National Park Service
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Natural Resource Stewardship and Science

# Development of the Geomorphological Map for Gateway National Recreation Area

## *Principal Characteristics and Components*

Natural Resource Report NPS/NRSS/GRD/NRR—2018/1600

**ON THE COVER**
Aerial imagery of Sandy Hook within Gateway National Recreation Area
Image credit: NASA Imagery
Obtained 20 September 2010 (pre-Sandy), extracted from Google Earth Pro on 21 April 2015

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# Executive Summary

This report incorporates the geomorphological map, its philosophical underpinnings, legend descriptions, and the GIS data layers for the three Units of Gateway National Recreation Area, Sandy Hook Unit NJ, Staten Island Unit NY, and Jamaica Bay Unit NY. The theme of the map follows the current scientific organization of geomorphological mapping that includes morphometrics, causative processes, and evolutionary stages. Surface form was interpreted from a variety of data that include recent orthophotos, recent Light Detection and Ranging (LiDAR) data sets, and spatial information on soils and vegetation. The archival information was augmented with field visits.

The geomorphological features of the Gateway site include: 1) a portion of a glacial terminal moraine; 2) coastal topography that was created during an early phase of coastal barrier spit / barrier island development; 3) coastal topography that developed with the downdrift extension of the barrier spit / barrier island systems; 4) coastal topography associated with the estuarine margins of embayments situated inland of the developing barrier spits / barrier islands; and 5) cultural modifications to the natural topography, consisting of excavation as well as accumulation. The geomorphological maps of the Units and their subdivisions and the map legend portray the spatial and temporal association of the surface features created during the several stages of landscape development, as well as the broad cultural modifications of the surface. This portrayal of surface form is based on data sets from 2010. A post-Hurricane Sandy geomorphological map has been prepared by these authors and is available as Psuty et al. (2017).

The GIS data layers of the several geomorphological maps can be viewed at user specified map scales and with customizable symbologies. Each of the map layers contained in this report meets the standards of Federal Geographic Data Committee (FGDC) compliant metadata. The full set of organized data layers is available from the National Park Service, Geologic Resources Division, PO Box 25287, Denver, Colorado, 80225 or via the Geologic Resources Inventory publications page http://go.nps.gov/gripubs.

# Acknowledgments

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# Introduction

Gateway National Recreation Area (GATE) is one of 270 National Park System components designated to have a digital geological map and an accompanying geological resources inventory report. These products are intended to provide a valuable synthesis of the physical makeup of the site and assist in applying appropriate strategies in the management of its natural and cultural resources. Under the sponsorship of the NPS Geological Resources Division, a scoping meeting was held at the GATE Headquarters on June 24, 2010 to discuss and identify the geological character and variety of resources extant at the site, and to provide direction to the compilation of the geological map. The product of the scoping meeting was a document that identified themes of interest to the managers of the site, sources of data appropriate to the mapping effort, potential geomorphological features, and considerations for inclusion (Thornberry-Ehrlich 2011).

The traditional geological map incorporates many rock formations that extend across time horizons and exhibit considerable structural control of the surface configuration. However, the relatively small size of GATE and the surficial presence of little more than a single, limited sedimentary formation led to the creation of a map that focuses on the geomorphological character of the site; i.e., the configuration of the surface topography. As a result, GATE is being represented by a geomorphological map rather than a geological map.

The concept of a geomorphological map traces its origins to Passarge (1914) and his representation of the surface character of the Stadtremba, Germany quadrangle that emphasized the presence of river terraces as specific physical features. Subsequent portrayals of the geomorphological character of the earth surface incorporated elements of the morphology as well as the origins of the features (processes) and their stages related to chronological development (St. Onge 1968). The modern geomorphological map uses the elements of form, functional processes, and sequential development to depict the evolution of surficial and spatial characteristics (Dramas et al. 2011). The geomorphological map presented in this report follows the three-fold communication of form in the landscape, developmental processes, and stages in spatial evolution. It has a geotemporal sequence of features that relates the surface characteristics to the stages of development. It addresses the action of the earth-forming processes on the deposition, erosion/mobilization, and subsequent accumulation of sediments to produce the resulting geomorphological characteristics at GATE. These processes continue to influence the development the landscape and, as a result, this map will serve to identify a stage in the evolution of the geomorphology of Gateway National Recreation Area. Many of the geomorphological features incorporated on these maps that were identified based on datasets collected in 2010, were affected by processes and responses associated with Hurricane Sandy in October 2012. A new series of geomorphological maps representing post-Sandy conditions has been prepared by these authors from post-Sandy sources and submitted to the NPS (Psuty et al. 2015).

## Site and Situation

Gateway National Recreation Area (Figure. 1) is composed of three geographical areas that have a general similarity in geomorphological development because they occur in a coastal setting exposed to waves and currents operating on sediment in alongshore transit. The three areas are: 1) the Sandy Hook Unit, 2) the Jamaica Bay Unit, and 3) the Staten Island Unit. Sandy Hook is a barrier spit extending northward along the northern margin of coastal New Jersey. The Staten Island Unit consists of a) the margin of a terminal moraine as well as three separate coastal sites under the influence of a southwesterly alongshore transport system that terminates at a barrier spit, and b) two artificial islands off of the Staten Island shore. The Jamaica Bay Unit is comprised by a) the downdrift portion of the Rockaway barrier island, terminating at Breezy Point, b) Plumb Beach, a easterly remnant of the Coney Island barrier island, c) a group of flood tide delta islands leading into Jamaica Bay, and d) a scattered plethora of wetlands and artificial fill along the margins of Jamaica Bay. Much of the landscape has been altered by the anthropogenic manipulation that has flattened a large proportion of the topographical expression. Sandy Hook has the greatest expanse of original coastal topography, whereas the Fort Wadsworth portion of the Staten Island Unit has the only example of Late Wisconsinan glacial topography.


**Figure 1.** Location of Units comprising Gateway National Recreation Area.

# Geomorphological Evolution

The conceptual approach to describing, depicting, and mapping the geomorphological characteristics of the site is based on the components of morphometrics, causative processes, and temporal sequence of development of the surface. This tripartite organization is the essence of modern geomorphological maps (Dramis et al. 2011) that combine the processes and the surface expression of the sedimentary formations (either in their erosional or depositional form). The legend (discussed later) is developed to track the evolution of the surface features and their associated causative processes, and to add the cultural imprint on to the landscape.

The spatial separation of Gateway NRA into three primary units creates a condition whereby different suites of processes operating over different temporal periods combine to add geomorphological variety to the landscape. The oldest topography is associated with a terminal moraine at Fort Wadsworth. The moraine and its adjacent outwash plain was deposited by a continental glacier about 16,0000 – 18,000 years ago, during Wisconsinan time when sea level was more than 100 m lower than today. The remainder of GATE surface topography is associated with coastal and estuarine processes operating at or near today's sea level position and creating beaches and dunes during the last several thousand years. Located at the apex of the New York Bight where there is an abrupt change in orientation of the coast line, GATE is at or near the end of an alongshore sediment transport system that brings sand from south to north along coastal New Jersey, and from east to west along coastal Long Island. On Staten Island, the principal transport direction is from northeast to southwest.

Thus, glacial processes produced the oldest topography in Gateway, succeeded by coastal waves and currents that converged on Lower New York Harbor. Sediment transport in that converging scenario resulted in an elongation of spits and islands in a downdrift direction.

### Sandy Hook Unit (SHU)

Although all of GATE has had considerable manipulation of the surface topography by humans, the SHU retains the highest proportion of "natural landscape", in large part because of its status as a military base guarding part of the entrance into New York Harbor. That condition restricted access to much of Sandy Hook and preserved a significant proportion of the original topography. The dominant landform is a series of accretionary foredune ridges that recount the extension of the spit northwesterly into Sandy Hook Bay. There is an active beach and foredune that extends along the entire ocean margin of the SHU. They are formed by the modern wave, current, and wind processes that transport sediment northerly. Inland of the active foredune are sequences of abandoned foredune ridges, each ridge representing the position of a former shoreline feature. The abandoned accretionary ridges vary in dimension and are classified as major (more than 4 m in crestal elevation), and minor (less than 4 m in crestal elevation). The major ridges tend to be coherent and consistent as they define the margin of Sandy Hook at some point in the geomorphological past. The minor ridges tend to be shorter and occupy a segment of Sandy Hook. It is likely that the major ridges defined the margin of Sandy Hook for a long period of time and that sediment accumulated at that shoreline position. The minor ridges also represent periods of accumulation to create the ridge

form, but they were part of the shore position for shorter periods and may represent more rapid northerly extension of Sandy Hook. The ridges are accompanied by inter-ridge swales, topographically low areas that were not filled with sand as the spit extended northerly. Occasionally, dune ridges of the spit extension closed off small embayments in the beach and caused the creation of isolated low-lying topography that today are sites of ponds or wetlands among the accretionary foredune ridges.

The bay side of Sandy Hook is characterized by three main features. 1) Narrow beaches and narrow dunes formed on the low energy bay shorelines where there is ample sand for the waves and currents to transport and accumulate in a beach-dune combination; they are most often found on the northwest facing portion of the bay shoreline, facing the direction of greatest wave fetch. 2) The back dune slope of the ocean-facing foredune system that is usually in areas protected from the maximum wave directions on the bay side. 3) Wetlands that formed on the lee side of the northwest facing beaches along the bay, and were associated with former distal portions of Sandy Hook and locations where sediment was transported around the end of the Hook and created a small embayment.

A large portion of Sandy Hook has been leveled to accommodate a military base and its accompanying infrastructure. It is a planar surface that has little of the original topography. Other elements of the human alteration are: 1) roads; 2) gun batteries; 3) bulkheads; 4) a massive seawall that begins at the base of the SHU and continues for 2.5 km along the southern ocean-facing portion of the SHU.

### Jamaica Bay Unit (JBU)

Similar to Sandy Hook, the geomorphological evolution of the JBU is related to alongshore sediment transport and downdrift extension of a coastal barrier into New York Harbor. An active beach extends the length of the ocean side of this park unit, and an active foredune occurs at the inland margin of the beach except at Riis Park and portions of the Breezy Point Cooperative sites.

In addition to the active foredune, there are occurrences of abandoned foredunes within areas of limited spatial extent. In the past, the westerly progression of the Rockaway barrier island created an accretionary foredune ridge and swale topography that gave character to the barrier island. Much of the foredune landscape has been modified by human development to produce the present day planar surface. Some accretionary foredune ridge and swale topography at the western terminus of Breezy Point was related to the accumulation of sediment updrift of the Rockaway Inlet jetty, constructed in 1933.

Much of the topography within Jamaica Bay is related to the flood-tide islands that formed on the inland margin of Rockaway Inlet as it migrated to the west. They are components of a flood tide delta that in the past received sand by a combination of tidal currents and wave action to build an extensive deltaic flat expanding into Jamaica Bay. At present, portions of the tidal deltaic islands are altered by human manipulation and have little of the original deltaic topography. Other portions of the islands are slowly disintegrating because of absence of sediment infusion by tidal action and because of the alterations caused by humans that resulted in localized erosion downdrift of a variety of structures. The margin of Jamaica Bay has a few locations of wetlands and localized compartments of beach and

dune topography. Most of the margin consists of topography that has been levelled, filled, elevated, and/or otherwise stabilized for anthropogenic use and was bulkheaded. The Plumb Beach area is an amalgam of natural and anthropogenic features. A large portion of the area was fill for the Belt Parkway, but downdrift sediment transport to the east has created a natural beach-dune system backed by a relatively pristine wetland. This site is occupying the former location of the backmarsh of an eroded barrier island.

## Staten Island Unit (SIU)

### *Fort Wadsworth*

The topography at this site is composed of Wisconsinan terminal moraine. It is a high ridge of glacial till deposited at the margin of the maximum extent of glacial ice during the Wisconsinan epoch. The terminal moraine has an irregular hummocky surface mostly modified by anthropogenic activity, with steep slopes at its northeastern and east-facing margins. There is an outwash plain south of the terminal moraine and fill at the base of a scarp in the outwash plain. At the margin of the fill, there is a narrow zone of beach and very low dune topography. A variety of bulkhead structures associated with the remains of a dock occupy the northeast corner of the shoreline, whereas the beach margin fronting the Verrazano Narrows is strewn with stone and concrete rip-rap.

### *Miller Field*

This is the site of an outwash plain that emanated from the terminal moraine. It has since been modified greatly. Most of it is a large planar surface, a former airfield, with a small wetland basin feature at the northern corner. The seaward margin is the site of a constructed sand barrier that currently has an active beach, and the barrier is bounded on its inland margin by a modest dune. There is a groin constructed near either margin at the beach. The alongshore transport is to the southwest, with a large offset in the shoreline beyond the groin on the downdrift margin.

### *Great Kills Park*

This site is largely an anthropogenic planar surface created by dredging of the marina from 1935 through 1948 and again in 1955. There is a narrow beach at the seaward margin that fronts a low cliff in the vicinity of the large parking lot. Alongshore transport is to the southwest. Eventually, to the southwest, a low foredune replaces the cliff. There are remnants of abandoned dunes in the downdrift portion of Great Kills Park, in the remains of a former barrier spit, replete with accretionary foredune features. There is a jetty at the downdrift end of the Park, with a navigation channel beyond the jetty leading from the harbor to the marina. The marina has a few small sections of beach at the margins of the fill, but most of the marina is lined by a bulkhead.

### *Legislative Boundary Areas*

In the legislation establishing the extent of Gateway National Recreation Area, the beach portions between Fort Wadsworth, Miller Field, and Great Kills Park were designated as within Gateway NRA. Along most of this distance, the morphology consists of an anthropogenically-created, trapezoidal ridge fronted by a beach. North of Miller Field, the constructed ridge is planar and is fronted by a wide beach. It is part of the city park system. South of Miller Field, the constructed planar surface is narrower, incorporating a very narrow beach backed by an artificial dunal ridge.

Toward the southwestern terminus of the constructed planar surface, there is a small natural beach and foredune area backed by a marsh.

### *Swinburne Island and Hoffman Island*

These are two artificial islands built from construction debris and completely surrounded by a stabilizing concrete bulkhead. The surfaces of the islands are planar and are sites of buildings that served several purposes in their history before being incorporated into GATE.

# Resources to Aid in Spatial Recognition of Features

A geographic information system (GIS) was developed for the construction of the geomorphological map of GATE. The GIS includes orthophotos, light detection and ranging (LiDAR) data sets, and additional sources of geographical information that are described below.

### Orthophotography

A total of 3 image tiles collected in 2010 by Pictometry (2010) with 0.25 m spatial resolution were obtained to provide aerial ortho-image coverage of the Sandy Hook Unit. A total of 382 image tiles collected in 2010 by New York State, with 0.5 ft spatial resolution, were obtained from the Department of Information Technology & Telecommunications (DoITT) – City of New York to provide aerial ortho-image coverage for the Staten Island Unit and the Jamaica Bay Unit (DoITT 2010).

### LiDAR

The LiDAR data set covering the Sandy Hook Unit was collected between August 28 and September 9, 2010 by the US Army Corps of Engineers (USACE), Joint Airborne Lidar Bathymetry Technical Center of eXpertise (JALBTCX) and made available online through the NOAA Coastal Services Center (USACE 2010). The data set incorporated topographic LiDAR data in Log ASCII Standard (LAS) format with the data points classified as either unclassified or ground. A second LiDAR data set, collected in 2007 by the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) were used to supplement the USGS data set where a gap existed (USGS/NASA 2009). These data were also in LAS format, with the data points classified as either unclassified or ground.

The LiDAR data set covering the Jamaica Bay Unit and the Staten Island Unit was collected by the Sanborn Map Company between April 14 and May 1, 2010 for Hunter College, CUNY, and was obtained through the NPS (Sanborn 2010). The data set incorporated topographic LiDAR data in LAS format with the data classified as unclassified, ground, low point, water, and/or overlap.

### Additional Sources

Other sources of spatially-organized data (see Table 1) include a vegetation map and report (Edinger et al. 2008) downloaded from the NPS Integrated Resource Management (IRMA) site, plus several geological reports (Gray Smith et al. 1999, Leatherman 1988, Psuty et al. 2005, and Psuty and Silveira 2008). Locations of buildings, infrastructure, and boundaries were accessed from a dataset provided by the NPS(NPS 2012). A roads data layer was provided by OpenStreetMap (2014), retrieved on March 31, 2014, and was modified as necessary from the 2010 orthophotos.

**Table 1**. Source and quality of spatial data

| Data | Year of Acquisition | Spatial Resolution | File Type | Source |
|---|---|---|---|---|
| Orthophotos | 2010 | 0.5 ft | .jp2 | DoITT – City of New York |
| Orthophotos | 2010 | 0.25 m | .tif | Pictometry |
| LiDAR | 2010 | n/a | LAS | Sanborn |
| LiDAR | 2010 | n/a | LAS | USACE |
| LiDAR | 2007 | n/a | LAS | USGS |
| Vegetation | 2008 | n/a | .shp | NPS IRMA |
| Roads | 2014 | n/a | GIS geodatabase | OpenStreetMap contributors |

## Methodology of Topographical Development

The initial approach of landform identification used 2010 orthophotos of GATE (see example in Fig. 2) to establish the geographical coordinates of the geomorphological units. The next phase utilized the bare earth LiDAR data sets for GATE, provided by the USACE, USGS, and Sanborn Map Company, to create digital elevation models (DEMs). However, the LiDAR bare earth DEMs produced by these data sets exhibited some noise due to areas of dense vegetation and buildings. To minimize these surface perturbations, the raw LiDAR data points were filtered using the Reduce Point Density method via Airborne LiDAR Data Processing and Analysis Tools (ALDPAT) (Zhang and Cui 2007) software to create a new bare earth DEM. The Reduced Point Density method searches for and chooses the point of minimum elevation within a specified area, or window, to represent that location. One to three iterations of this filtering were applied to the bare earth LiDAR points, enlarging the window each time (three iterations [1m, 3m, and 5m windows] for Sandy Hook, one iteration [1 m window] for the rest of GATE). Each subsequent iteration was applied to the filtered data points of the previous iteration. Therefore, a bare earth LiDAR surface was produced from the third iteration of this filtering process at Sandy Hook and the first iteration elsewhere in Gateway. The resulting reduced point density DEM layer is somewhat less detailed because the more minor variations have been smoothed to emphasize the general trends in elevation (see example in Fig. 3).


**Figure 2**. Orthophoto of northern portion of Sandy Hook Unit, Gateway NRA.

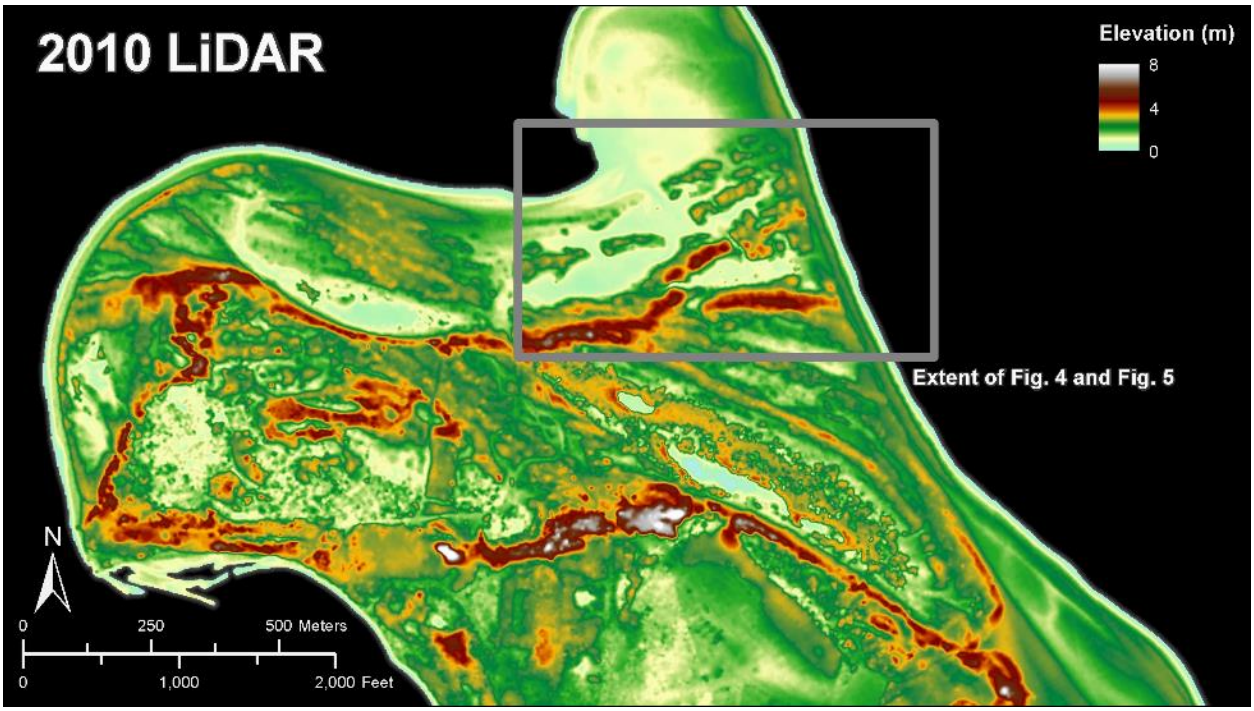


**Figure 3**. Digital elevation model (DEM) created from 2010 LiDAR data set with reduced point density, northern portion of Sandy Hook Unit, Gateway NRA.

A further refinement of the DEM incorporated the identification of changes in slope and dimensions of relief to help define the boundaries of the geomorphological categories and focus on the major changes. Thus, isolines of slopes were plotted to depict boundaries between ridges and swales, and measures of relief were used to eliminate minor topographical changes (Fig. 4). The result was a landform categorization into ridges and swales of various dimensions and continuity based on changes in slope and local relief. After the juxtaposition of dune features was determined, their sequential evolution was interpreted using the fundamentals of sediment transport direction, sediment supply, and sediment budget. This process eventually outlined the distribution of active and abandoned dune ridges, with the abandoned ridges subdivided into major and minor forms based on elevation (Fig. 5). An additional enhancement of the elevation portrayal was performed by adding a shading effect generated by applying the hillshade tool in ArcGIS on the reduced point density DEM layers and incorporating that view in the geomorphological map (see example in Fig. 6). The hillshade tool simulates illumination and shading of a 3-dimensional topographic surface, creating the appearance of relief on a 2-dimensional surface.

A vegetation map was used as supplemental information in the manual digitization of geomorphological features. Specifically, the 2008 vegetation map of GATE and 2010 orthophotos were used to identify the extent of marsh. Orthophotos provided contextual information regarding the positioning of landscape modifications, erosion-control structures, beaches on the oceanside and bayside, and other natural and anthropogenic features on the landscape. The topographical interpretations of areas of dense vegetation and low relief were verified through field visits.

Throughout the map generation process, all of the ancillary resources were consulted to help in the identification of the surface features, their characteristics, and their boundaries. Continuous feedback between site-specific landform designation and general categorization resulted in a consistency of landform features throughout GATE.

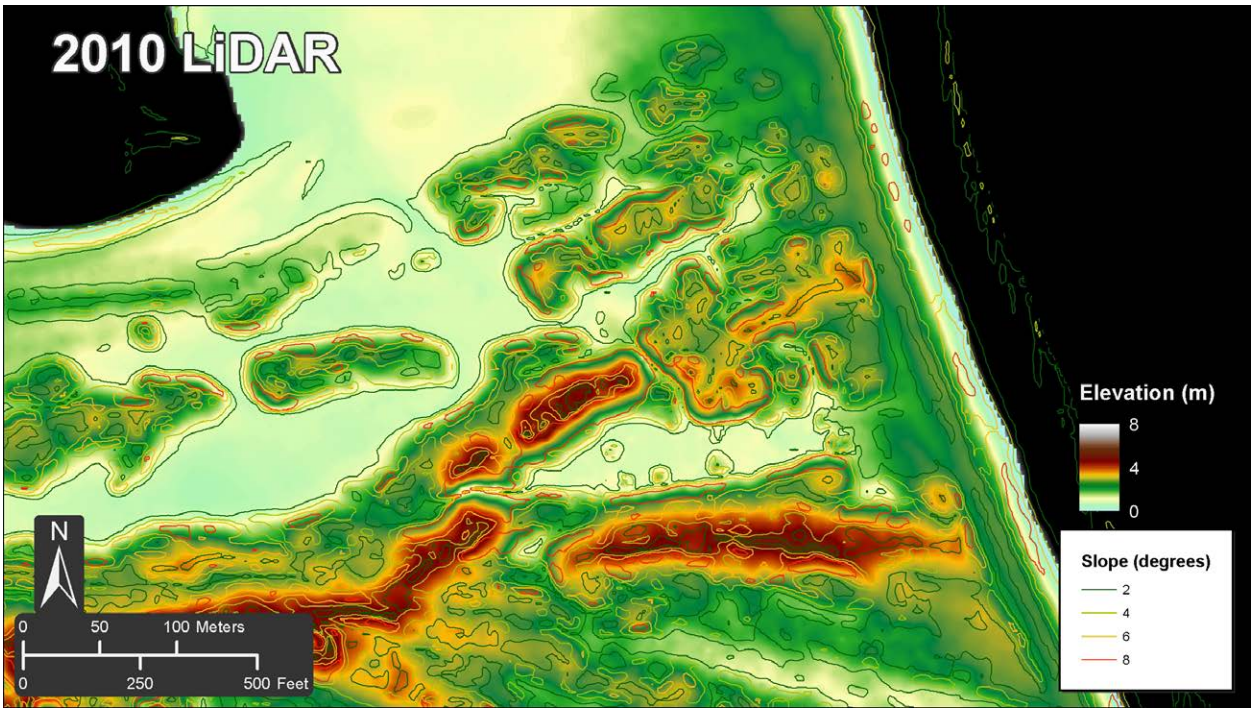


**Figure 4**. Incorporation of slope variable to define landform boundaries within the DEM, northern portion of Sandy Hook Unit, Gateway NRA.

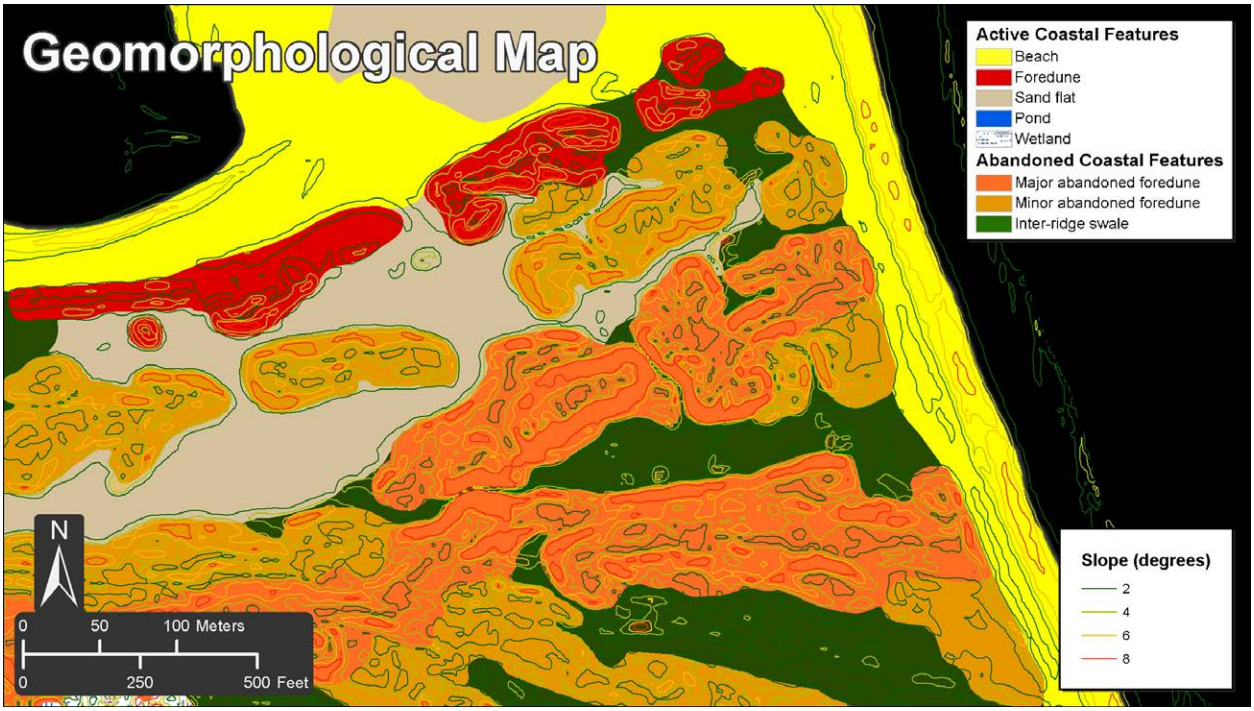


**Figure 5**. Distribution of geomorphological features, incorporating elevation, relief, slope, and supporting resources, northern portion of Sandy Hook Unit, Gateway NRA.

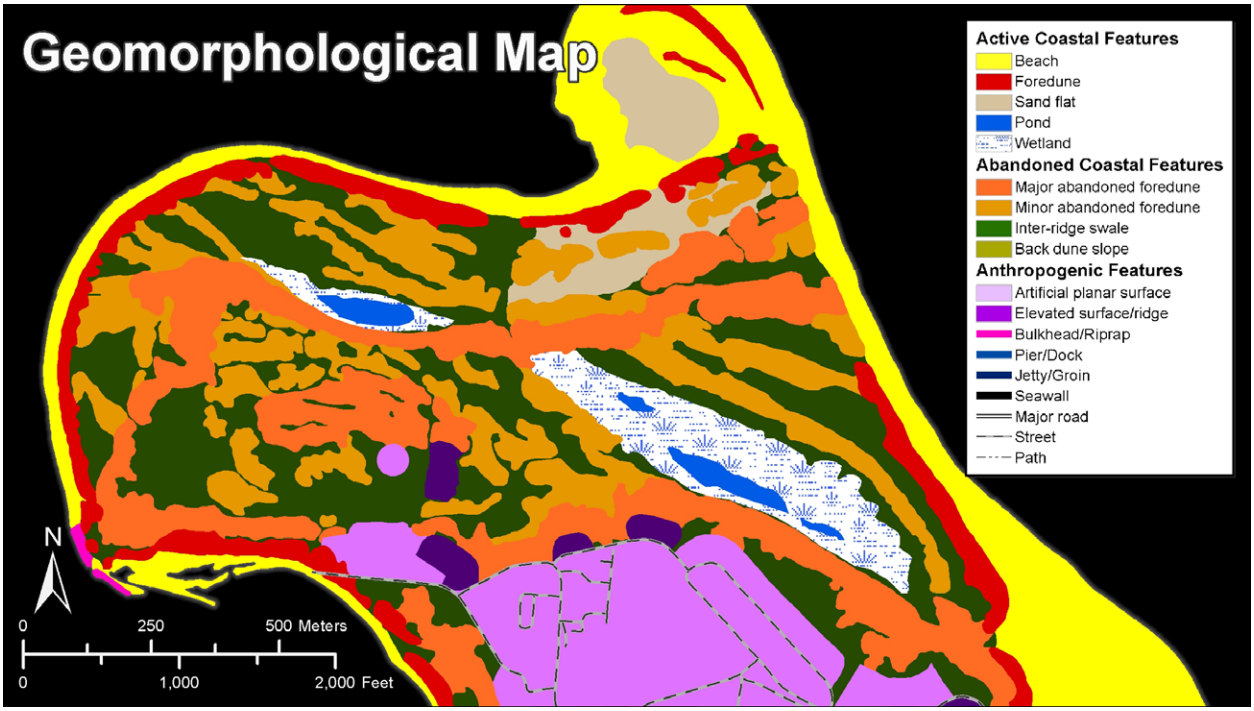


**Figure 6**. Geomorphological map incorporating active features, abandoned features, and the anthropogenic characteristics of the northern portion of Sandy Hook Unit, Gateway NRA.

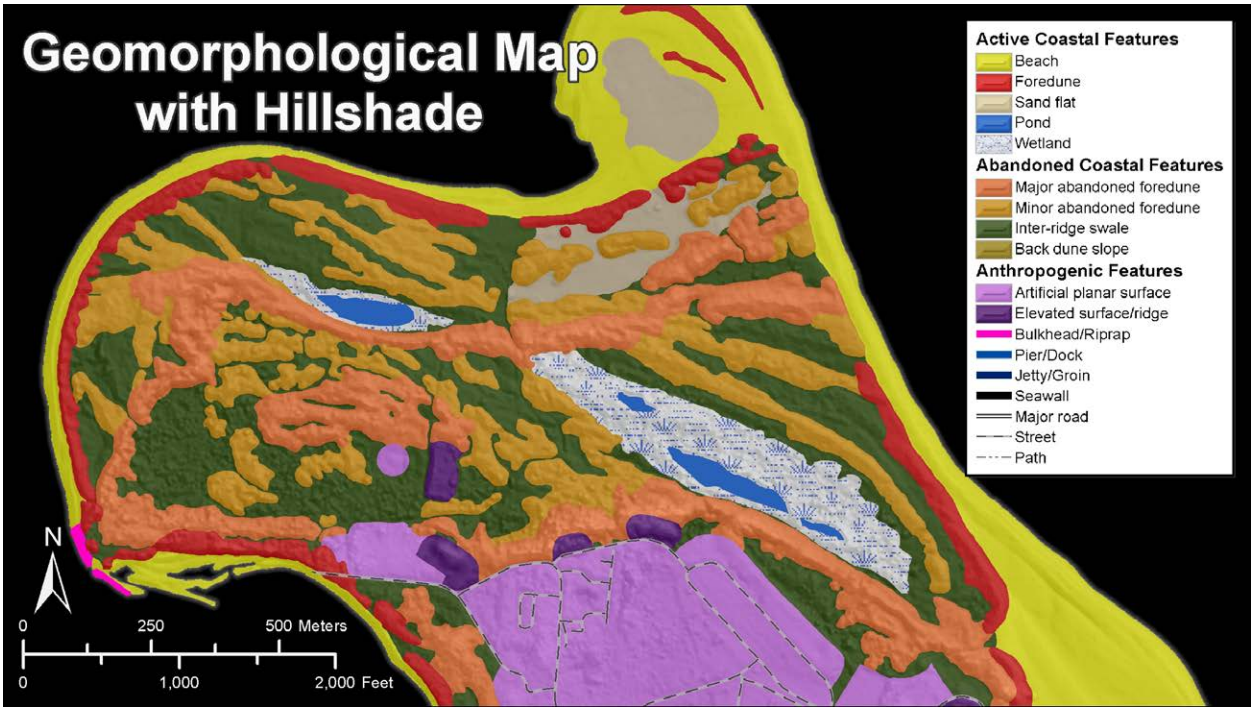


**Figure 7**. Geomorphological map incorporating the hillshade effect, northern portion of Sandy Hook Unit, Gateway NRA.

# Legend: Categories and Symbolization of Geomorphological Features

The legend is organized relative to the geomorphological evolution of the site, incorporating the relative sequence of coastal landform development from youngest to oldest (Fig. 8). The youngest features are those that are currently in active development, the beach and the associated dune ridge at its inland margin. Other active features include wetlands and ponds that possess a location, elevation, and areal extent determined, in part, by the modern sea level. Inland of the active foredunes are abandoned dune ridges that were formerly adjacent to an active beach. The abandoned dunes remain as ridges whereas the old beach features are now swales separating the dune features. In general, the abandoned dune ridges and swales constitute the majority of the landforms in these coastal accretionary systems. The oldest landforms in GATE are on Staten Island where parts of a large glacial terminal moraine and its associated outwash plain dominate the Fort Wadsworth topography. The landforms features are thus composed of active coastal forms, abandoned coastal forms, and ancestral glacial forms. Superimposed on the variety of landforms are manipulations and constructions of anthropogenic origin that have altered the landscape and constitute a separate category.

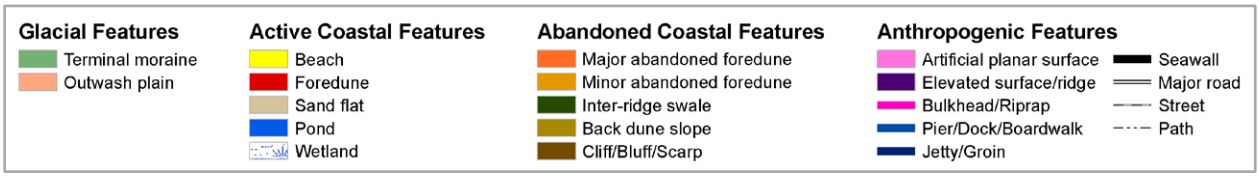


**Figure 8**. Categories of geomorphological features, and of surficial features created by anthropogenic activity.

**Table 2.** Geomorphological Features in the Gateway National Recreation Area

| Geomorphological Classification | Conceptual Basis | Physical Description and Identification |
|---|---|---|
| *Active Features: Beach* | Wave-deposited accumulation of sediment, specifically the bare sand area seaward of the foredune. Regularly inundated by waves during high-water phases of the tidal cycle and modest storms. Dominant direction of wave approach determines the alongshore sediment pathway. | Area of low, nearly planar elevation exposed to waves on oceanside and bayside margins of the barrier spits. A very prominent feature that tends to be broad, continuous, and have sparse to no vegetation. Extends from the lowest tide level to the toe of the active foredune. |
| *Active Features: Foredune* | Sand ridge formed by eolian (wind-blown) and water processes at the inland margin of a beach, parallel to the coastline. Vegetated by pioneer species that help trap sediment. Dune is actively participating in seasonal sediment exchange with the beach. | A continuous, linear feature of elevated topography (positive relief) that is parallel to the shoreline and immediately adjacent to the beach. |
| *Active Features: Wetland* | A general term describing an area of very low elevation vegetated by saltwater, brackish water, and freshwater plants. Often found in areas sheltered from ocean waves such as in bays, estuaries, or on the baysides of spits. | Wetlands are roughly approximated by areas of very low (nearly sea-level) elevation. Marsh vegetation is often distinctly visible on orthophotos. In places where the exact position of the wetland boundary is uncertain in the topography, vegetation maps may depict their extent. |
| *Active Features: Pond* | Area of open water within the boundaries of the barrier spit or adjacent to estuarine margins. Often occurs as ponds within wetlands. | Inland water bodies are distinctly visible on orthophotos. Only water bodies visible at the map scale are delineated. |
| *Active Features: Sand flat* | A relatively level, low elevation (within tidal range), sandy area formed by processes other than ocean waves on beaches. | Subtle, linear feature that is often narrow and discontinuous, in the vicinity of the beach, and has sparse to no vegetation. Usually occurring on the bayside of the barrier spit, often forming on the margin of a wetland. |
| *Abandoned Features: Major abandoned foredune* | A previously active foredune that is no longer in active sediment transfer with the beach. Often found parallel to or adjacent to an active foredune. May have been reworked by winds into parabolic, hummocky, or dissected features. | Foredune ridge may be generally linear and intact or dissected, depending on the age of the feature and the influence of wind, waves, and human activity. The original, relatively high elevation is often preserved long after the dune has been abandoned. Usually in relatively close proximity to the active foredune ridge; i.e. ridges not separated by a major interdune swale. A dune is considered major if its ridge has an elevation above 4 meters. |

**Table 3 (continued).** Geomorphological Features in the Gateway National Recreation Area

| Geomorphological Classification | Conceptual Basis | Physical Description and Identification |
|---|---|---|
| *Abandoned Features: Minor abandoned foredune* | A previously active foredune which is no longer in active sediment transfer with the beach. Often found parallel or adjacent to active foredune. May have been reworked by winds into parabolic, hummocky, or dissected features. A minor abandoned dune either did not fully develop before being abandoned or has since lost elevation by the reworking of winds. | Foredune ridge may be generally linear and intact or dissected, depending on the age of the feature and the influence of wind and other natural and/or cultural activities. The original elevation is often preserved long after the dune has been abandoned. Usually in relatively close proximity to the active foredune ridge; i.e. ridges not separated by a major interdune swale. A dune is considered minor if its ridge has an elevation below 4 meters. |
| *Abandoned Features: Inter-ridge swale* | Seaward accumulation of dune sand that forms during time of abundant sediment supply (shoreline progradation), between the growth of sequential, parallel foredune ridges. | A linear hollow or topographic depression between parallel dune ridges that may be parallel to the shoreline. Swale will have lower elevation and negative relief in relationship to the adjoining dune ridges. |
| *Abandoned Features: Back dune slope* | Low area immediately inland of the leeward slope of the inland-most dune ridge. It is the feature at the inland margin of the dune-forming processes. | Located on the inland margin of a dune ridge or series of dune ridges. Elevation and slope are generally low and tend to decrease toward the bay side, i.e., slopes away from the dune ridge toward the water. |
| *Glacial Features: Terminal moraine* | Glacial deposit at the margin of the extent of the glacial advance. Consists of unsorted till deposited on earlier landscape. | A large hummocky ridge, usually an abrupt change in topography, rising quickly to the greatest heights in the area. |
| *Glacial Features: Outwash plain* | A broad surface emanating from the terminal moraine. Created by meltwaters discharging beyond the terminal moraine and depositing sediment by glacio-fluvial processes. | A low planar surface sloping downward beyond the margins of the terminal moraine. It is frequently fan-shaped, leading from gaps or low areas in the terminal moraine. May have kettle holes caused by stranded blocks of ice. |
| *Anthropogenic Features: Artificial planar surface* | A human-made flat or planar surface that has been leveled to site a structure such as a highway or building. Underlying topography is destroyed or covered up. | Elevation of surface is nearly or completely homogeneous and level. Abrupt interruption of adjacent naturally occurring topography. Boundary of surface is often clearly visible on the orthophotos. |
| *Anthropogenic Features: Elevated surface/ridge* | Area where the land has been intentionally elevated by humans for the construction of buildings or to assist in military operations. Such features include gun and mortar batteries built into dunes or disguised as dunes, as well as sites constructed to conceal missile locations. | Marked by variability in elevation, and often with the appearance of a dune or large topographic high. Specific sites can be identified from orthophotos and their boundaries determined based on LiDAR. They do not display the same homogeneity in elevation that is evident with cultural planar surfaces. |

**Table 4 (continued).** Geomorphological Features in the Gateway National Recreation Area

| Geomorphological Classification | Conceptual Basis | Physical Description and Identification |
|---|---|---|
| *Anthropogenic Features: Erosion control structures* | An engineered structure built to stabilize the shoreline, reduce sediment erosion, and protect any existing development. These features include, among others: **Jetty –** hard structure at the terminus of a beach, meant to prevent sediment from entering a navigation channel;<br><br>**Groin** – hard structure of rock, wood, and/or concrete extending orthogonally from the shoreline into the water, typically reducing alongshore sediment transport;<br><br>**Bulkhead** – vertical wall of wood, metal, or concrete, defining an edge in the landform feature;<br><br>**Riprap –** stone or rubble piled along the margin of a landform feature;<br><br>**Seawall** – a dike constructed to rise above the landform and prevent storm surge from penetrating inland. | Erosion control structures are primarily identified from orthophotographs. These structures, such as jetties, groins, bulkheads, and seawalls, have been constructed in many parts of the barrier spit over the course of its modern use. They are usually at the water's edge and are defining the margin of a landform or an anthropogenic feature. They are plotted in the report by Dallas et al. (2013). |
| *Anthropogenic Features: Pier/dock/boardwalk* | A structure built into the water for the mooring of ships and boats, or over the land to accommodate pedestrians | Projections into the water, either as single units or in groups to constitute a marina or boat basin. Elevated walkways near the beach. |

## Final Product

The generation of the Gateway National Recreation area geomorphological map consists of 29 panels, covering the extent of the three major units. They are incorporated herein as appendices. One set of panels is without hillshade. One set of panels incorporates hillshade.

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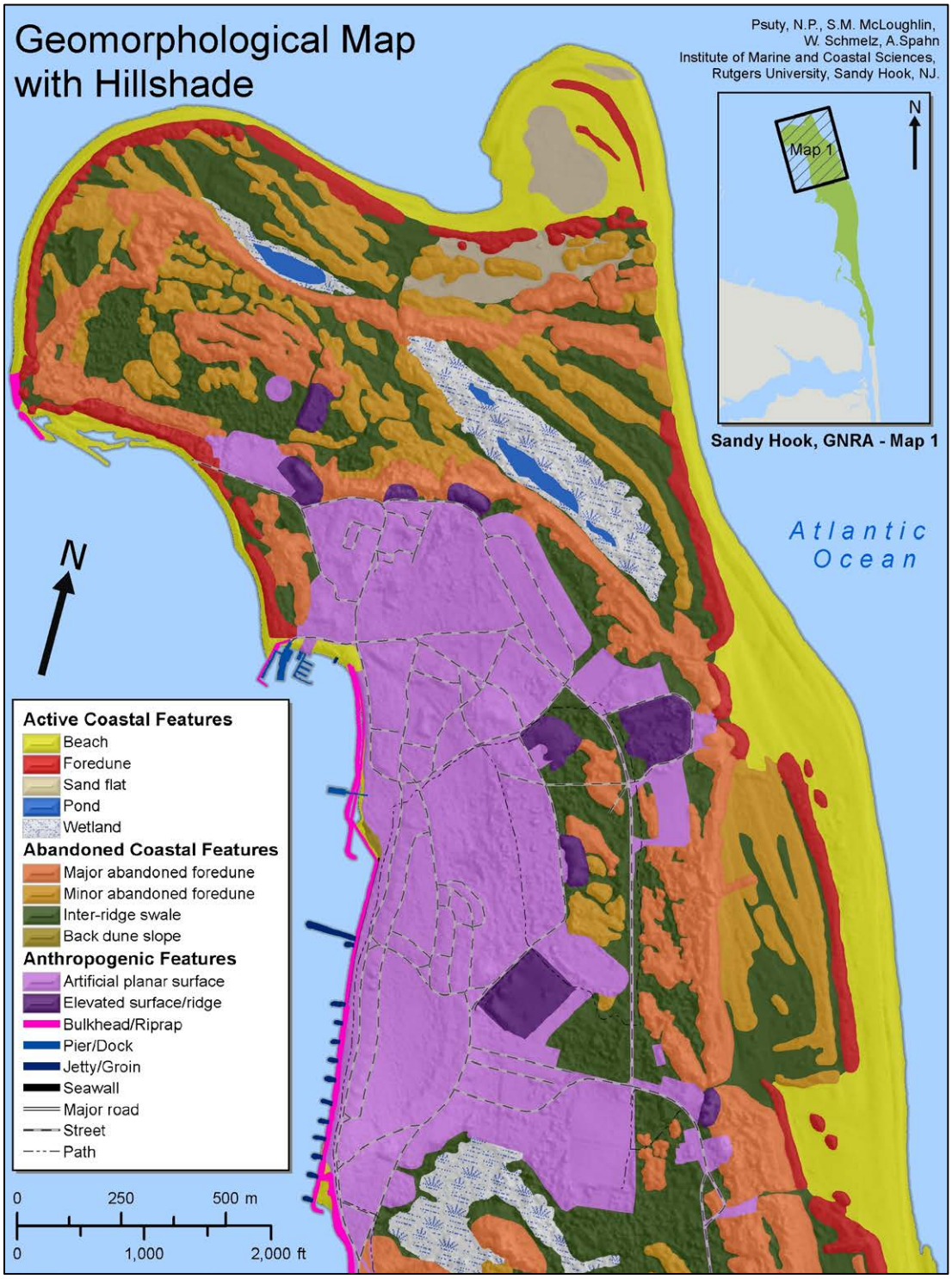
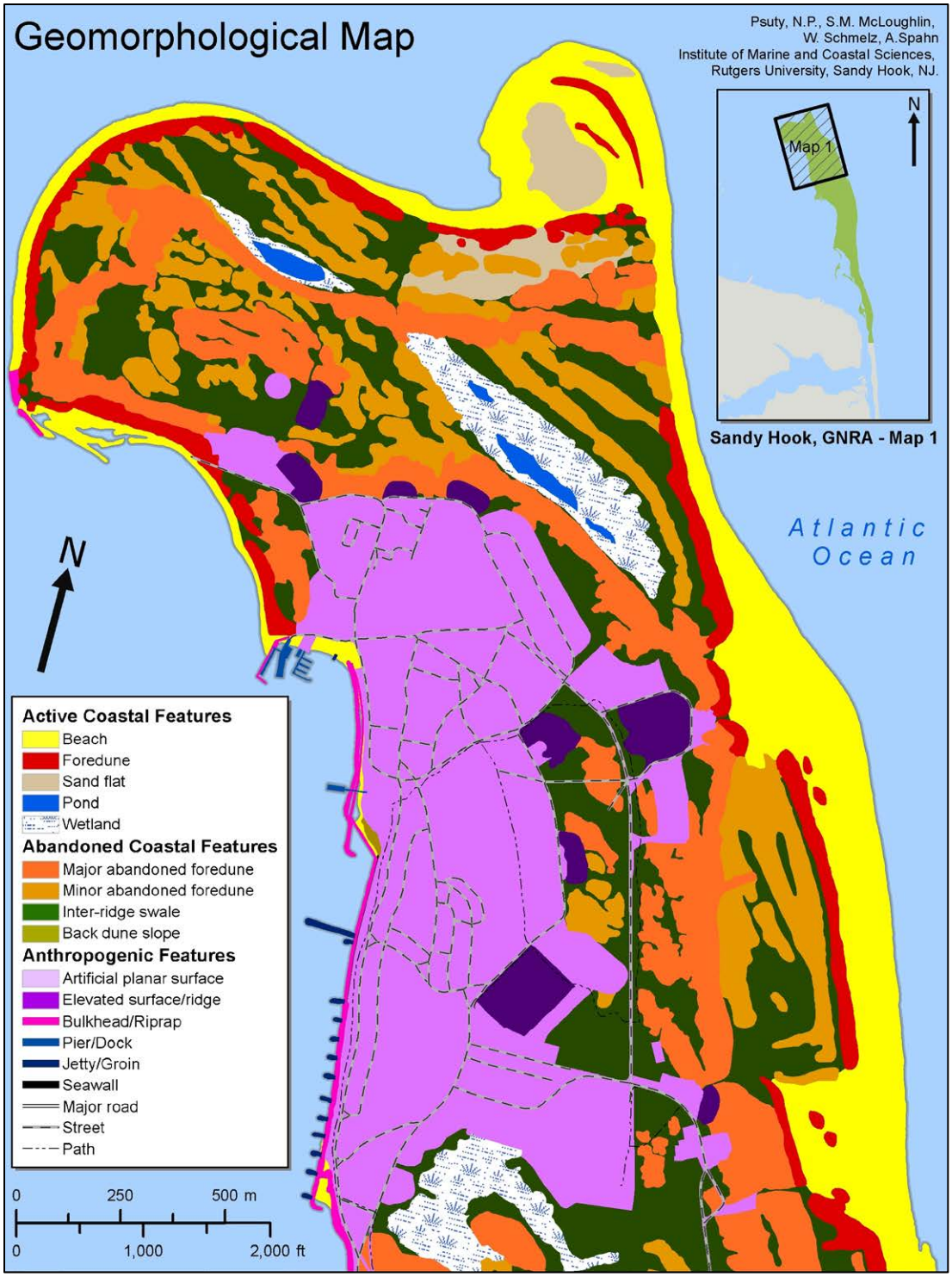
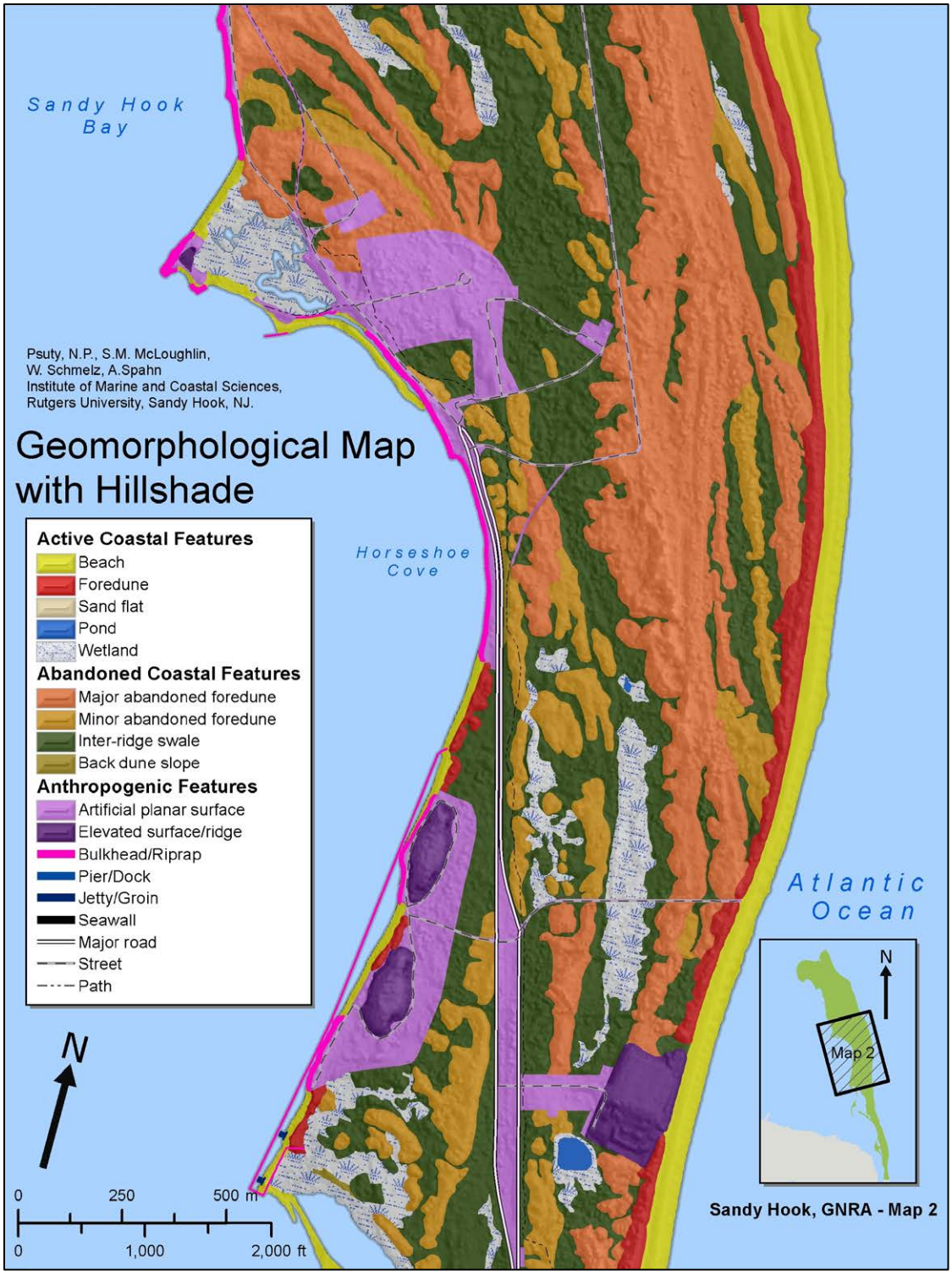
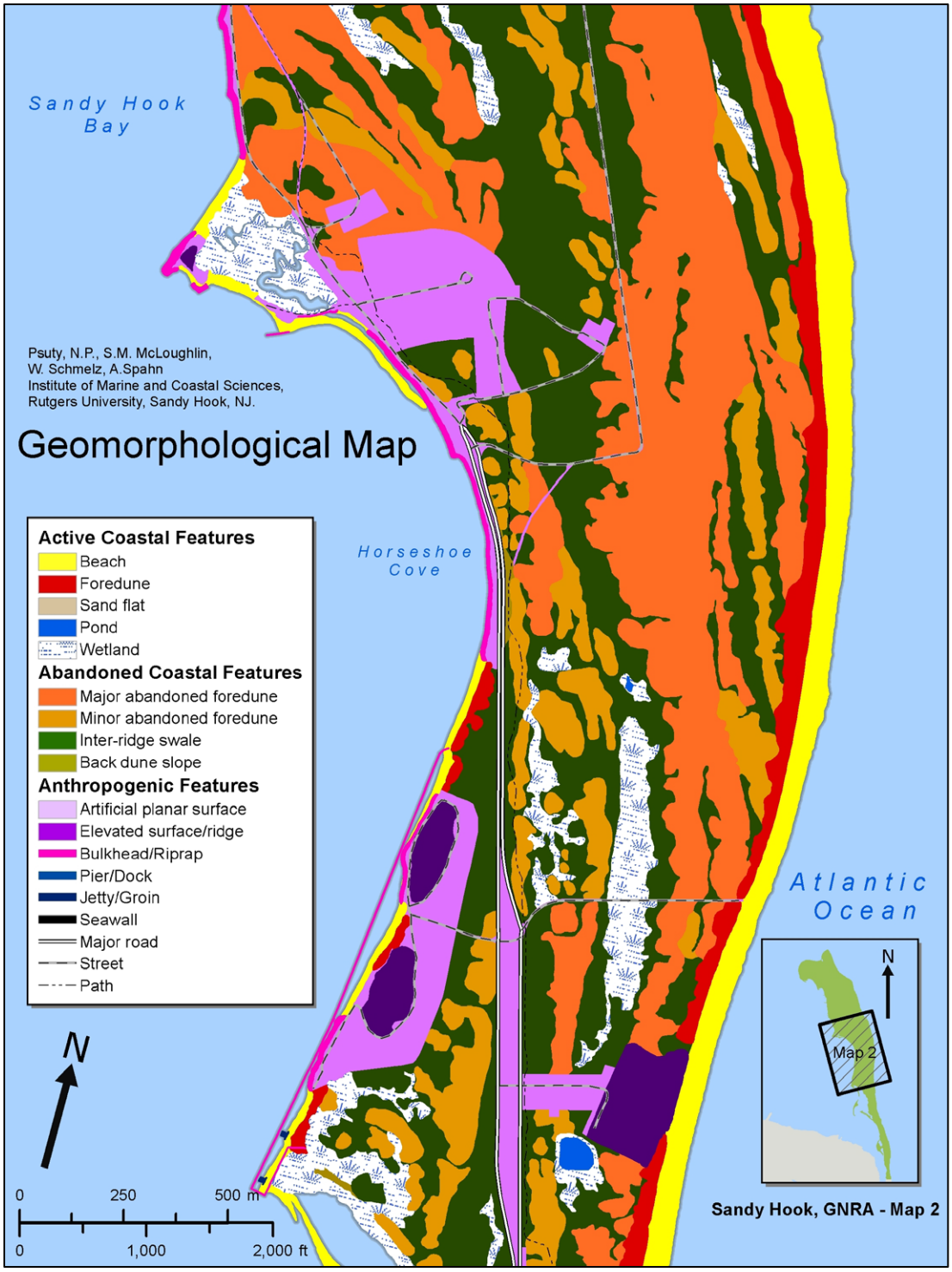
# Appendix: Maps of Gateway National Recreation Area Geomorphology, with and without Hillshade

## Sandy Hook Unit (SHU)




Geomorphological Map
Psuty, N.P., S.M. McLoughlin,
W. Schmelz, A.Spahn
Institute of Marine and Coastal Sciences,
Rutgers University, Sandy Hook, NJ.
N
Map 1
Sandy Hook, GNRA - Map 1
Atlantic
Ocean
N
Active Coastal Features
Beach
Foredune
Sand flat
Pond
Wetland
Abandoned Coastal Features
Major abandoned foredune
Minor abandoned foredune
Inter-ridge swale
Back dune slope
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock
Jetty/Groin
Seawall
Major road
Street
Path
0 250 500 m
0 1,000 2,000 ft


Sandy Hook Bay
Psuty, N.P., S.M. McLoughlin,
W. Schmelz, A.Spahn
Institute of Marine and Coastal Sciences,
Rutgers University, Sandy Hook, NJ.
Geomorphological Map with Hillshade
Active Coastal Features
Beach
Foredune
Sand flat
Pond
Wetland
Abandoned Coastal Features
Major abandoned foredune
Minor abandoned foredune
Inter-ridge swale
Back dune slope
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock
Jetty/Groin
Seawall
Major road
Street
Path
Horseshoe Cove
Atlantic Ocean
N
Map 2
N
0 250 500 m
0 1,000 2,000 ft
Sandy Hook, GNRA - Map 2


Sandy Hook Bay
Psuty, N.P., S.M. McLoughlin,
W. Schmelz, A.Spahn
Institute of Marine and Coastal Sciences,
Rutgers University, Sandy Hook, NJ.
Geomorphological Map
Active Coastal Features
Beach
Foredune
Sand flat
Pond
Wetland
Abandoned Coastal Features
Major abandoned foredune
Minor abandoned foredune
Inter-ridge swale
Back dune slope
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock
Jetty/Groin
Seawall
Major road
Street
Path
Horseshoe Cove
Atlantic Ocean
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0 250 500 m
0 1,000 2,000 ft
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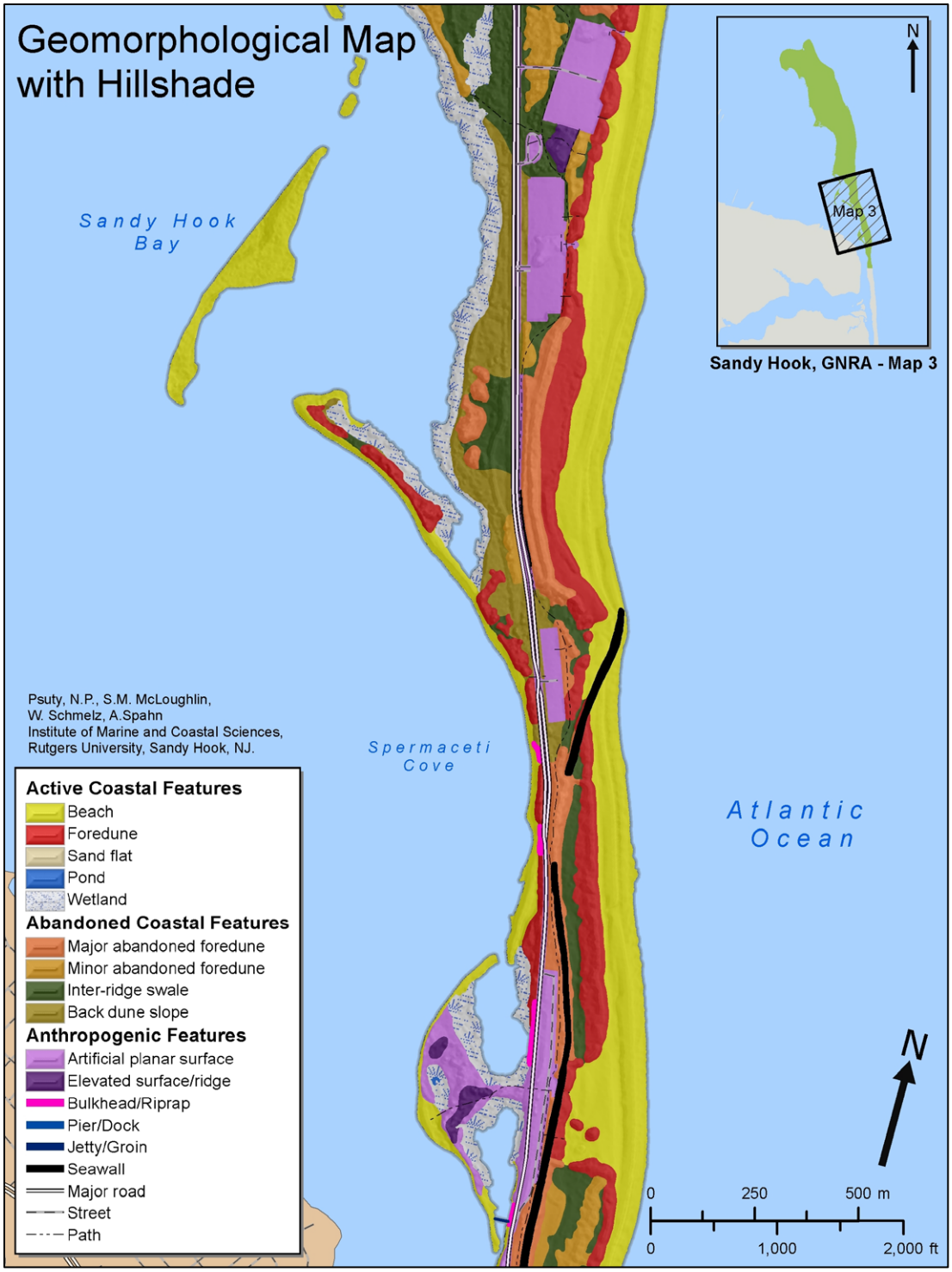
Map 2
Sandy Hook, GNRA - Map 2


Geomorphological Map
with Hillshade
Sandy Hook
Bay
Spermaceti
Cove
Atlantic
Ocean
N
Map 3
Sandy Hook, GNRA - Map 3
Psuty, N.P., S.M. McLoughlin,
W. Schmelz, A.Spahn
Institute of Marine and Coastal Sciences,
Rutgers University, Sandy Hook, NJ.
Active Coastal Features
Beach
Foredune
Sand flat
Pond
Wetland
Abandoned Coastal Features
Major abandoned foredune
Minor abandoned foredune
Inter-ridge swale
Back dune slope
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock
Jetty/Groin
Seawall
Major road
Street
Path
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250
500 m
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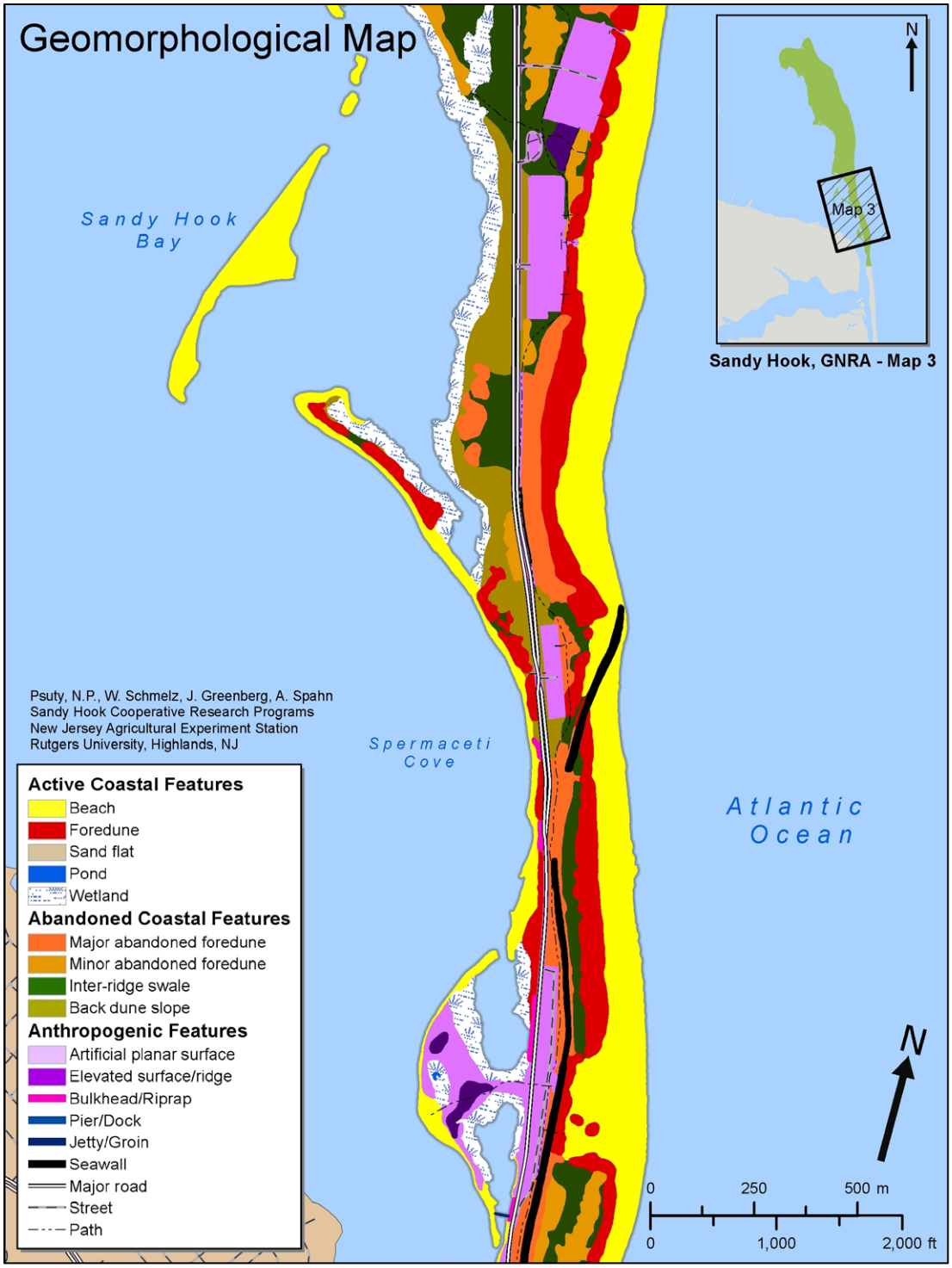
Geomorphological Map
Sandy Hook Bay
Spermaceti Cove
Atlantic Ocean
Map 3
N
Sandy Hook, GNRA - Map 3
Psuty, N.P., W. Schmelz, J. Greenberg, A. Spahn
Sandy Hook Cooperative Research Programs
New Jersey Agricultural Experiment Station
Rutgers University, Highlands, NJ
Active Coastal Features
Beach
Foredune
Sand flat
Pond
Wetland
Abandoned Coastal Features
Major abandoned foredune
Minor abandoned foredune
Inter-ridge swale
Back dune slope
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock
Jetty/Groin
Seawall
Major road
Street
Path
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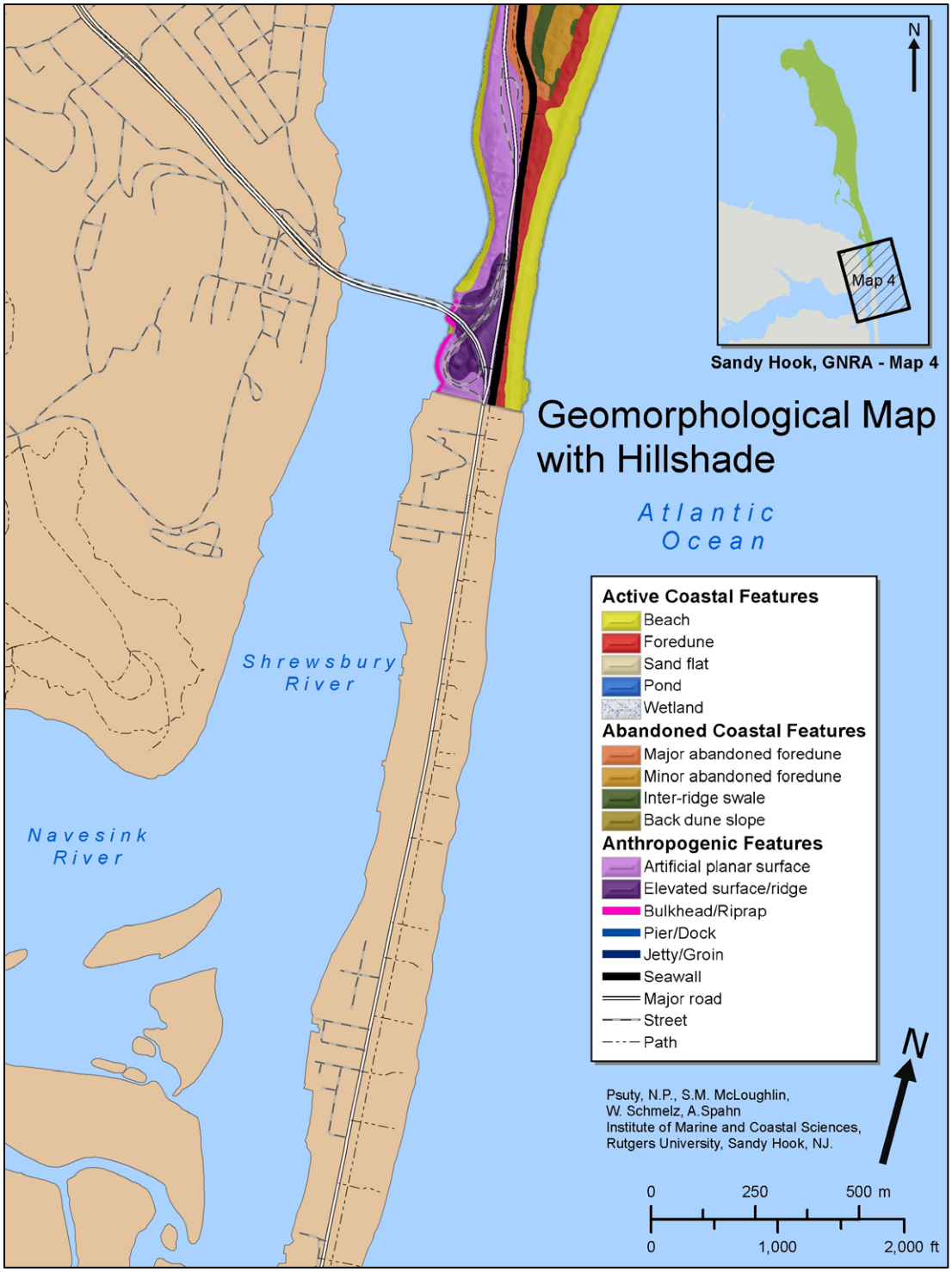
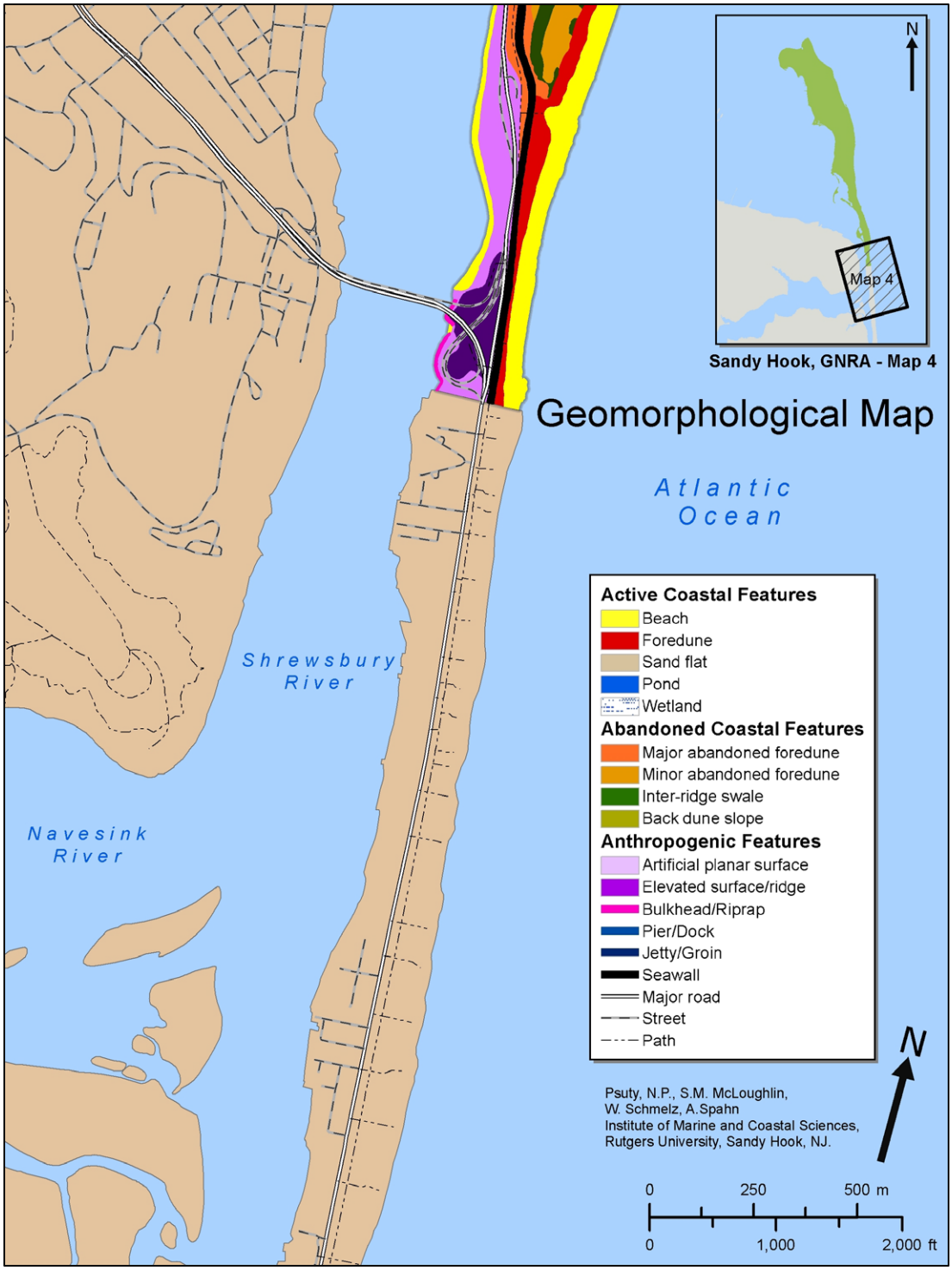

N
Map 4
Sandy Hook, GNRA - Map 4
Geomorphological Map with Hillshade
Atlantic Ocean
Shrewsbury River
Navesink River
Active Coastal Features
Beach
Foredune
Sand flat
Pond
Wetland
Abandoned Coastal Features
Major abandoned foredune
Minor abandoned foredune
Inter-ridge swale
Back dune slope
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock
Jetty/Groin
Seawall
Major road
Street
Path
N
Psuty, N.P., S.M. McLoughlin,
W. Schmelz, A.Spahn
Institute of Marine and Coastal Sciences,
Rutgers University, Sandy Hook, NJ.
0 250 500 m
0 1,000 2,000 ft


N
Map 4
Sandy Hook, GNRA - Map 4
Geomorphological Map
Atlantic Ocean
Shrewsbury River
Navesink River
Active Coastal Features
Beach
Foredune
Sand flat
Pond
Wetland
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Major abandoned foredune
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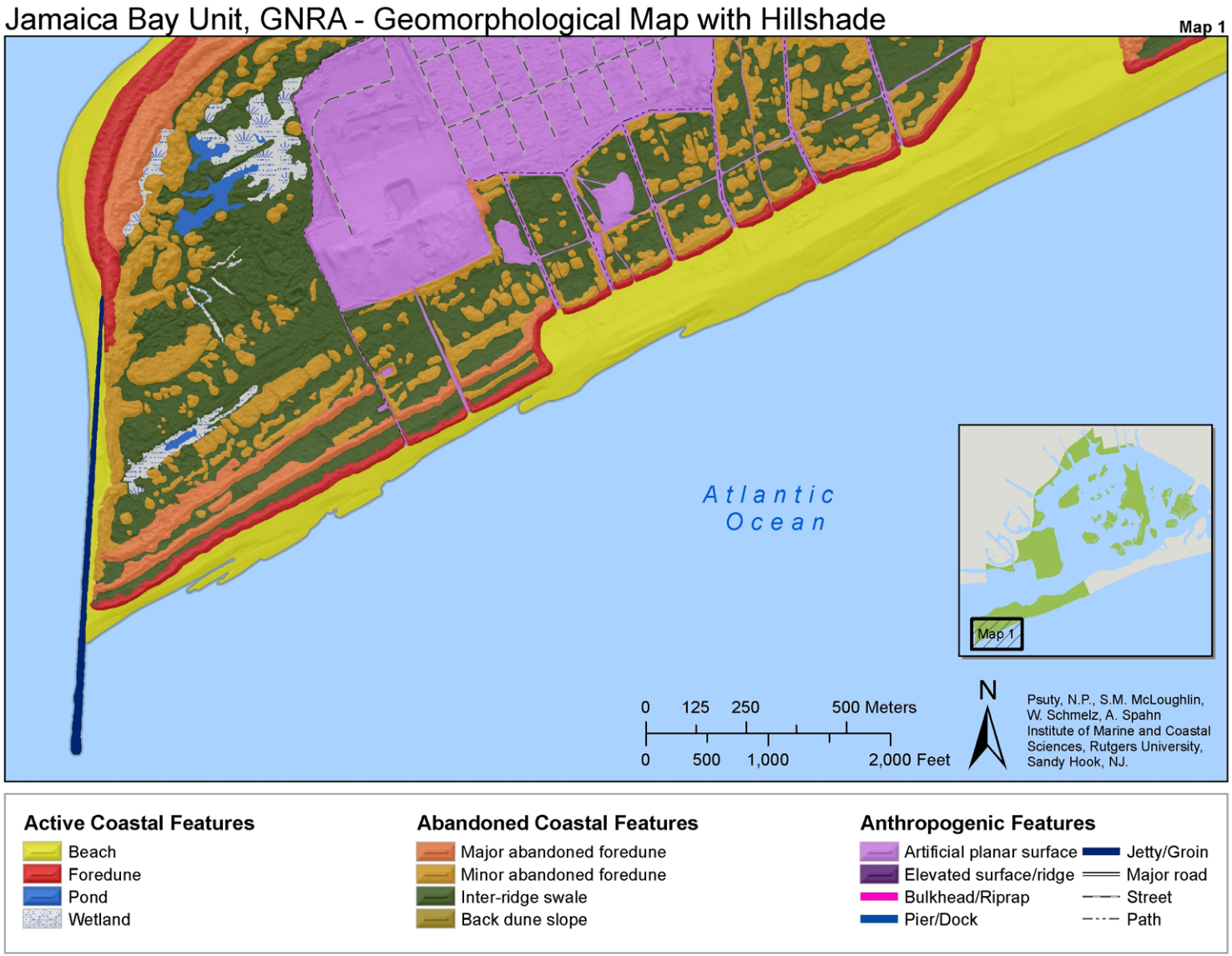
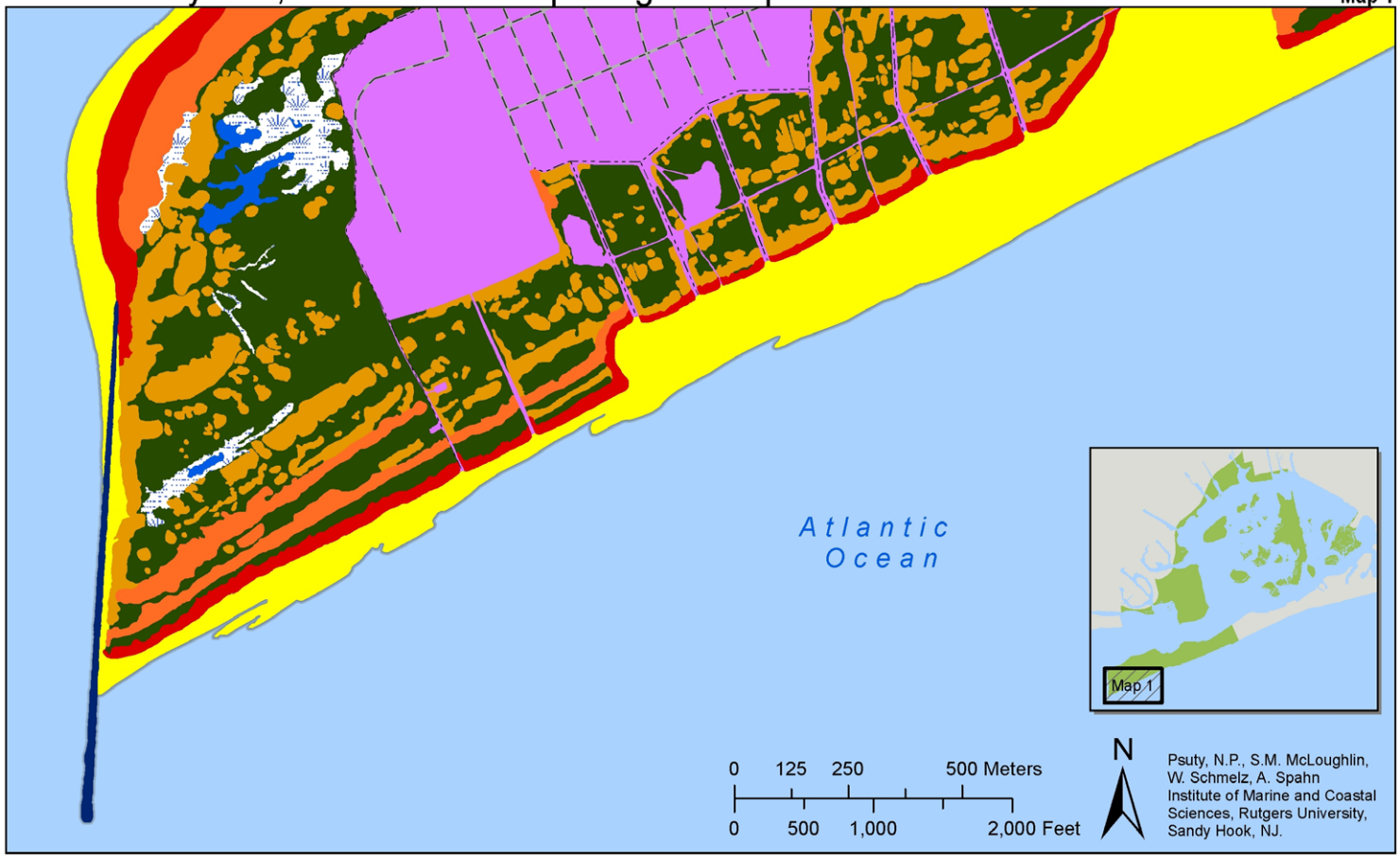
Inter-ridge swale
Back dune slope
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock
Jetty/Groin
Seawall
Major road
Street
Path
N
Psuty, N.P., S.M. McLoughlin,
W. Schmelz, A.Spahn
Institute of Marine and Coastal Sciences,
Rutgers University, Sandy Hook, NJ.
0 250 500 m
0 1,000 2,000 ft

**Jamaica Bay Unit (JBU)**



## Jamaica Bay Unit, GNRA - Geomorphological Map

Map 1



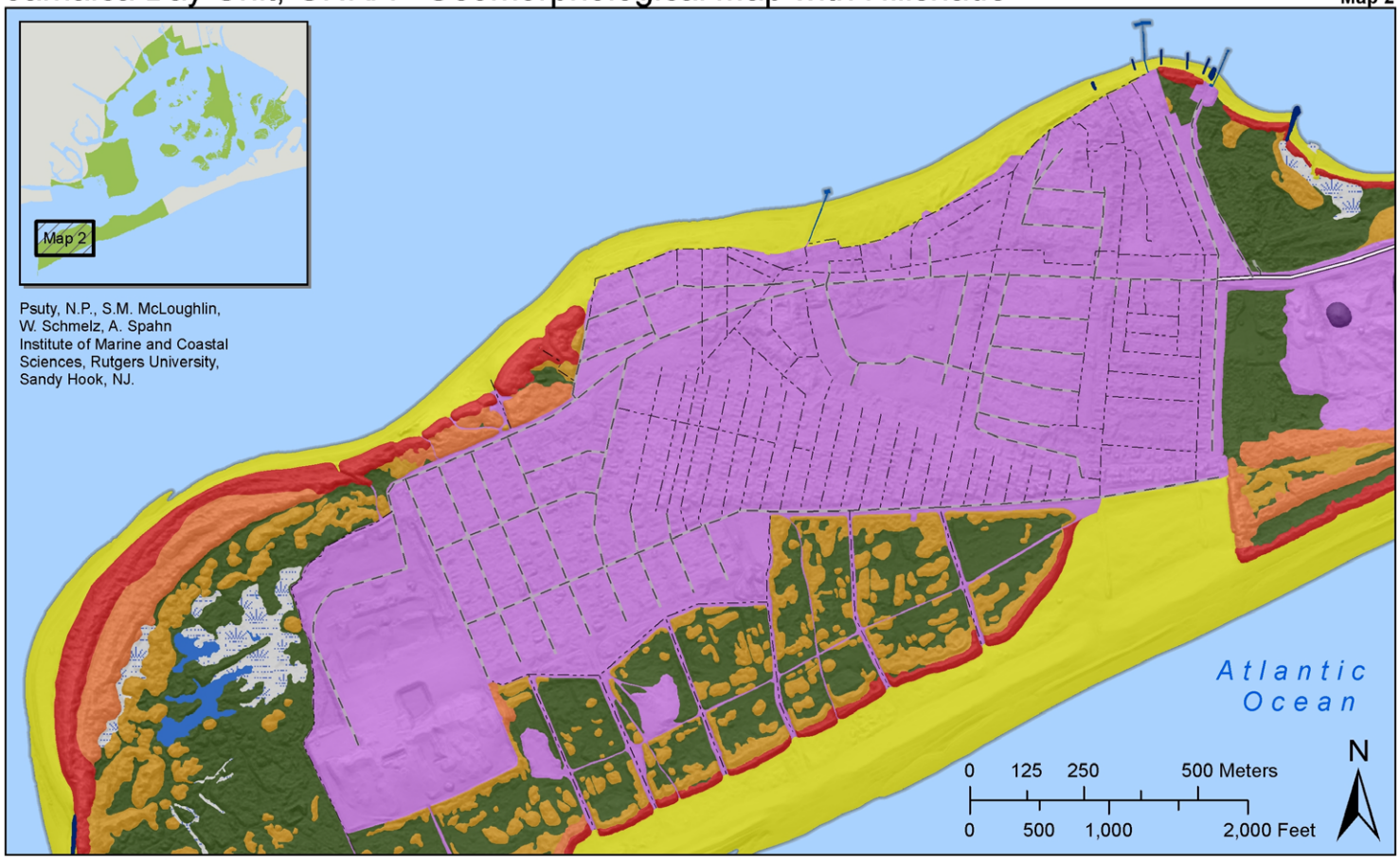

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 2**




**Active Coastal Features**

- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**

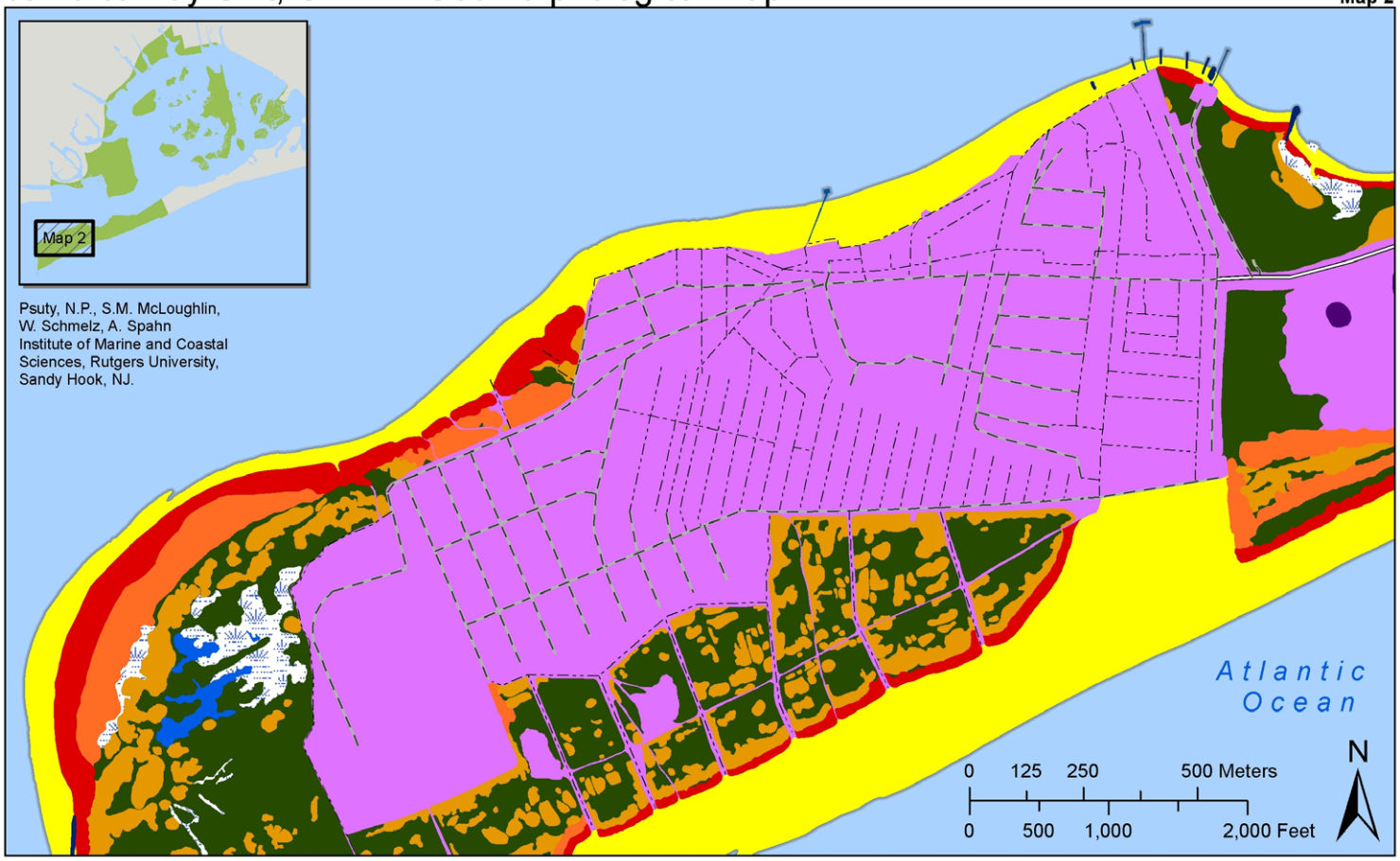
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**

- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 2**



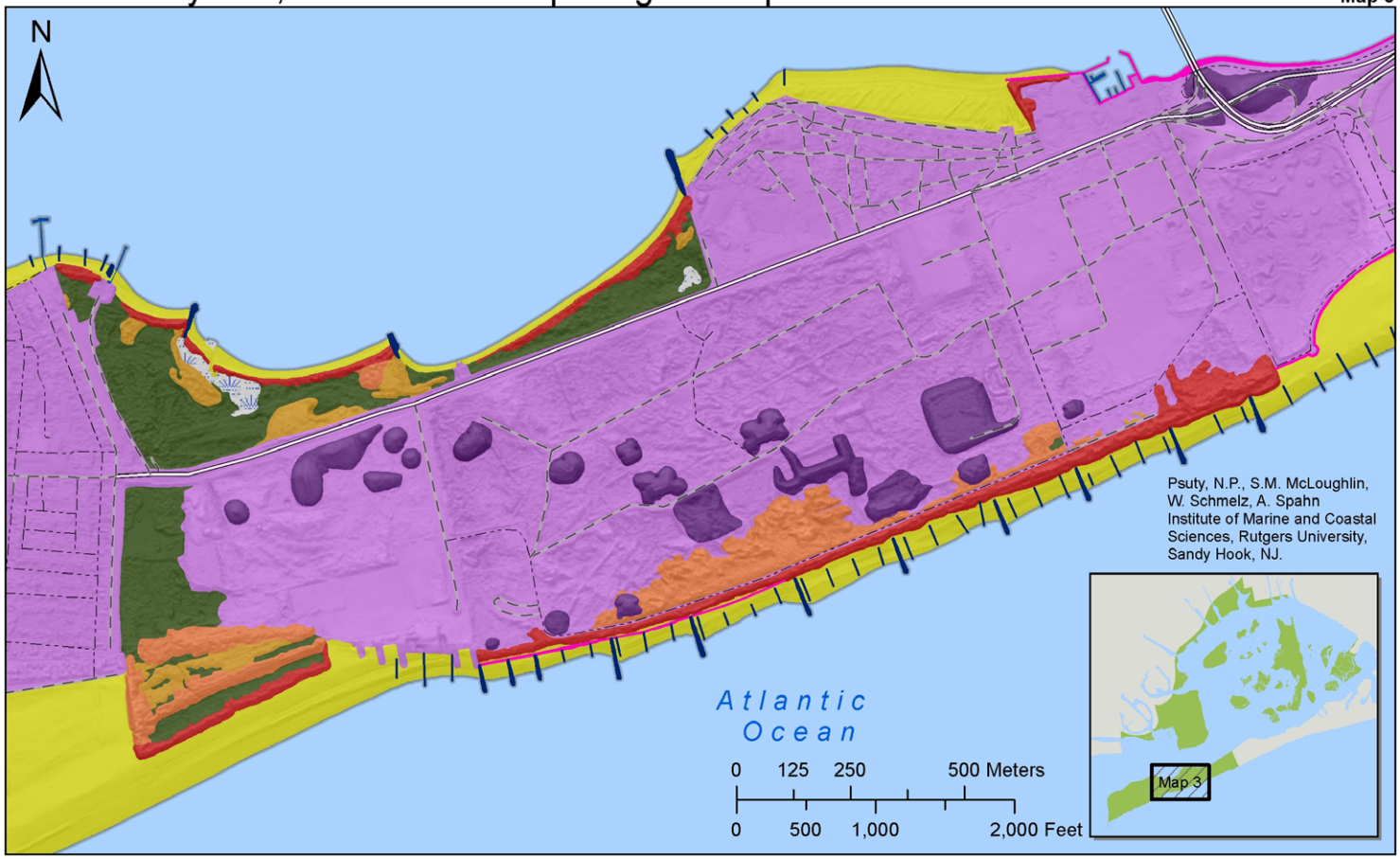

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

Map 3



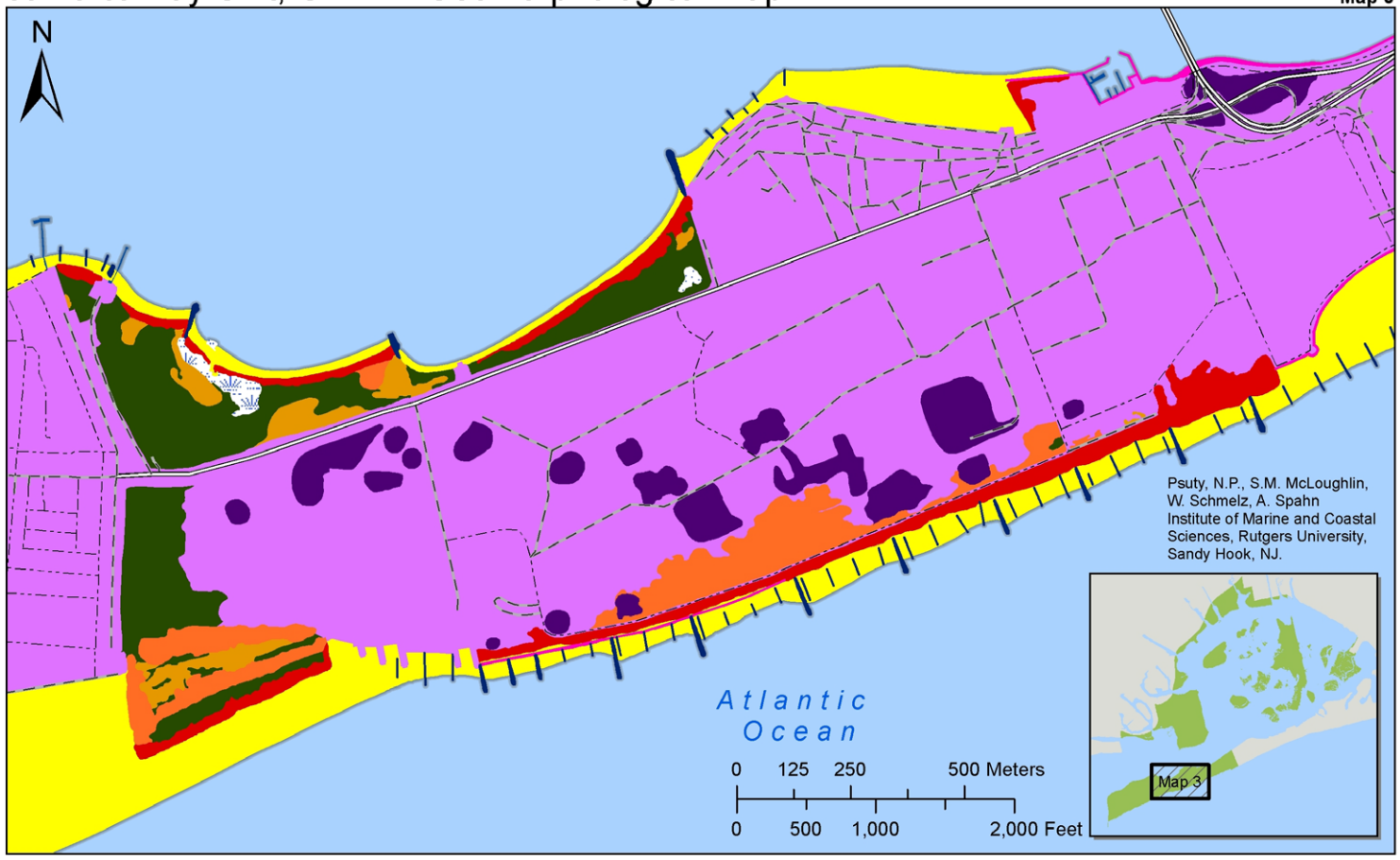

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 3**



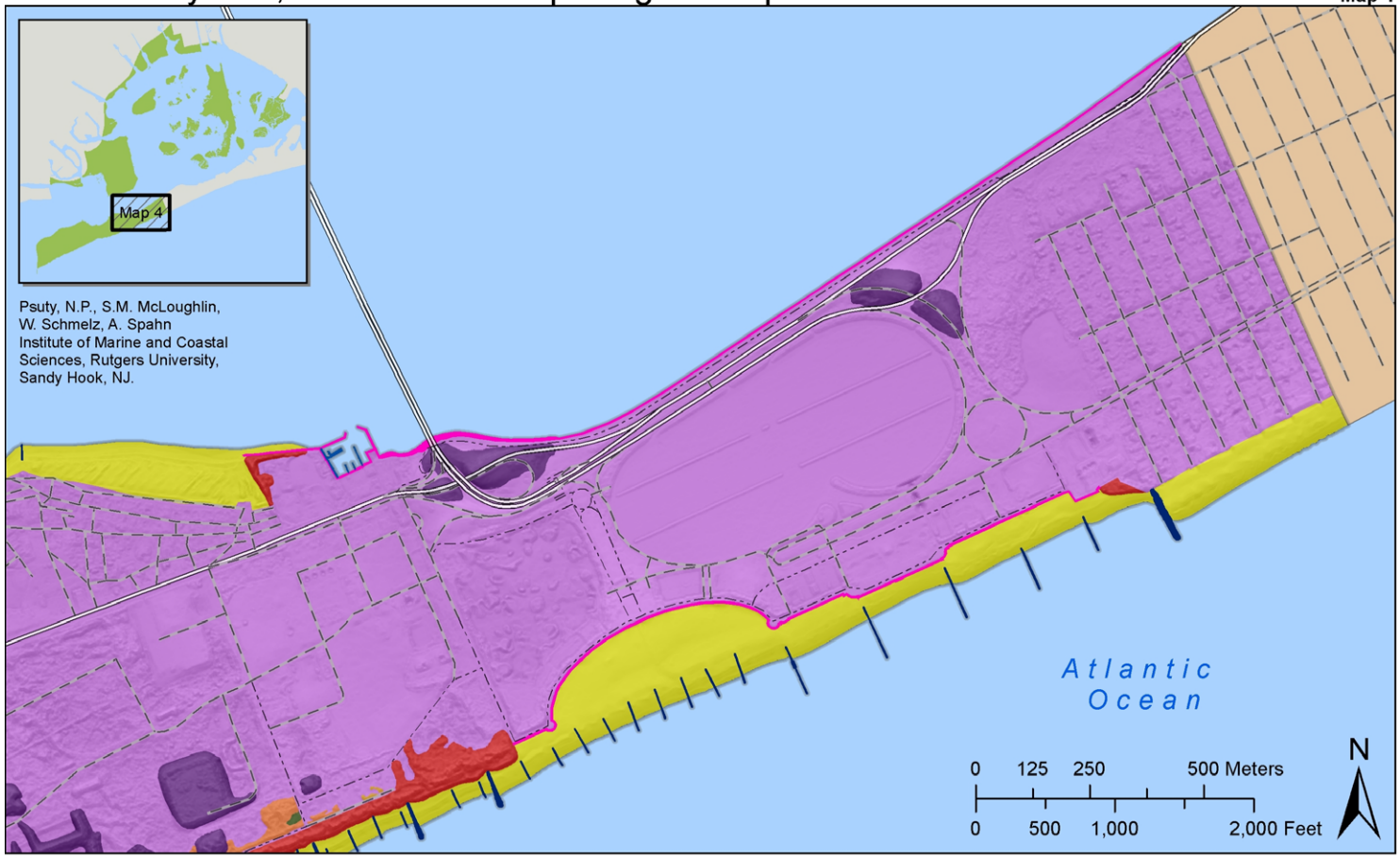

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 4**



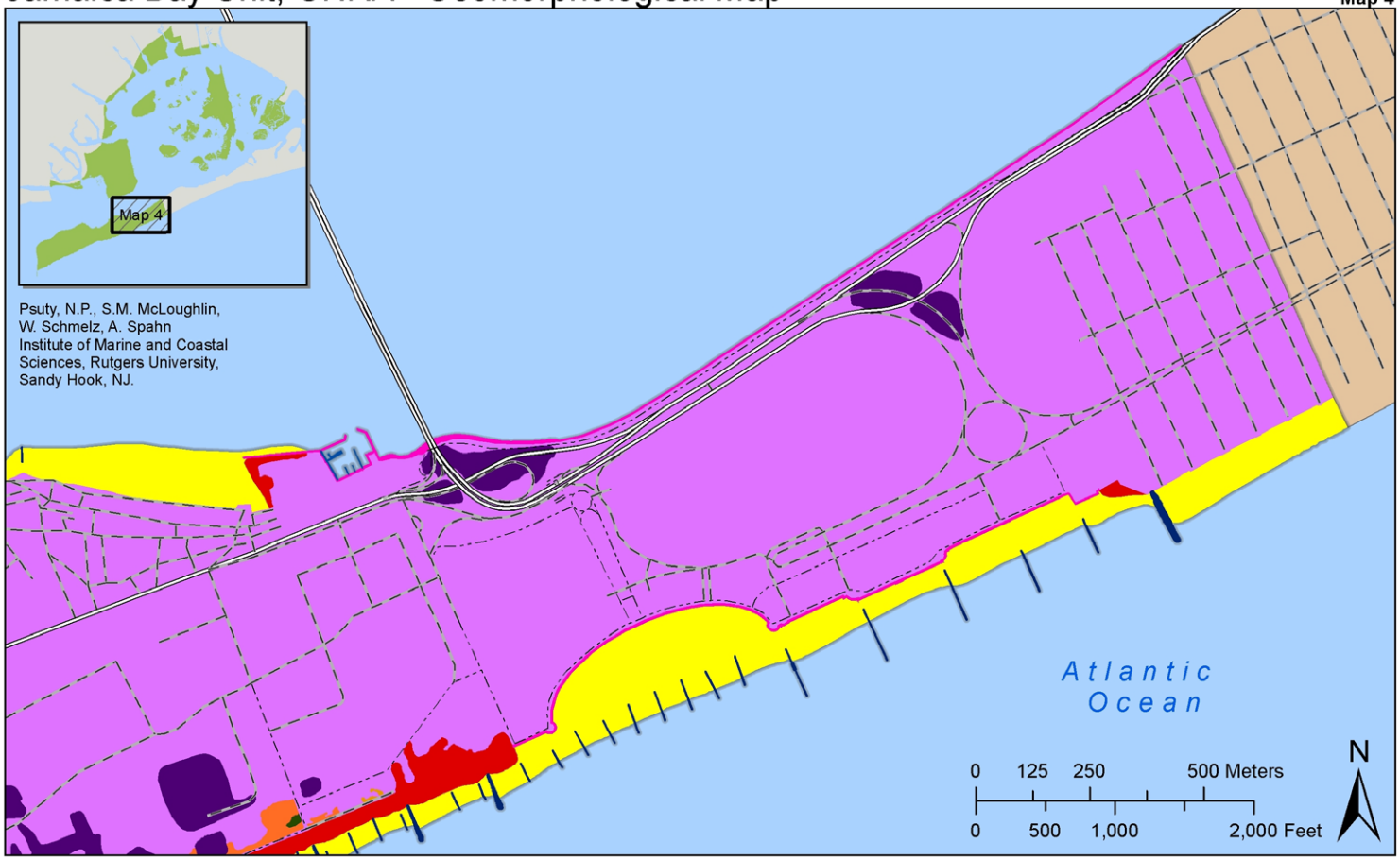

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 4**



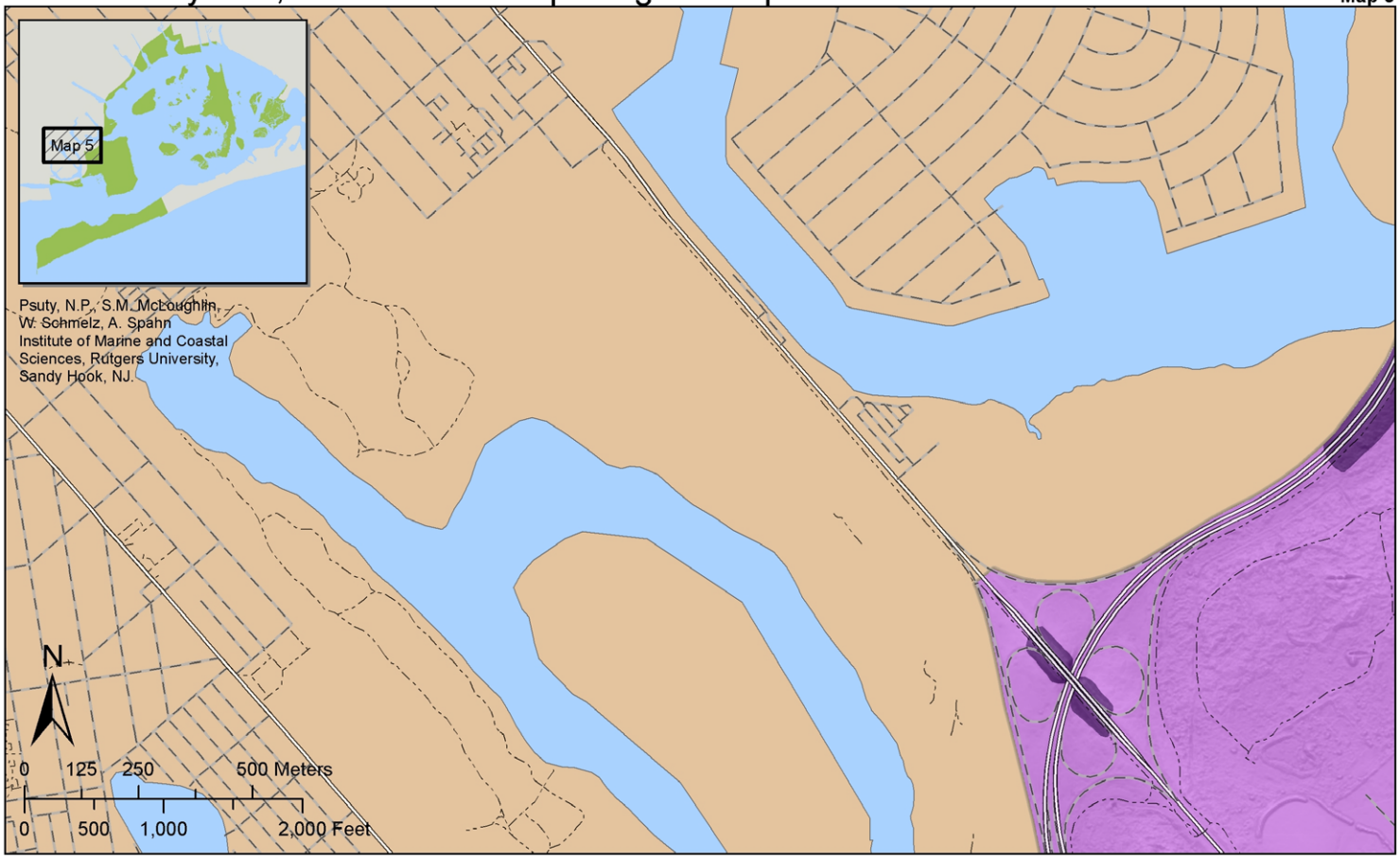

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 5**



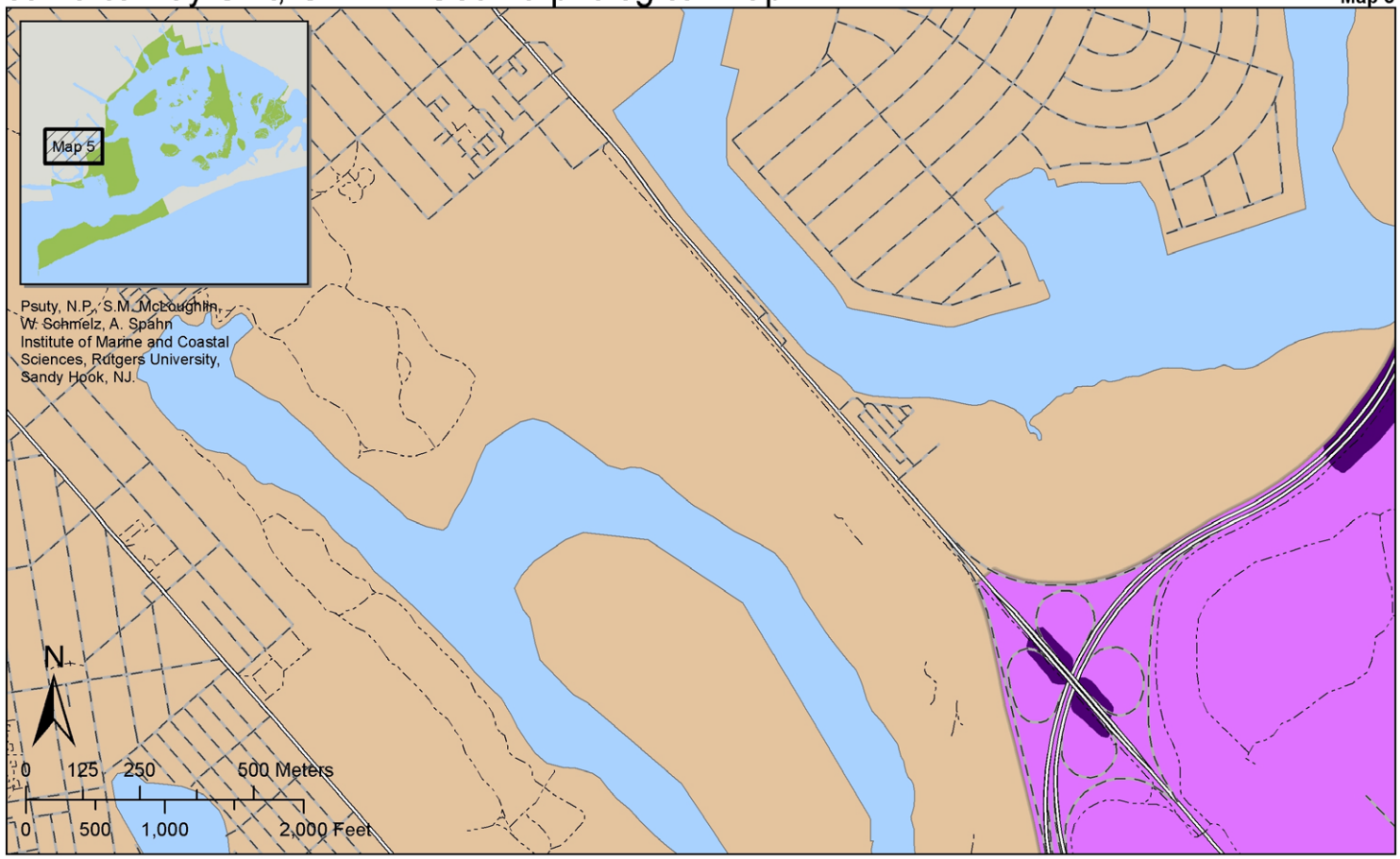

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 5**




**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

Map 6

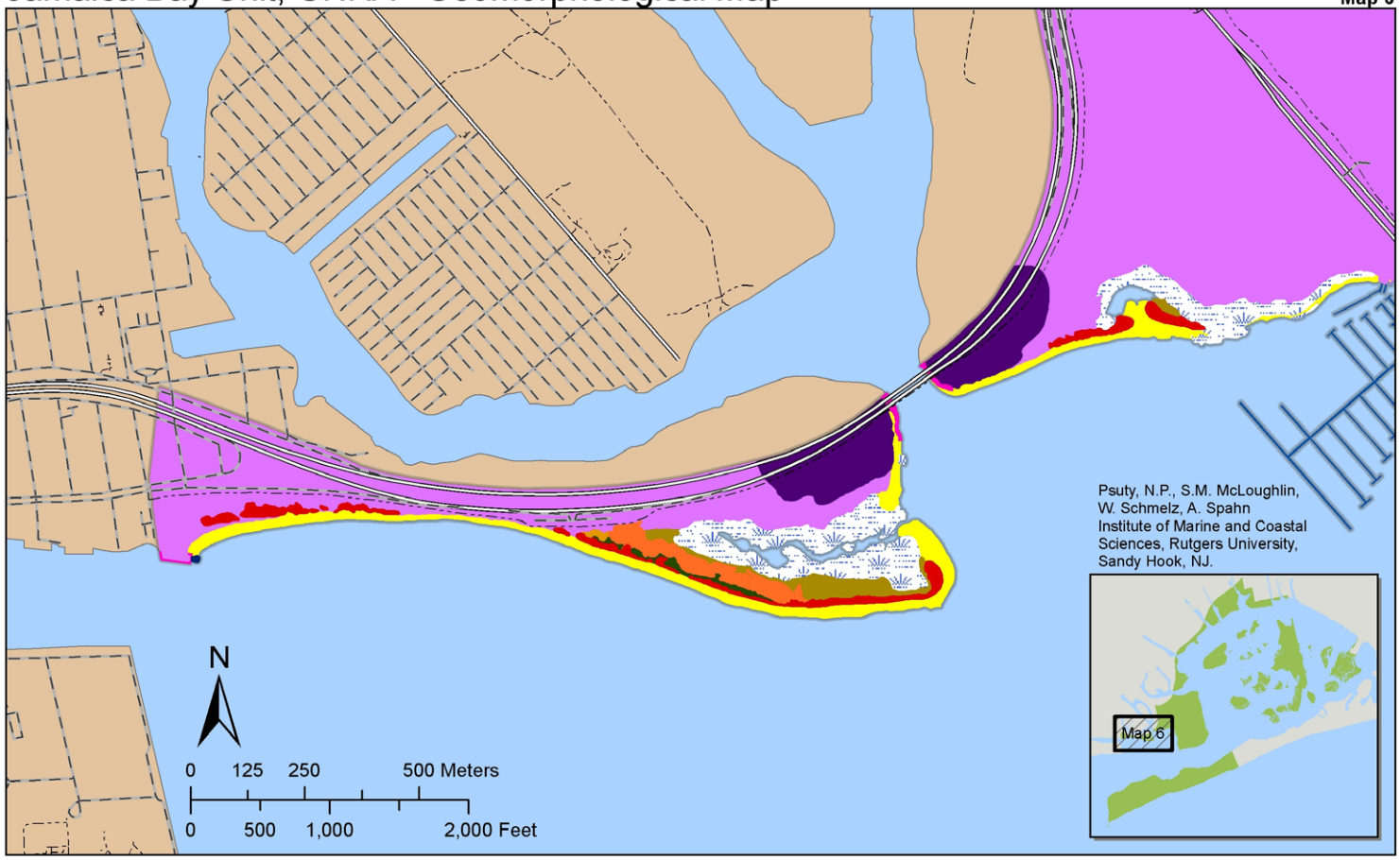

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 6**



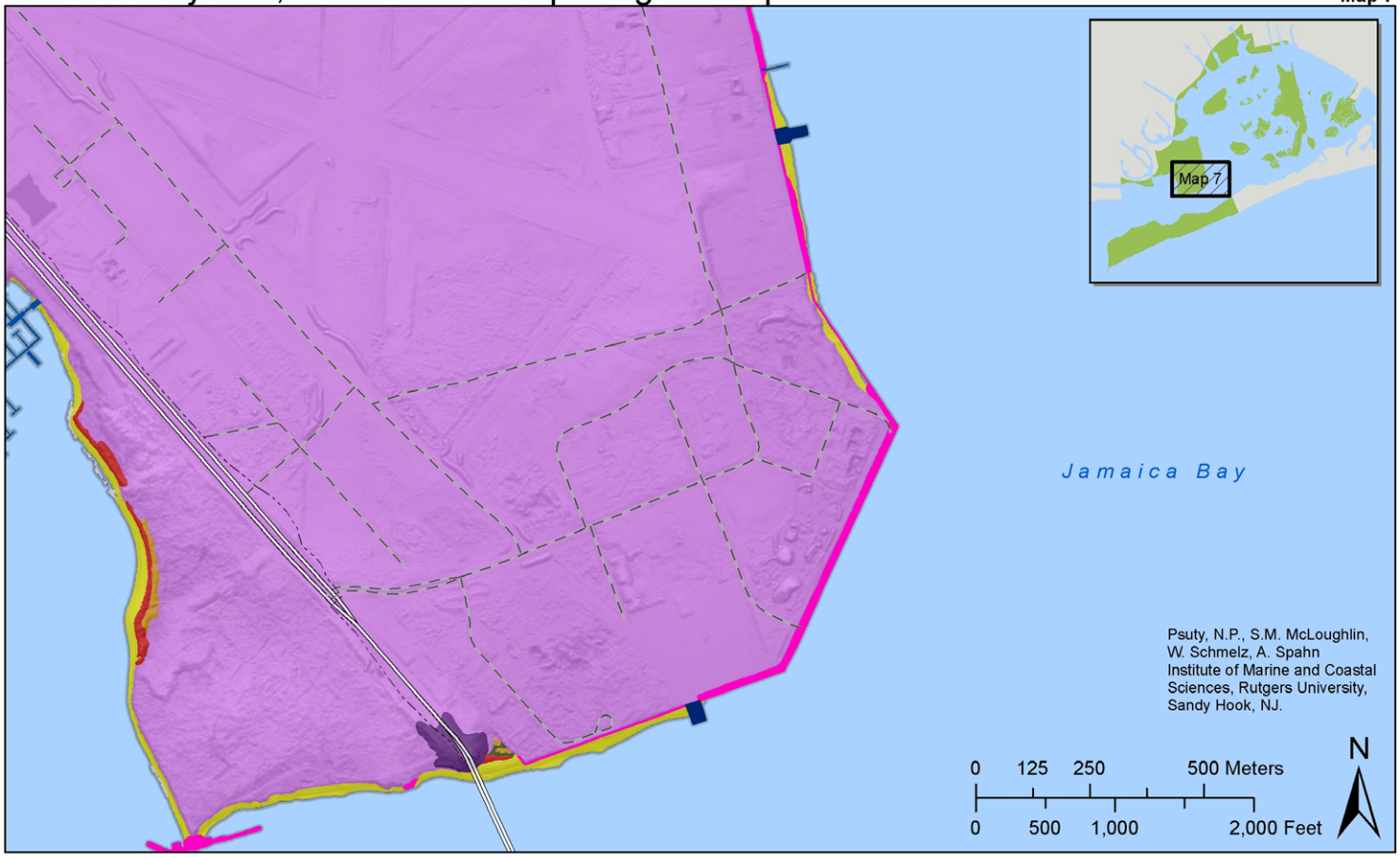

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 7**



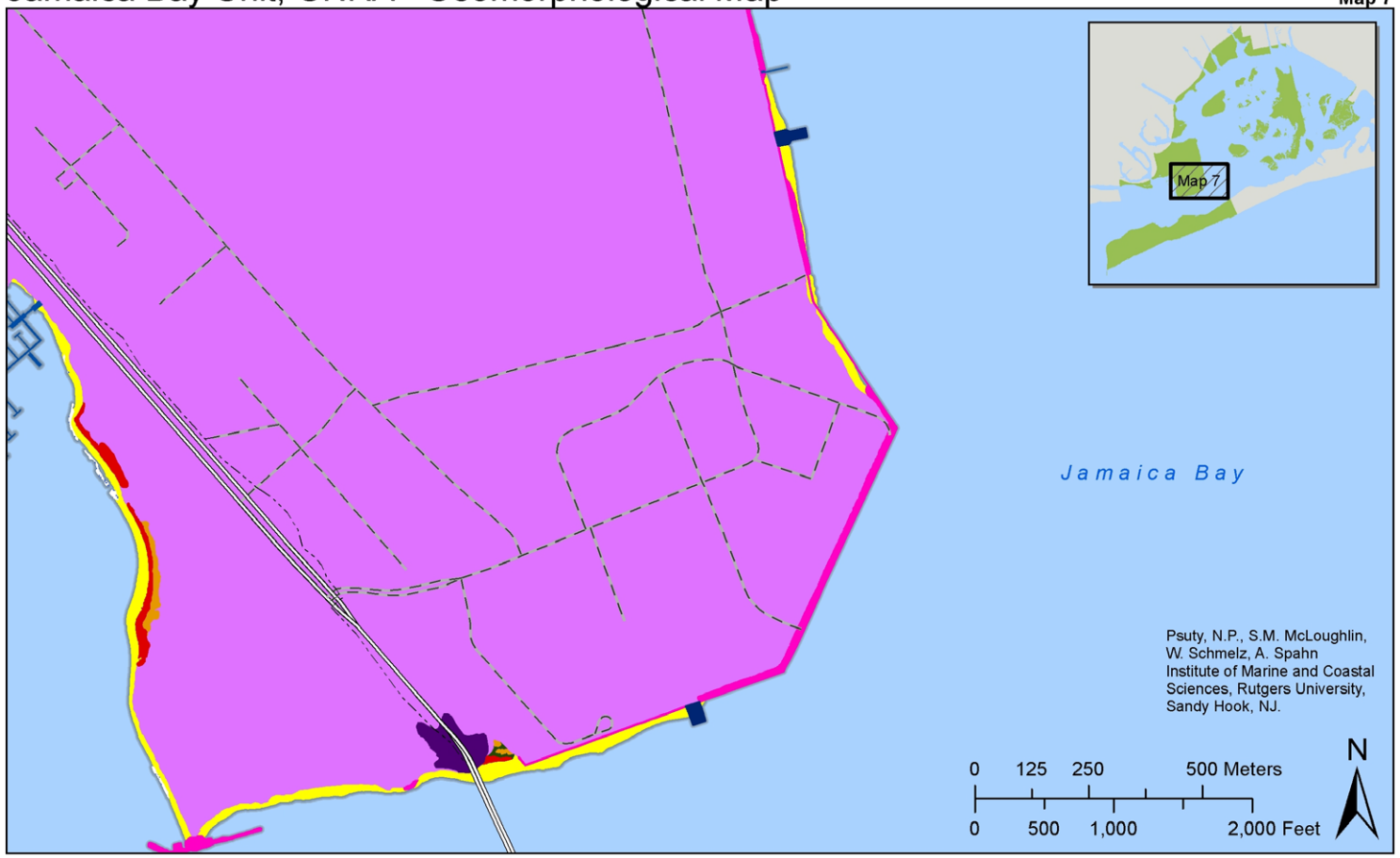

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 7**



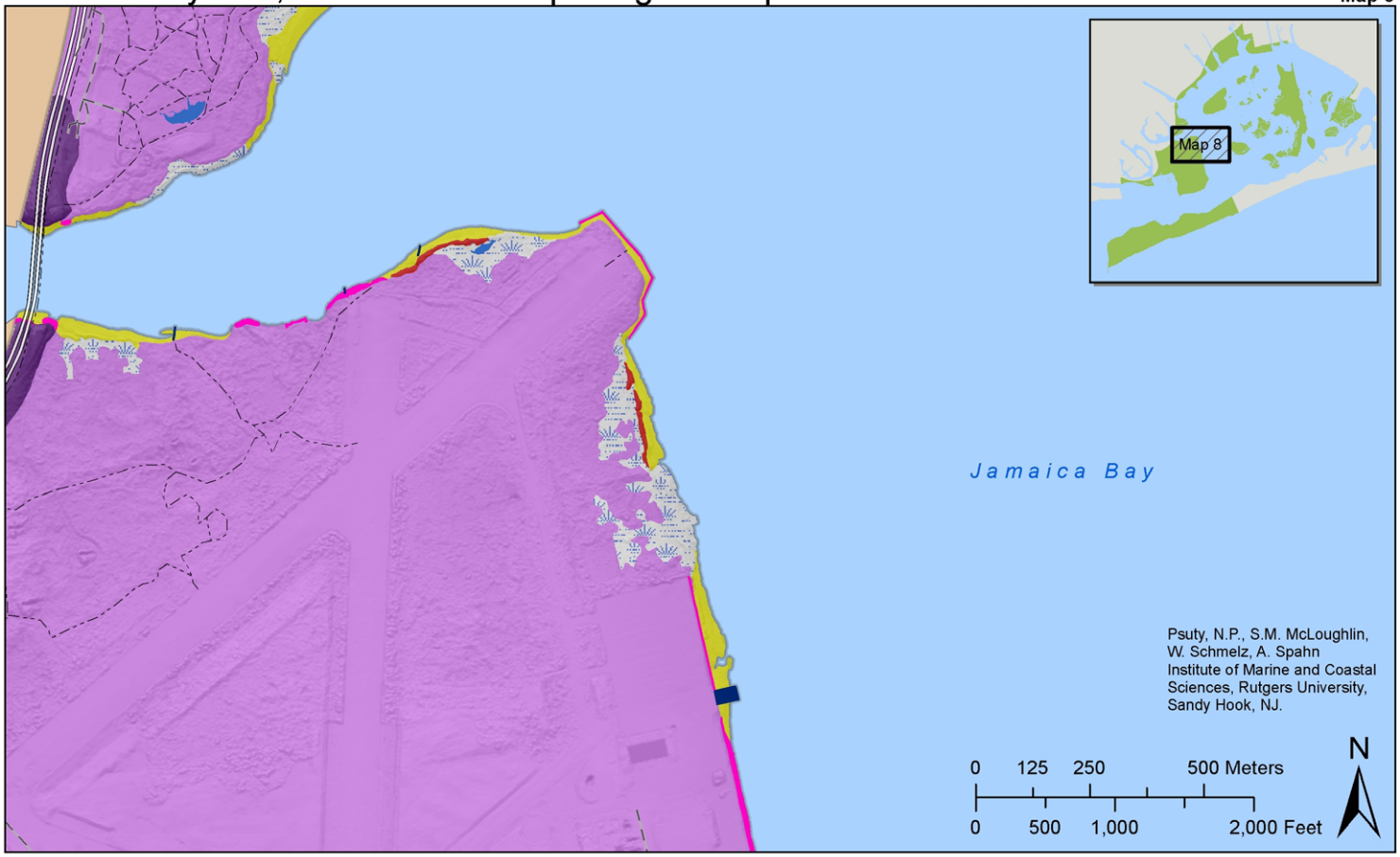

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

Map 8



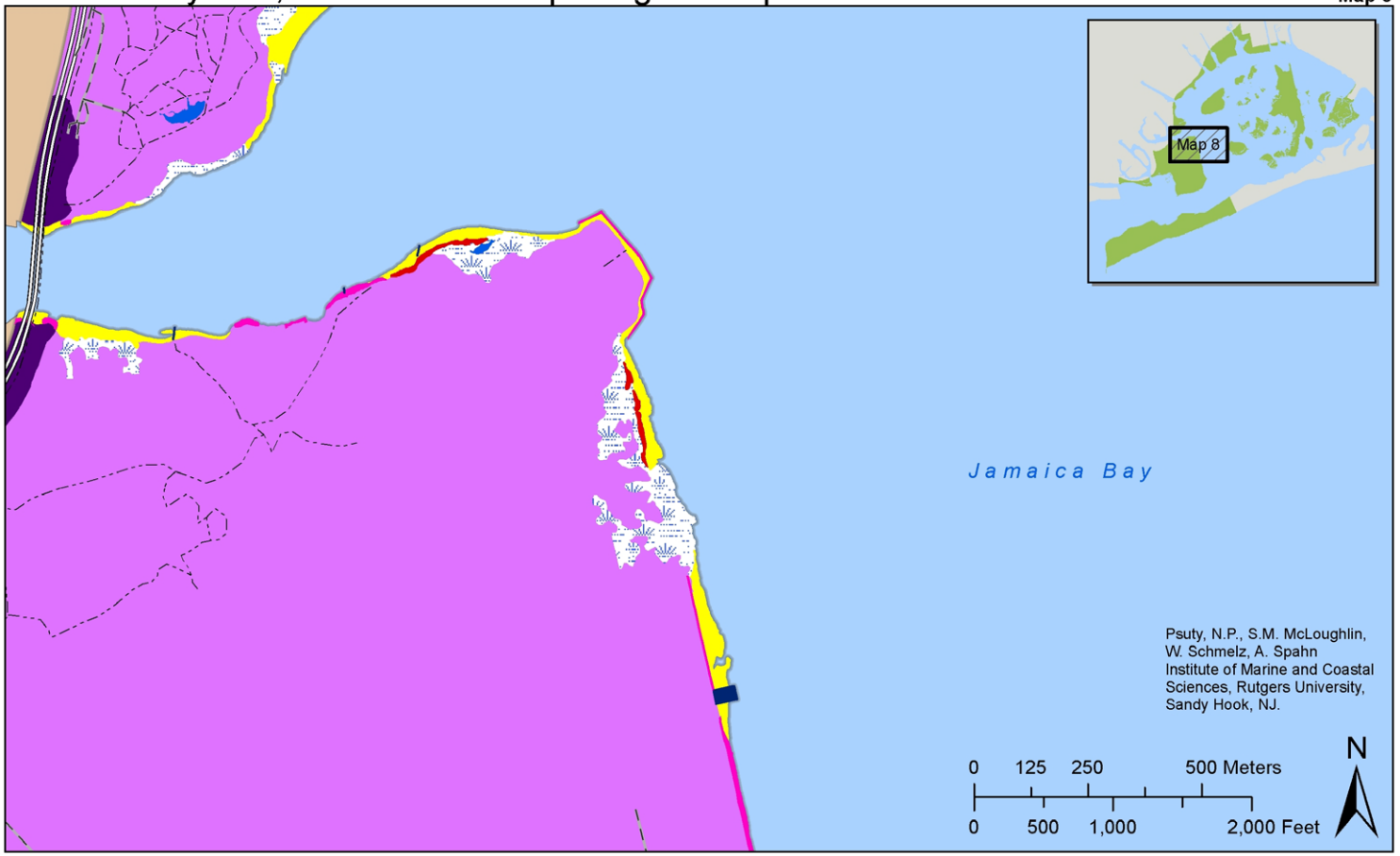

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 8**



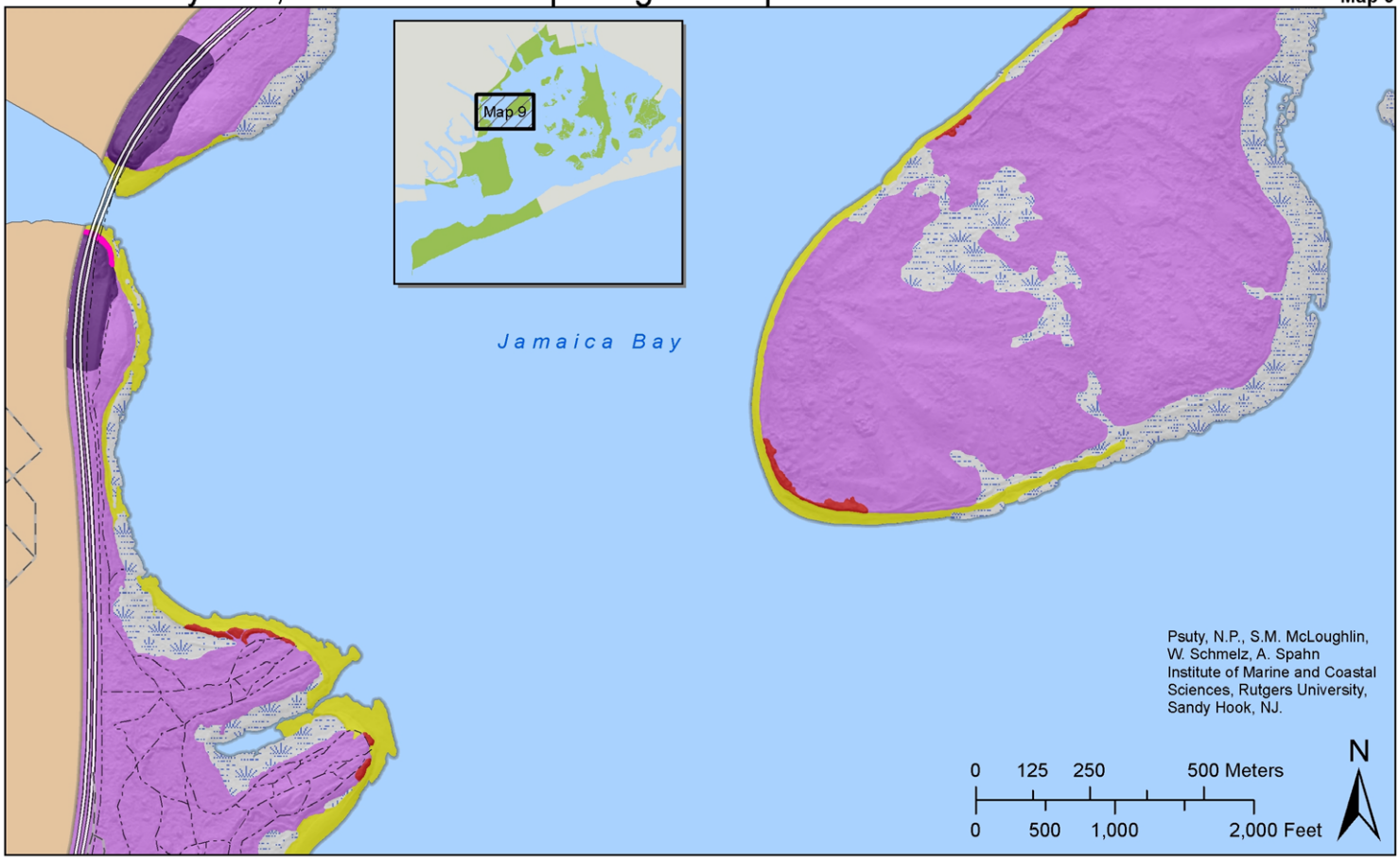

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 9**



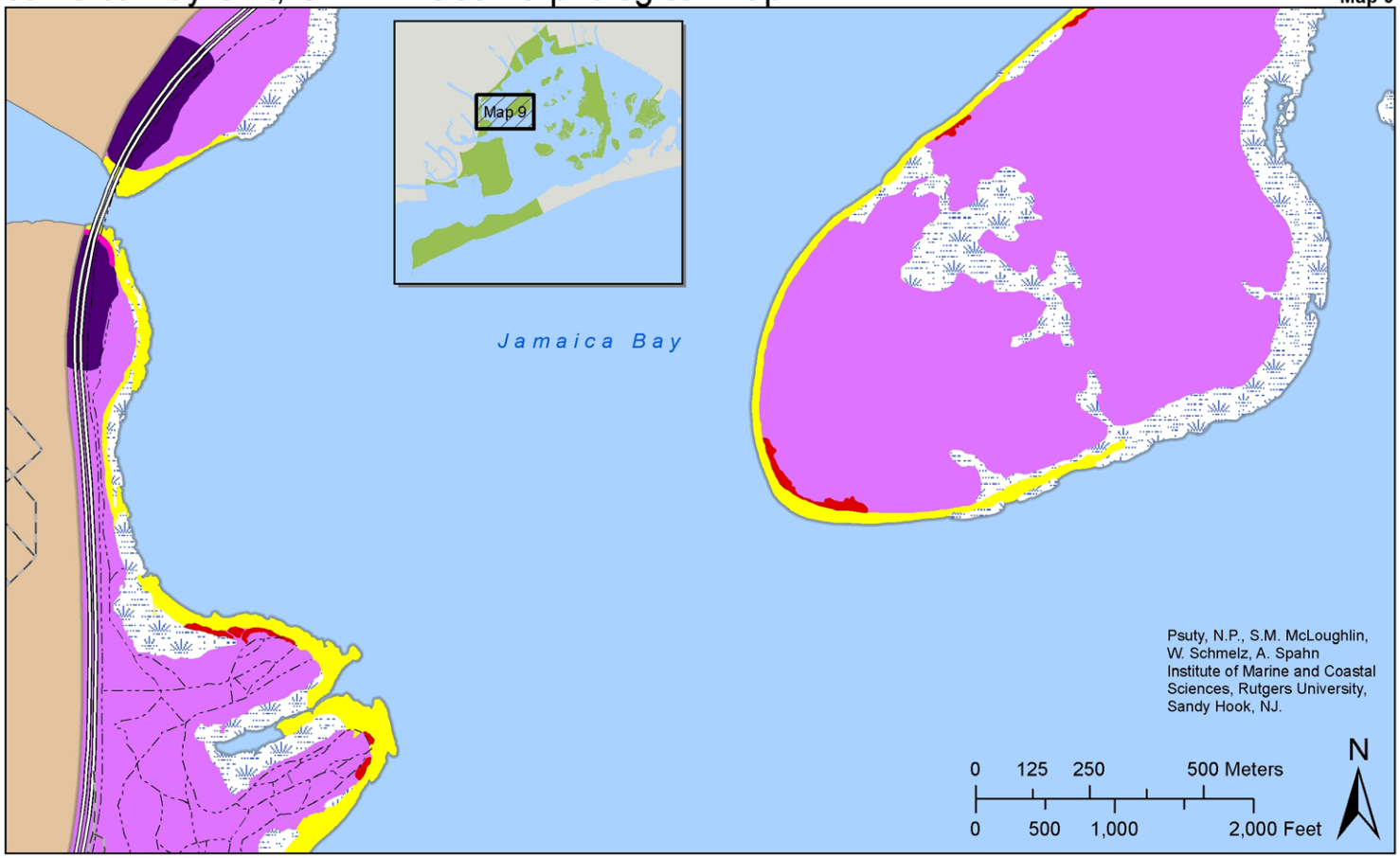

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 9**




**Active Coastal Features**

- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**

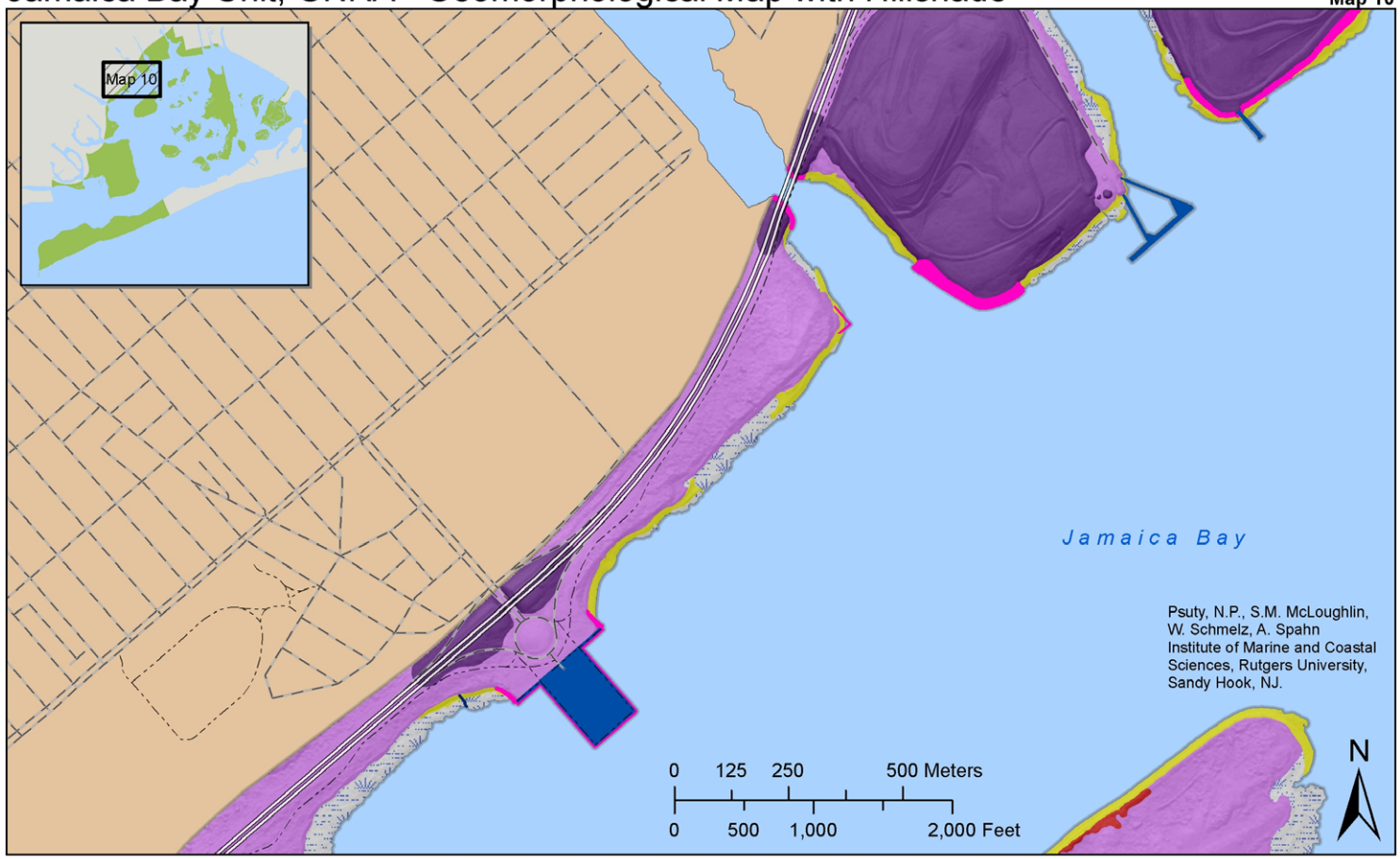
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**

- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

Map 10



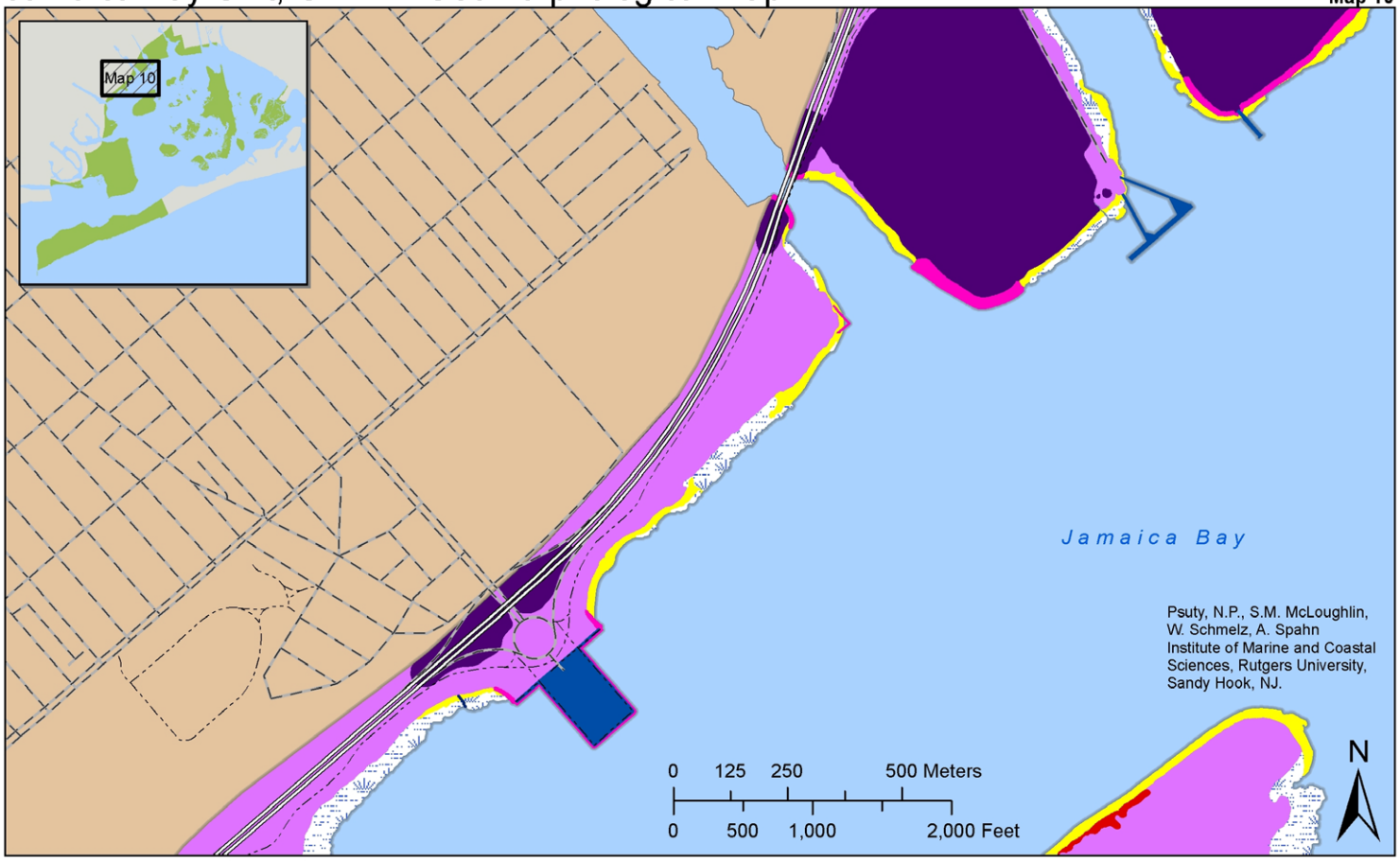

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 10**



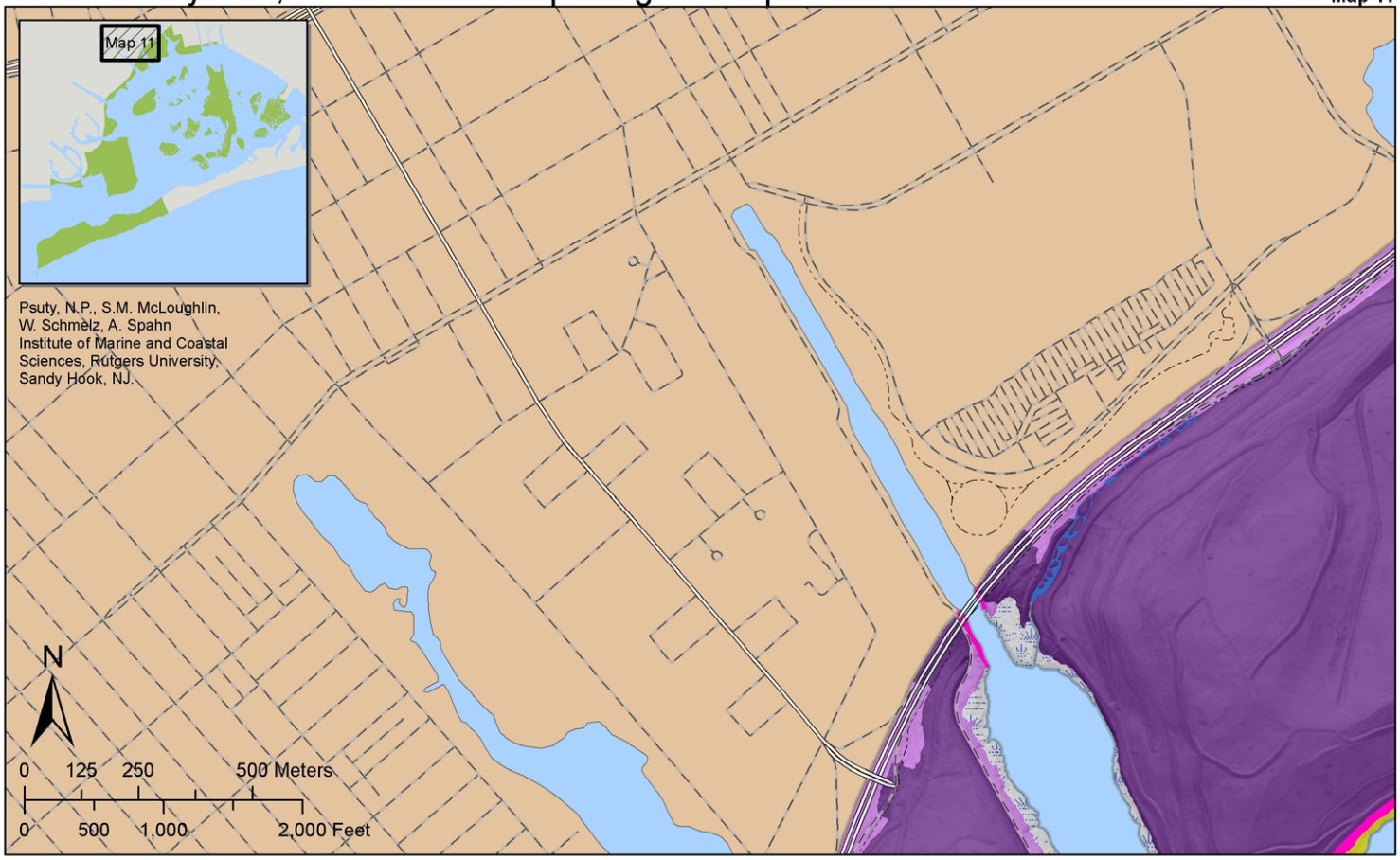

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

Map 11



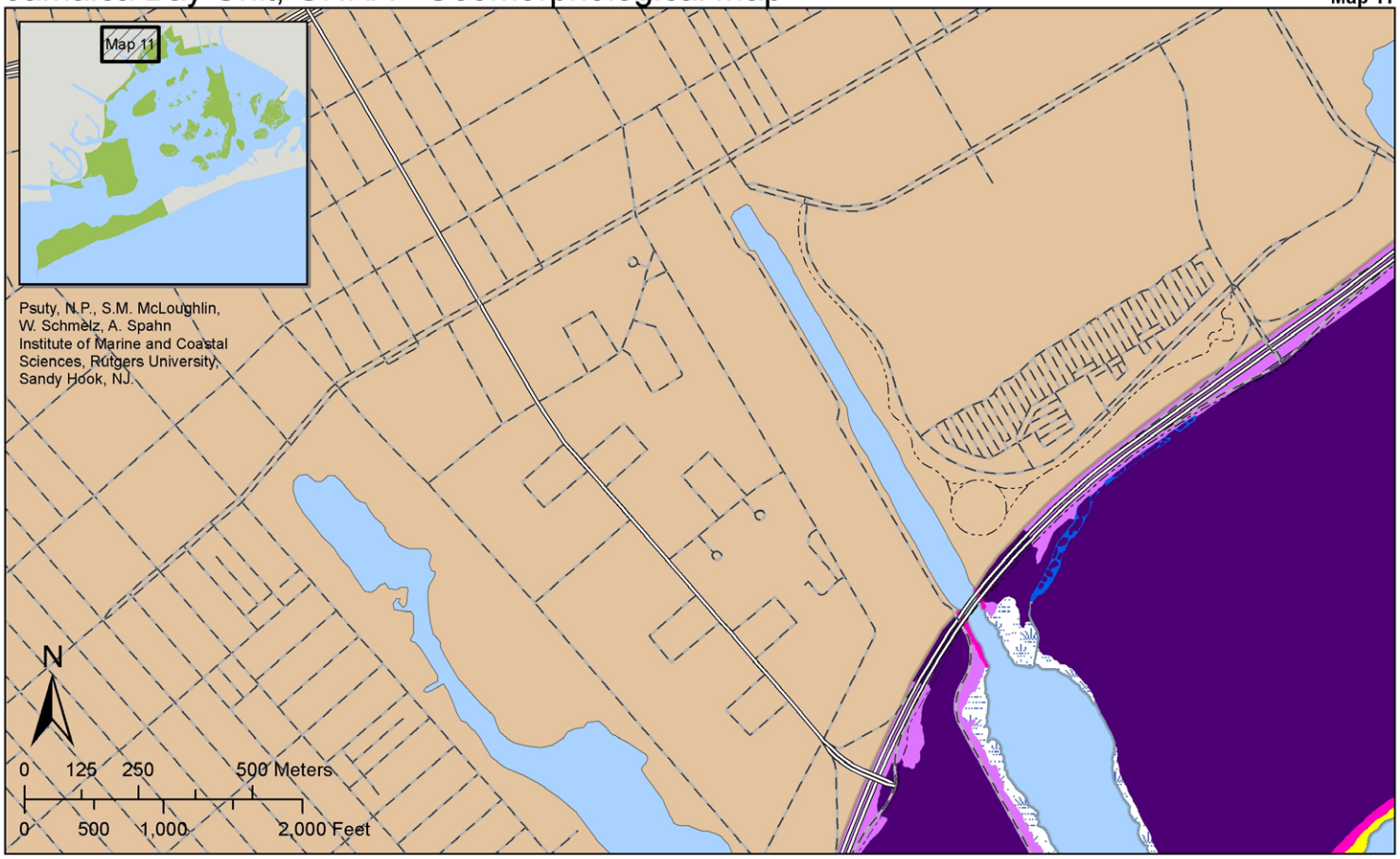

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 11**




**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 12**

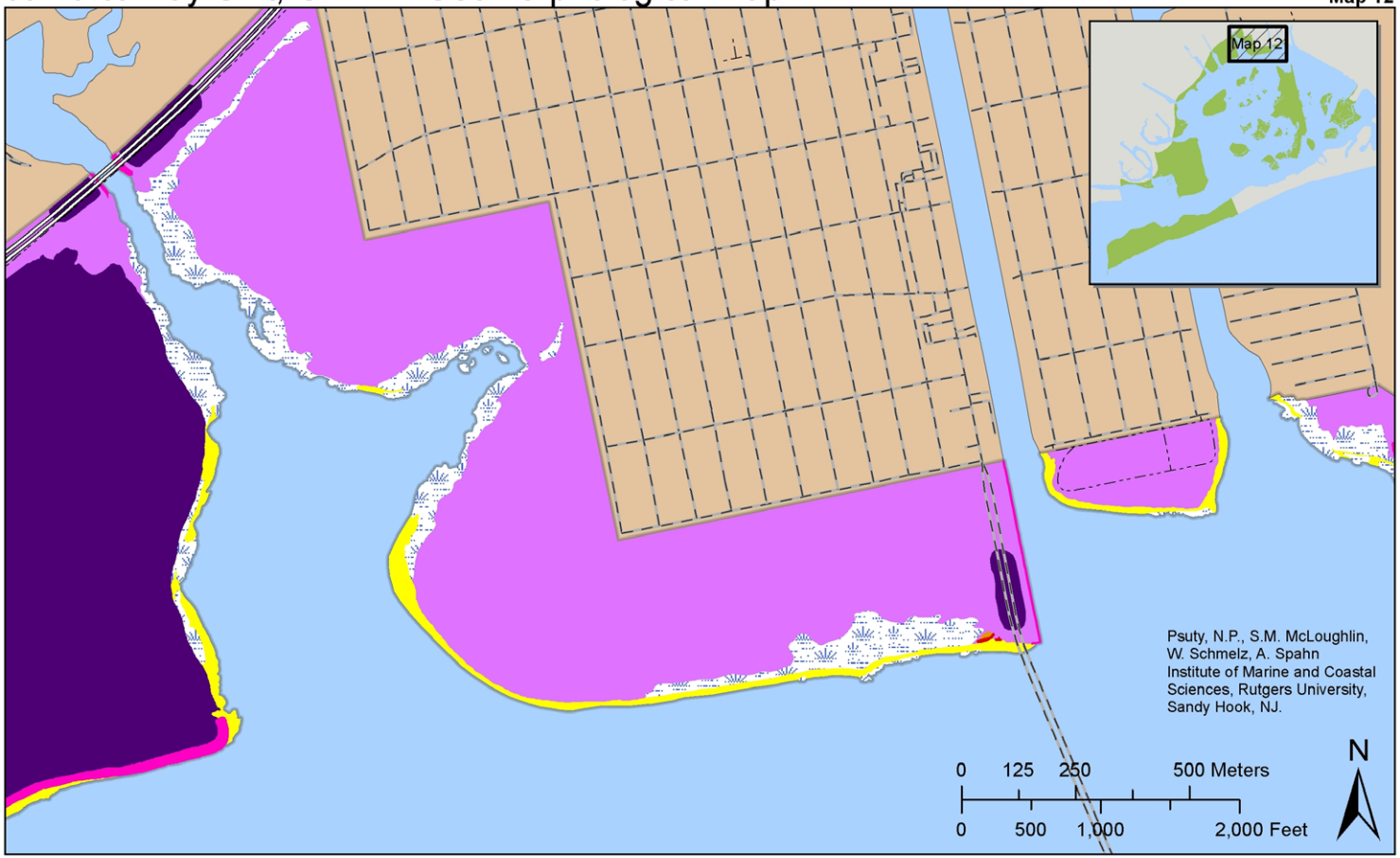

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 12**



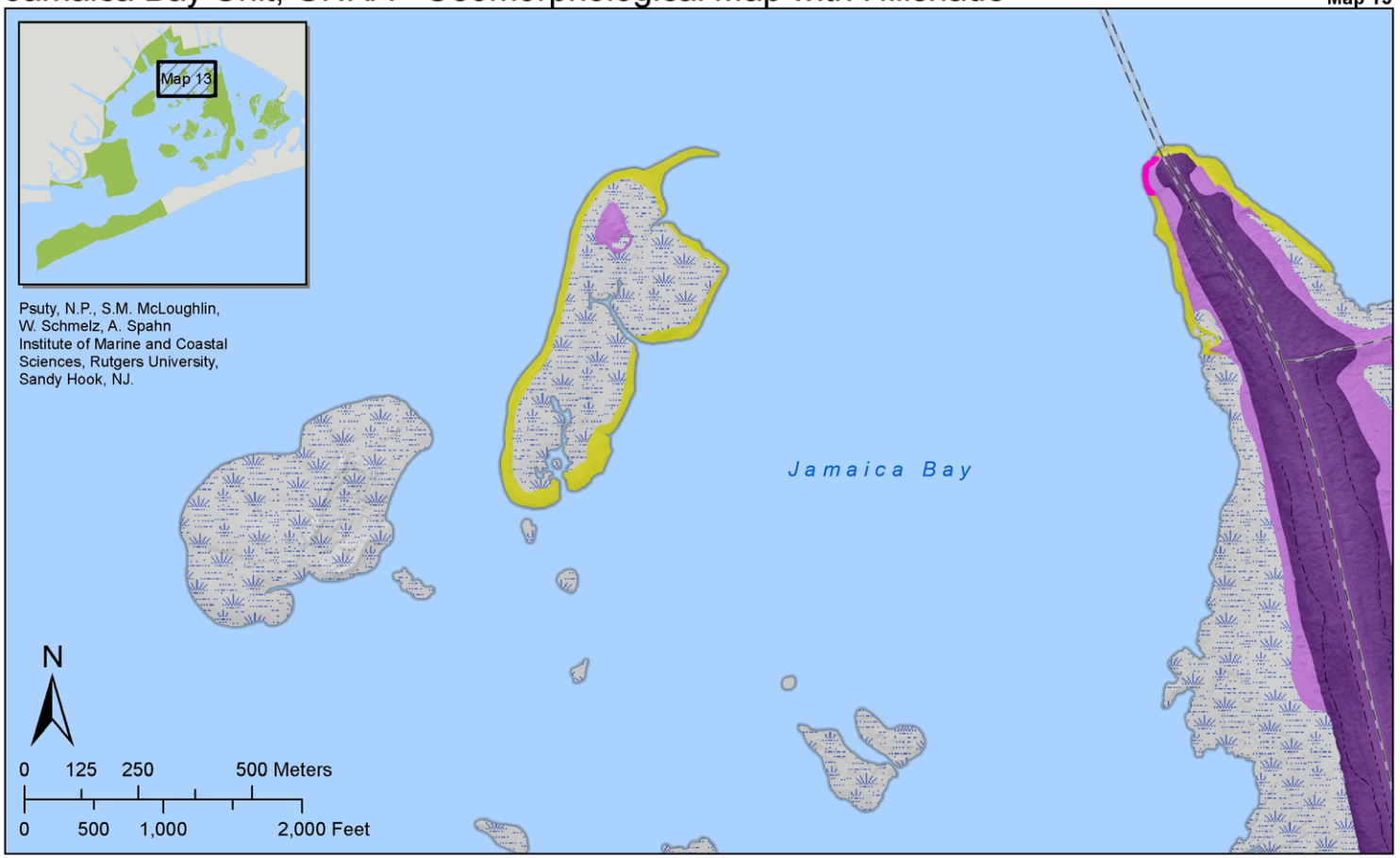

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 13**



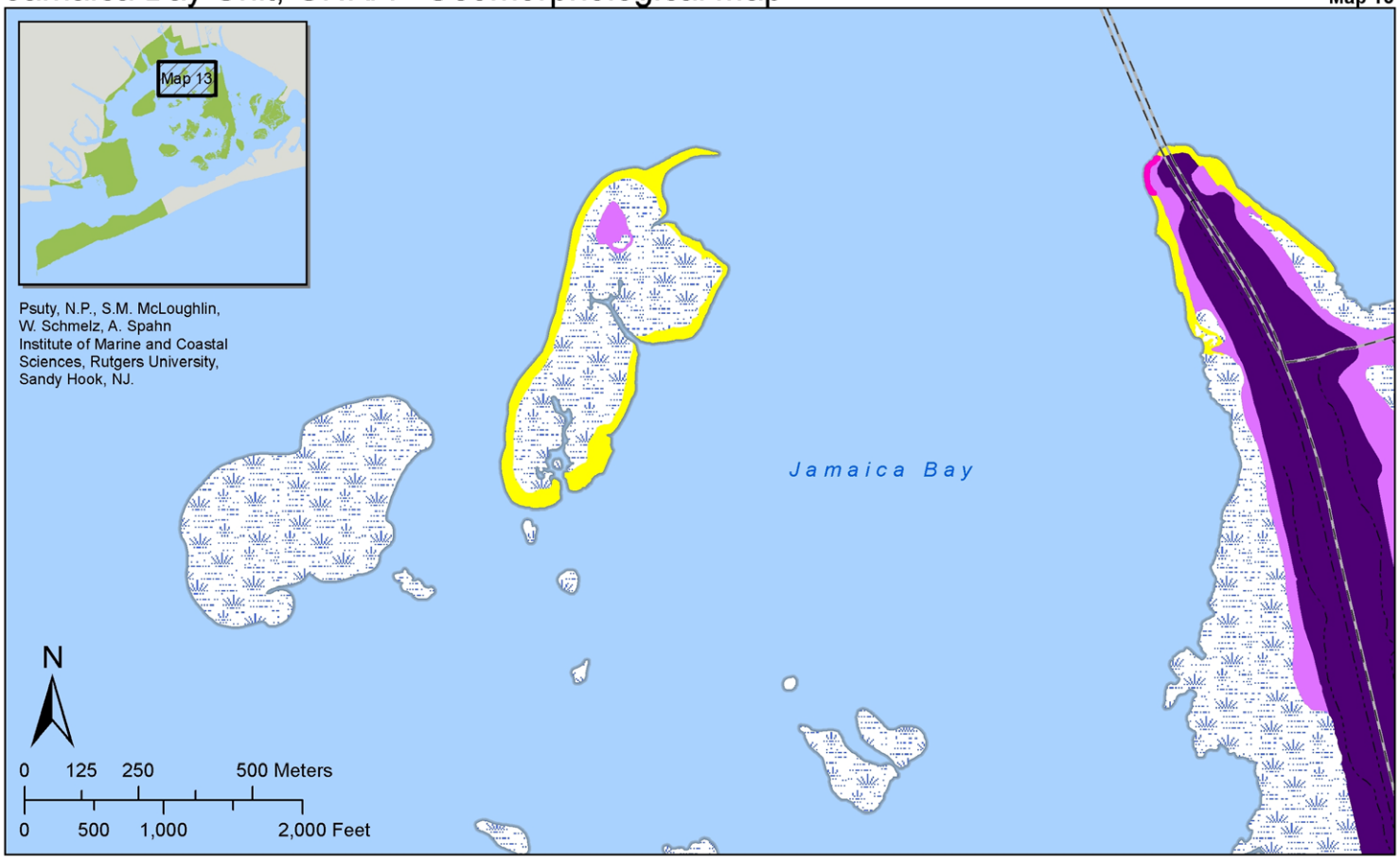

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

Map 13



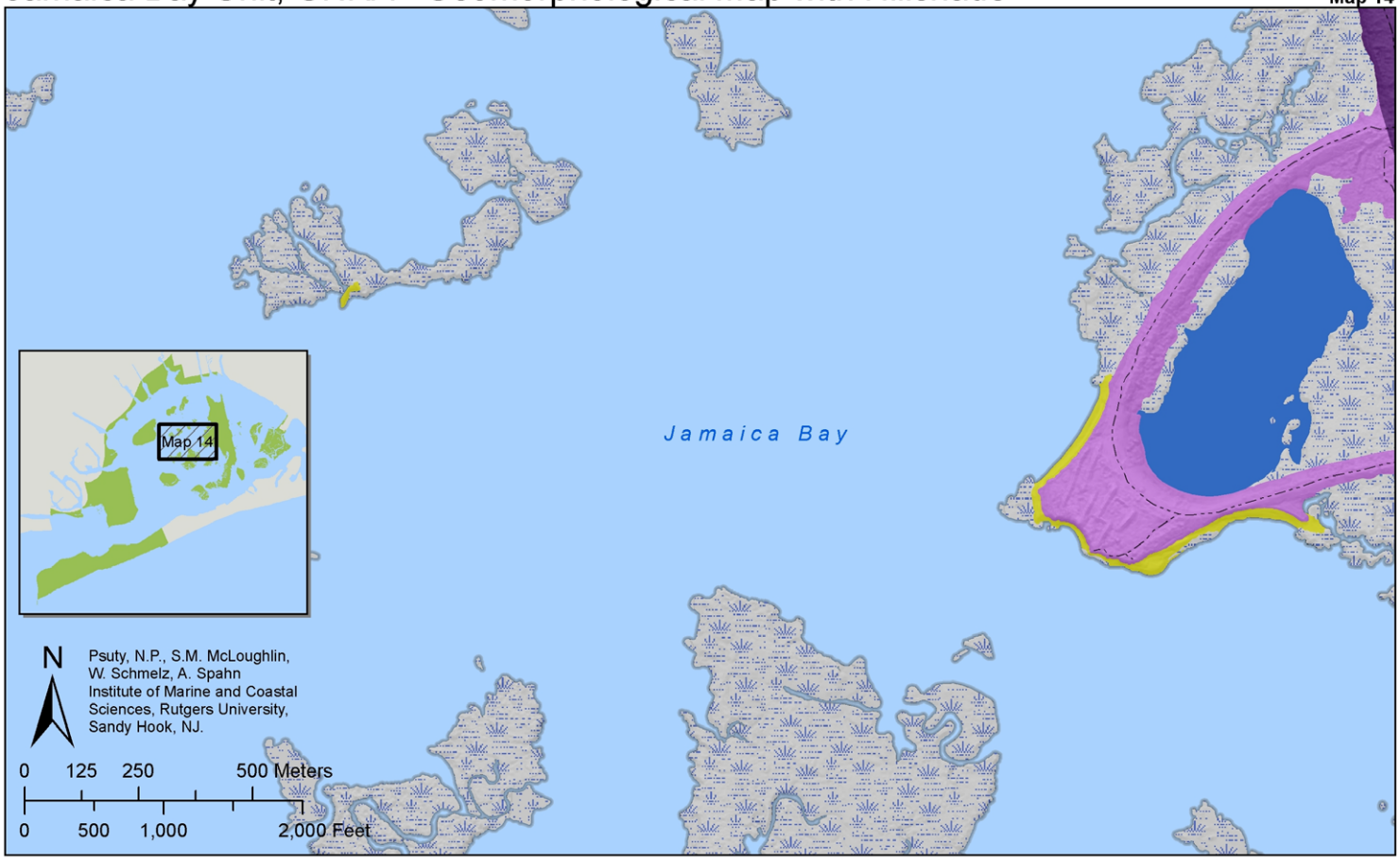

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

Map 14

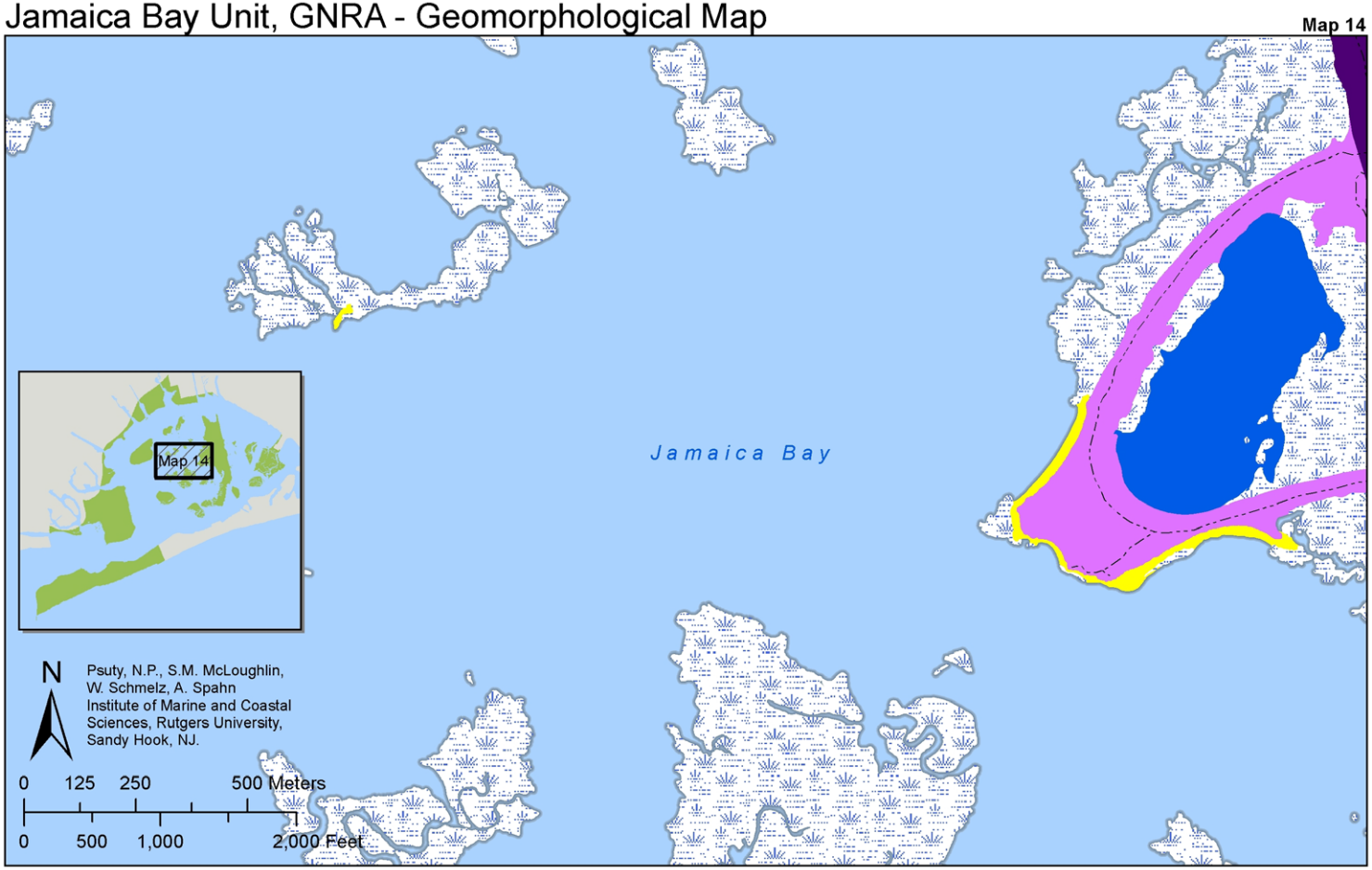



**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map



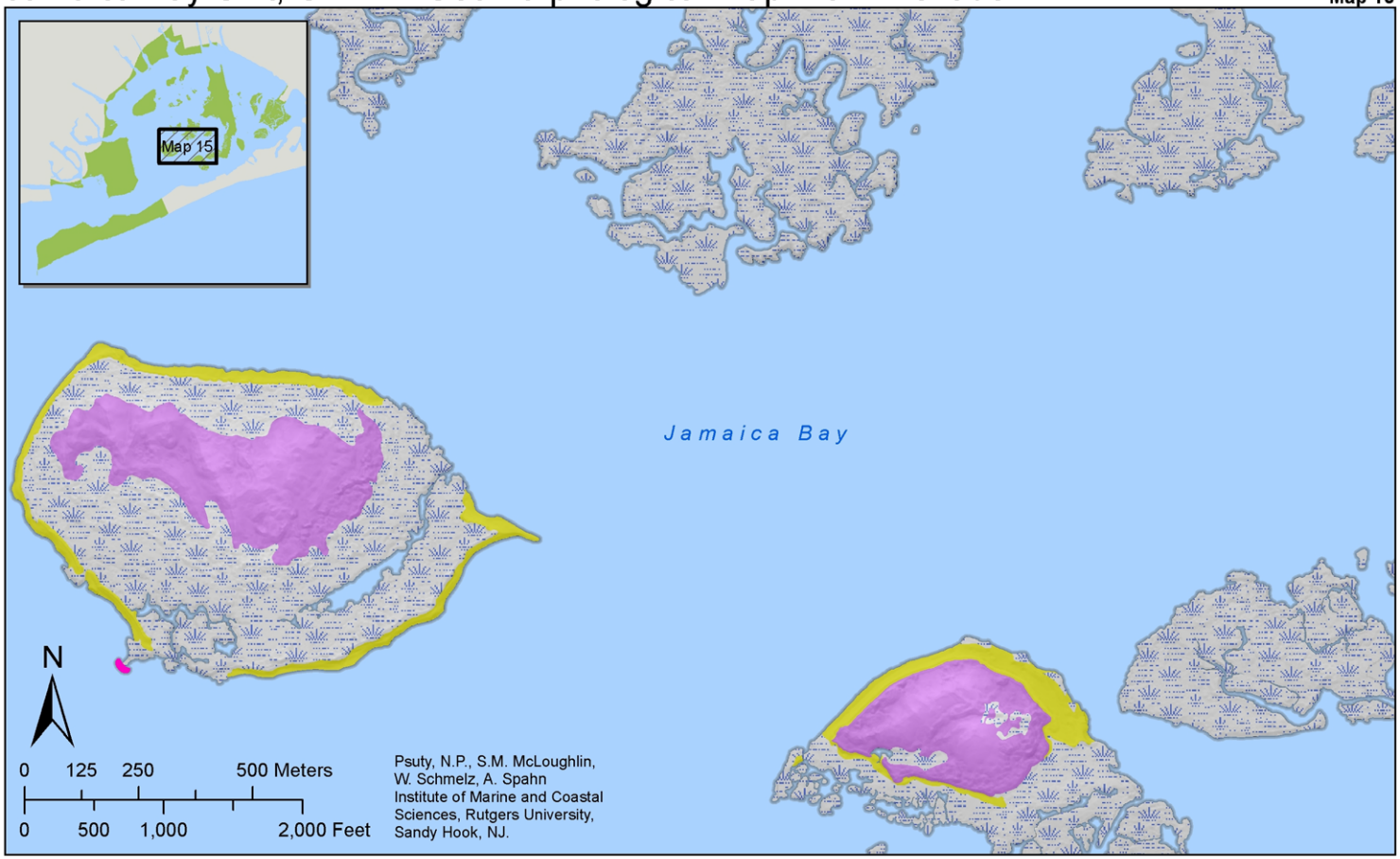

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

## Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 15**



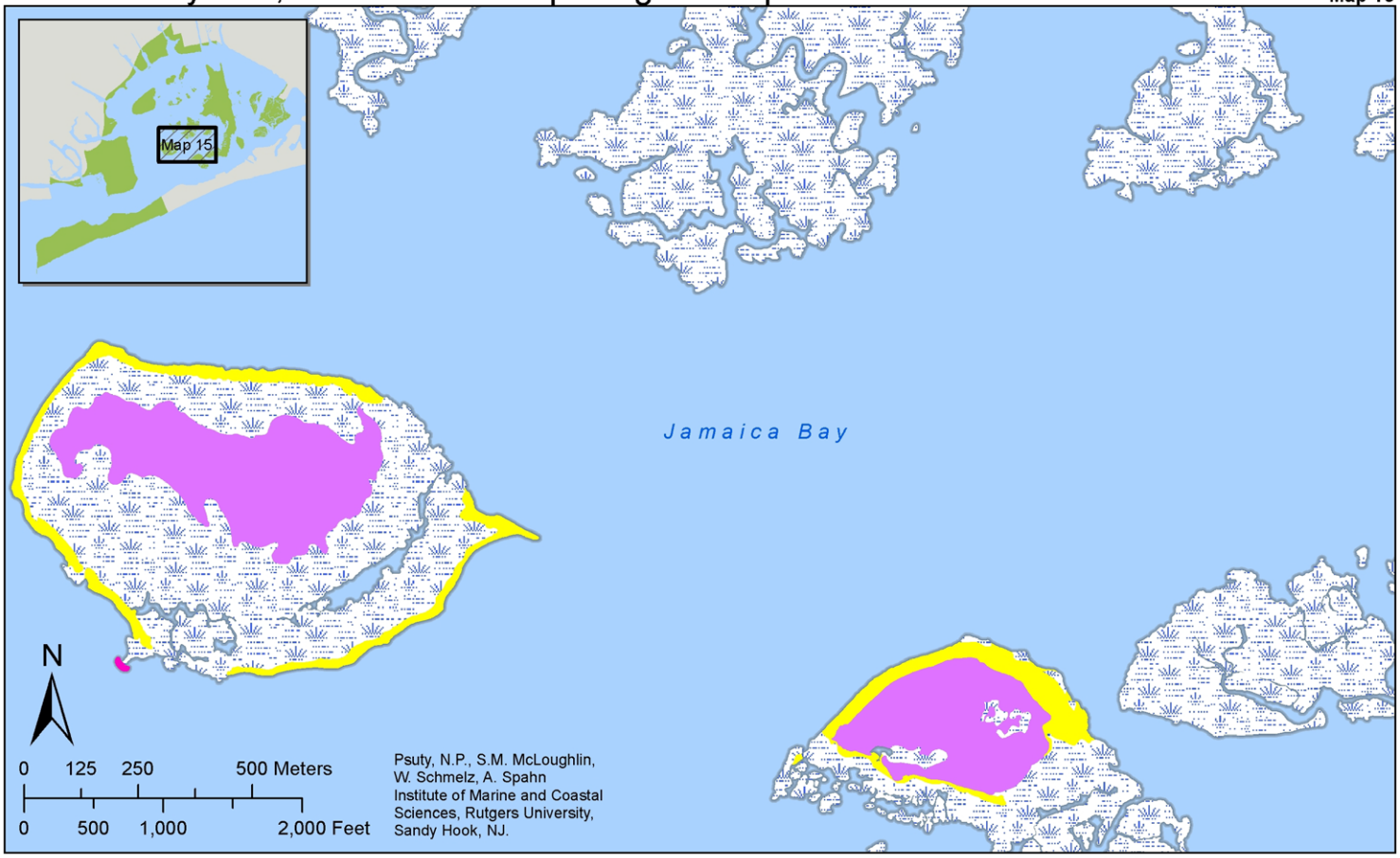

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

Map 15



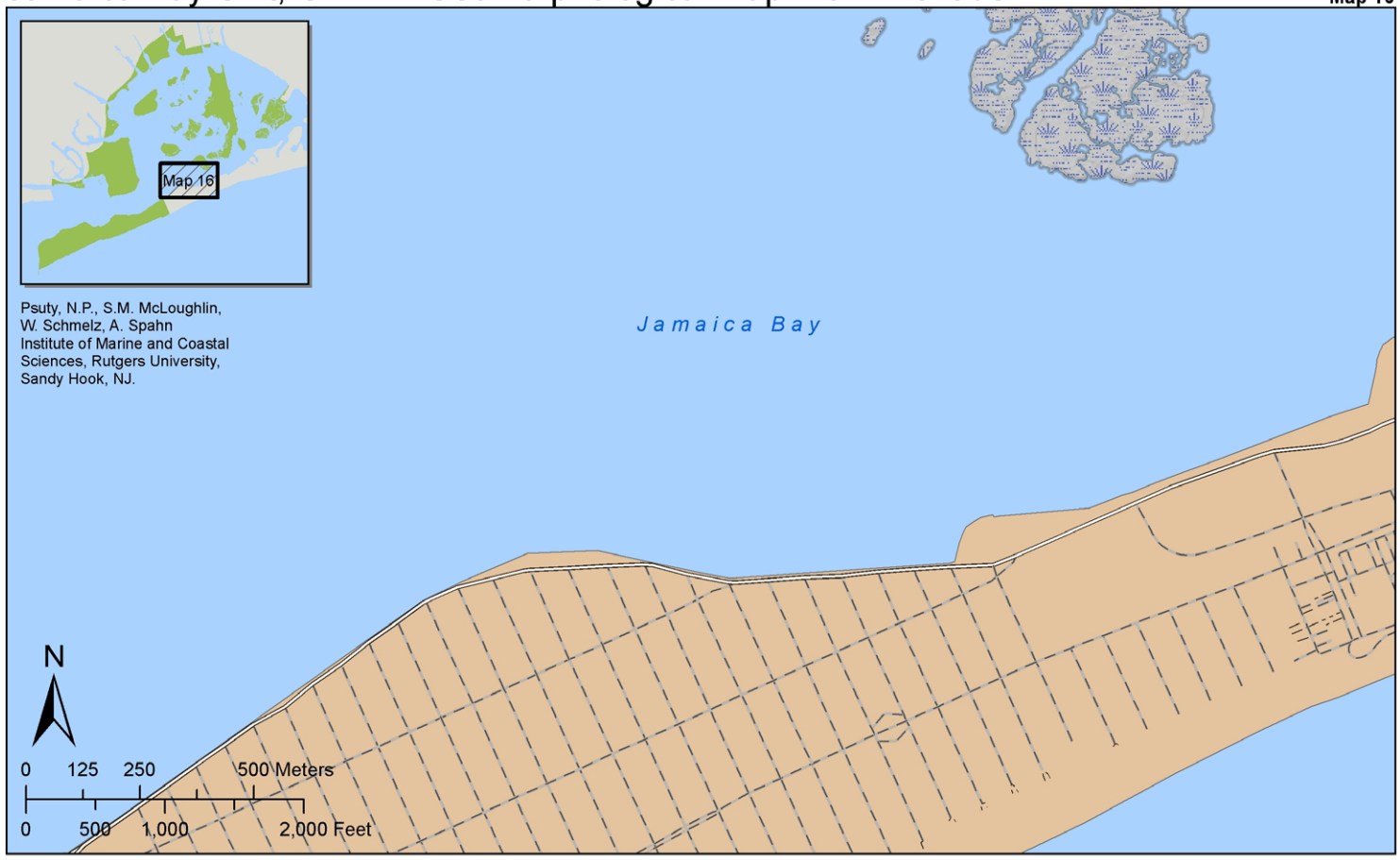

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 16**



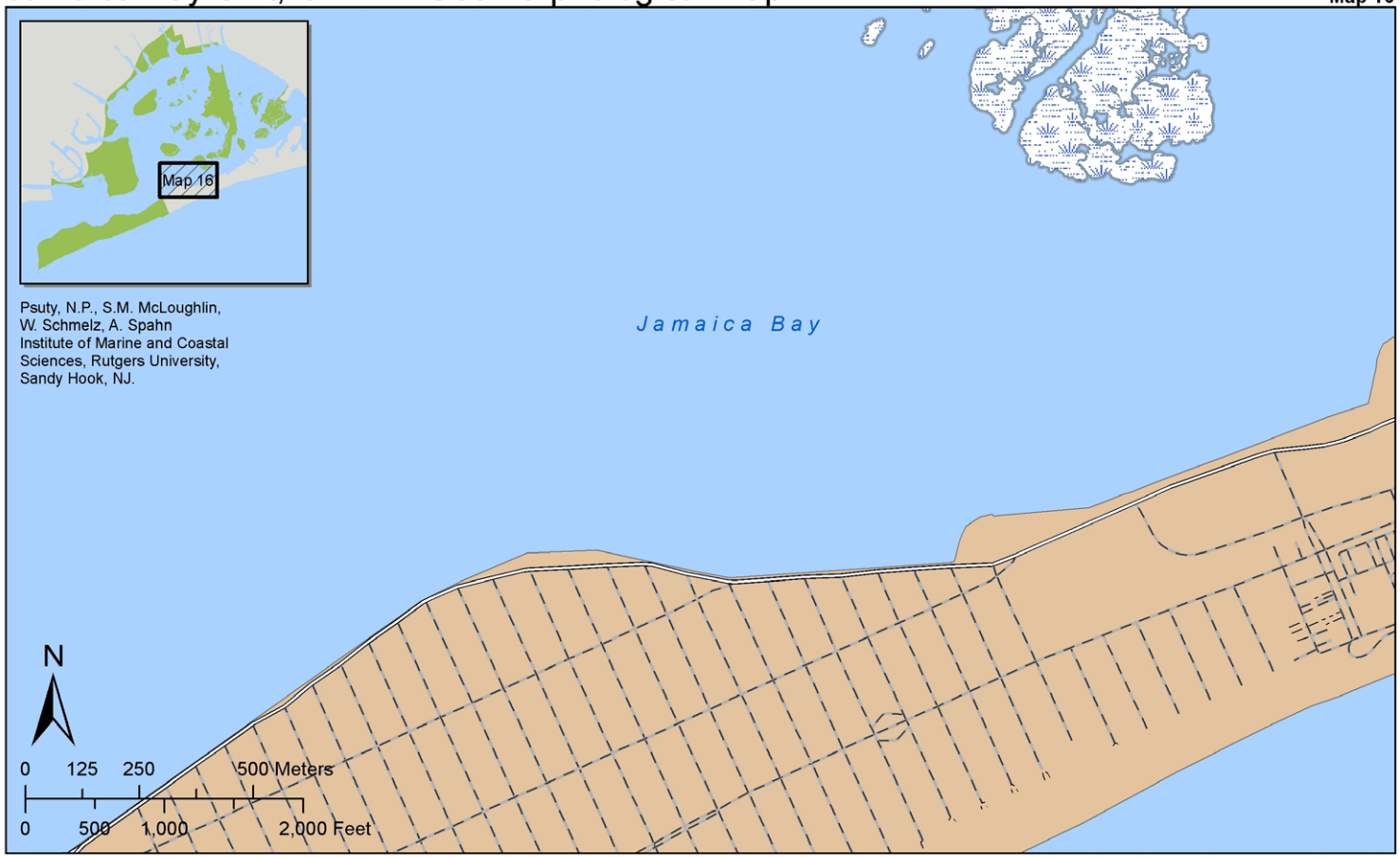

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 16**



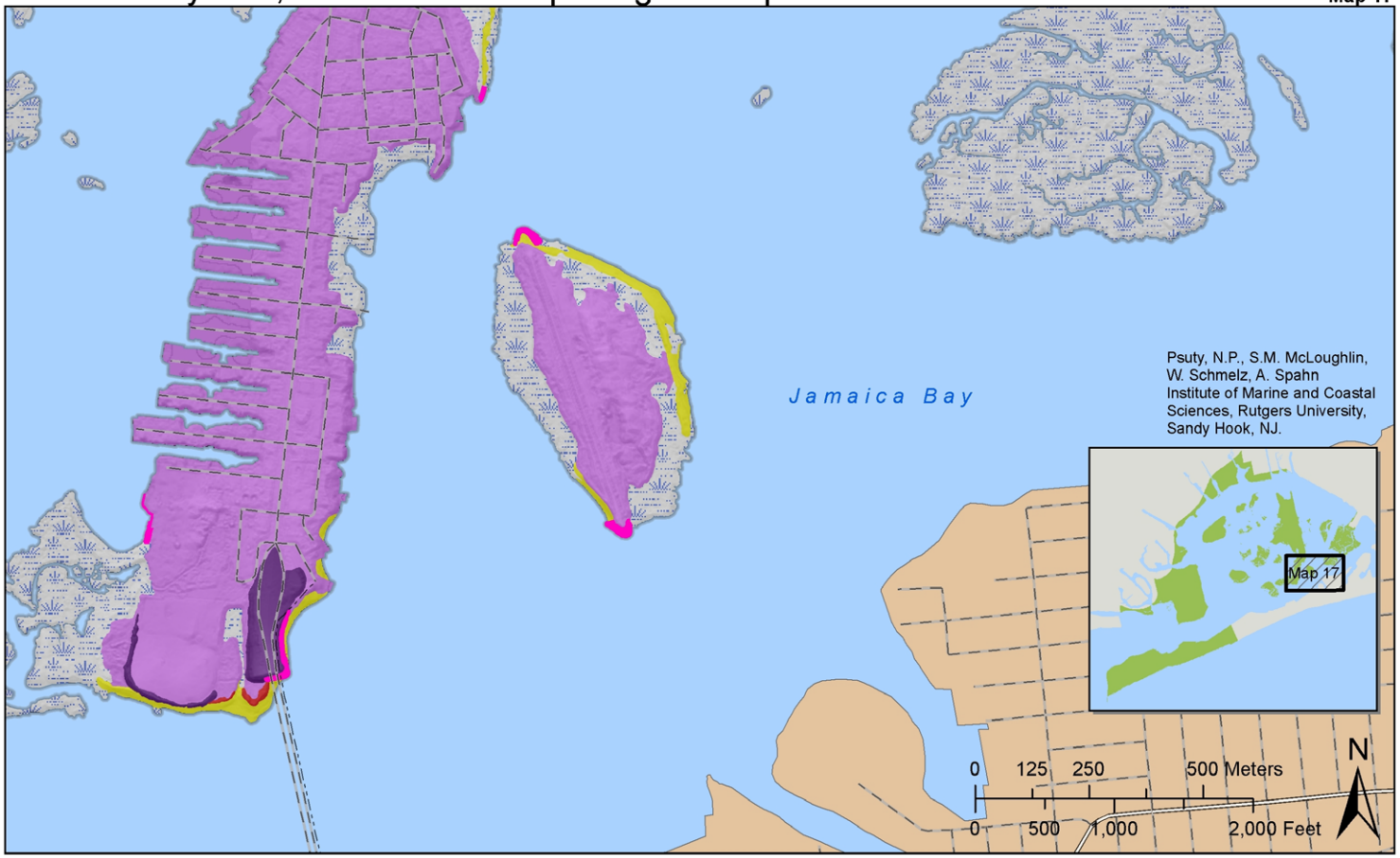

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 17**



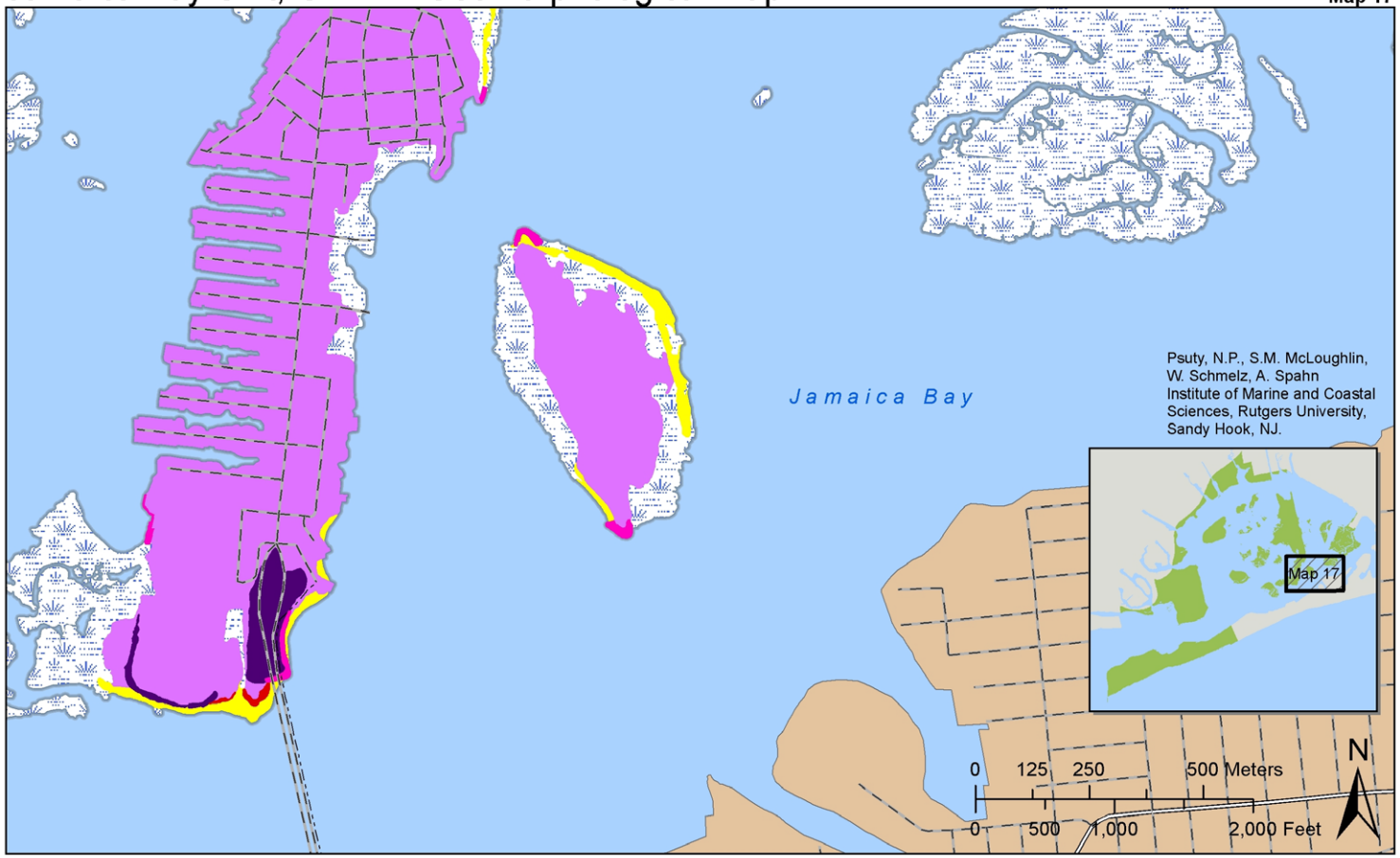

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 17**



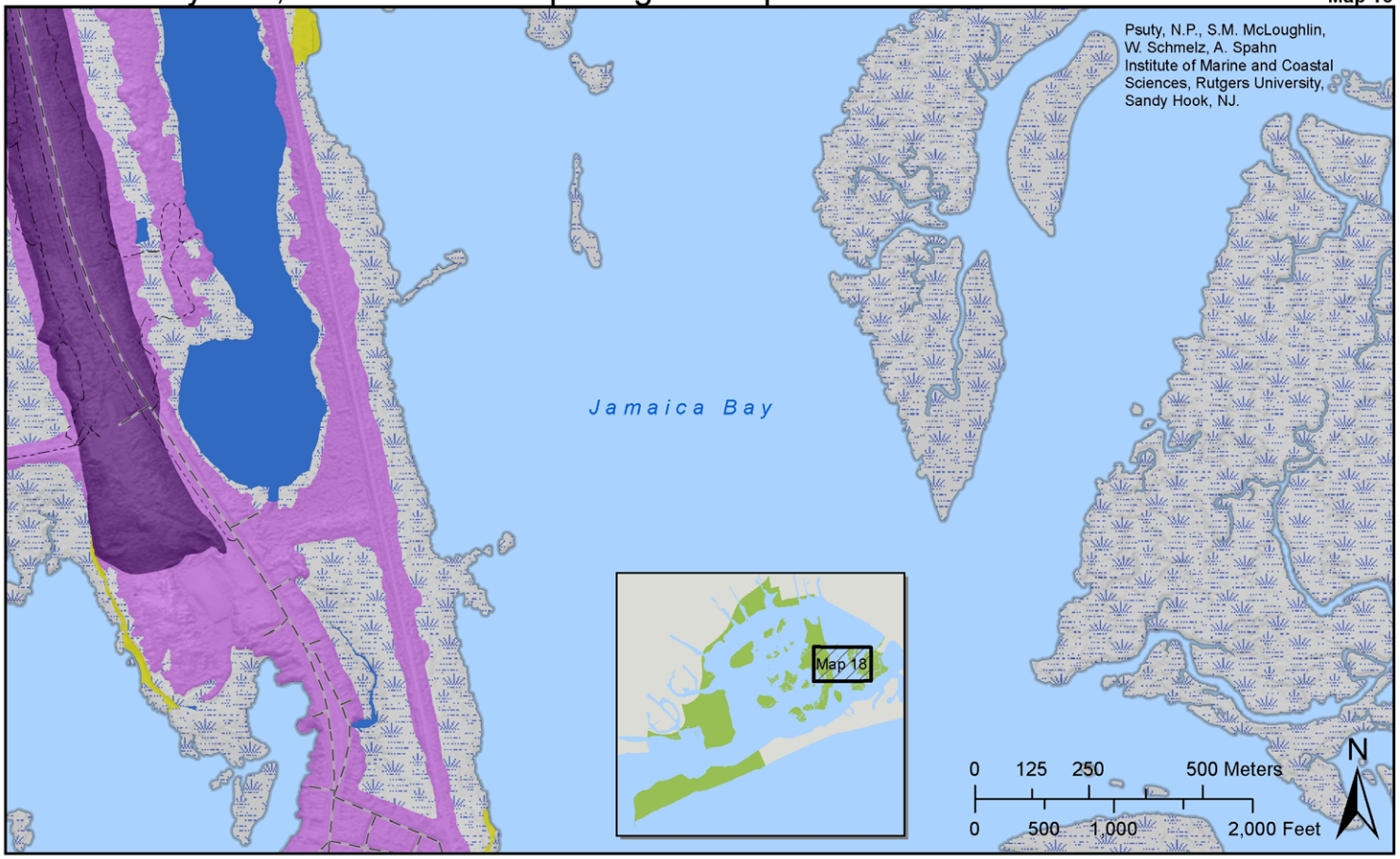

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 18**



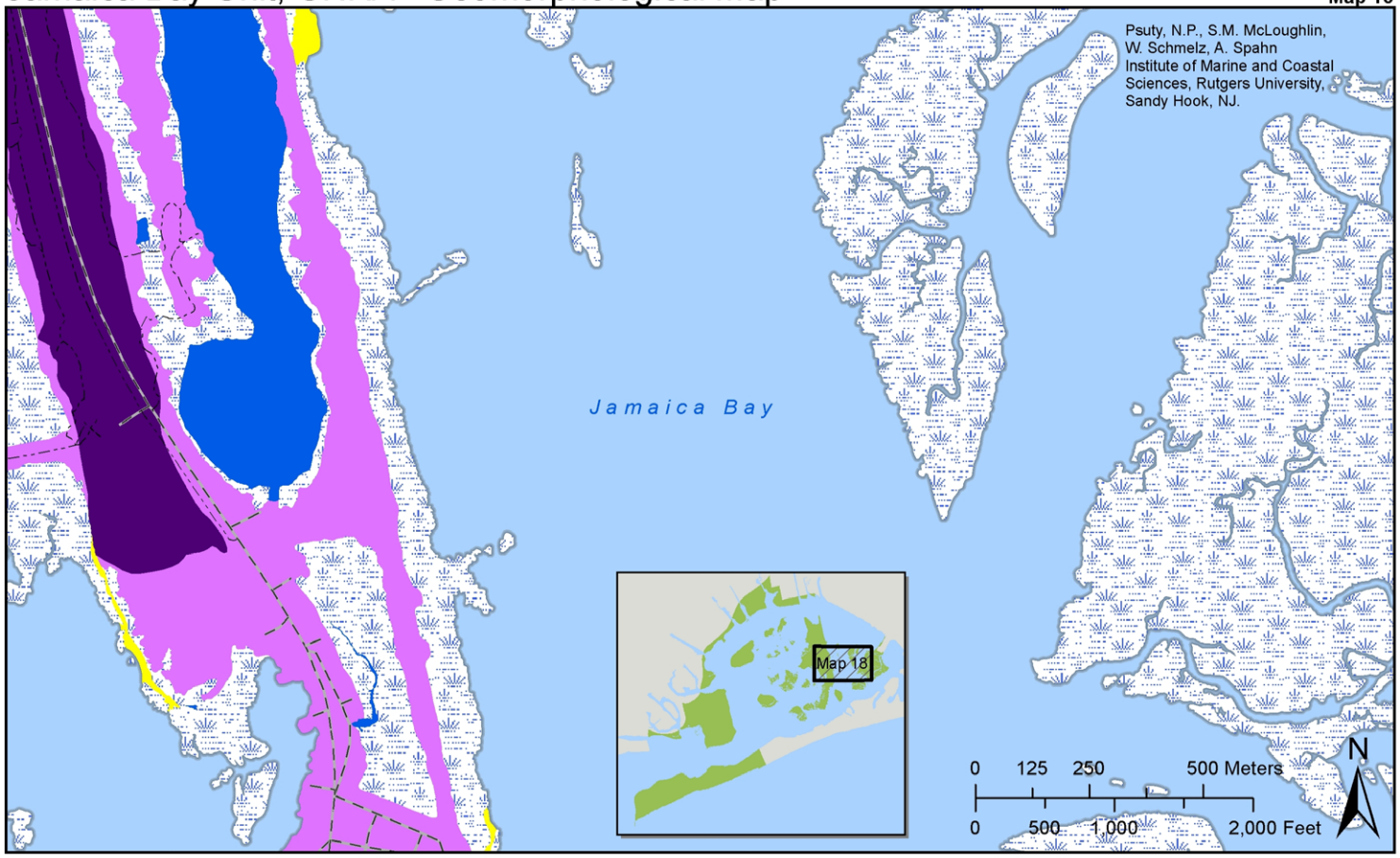

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 18**




**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

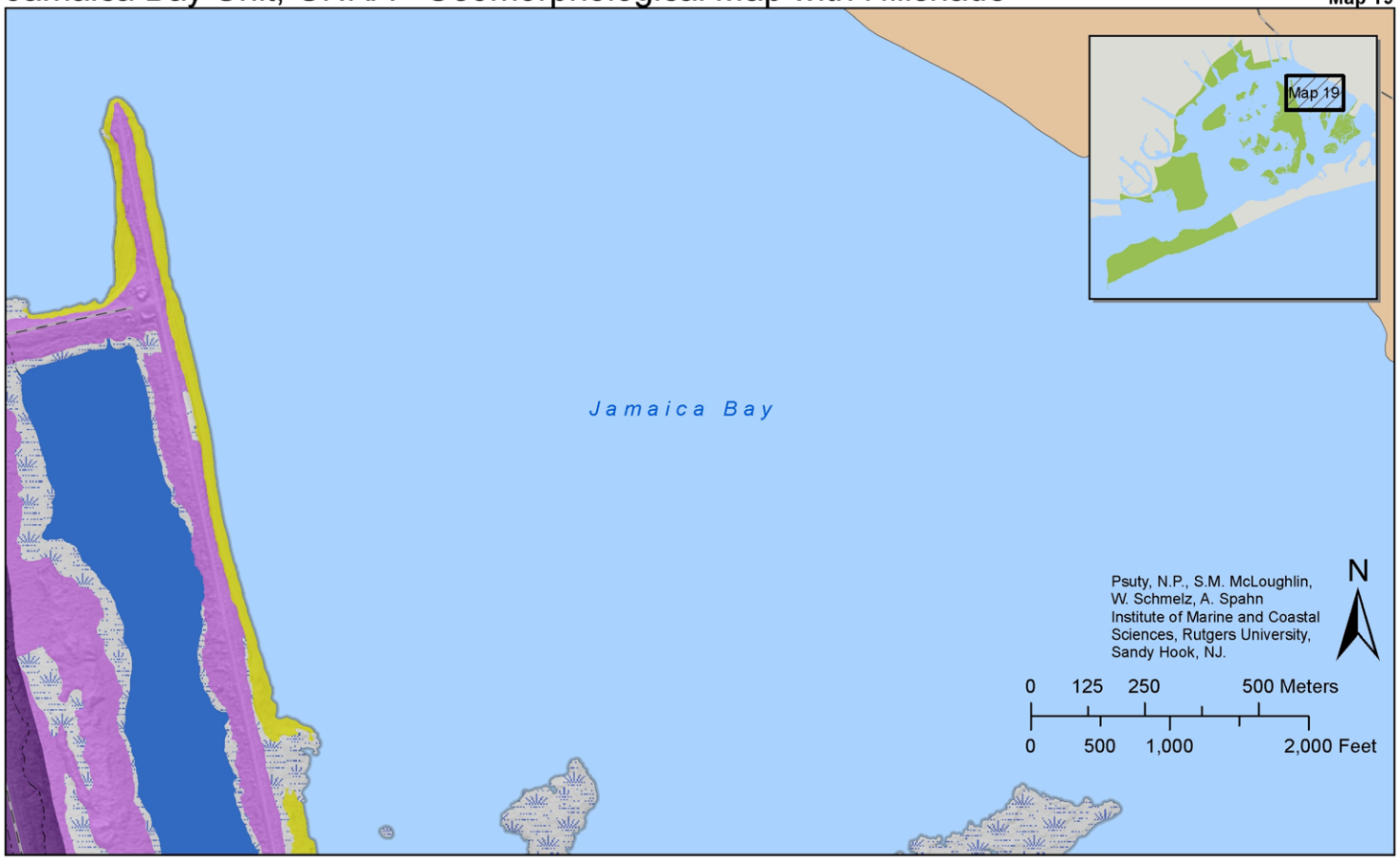
**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

Psuty, N.P., S.M. McLoughlin, W. Schmelz, A. Spahn
Institute of Marine and Coastal Sciences, Rutgers University, Sandy Hook, NJ.

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

**Map 19**



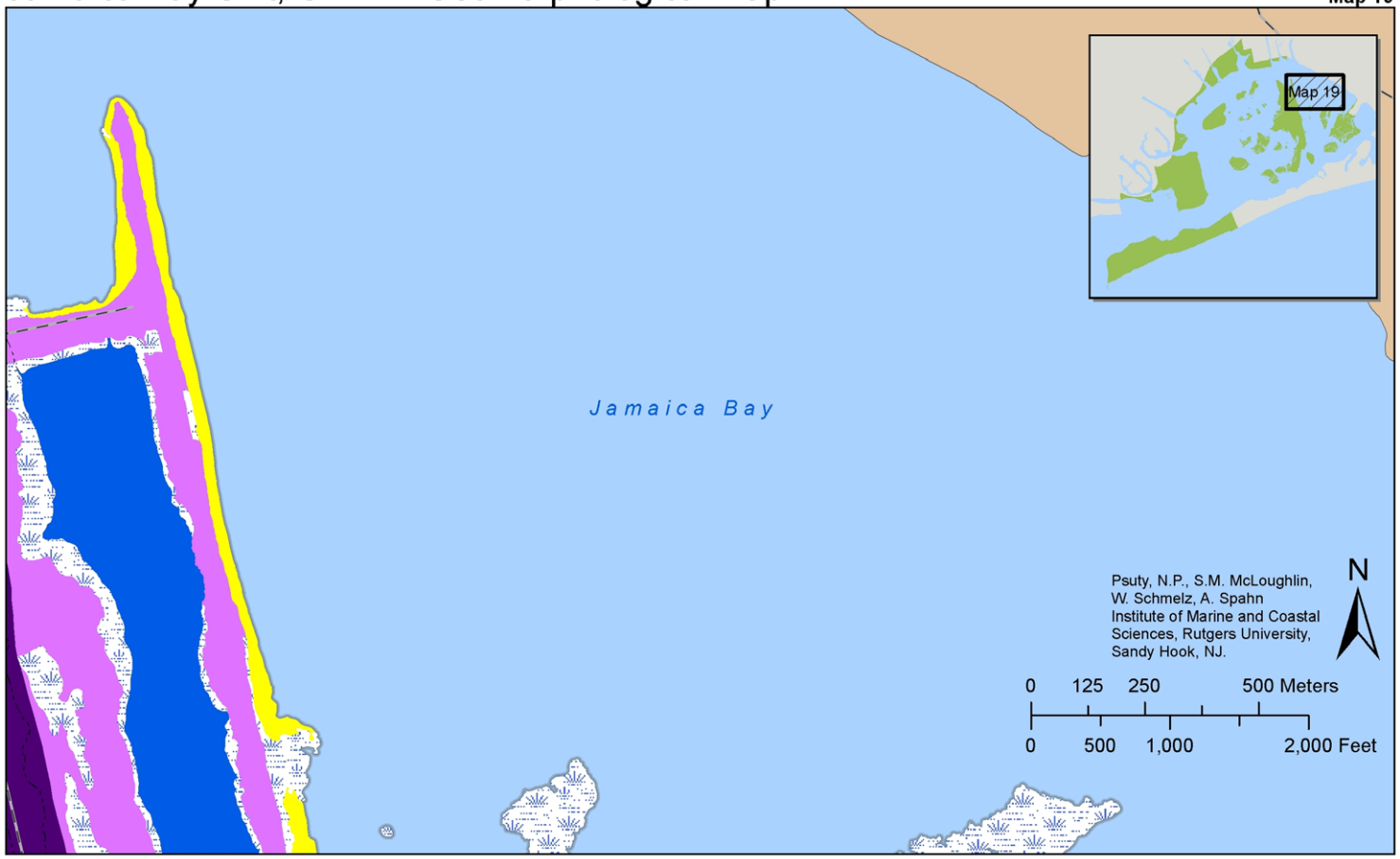

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

**Map 19**




**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
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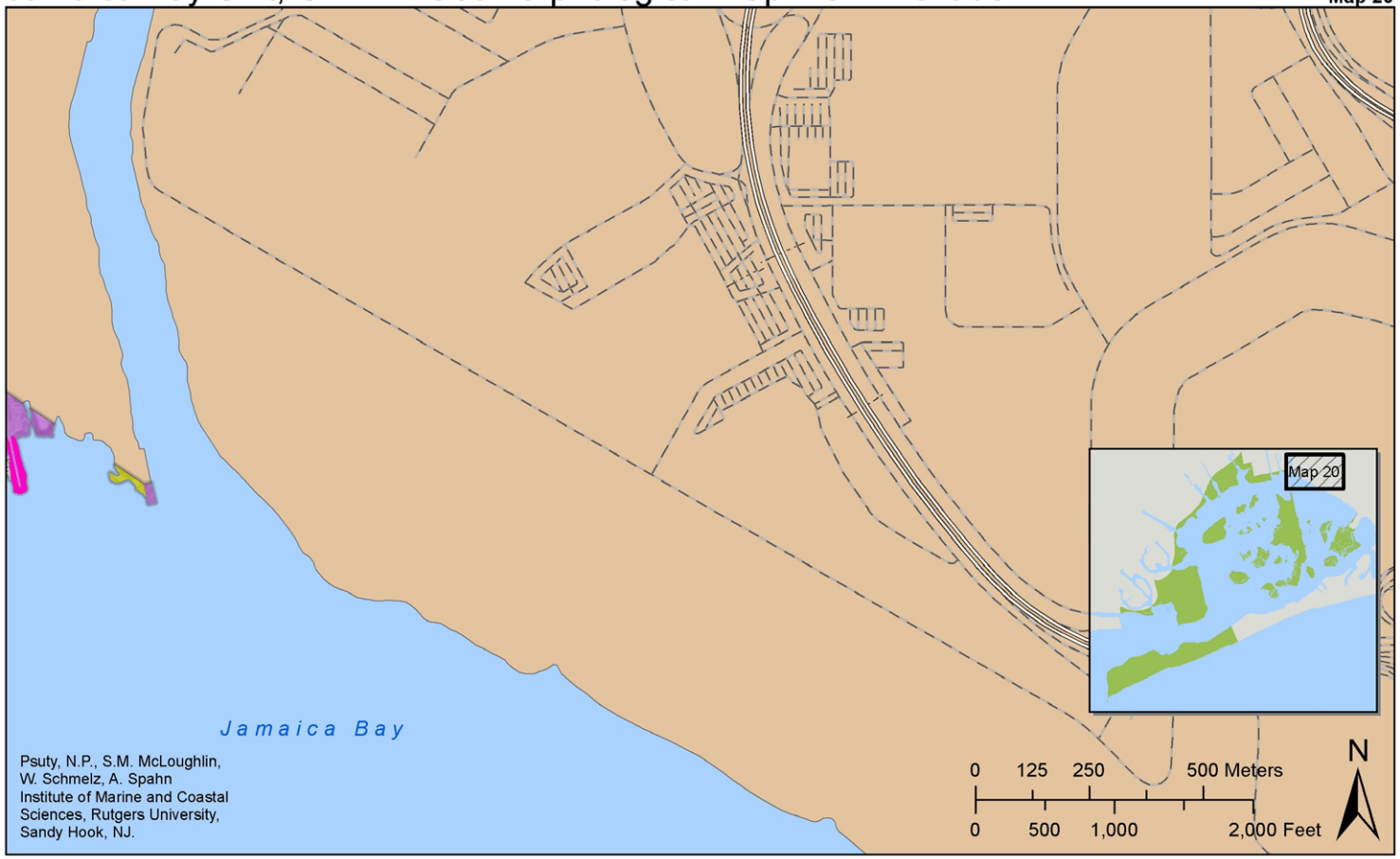
**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade

Map 20



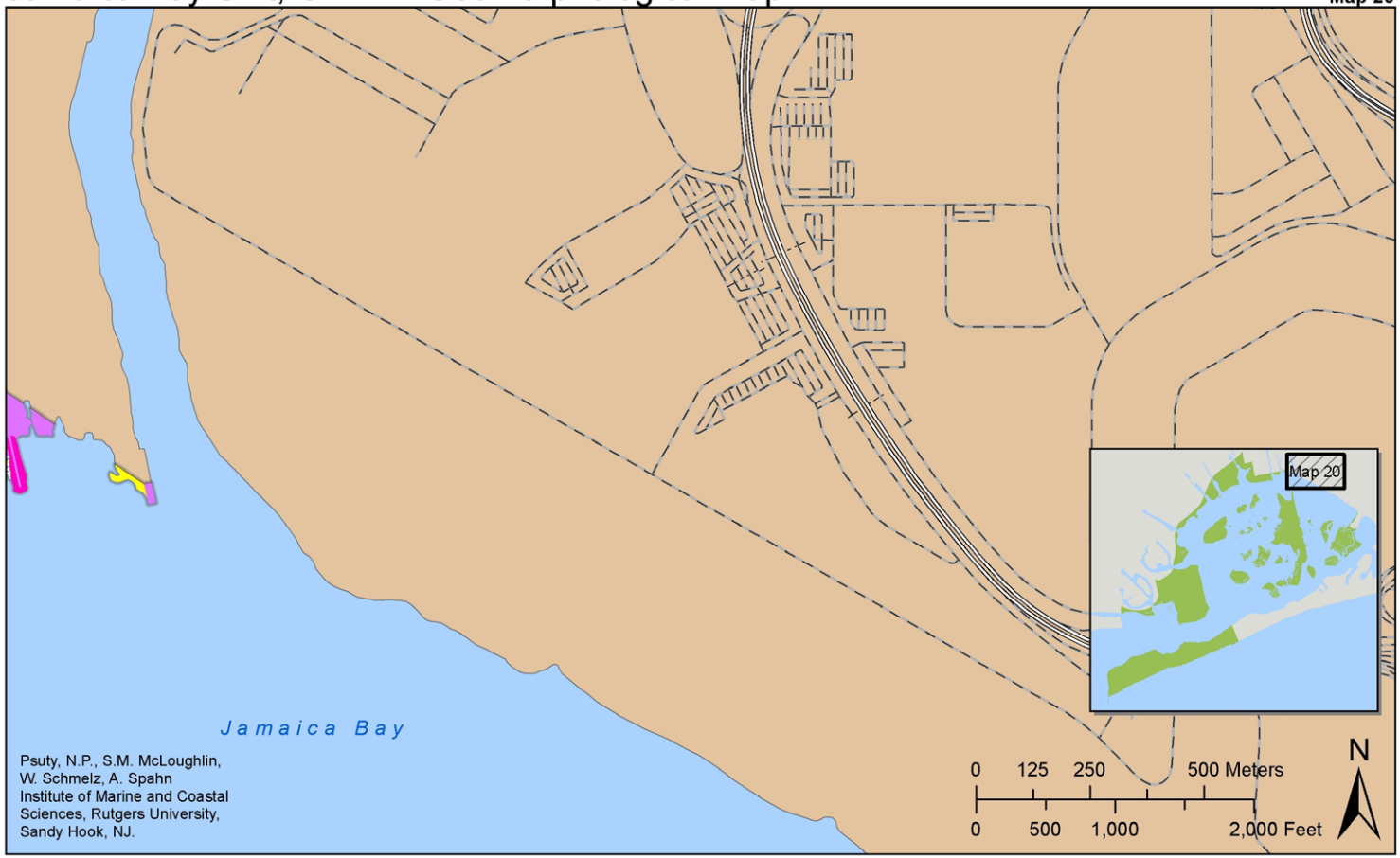

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map

Map 20




**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
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- Bulkhead/Riprap
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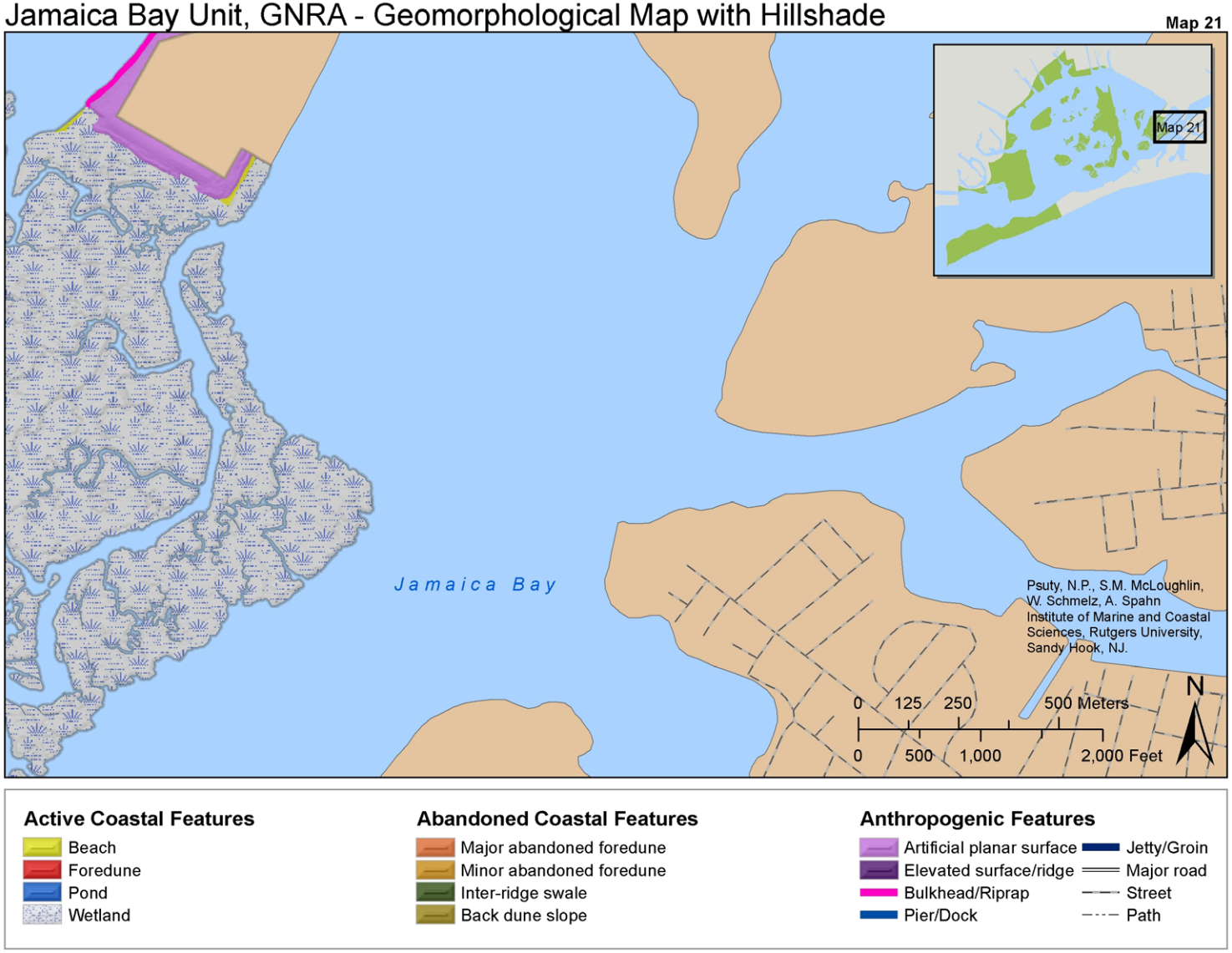
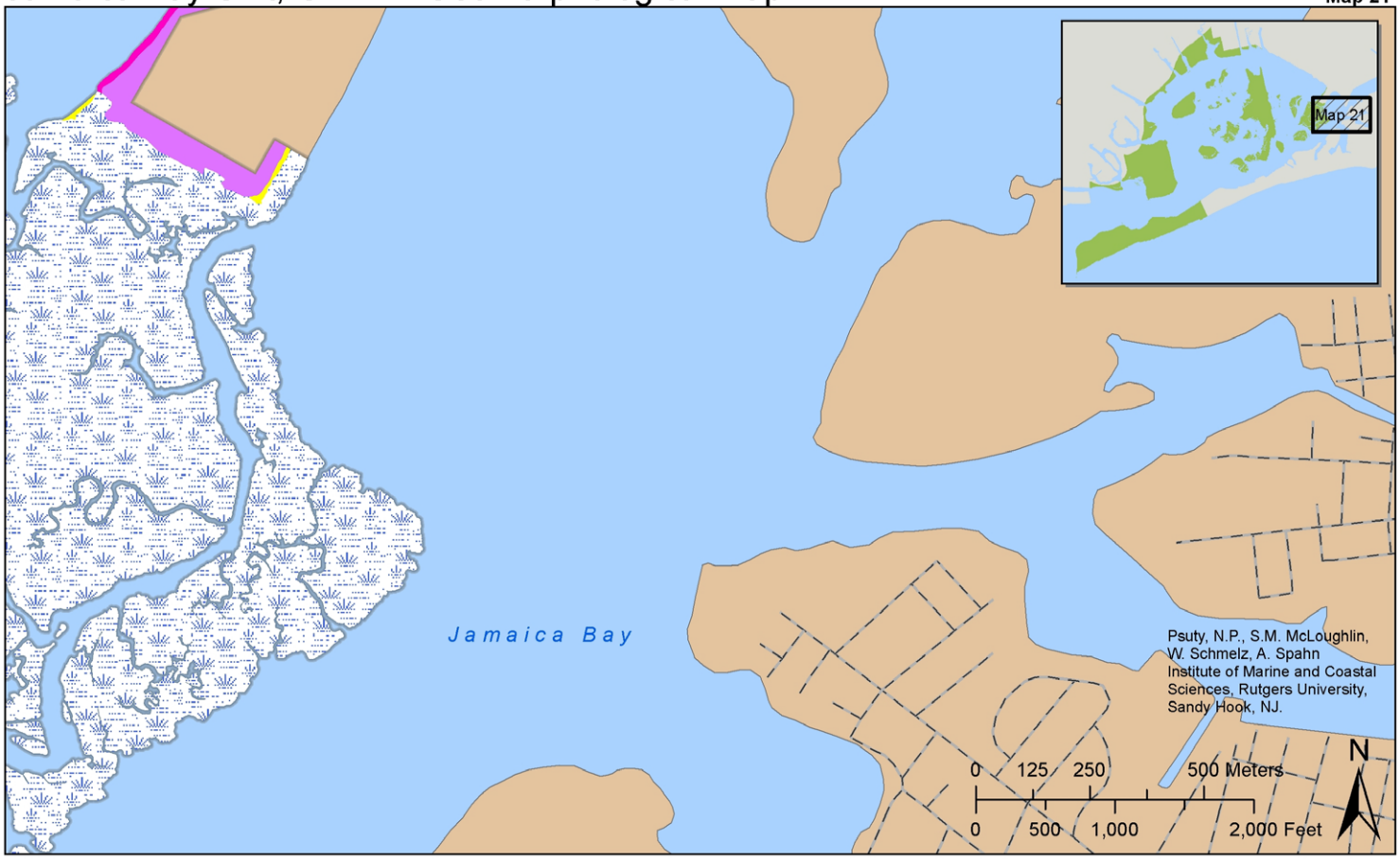
- Street
- Path

# Jamaica Bay Unit, GNRA - Geomorphological Map with Hillshade



# Jamaica Bay Unit, GNRA - Geomorphological Map

Map 21

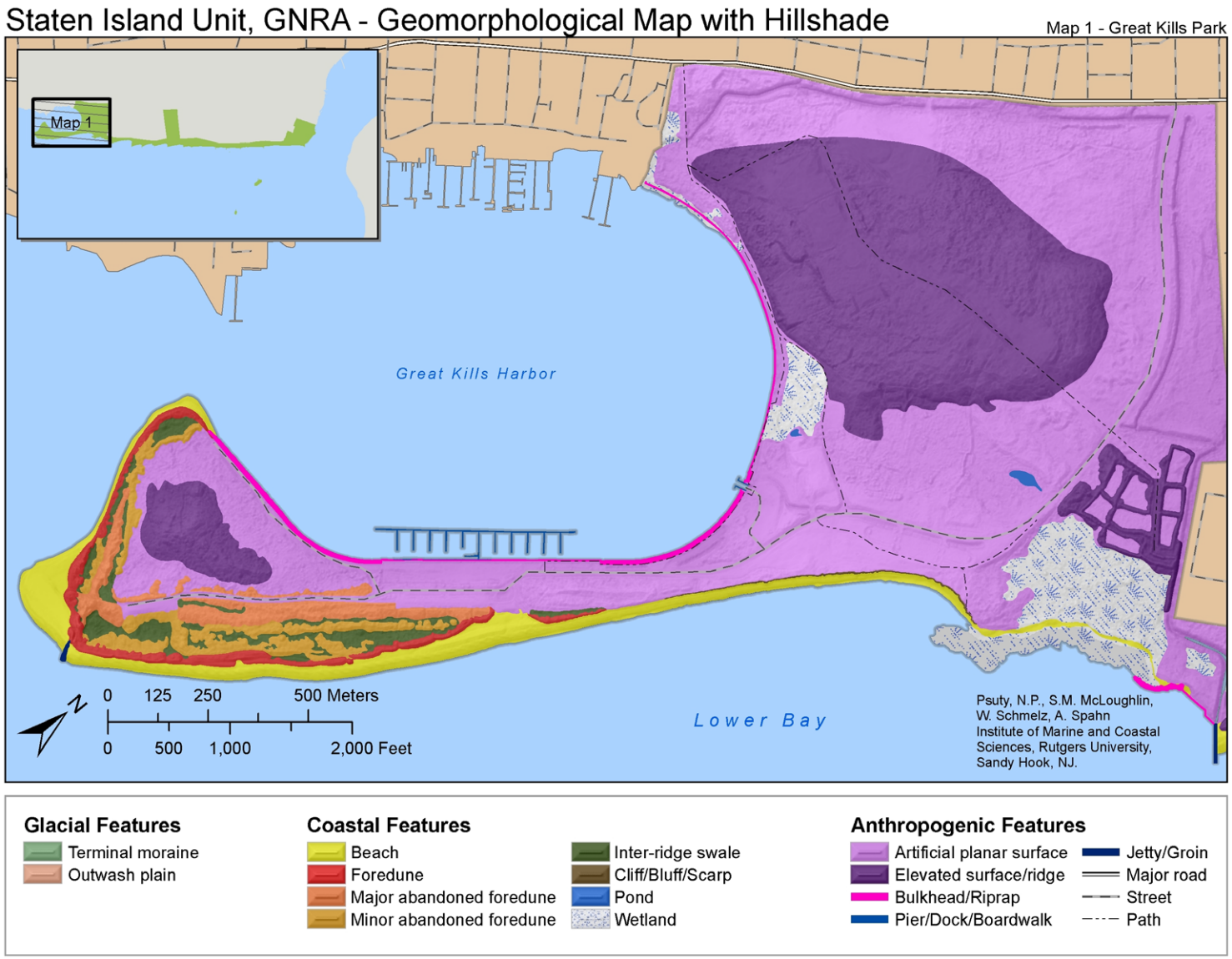


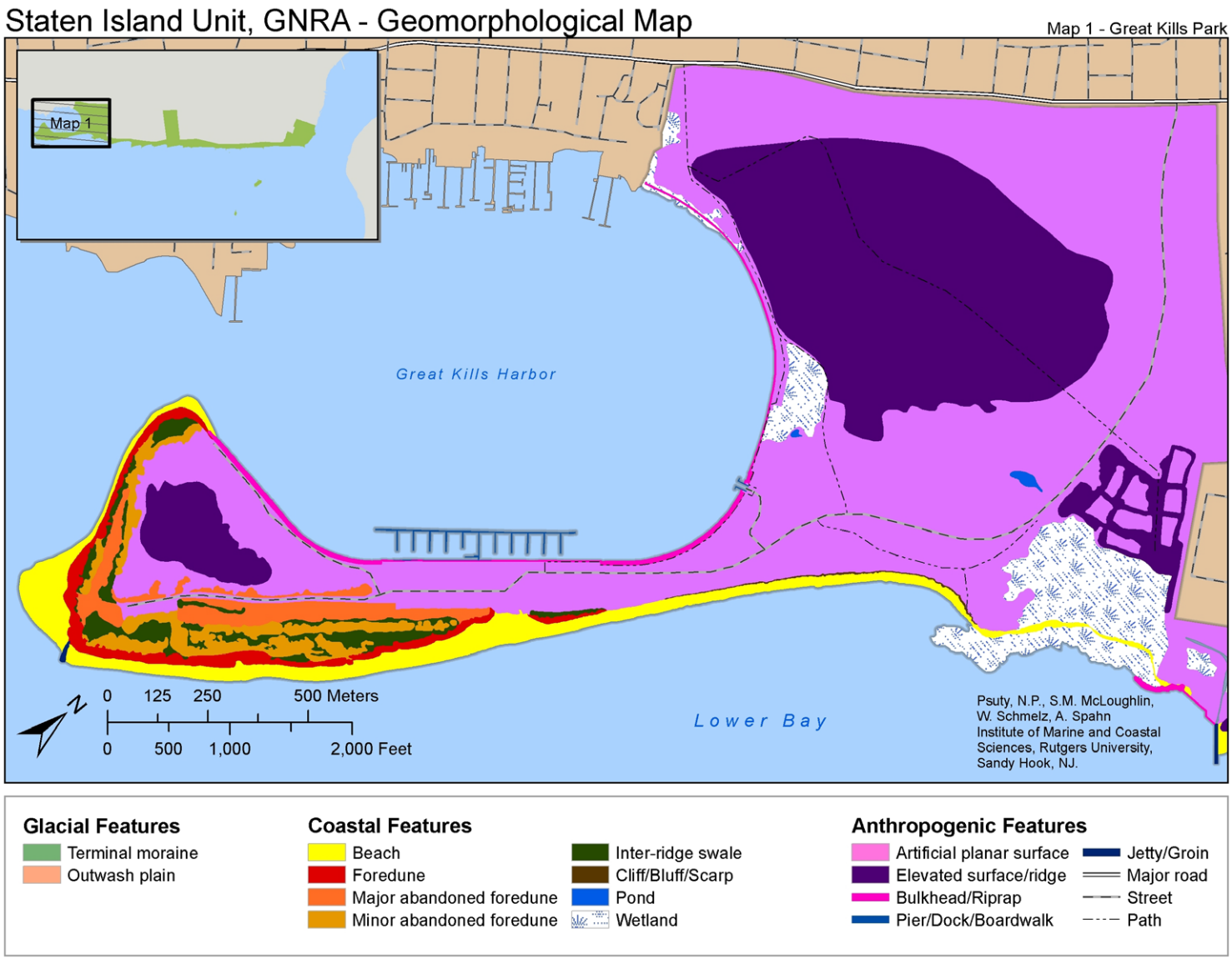

**Active Coastal Features**
- Beach
- Foredune
- Pond
- Wetland

**Abandoned Coastal Features**
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Back dune slope

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock
- Jetty/Groin
- Major road
- Street
- Path

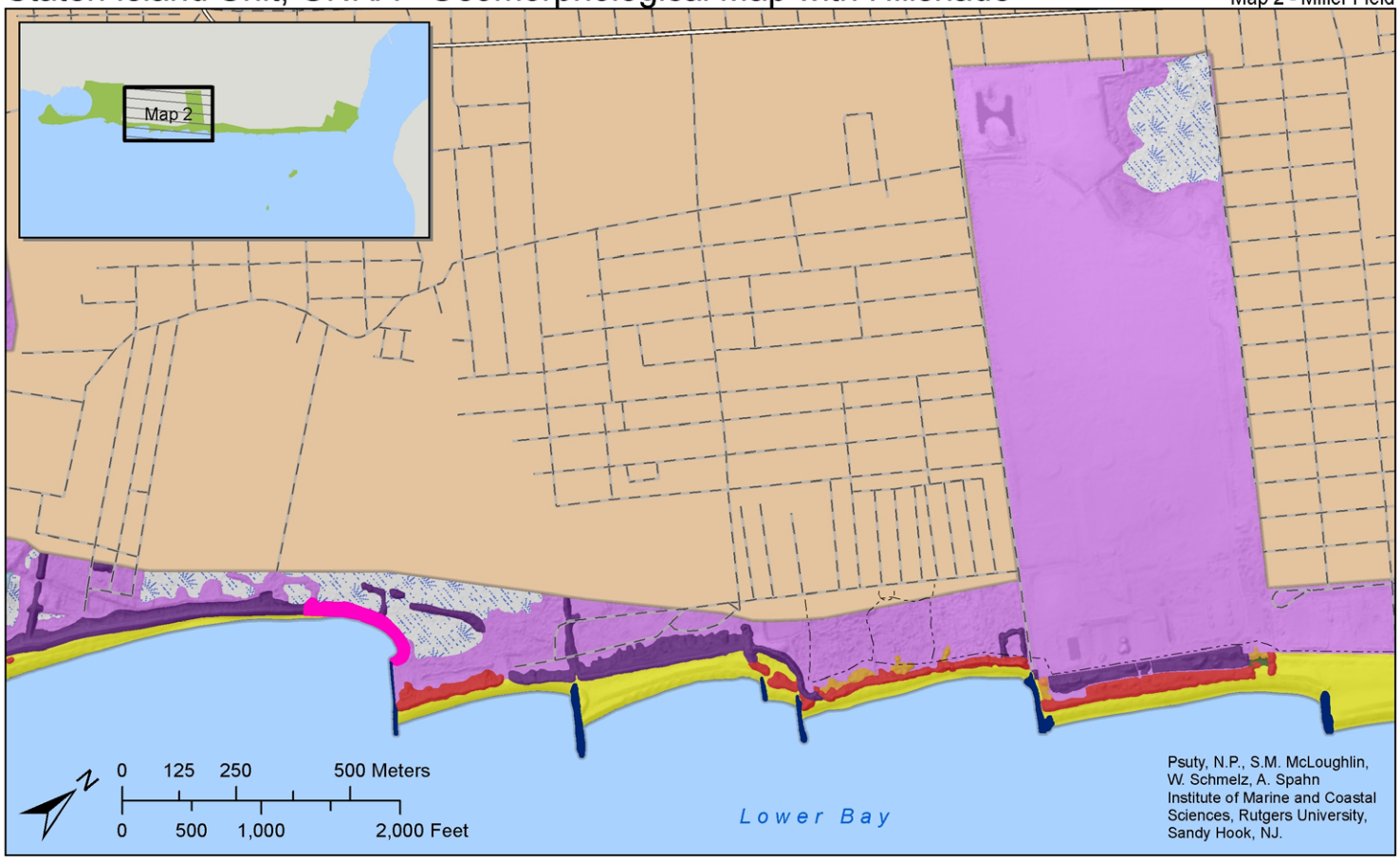
## Staten Island Unit (SIU)




Staten Island Unit, GNRA - Geomorphological Map
Map 1 - Great Kills Park
Map 1
Great Kills Harbor
Lower Bay
0 125 250 500 Meters
0 500 1,000 2,000 Feet
Psuty, N.P., S.M. McLoughlin, W. Schmelz, A. Spahn
Institute of Marine and Coastal Sciences, Rutgers University, Sandy Hook, NJ.
Glacial Features
Terminal moraine
Outwash plain
Coastal Features
Beach
Foredune
Major abandoned foredune
Minor abandoned foredune
Inter-ridge swale
Cliff/Bluff/Scarp
Pond
Wetland
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock/Boardwalk
Jetty/Groin
Major road
Street
Path

## Staten Island Unit, GNRA - Geomorphological Map with Hillshade

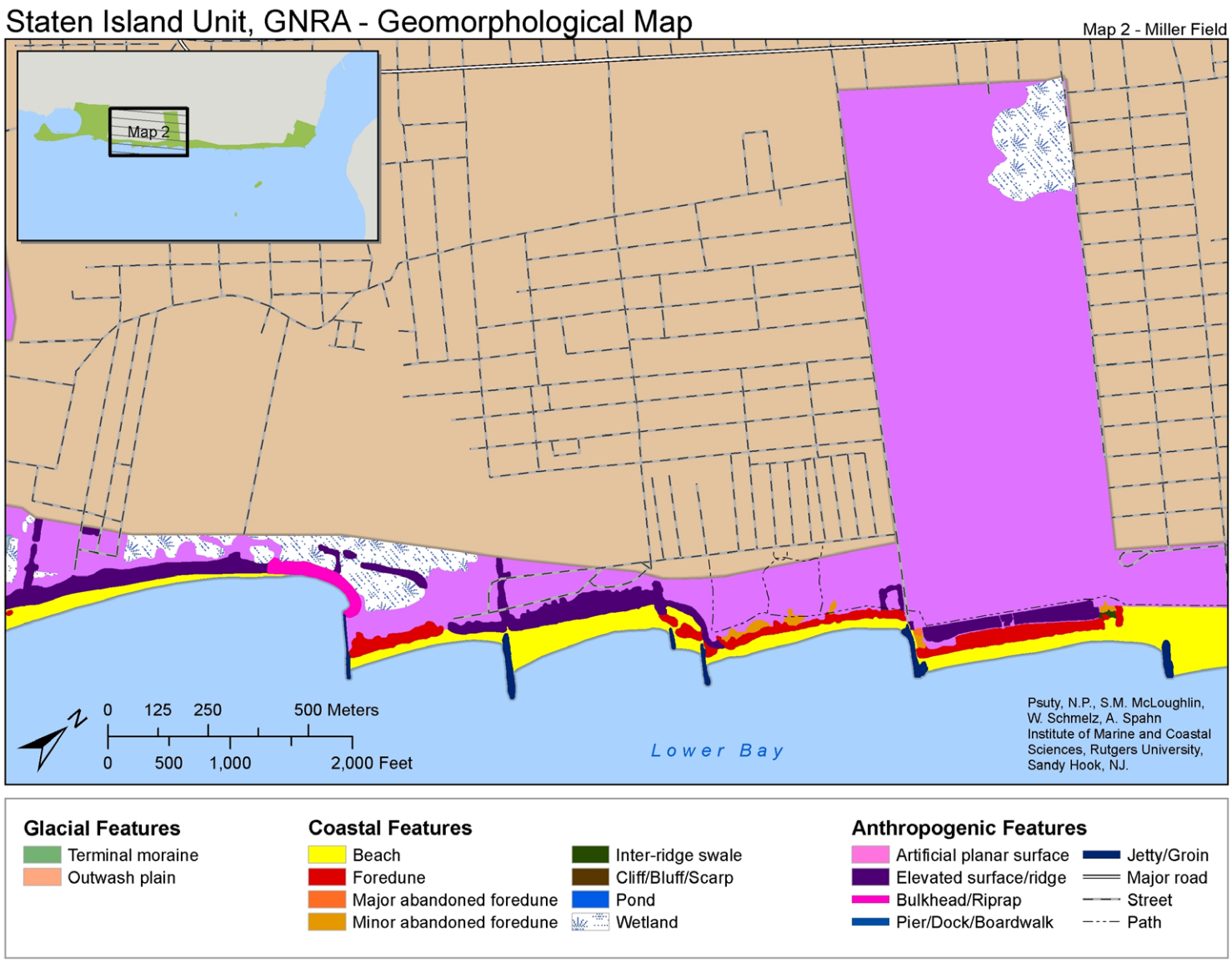
Map 2 - Miller Field




**Glacial Features**
- Terminal moraine
- Outwash plain

**Coastal Features**
- Beach
- Foredune
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Cliff/Bluff/Scarp
- Pond
- Wetland

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock/Boardwalk
- Jetty/Groin
- Major road
- Street
- Path


Staten Island Unit, GNRA - Geomorphological Map
Map 2 - Miller Field
Map 2
0 125 250 500 Meters
0 500 1,000 2,000 Feet
Lower Bay
Psuty, N.P., S.M. McLoughlin, W. Schmelz, A. Spahn
Institute of Marine and Coastal Sciences, Rutgers University, Sandy Hook, NJ.
Glacial Features
Terminal moraine
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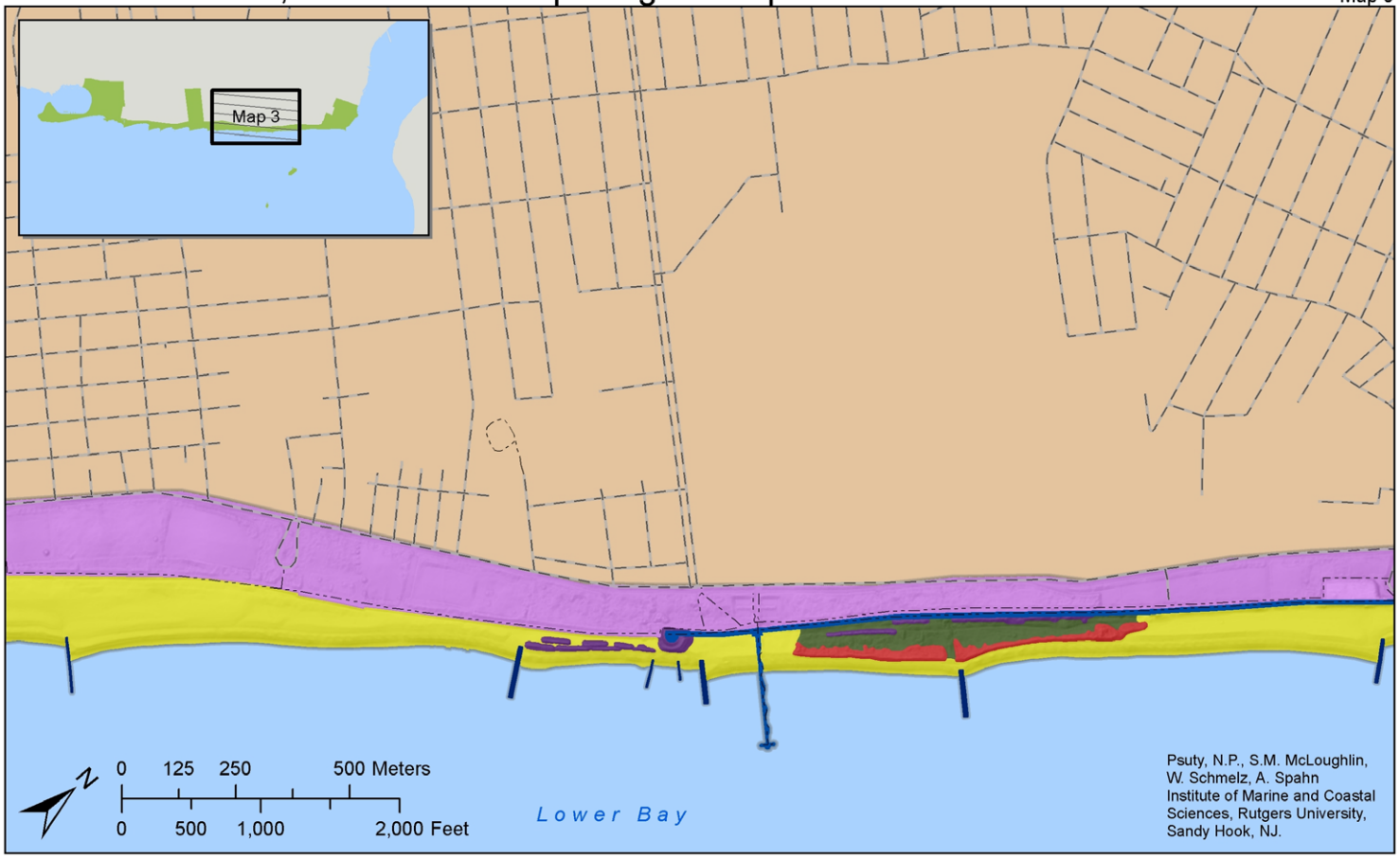
Beach
Foredune
Major abandoned foredune
Minor abandoned foredune
Inter-ridge swale
Cliff/Bluff/Scarp
Pond
Wetland
Anthropogenic Features
Artificial planar surface
Elevated surface/ridge
Bulkhead/Riprap
Pier/Dock/Boardwalk
Jetty/Groin
Major road
Street
Path

## Staten Island Unit, GNRA - Geomorphological Map with Hillshade

Map 3



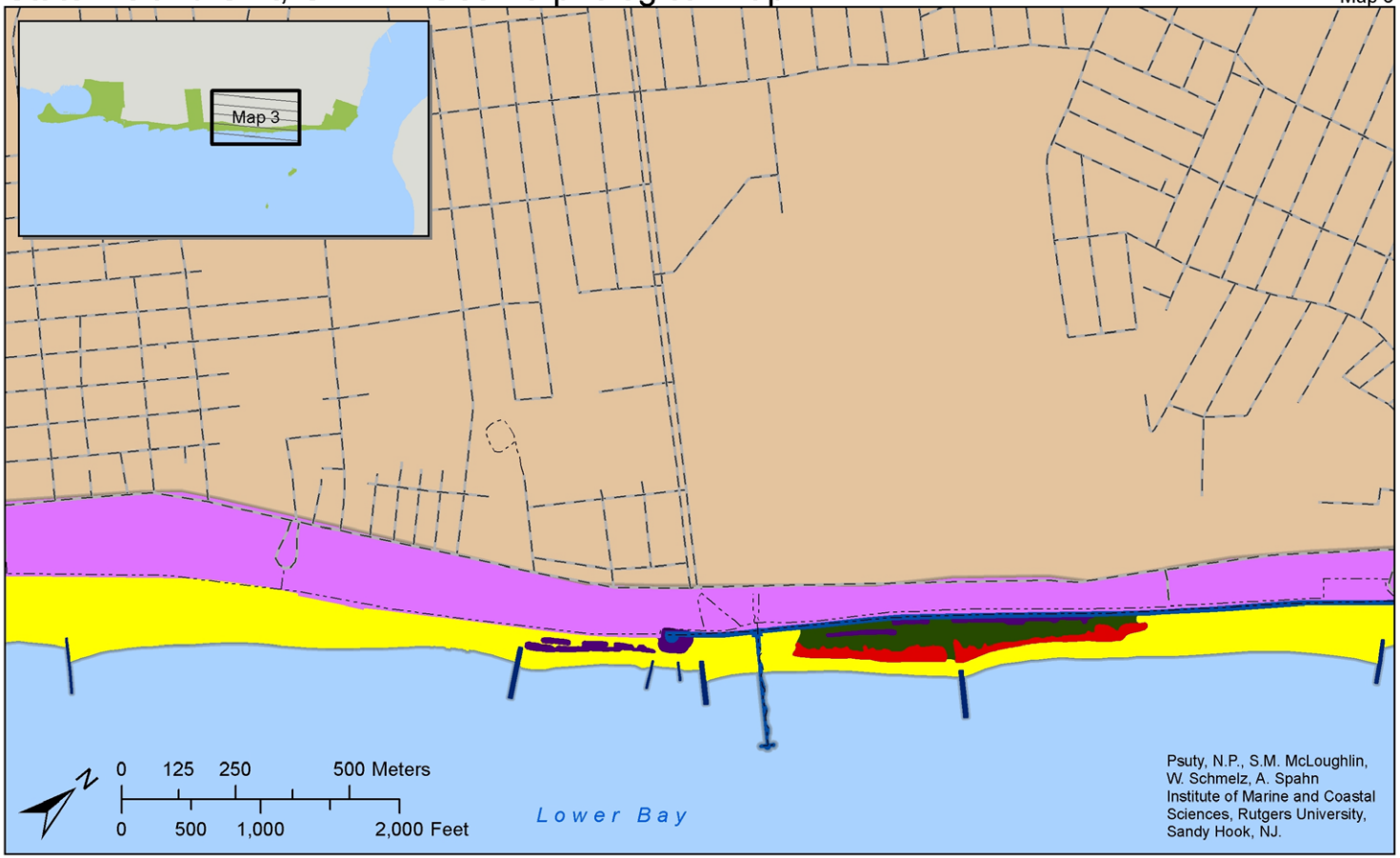

**Glacial Features**
- Terminal moraine
- Outwash plain

**Coastal Features**
- Beach
- Foredune
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Cliff/Bluff/Scarp
- Pond
- Wetland

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock/Boardwalk
- Jetty/Groin
- Major road
- Street
- Path

# Staten Island Unit, GNRA - Geomorphological Map

Map 3

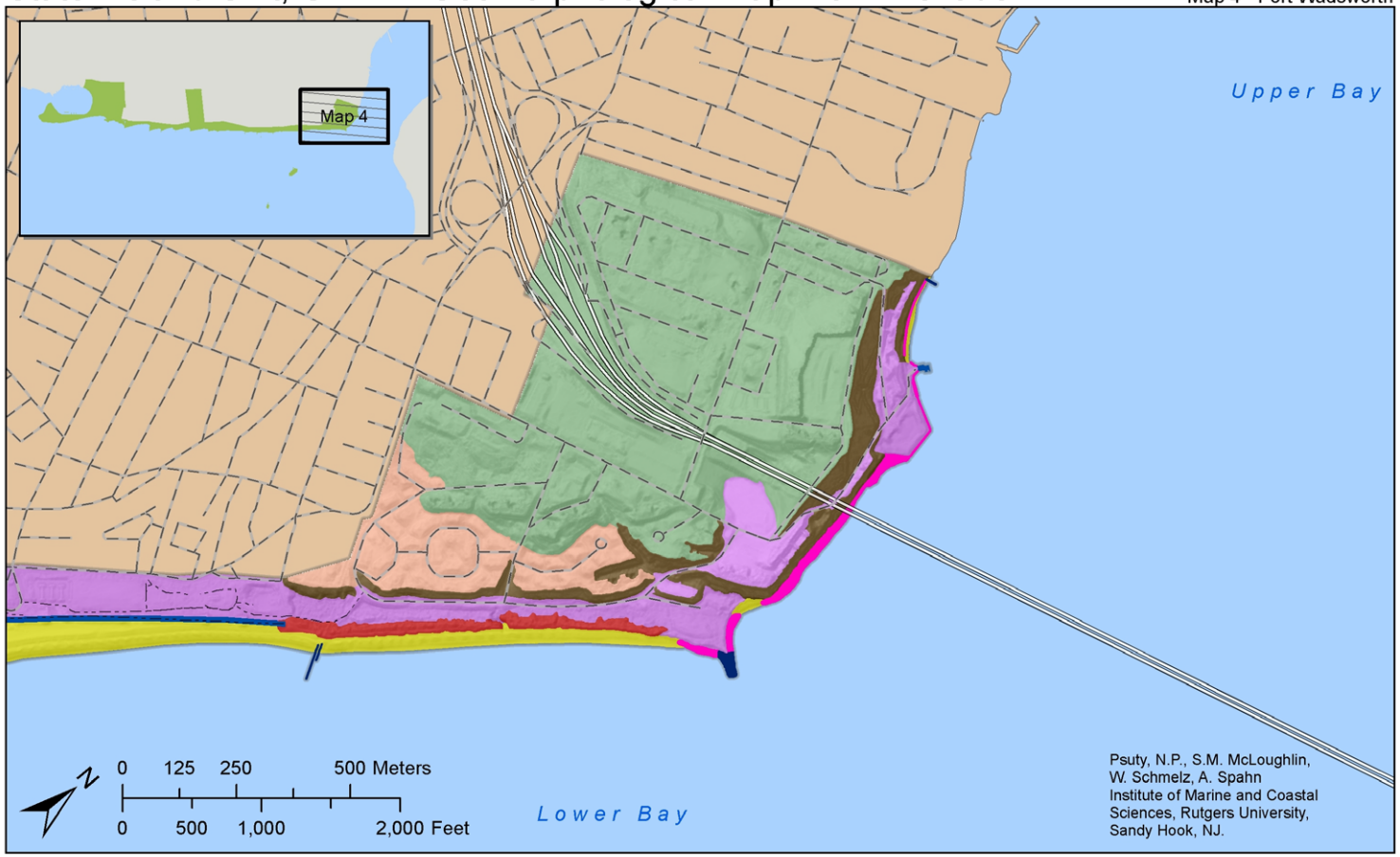



**Glacial Features**
- Terminal moraine
- Outwash plain

**Coastal Features**
- Beach
- Foredune
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Cliff/Bluff/Scarp
- Pond
- Wetland

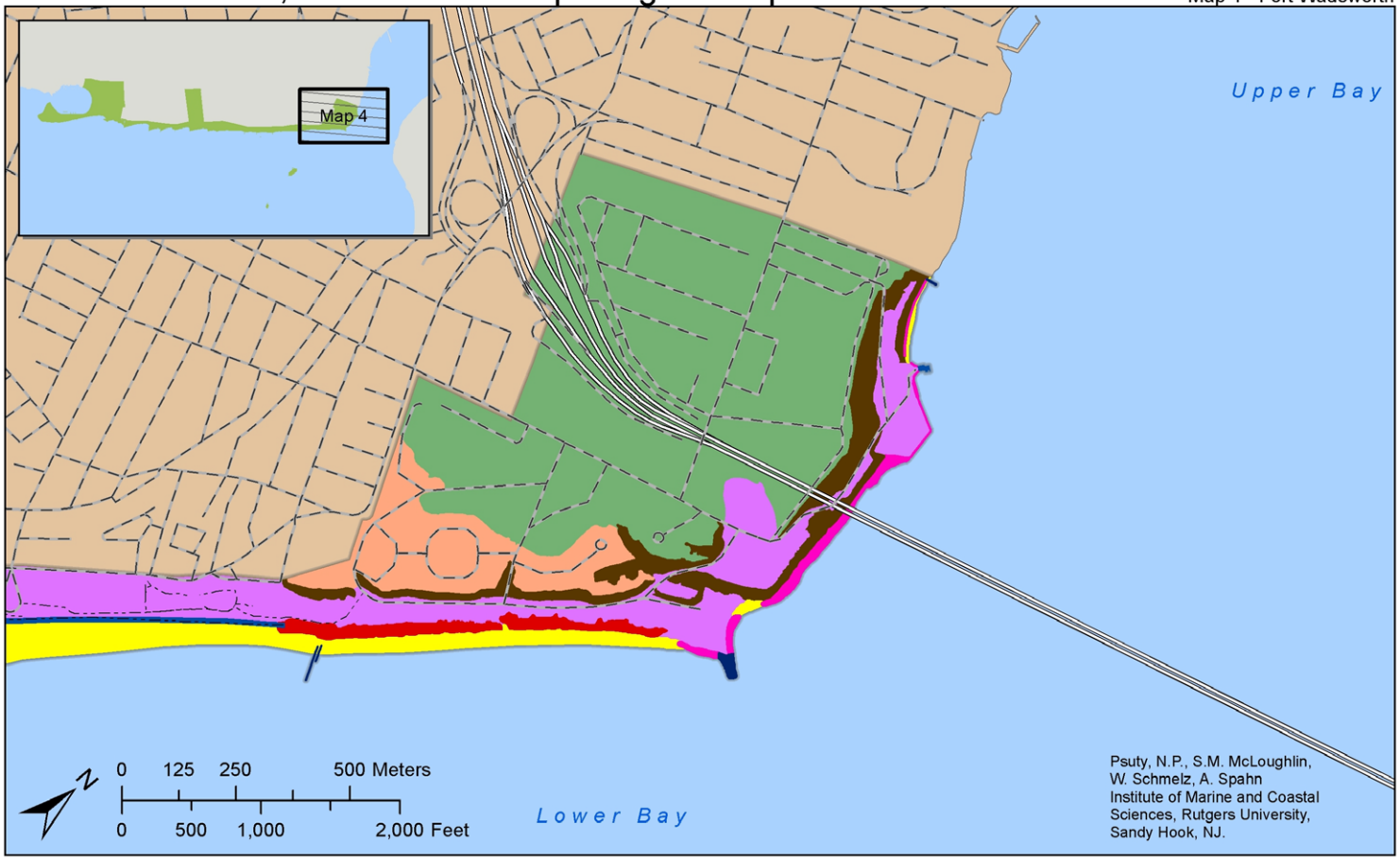
**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock/Boardwalk
- Jetty/Groin
- Major road
- Street
- Path

# Staten Island Unit, GNRA - Geomorphological Map with Hillshade



# Staten Island Unit, GNRA - Geomorphological Map

Map 4 - Fort Wadsworth



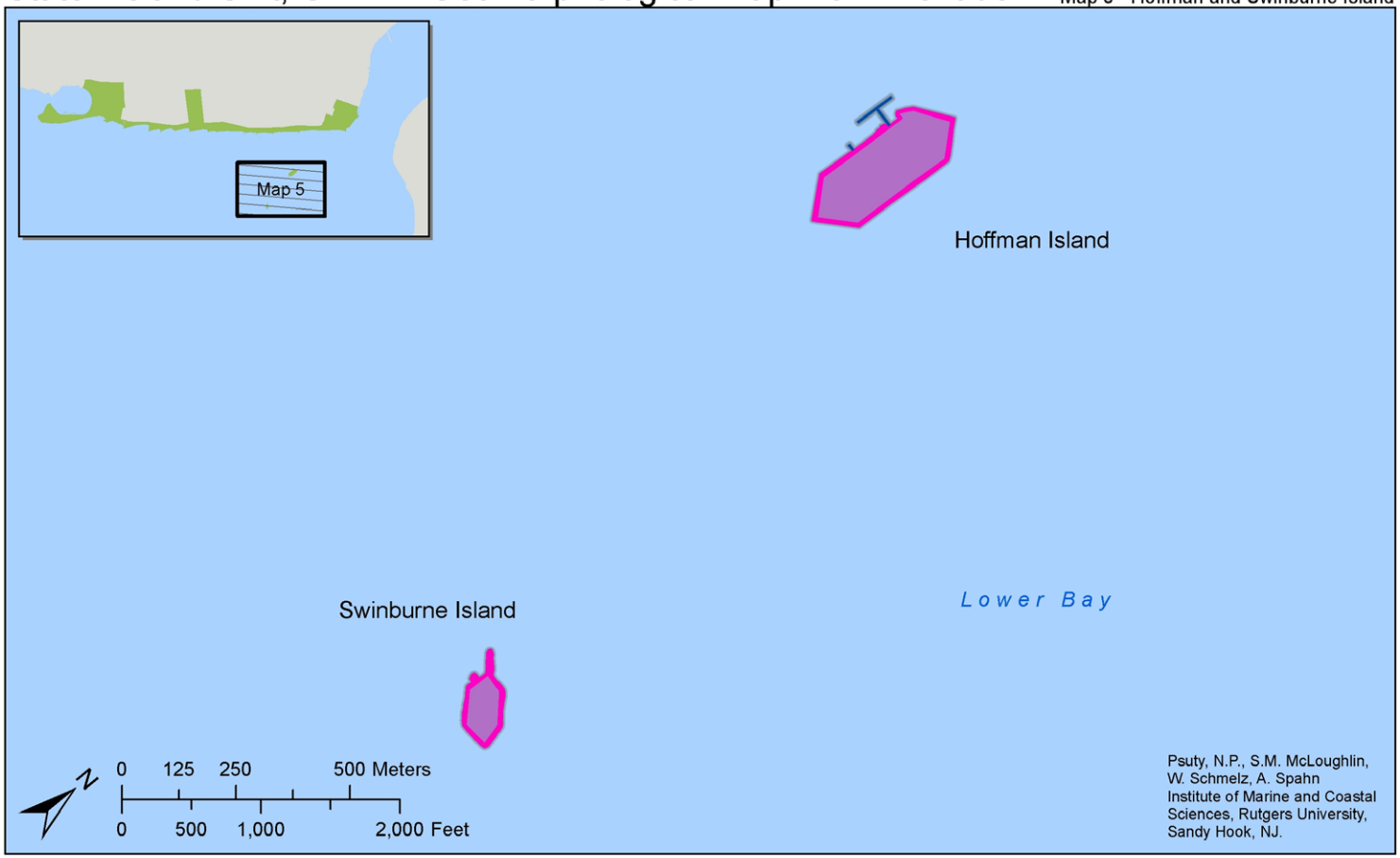

**Glacial Features**
- Terminal moraine
- Outwash plain

**Coastal Features**
- Beach
- Foredune
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Cliff/Bluff/Scarp
- Pond
- Wetland

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock/Boardwalk
- Jetty/Groin
- Major road
- Street
- Path

# Staten Island Unit, GNRA - Geomorphological Map with Hillshade

Map 5 - Hoffman and Swinburne Island



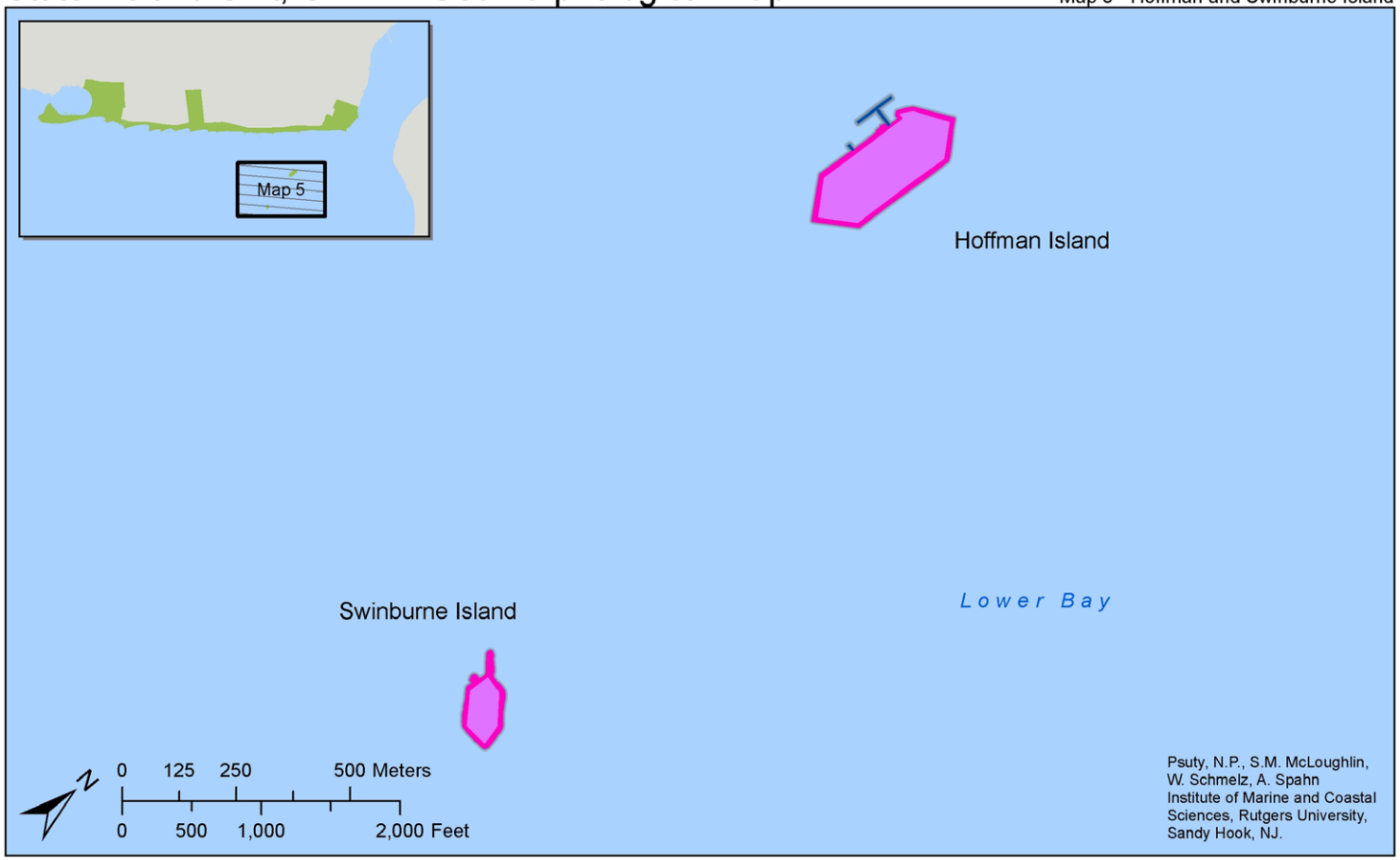

**Glacial Features**
- Terminal moraine
- Outwash plain

**Coastal Features**
- Beach
- Foredune
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Cliff/Bluff/Scarp
- Pond
- Wetland

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock/Boardwalk
- Jetty/Groin
- Major road
- Street
- Path

# Staten Island Unit, GNRA - Geomorphological Map

Map 5 - Hoffman and Swinburne Island




**Glacial Features**
- Terminal moraine
- Outwash plain

**Coastal Features**
- Beach
- Foredune
- Major abandoned foredune
- Minor abandoned foredune
- Inter-ridge swale
- Cliff/Bluff/Scarp
- Pond
- Wetland

**Anthropogenic Features**
- Artificial planar surface
- Elevated surface/ridge
- Bulkhead/Riprap
- Pier/Dock/Boardwalk
- Jetty/Groin
- Major road
- Street
- Path

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 646/142827, March 2018


**Natural Resource Stewardship and Science**
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