pers. Comm. Annette Baden (USACE)

[1]Area is very approximate.

Appendix H. Sandy Hook unit coastal structure data

ID	Location	Structure	Material	Year Built	Year Maintained	Length (m)	[1]Source
191	Southern Sandy Hook	Seawall	Rock	1900–1926	2001	[2]2,524	1
192	Southern Sandy Hook	Groin	Wood	1915		15	2
193	Southern Sandy Hook	Groin	Wood	1915		15	2
194	Southern Sandy Hook	Groin	Wood	1915		15	2
195	Southern Sandy Hook	Groin	Wood	1915		15	2
196	Southern Sandy Hook	Groin	Wood	1915		38	2
197	Southern Sandy Hook	Groin		Before 1995		127	3
198	Southern Sandy Hook	Groin		Before 1995		95	3
199	Southern Sandy Hook	Groin		Before 1995		143	3
200	Southern Sandy Hook	Groin		Before 1995		120	3
201	Southern Sandy Hook	Groin		Before 1995		135	3
202	Southern Sandy Hook	Groin		Before 1995		160	3
203	Southern Sandy Hook	Seawall	Sheet pile	1988		184	4
204	Gunnison Beach	Groin	Wood	Before 1975		138	5
205	North Beach	Groin	Rock	Before 1975		107	5
206	NW tip of Sandy Hook	Revetment	Rock	Before 1991		87	3
207	NW tip of Sandy Hook	Revetment	Rock	Before 1991		83	3
208	Sandy Hook Coast Guard Station	Breakwater	Wood	Before 1991		122	3
209	Sandy Hook Coast Guard Station	Pier	Concrete and wood	Before 1995, After 1991		69	3
210	Sandy Hook Coast Guard Station	Pier	Concrete and wood	Before 1991	Early 1990s	90	3, 6
211	Sandy Hook Coast Guard Station	Pier	Concrete and wood	1970s	2007	21	3, 6
212	Sandy Hook Coast Guard Station	Pier	Concrete and wood	1970s	Early 1990s, 2007	16	3, 6
213	Sandy Hook Coast Guard Station	Pier	Concrete and wood	1970s	2007	106	3, 6
214	Sandy Hook Coast Guard Station	Groin		Before 1991	late 2000s	13	3
215	North of Ft Hancock Officers' Row	Bulkhead	Wood	1878		493	7, 8
216	North of Ft Hancock Officers' Row	Revetment	Rock			487	
217	North of Ft Hancock Officers' Row	Bulkhead	Wood	1897	1898,1899, 1900,1901, 1904, 1965.	203	7, 9
218	Sandy Hook Ferry Pier	Pier	Wood	mid 2000s	2011	96	3
219	Ft Hancock Officers' Row	Seawall	Concrete	1897	1965	362	9, 10
220	Ft Hancock Officers' Row	Revetment	Rock	1899	1901	866	7
221	Ft Hancock Officers' Row	Groin	Wood and rock	Before 1991		124	3
222	Ft Hancock Officers' Row	Groin	Rock	Before 1991		24	3

ID	Location	Structure	Material	Year Built	Year Maintained	Length (m)	[1]Source
223	Ft Hancock Officers' Row	Groin	Rock	Before 1991		32	3
224	Ft Hancock Officers' Row	Groin	Rock	Before 1991		17	3
225	Ft Hancock Officers' Row	Groin	Rock	Before 1991		21	3
226	Ft Hancock Officers' Row	Groin	Rock	Before 1991		24	3
227	Ft Hancock Officers' Row	Groin	Rock	Before 1991		27	3
228	Ft Hancock Officers' Row	Groin	Rock	Before 1991		27	3
229	Ft Hancock Officers' Row	Groin	Rock	Before 1991		27	3
230	Ft Hancock Officers' Row	Groin	Rock	Before 1991		31	3
231	Ft Hancock Officers' Row	Groin	Rock	Before 1991		28	3
232	Ft Hancock Officers' Row	Groin	Rock	Before 1991		27	3
233	Ft Hancock Officers' Row	Groin	Rock	Before 1991		24	3
234	South of Ft Hancock Officers' Row	Revetment	Rock	Before 1991		651	3
235	Battery Arrowsmith	Revetment	Concrete	Early 1990s		155	3
236	Battery Arrowsmith	Revetment	Concrete	Early 1990s		38	3
237	Battery Arrowsmith	Bulkhead	Wood			55	
238	Battery Arrowsmith	Revetment	Rock	Before 2002		123	3
239	Horseshoe Cove Marsh	Revetment	Rock gabions	Before 2002		72	3
240	Horseshoe Cove Marsh	Revetment	Rock gabions			3	
241	Horseshoe Cove Marsh	Revetment	Rock	Before 1995		19	3
242	South of Horseshoe Cove	Revetment	Rock	1954	1988	887	10, 11
243	Battery Kingman to Ammunition Bunkers	Bulkhead	Wood	1961		1,399	9
244	Battery Kingman	Revetment	Rock	Before 2002, after 1995		288	3
245	Battery Mills	Revetment	Concrete	Before 1995		191	3
246	Ammunition Bunkers	Groin	Concrete	Before 1995		13	3
247	Ammunition Bunkers	Groin	Concrete	Before 1995		13	3
248	Spermaceti Cove	Bulkhead	Rock	Before 1870		1,227	10
249	South of Spermaceti Cove	Revetment	Rock	1988		53	11
250	South of Spermaceti Cove	Revetment	Rock	Before 1995		573	3
251	Southern Sandy Hook	Bulkhead	Steel		2001	56	12
252	Southern Sandy Hook	Groin		Before 1995		38	3
253	Southern Sandy Hook	Revetment	Rock	Before 2010, after 2008		72	3
254	Southern Sandy Hook	Revetment	Rock	Before 1995		121	3

[1]Source: 1: Psuty et al. (2010), 2: USACE (2013b), 3: Google Earth (2012), 4: Hoffman (no date), 5: Nordstorm (1979), 6: Brian McCabe (USCG), 7: Bearss (1981), 8: Bearss (1988), 9: Bearss (1982), 10: Tom Hoffman (NPS), 11: Orko Engineering (1988), 12: NPS (2001).

[1]Seawall extends south an additional approximately 9 km (5.6 mi) to southern Monmouth Beach, NJ.

Appendix I. Sandy Hook unit beach nourishment data

This table contains only those beach nourishment projects where a year and an approximate location could be determined and, therefore, represents only a fraction of the total nourishment projects that have occurred in the area. Refer to the Sandy Hook unit section in the report for discussion of other nourishment projects.

Location	First Year	Renourish. Year	Volume (m^3)	[1]Length (m)	In GATE	Lead Con Agcy	[2]Source
Sea Bright to Monmouth Beach	1963	Jan 1994–Dec 1995, Aug 2001–Dec 2002	6,218,130	4,929	No	USACE	1, 2
North Beach	Sept. 1975	1976	268,890	365	Yes	USACE and NPS	3, 4
South Beach Critical Zone	Sept–Dec 1977		152,928	1,445	Yes	NPS	3
South Beach Critical Zone	Jan–Feb 1980		15,300	549	Yes	NPS	7
South Beach Critical Zone	Nov 1982–Jun 1984	Aug 1989–Jan 1990	4,800,000	1,502	Yes	USACE and NPS	5
Sea Bright	July 1995–Nov 1996		2,905,310	3,717	Partially	USACE	1, 2
South Beach Critical Zone	Jan–Mar 1997		45,873	1,057	Yes	NPS	6
South Beach Critical Zone	Dec 1997–Mar 1998	Nov 2002	413,242	1,063	Yes	USACE and NPS	6
Long Branch	1999	Aug 2008–Feb 2009	3,844,950	6,332	No	USACE	1, 2

[1]Length is very approximate.

[2]Source: 1: USACE (no date), 2: USACE (2012c), 3: Nordstrom et al. (1979), 4: Valverde et al. (1999), 5: Psuty and Namikas (1991), 6: NPS (2004), 7: Bruce Lane (NPS).

Appendix J. Sandy Hook unit dredging data

Dredge volumes reported below only represent sediment that was removed from sections of navigation channels adjacent to the Sandy Hook unit (see Figure 36 for locations).

Location	First Year	Last Year	Episodes	Volume (m^3)	Ld Con Agcy	In GATE	[1]Area (m^2)	Source
Sandy Hook Channel	1884	2011	21	[2]3,274,189	USACE	Partial	1,667,149	Annette Baden (USACE)
Shrewsbury River Channel	1927	2011	14	498,510	USACE	No	525,119	Annette Baden (USACE)

[1]Area is very approximate and includes only the part of the channel near GATE (see Figure 36).
[2]Volume includes dredging from 1960 to 2011 only.

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