NEW YORK-NEW JERSEY HARBOR AND TRIBUTARIES

NEW YORK DISTRICT

Interim Report GIS Appendix

Contents

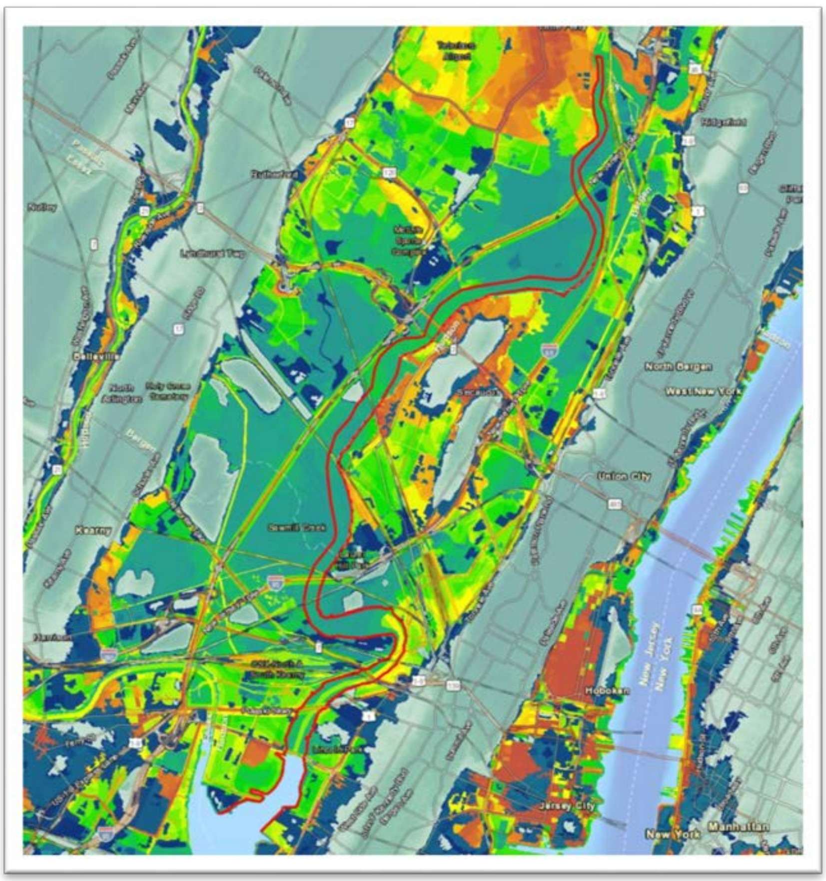
GIS Report

GIS Report Addendum

FINAL
REPORT

New York-New Jersey Harbor and Tributaries Coastal Storm Risk Management Feasibility Study Support for Enhanced Tier 2 GIS Analysis

Contract Number# W912BU-15-D-0004
Task Order# W912DS-17-F0045



Prepared for:

U.S. Army Corps of Engineers New York District

August 20, 2018

Table of Contents

Figures

Tables

This page intentionally left blank.

Section 1

Introduction

The New York District (New York District) of the U.S. Army Corps of Engineers (USACE) is conducting a Comprehensive Coastal Storm Risk Management (CSRM) Feasibility Study for the New York - New Jersey Harbor and Tributaries (NYNJHATS) coastal area in response to historical storms impacting the area, specifically Hurricane Sandy. The NYNJHATS CSRM Feasibility Study leverages work completed by the North Atlantic Coast Comprehensive Study (NACCS) in 2015 to contribute to the resilience of communities, infrastructure and the environment.

The study area encompasses the New York Metropolitan Area, including the most populous and densely populated city in the United States and the six most populated cities in New Jersey. The shorelines of some of the NYNJHATS study area are characterized by low elevation areas, are developed with residential and commercial infrastructure and are subject to tidal flooding during storms. The study area covers more than 2,150 square miles and comprises parts of 25 counties in New Jersey and New York, including Bergen, Passaic, Morris, Essex, Hudson, Union, Somerset, Middlesex and Monmouth Counties in New Jersey; and Rensselaer, Albany, Columbia, Greene, Dutchess, Ulster, Putnam, Orange, Westchester, Rockland, Bronx, New York, Queens, Kings, Richmond and Nassau Counties in New York. For the purposes of this study, the Capital District region extends upstream to the location of the Federal Lock and Dam in Troy, NY (**Figure 1**)[1]. This figure divides the NYNJHATS study area into 34 individual shoreline and tributary segments.

The NYNJHATS study will consider past, current and future CSRM and resilience planning initiatives as well as projects underway by USACE and other Federal, State and local agencies. The USACE Project Delivery Team (PDT) is currently evaluating and scoping CSRM measures within the study area to better screen project alternatives. Coordination with local sponsors and partners as well as public and resource agencies is ongoing to identify a Tentatively Selected Plan (TSP).

[1] Figure 1 was developed by the NYNJHATS PDT early in the study process and has since been superseded. As of the release of the Interim Report the study has been divided into nine regions (see Interim Report Figure 2 NYNJHATS Region Index) however the maps in Appendix C of this report represent the 34 segments depicted in Figure 1 therefore it remains within this report.

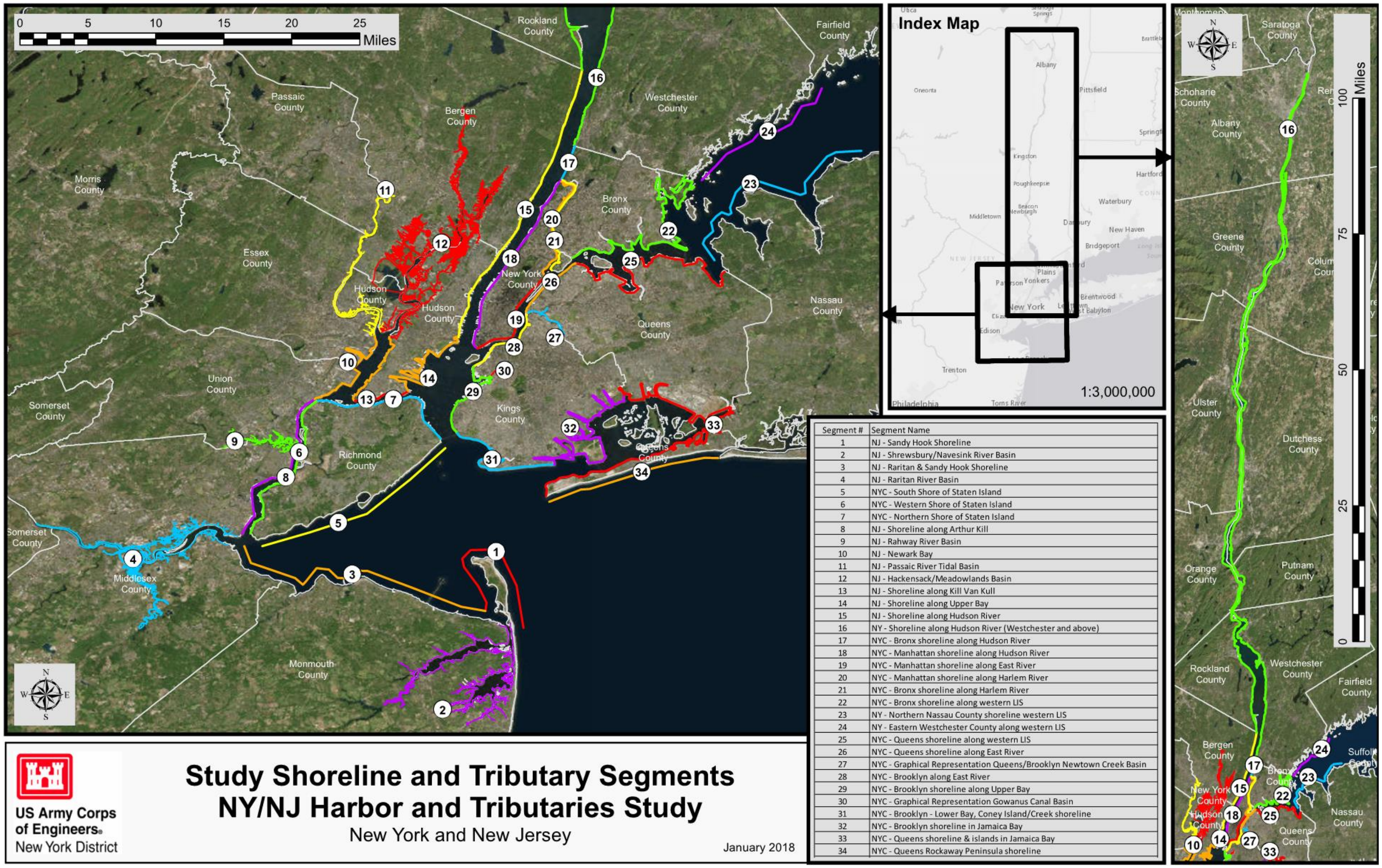


Figure 1 - New York - New Jersey Harbor and Tributaries Study Area

1.1 Purpose

The NACCS included a coordinated geographic information system (GIS) data collection effort from Virginia to Maine available immediately following Hurricane Sandy. Gahagan & Bryant Associates (GBA)/CDM Smith supported USACE by conducting an initial analysis of vulnerability, exposure and risk for the NYNJHATS CSRM Study Integrated Strategy document in January 2015.

Building on the efforts completed by the NACCS, the purpose of the current 2017-2018 effort is to enhance the previous work to evaluate current and future risk within the NYNJHATS study area. Through the USACE Coastal Planning Center of Expertise, USACE contracted GBA/CDM Smith to conduct the following activities:

- Collect pertinent GIS data within the NYNJHATS study area
- Evaluate vulnerability of flooding, exposure and risk within the NYNJHATS study area using the NACCS framework (discussed in further detail in **Section 2**)
- Develop fact sheets summarizing the characteristics of the 34 NYNJHATS Study Segments
- Develop fact sheets summarizing the details of 28 Projects of Significant Impact to the NYNJHATS

This report focuses on the GIS data collection and subsequent analysis and is organized into the following sections:

- **Section 1 - Introduction**
- **Section 2 - Background**
    - Provides background on previous work and its incorporation into current work
- **Section 3 - Data Collection**
    - Summarizes the data collected as part of this effort
- **Section 4 - GIS Analysis Methodology**
    - Details a step-by-step overview of the GIS analysis
- **Section 5 - GIS Analysis Results**
    - Demonstrates the vulnerability, composite exposure and composite risk indices for the Future without Project Condition
- **Section 6 – References**

This page intentionally left blank.

Section 2

Background

This section provides background information on the NACCS and related efforts that occurred in 2015. This study is established on the data collection and analysis first performed as part of the NACCS in support of the resilient coastal communities. Some key terms, defined in the NACCS, are used throughout this report.

2.1 Key Terminology

Exposure is the presence of people, infrastructure and/or environmental resources affected by coastal storm flooding hazard. A higher density of these assets produces relatively higher exposure to coastal storm flood hazard. Categories of exposure include critical infrastructure, population density, social vulnerability, cultural assets, environmental resources, etc. Exposure categories are discussed in greater detail in **Section 4.1**.

Exposure Weight is the relative level of importance that is assigned to exposure assets (individual data layers) based on professional judgment and for the GIS analysis, in consultation with the PDT, local sponsors and partners. Weights are defined on a scale of 0-100 with 100 being the highest value. Exposure weights are discussed in greater detail in **Section 4.1.9**.

Index Weight is the relative level of importance of an exposure category compared to other exposure categories. An index is a group of individual data layers of a similar category that have been grouped together. Weights are assigned to each of the indices based on professional judgment and in consultation with the PDT, local sponsors and partners. GBA/CDM Smith developed a GIS tool to facilitate varying the weights to inform the study. The sum of these weights cannot exceed 100. Index weights are discussed in greater detail in **Section 4.1.**

Vulnerability to coastal storm flood hazard is a function of the exposure of receptors or assets to the hazard, the sensitivity of the receptors or assets within the system to the hazard and adaptive capacity of the receptors or assets within the system to recover from and withstand the reoccurrence of the coastal flood event. Given the expansive scale of the NACCS, probability of occurrence is used as a measure of the receptors' or assets' sensitivity to the coastal flood hazard. Flooding methodology is discussed in greater detail in **Section 4.2**.

Risk of a coastal storm event is its probability of occurrence (i.e., vulnerability) multiplied by the consequences (i.e., exposure). The consequences are measured in terms of life safety, property and asset damages. Composite risk results are described in further detail in **Section 5**.

Residual risk is the flood risk that remains to people and assets after all implementation efforts to reduce risk are completed. It is important to identify residual risk to account for extreme flood extents associated with a catastrophic event. Often, flood risk management measures do not reduce risk associated with an extreme event.

Future without Project Condition (FWOPC) is a reasonable projection of what the future conditions will be if this study recommends the no action alternative. There are several CSRM projects that could affect the plan selection process because they are of large enough scale to affect the benefit-cost analysis for this study. The projects are expected to have permits and funding for construction secured by July 2020, indicating that these projects are most likely to be implemented. These projects are considered the Future without Project condition (FWOPC). The FWOPC projects factored into this analysis are discussed in **Section 4.3.4**.

2.2 North Atlantic Coast Comprehensive Study Coastal Storm Risk Management Framework

The NACCS Main Report introduces and discusses the CSRM Framework as a tiered step-by-step approach (**Figure 2**). Tier 1, 2 and 3 represent different scales of desktop analysis.

After Hurricane Sandy in 2012, national datasets were used to complete a Tier 1 GIS analysis for the regional application of the framework to illustrate the exposure, vulnerability and risk for the entire NACCS study area (Virginia to Maine). In the NACCS, the first five steps of the CSRM Framework were completed at a conceptual level: Initiate Analysis, Characterize Conditions, Analyze Risk and Vulnerability, Identify Possible Solutions and Evaluate and Compare Solutions. The goal of the NYNJHATS CSRM Feasibility Study is to enhance the work originally done by the NACCS and continue with the framework to select, develop and execute the plan.

Figure 2 - NACCS Coastal Storm Risk Management Framework

2.3 NACCS Tier 1 and 2 Analysis (2014-2015)

As part of the NACCS, a Tier 1 and Tier 2 analysis was completed on a state-wide basis. This section is a general summary of the methodology. The Tier 1 and Tier 2 analysis are described in detail in the NACCS Main Report, Appendix C - Planning Appendix and the Tier 2 Analysis Report as part of the NYNJHATS Integrated Strategy Report. The results of the initial Tier 2 analysis for the States of New York and New Jersey are found in the NACCS Appendix D - State and District of Columbia Analyses Appendix.

2.3.1 Exposure

The Tier 1 analysis required identifying the various categories to characterize exposure. Using the spatial data layers and a weighting scheme for each dataset included in the analysis, an exposure index was developed to characterize the relative exposure to coastal flood hazard. Details on weights are described in the NACCS reports and appendices.

The spatial layers were obtained from various sources, primarily from national datasets and publicly available information. Some infrastructure data included in the analysis is not publicly available due to security purposes. The Homeland Security Infrastructure Program (HSIP) Gold

2012 geodatabase was obtained from the National Geospatial Intelligence Agency. Various data layers included in the HSIP Gold 2012 database were selected and defined as critical infrastructure. Other datasets include the US Geological Survey (USGS) National Hydrography Dataset and 10-meter digital elevation model, National Oceanic and Atmospheric Administration's (NOAA) Environmental Sensitivity Index data, US Fish and Wildlife Service (USFWS) National Wetland Inventory, the Nature Conservancy Eco-regional Priorities and the U.S. Census Data. The NACCS Tier 1 analysis focused on the following exposure categories and criteria:

- **Population Density and Infrastructure:** Population density includes identification of the number of persons within an areal extent across the study area; infrastructure includes critical infrastructure that supports the population and communities. These factors were combined to reflect overall exposure of the built environment. Within this category, Population Density was assigned a factor of 30 percent with infrastructure assigned a factor of 70 percent. As a whole, this category constituted 80 percent of the total exposure.
- **Social Vulnerability Characterization:** Social vulnerability characterization includes certain segments of the population that may have more difficulty preparing for and responding to coastal flood events. As a whole, this category constituted 10 percent of the total exposure.
- **Environmental and Cultural Resources:** The environmental and cultural resources exposure captures important habitat and cultural resources that would be affected by storm surge, winds and erosion. There are three subcategories within this type of exposure: environmental, habitat and cultural and assigned 30 percent, 30 percent and 40 percent, respectively. As a whole, this category constituted 10 percent of the total exposure.

Within individual exposure categories, weights were assigned to characterize the relative level of importance of each data layer compared to other data layers within the category as it relates to direct and or indirect effects to population and communities during a coastal flood event. Individual datasets were weighted and combined to form the three exposure categories (and their sub-categories). The composite index was developed to represent exposure to the system, along with an independent analysis of exposure to the three individual categories. Detailed discussion is described in the NACCS Appendix C - Planning Appendix.

2.3.2 Vulnerability

At the time the initial Tier 1 and Tier 2 analysis was being completed, a concurrent effort of modeling storm surge was in progress. Thus, for the initial analysis, surrogate flooding extents and probability of flooding were assigned. There were three floodplain inundation scenarios: Category 4 Maximum of Maximum (MOM) envelope of high water from the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model, 1 percent flood plus three feet and the 10 percent flood. In total, three grids of inundation extent were created. The bands correspond with the flooding source to the 10 percent inundation extent, the 10 percent to the 1 percent plus three feet extent and the 1 percent plus three (3) feet to the Category 4 MOM inundation extent. The 1 percent plus three feet extent was defined as the Category 2 MOM because at the study area scale, since some areas did not have FEMA 1 percent flood mapping. Detailed discussion is described in the NACCS Appendix C - Planning Appendix.

2.3.2 Risk

USACE and GBA/CDM Smith developed a composite risk index for the NYNJHATS study area by multiplying the composite exposure data by the vulnerability data. Maps and illustrations of the composite risk for the study area are found in the Tier 2 Analysis Report in the NYNJHATS Integrated Strategy Report.

2.4 Enhanced Tier 2 GIS Analysis

Nearly six years after Hurricane Sandy, this study leverages the data and processes completed for the NACCS to address the following immediate needs:

- Available exposure data has since been updated. Nationwide, regional and local datasets are updated and made newly available.
- Since the NACCS covered such a broad area, city or area-specific exposure, datasets were not incorporated due to lack of consistent coverage across regions and states. Because this study is focused primarily on the NYNJHATS area, additional refinement to data are included by factoring such data as passenger volume and ridership on a location-by-location basis into the development of weights applied to those data layers.
- Additional datasets, not included in the NACCS, are incorporated to enhance the study output, notably building replacement value and employment data.
- In coordination with USACE and local sponsors, modifications to weighting and datasets preferences can be incorporated. The weights as defined in the NACCS were rigid for consistency across the NACCS study area. Flexibility of on-the-fly weighting of exposure indices allows for a comparison of different preferences.
- In the NACCS, exposure indices were a function of the three broad exposure categories: 1) Population Density and Infrastructure, 2) Social Vulnerability and 3) Environmental and Cultural Resources. Each of these exposure categories were comprised of subcategories (i.e., population density and infrastructure were combined as one index; environmental and cultural resources index was comprised of environmental data layers, habitat and cultural resources). For the Enhanced Tier 2 GIS Analysis, where possible, exposure categories were separated so that each exposure index can be assigned its own weight. This simplifies the risk equation, allows for expansion with additional categories and clarifies the impact of weighting on the final risk product.
- USACE or local projects have modified the shoreline in the NYNJHATS study area. Best available ground surface elevation data can be obtained to represent current conditions. Where current conditions do not reflect the FWOPC, surface elevations can be developed to reflect anticipated future changes expected by projects likely to be implemented within the FWOPC time horizon.

- ADCIRC storm surge modeling, completed as part of the NACCS, is now available to determine inundation extents for typical and extreme flooding events. The Enhanced Tier 2 GIS Analysis utilized this data in developing the floodplains associated with the vulnerability index.

This page intentionally left blank.

Section 3

Data Collection

3.1 Exposure Data

As part of the data collection efforts, GBA/CDM Smith sent a data request via email to Federal, State, local and non-government organizations in Albany, Columbia, Ulster, Nassau, Dutchess, Greene, Orange, Putnam, Rensselaer, Rockland, Ulster, Westchester counties, New York City, National Park Service, Scenic Hudson, National Estuarine Reserve, New York State contacts in New York State Department of Environmental Conservation (NYSDEC), NYS Thruway and NYS Office of Information Technology Services (NYSITS). In New Jersey, the data request was sent to Bergen, Passaic, Essex, Hudson, Union, Somerset, Middlesex counties, the City of Newark, City of West Orange and City of Clifton.

The purpose of this data request was to determine if there were any updated or new datasets applicable to the completion of the Enhanced Tier 2 GIS Analysis. Similar to the NACCS, the following data were requested:

Environmental and Cultural Resources: Priority areas (layers from US Fish and Wildlife Service [USFWS]); coastal barrier islands; USFWS refuges; USFWS protected areas; USFWS priority areas; rare, threatened and endangered species; colonial nesting water birds; The Nature Conservancy conservation areas; city, county, State and Federal parks > 100 acres; seagrass; emergent marshes; wetlands, shorelines; hydrologic layers including, lakes, ponds, river, streams, etc., National Monuments and National Historic Landmarks, or local historic sites.

Infrastructure: airport boundaries; all places of worship; Amtrak stations; bus stations; cellular towers; colleges/universities; communication centers; dams; electric generating units; electric power generation plants; emergency medical services; energy distribution control facilities; ferries; fire stations; gas stations; hospitals; intermodal terminal facilities; law enforcement location; local emergency operation centers; national shelter system; natural gas (liquid natural gas) import terminals; natural gas compressor stations; natural gas import/export points; natural gas receipt and delivery points; natural gas storage facilities; nuclear power plants; nursing homes; oil and natural gas interconnects; oil refineries; pier/wharf/quay; petroleum pumping stations; pharmacies; terminals/storage facilities/tank farms; ports; private schools; public schools; railroad bridges; railroad stations; railroad tunnels; railroad yards; receiving hospitals; road and railroad bridges; service providers; state emergency operation centers; substations; urgent care facilities; wastewater pump stations; wastewater treatment plants; water treatment facilities; hurricane evacuation routes; transmission lines; railroad; road and railroad tunnels; pipeline distribution system; canals; channels; oil and natural gas pipelines; and ferry routes.

Very few contacts responded with specific local data. Some respondents referenced publicly available GIS clearinghouse websites. Applicable data were downloaded from various sources. **Table 1** summarizes the sources of spatial data for this study. The weighting methodology is described in **Section 4.1** and summarized in **Table 4** in **Section 4.1.9**.

Table 1 - Online Data Sources

SOURCE	WEBSITE
NJ Geographic Information Network (NJGIN)	https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp
NJGIN County Outreach List	https://njgin.state.nj.us/NJ_NJGINExplorer/jviewer.jsp?pg=county_contact_list
NJ Department of Environmental Protection (NJDEP) GIS	http://www.nj.gov/dep/gis/landscape.html
Meadowlands Commission GIS	http://meri.njmeadowlands.gov/maps/
NJ Division of Fish and Wildlife	http://www.njfishandwildlife.com/ensp/landscape/about.htm
Northeast Ocean Data	http://www.northeastoceandata.org/
NJ Department of Transportation (NJDOT)	http://www.state.nj.us/transportation/gis/map.shtm
North Jersey Transportation Planning Authority (NJTPA)	http://www.njtpa.org/Data-Maps/Maps-GIS-Data.aspx
NJ Department of State (NJDOS)	http://www.nj.gov/state/planning/spc-research-resources-gis.html
NJ Highlands	http://data-njhighlands.opendata.arcgis.com/
New York State GIS Clearinghouse	http://gis.ny.gov/
New York City Open Data	https://opendata.cityofnewyork.us/

3.2 Elevation Data

In addition to exposure data, GBA/CDM Smith acquired both ground surface and bathymetric elevation data.

The USGS-led Coastal National Elevation Database (CoNED) Project was the primary source for all topographic and analysis. This dataset consisted of a topo-bathymetric DEM (TBDEM) at a spatial resolution of 1 meter, covering all of New Jersey, New York City, Long Island and the lower Hudson Valley. CoNED's coverage ended near Kingston, NY; thus, local topographic sources were used. These included the Columbia Rensselear 2015/16 (1 meter), Capital District 2008 (2 meter) and Green 2010 (2 meter) surveys. Datasets not already at 1 meter were resampled to match the resolution of CoNED.

3.3 Additional Sources of Data

National datasets from the US Census, USFWS, Homeland Infrastructure Foundation-Level Data (HIFLD), National Register of Historic Places and Federal Emergency Management Agency (FEMA) were acquired to determine population, building value, social vulnerability and employment metrics. These are described in further detail in **Section 4.1.1** to **Section 4.1.8**.

This page intentionally left blank.

Section 4

Methodology

The methodology for the Enhanced Tier 2 GIS Analysis follows the same basic procedures and framework as the NACCS Tier 1 and Tier 2 efforts. The purpose of the analysis is to assign a relative value or score to areas within the NYNJHATS study area representing the exposure, probability and risk of these areas due to coastal flooding. This section of the report details the GIS processes and methodologies employed to derive the results.

The primary components of the Enhanced Tier 2 GIS Analysis are the total exposure and vulnerability (i.e., probability of a coastal storm surge event) as defined in **Section 2.1**. **Figure 3** shows the overall GIS analysis workflow used to conduct the study. The equation for calculating risk is as follows:

$$Risk = Vulnerability \times \sum_{i}^{n} Exposure \times Weight$$

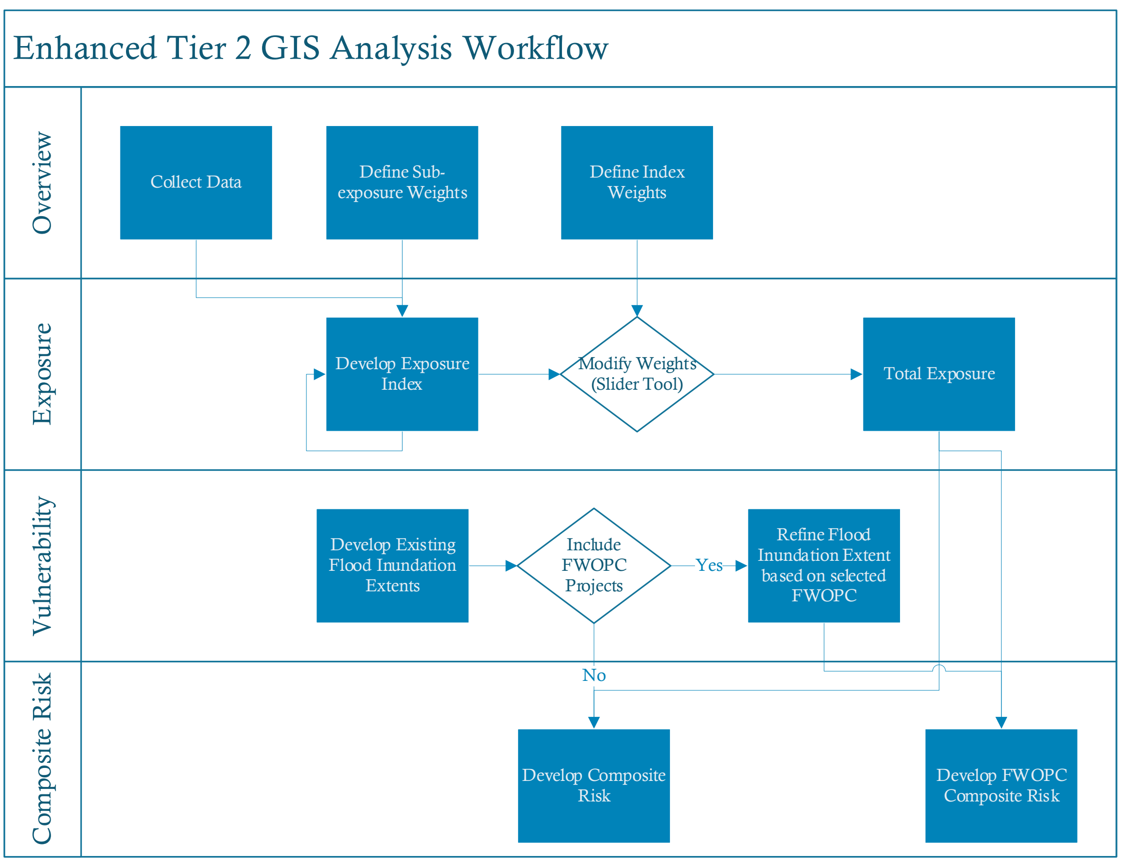


Figure 3 - GIS Analysis Workflow

Table 2 lists the spatial settings used throughout the analysis to ensure consistency.

Table 2 - GIS Data Settings

Coordinate System	NAD 83 UTM 18N
Unit	Meter
Vertical Datum	NAVD88
Raster Cell Size	10 Meter

4.1 Exposure Methodology

The total exposure raster is a composite of eight individual exposure rasters that represent eight various categories/indices: population density, infrastructure, building value, social vulnerability, employment, cultural resources, habitat and environmental resources. Total exposure is derived using a weighted sum. **Table 3** depicts the default index weights[1] applied to calculate the total exposure chosen in consultation with USACE. **Table 4** in **Section 4.1.9** summarizes the data layers, data type, processing, and exposure weight used for this analysis.

Table 3 - Exposure Index Weights

CATEGORY	WEIGHT
Population Density	25%
Infrastructure	25%
Building Value	20%
Social Vulnerability	10%
Employment	10%
Cultural	4%
Environmental	3%
Habitat	3%
TOTAL	**100%**

As discussed in **Section 2.3.1**, exposure indices in the NACCS were a function of three broad exposure categories. The broad exposure categories were initially separate indices - for example, the population density was separate from infrastructure and was combined to create the Population Density and Infrastructure exposure index. A similar combination of indices occurred for the environmental and cultural resources. The three-step calculation of exposure, combination of exposure indices and re-calculation of the total exposure index was complex.

[1] The default exposure index weights used in the evaluation of alternatives and features were changed following the production of this report. Details explaining this change and the reasoning are explained within the Report Addendum.

Thus, for the Enhanced Tier 2 GIS Analysis, each exposure index is assigned its own weight (**Table 3**). This simplifies the risk equation and clarifies the impact of weighting on the final risk product. This improves transparency of the values used in this analysis. It also allows flexibility in how weights are applied to each index in relation to other indices. Additionally, a "slider tool" was developed to allow for interactive manipulation of the exposure index weights depending on the user's preference. This enables different users to specify and compare different index weights and create new total composite exposures with minimal effort.

4.1.1 Population Density

The population density exposure index was compiled using 2010 Census Population data with 2017 Census Block Geometry. The population density was calculated as persons per square mile, then a log transformation was applied to the dataset. Lastly, the dataset was normalized to a scale of 100 using a log transformation. The steps below detail the processing.

Source: U.S. Census Blocks 2010 Population Data and 2017 Geometry
https://www.census.gov/geo/maps-data/data/tiger.html
Processing:

1. Remove Census Blocks outside of the study area. Do not use the Clip tool. Use the Select by Location tool set to ensure the entire Census Block is used. If clipping of the dataset is used, the density calculation will be incorrect.
2. Project to UTM 18N.
3. Use the Join Field tool to join the population data from the Census data table.
4. Add a field named PopDen (type: float).
5. Add a field named Area_sqmi (type: float).
6. Calculate the geometry of the Area_sqmi field to square miles.
7. Calculate the PopDen field = !POP10!/!Area_acres! to calculate the population density per square acre.
8. Inspect results for outliers.
   a. An outlier is identified as population per square acre greater than or equal to 1000. There were roughly 30 outliers.
   b. Merge the outliers into the appropriate adjacent Census Block. (**Figure 4** below shows half of the population of this high rise is assigned to the road, resulting in an extremely high population density)

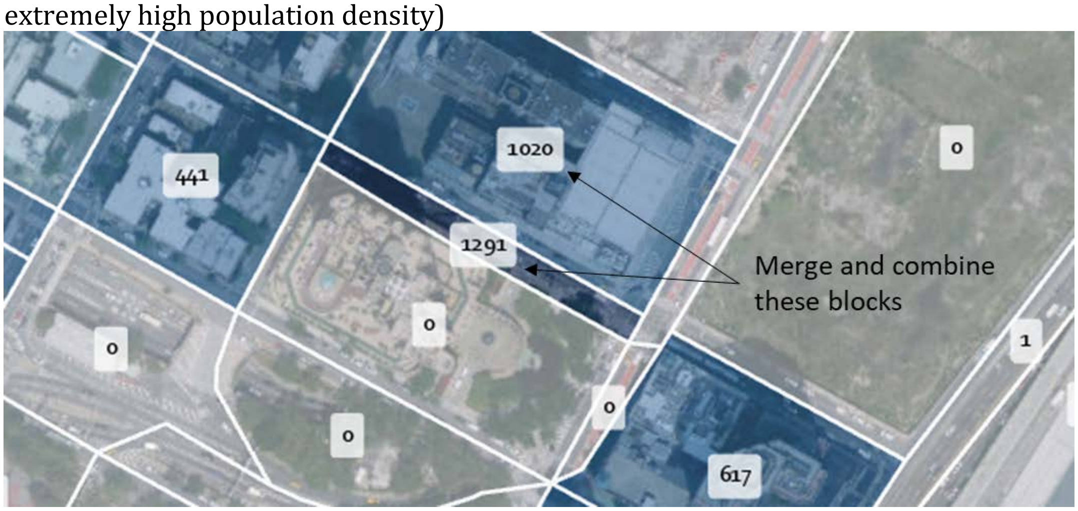


Figure 4 - Outliers in Census Block

   c. Recalculate the area and population density.
9. Apply a log transformation to a new field named log_popden by using the command:
   a. math.log10(!PopDen!)
10. Normalize the data to 0-100 scale using feature scaling to a new field named lognorm_popden using the command:
   a. !log_popden!/max(!log_popden!)*100
11. Convert the polygons to a raster using the lognorm_popden as the value field with a cell size of 10 meters.

Data Scaling Transformations

The raw population data values range from 0 - 8,634. To have a consistent comparison across all exposure categories, a range of 0 - 100 was chosen in consultation with USACE. Initially, a feature scaling transformation was applied to compress the data to a range of 0 - 100. **Figure 5** and **Figure 6** depict the population density data scaled to 0 - 100. However, this did not produce a desirable result due to the exponential nature of population data. To address this, a log transformation was applied.

Figure 7 and **Figure 8** depict the population density with a log transformation applied. The log transformation reduces the overall skew and reduces the impact of any additional outliers. This same transformation was applied to both the Building Value and Employment exposure datasets.

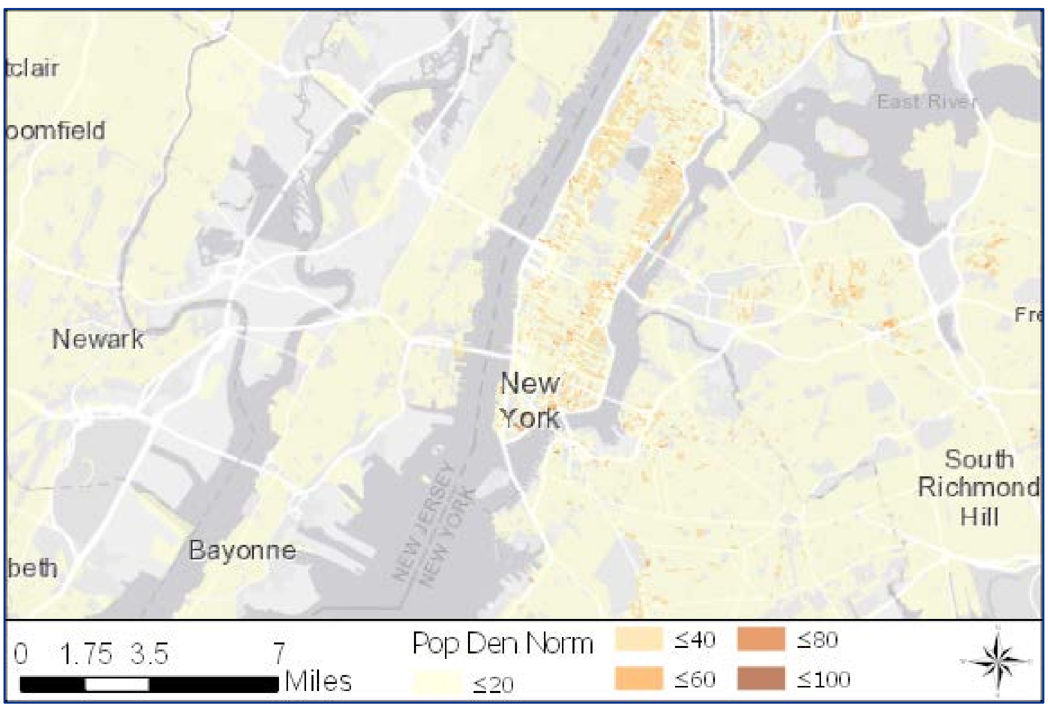


Figure 5 - Population Density

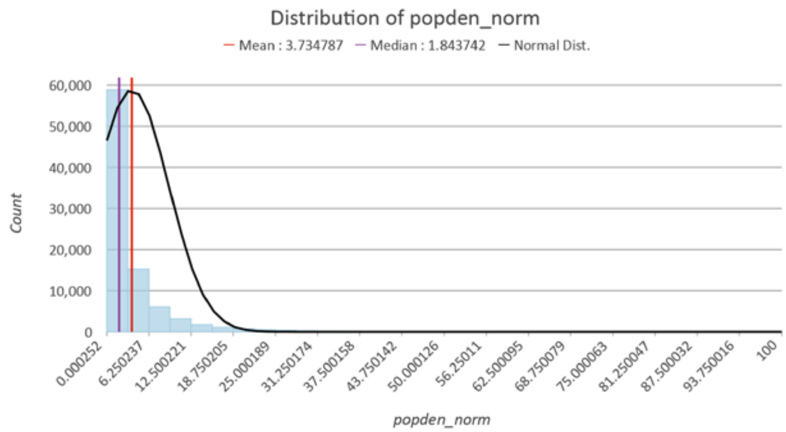


Figure 6 - Population Density Histogram

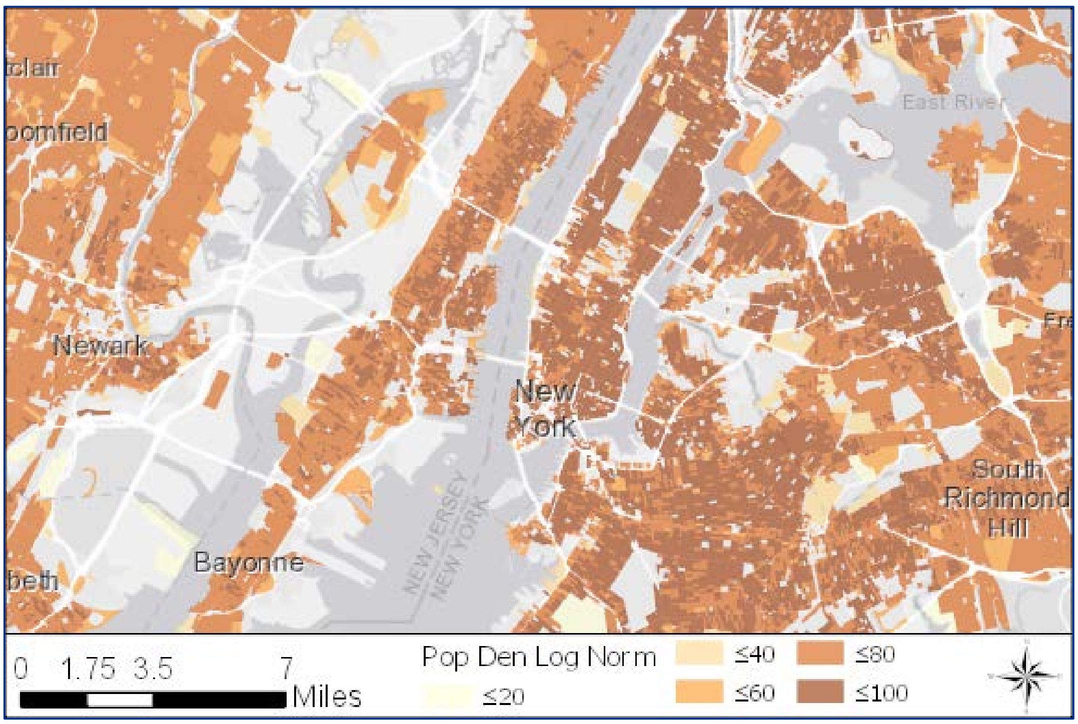


Figure 7 - Population Density Log Normalized

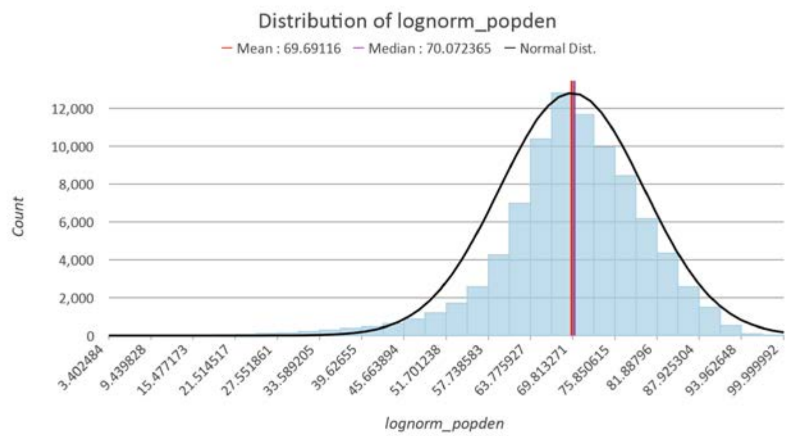


Figure 8 - Population Density Log Normal Histogram

4.1.2 Infrastructure

The infrastructure exposure index was compiled from 45 separate data layers representing critical infrastructure such as highways, evacuation routes, critical facilities emergency shelters, etc. For a full list of the data layers, refer to **Section 4.1.9**. The data was compiled into a single seamless raster using the steps below.

Source: Various, refer to **Section 4.1.9** for more detailed discussion.
Processing:
General:

A snap raster is used throughout the Infrastructure process to ensure alignment to the base grid of the study area. To create the snap raster, convert the integrated strategies tier 2 boundary to a raster with a cell size of 10. The resulting raster is used as the snap raster within the environment settings for all subsequent processes.

Linear Data:

All linear data was converted to polygons representing their true coverage. For example, interstate highways were set to a 90-foot buffer based on the assumption that the majority of the highways in the study area are four lanes wide and a single lane width ranges between 12 - 26 feet.

1. Clip data to NYNJHATS study area boundary.
2. Buffer lines to polygons using the width specified in **Table 4** in **Section 4.1.9**.
3. Add a weight field and populate the field with the weight from **Table 4** in **Section 4.1.9**.
4. Convert each polygon feature class to a 10-meter cell raster using weight as the field.
5. Mosaic all rasters together using the maximum value as the mosaic operator and save the raster result as INFRA_LINE.

Polygon Data:

“Airport boundaries” is the only data layer that was represented as polygons in this study. The weight for airports was initially set to a maximum value of 100. However, in consultation with USACE and local sponsors, the weighting was adjusted to reflect passenger volume through the airports within the study area (John F. Kennedy International Airport, Newark Liberty International Airport, LaGuardia Airport and Teterboro Airport). A log transformation was applied to the passenger volume to ensure consistency with the other exposure transformations. The results are shown in **Figure 9**. The steps for defining the passenger volume are below.

Source: Port Authority of New York and New Jersey. 2017 Airport Traffic Report. https://www.panynj.gov/airports/pdf-traffic/ATR2017.pdf
Processing:

1. Determine passenger volume by airport.
2. Apply a log transformation to passenger volume for consistency with other transformations and to account for the exponential nature of passenger volume.
3. Scale log transformation to a maximum of 100 using feature scaling.
4. Apply results to the feature class in the weight field.
5. Convert to the polygons to a raster using the weight field with a cell size to 10 meters. Save the raster result as INFRA_POLY.

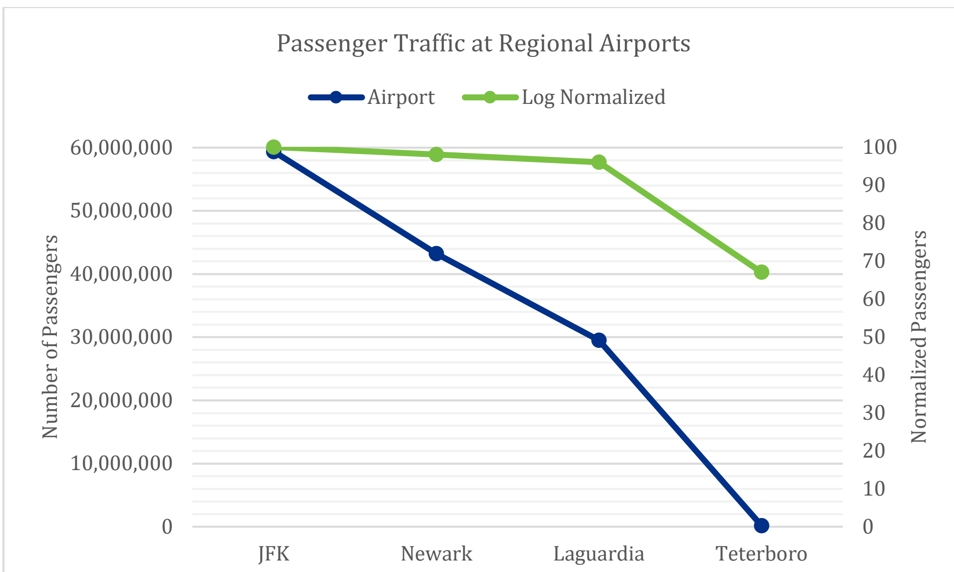


Figure 9 - Airport Passenger Traffic

Point Data:

Using point data for this analysis is complex. There are roughly 40 data layers in this analysis, each of which have individual, user-defined weights. Initially, the Inverse Data Weighting (IDW) process was used to develop a seamless surface based on the point data. This was completed to coincide with the similar processing used for the NACCS. Throughout the course of the study, several issues were encountered with the IDW process.

Issue 1: The IDW process has an unlimited search radius. This resulted in interpolation of the raster from a point location that is relatively far away. This was remedied by applying a buffer tolerance.

Issue 2: The buffer tolerance was divided into three distances: 0.5 mi, 0.25 mi and 100 ft based on the infrastructure's relative level of importance and radius of influence. For example, the buffer distance for a hospital is set to 0.5 mi while the distance for a gas station is set to 0.25 mi. **Table 4** in **Section 4.1.9** contains the full list of weights and buffer distances. When the three rasters for each of the buffer distances were overlain and combined into one raster, there were three potential options identified: using the maximum value of the three rasters, using the average value, or the weighted sum. None of these three options produced the desired results.

Resolution: The IDW was abandoned and replaced with buffers based on the buffer tolerance, summing the overlapping polygons and normalizing to maximum of 100. This method provided the best results and has the added bonus of accounting for point density, which the IDW did not.

Comparable to the passenger volume for airports, a similar methodology to determine weight was applied for passenger ridership on railroad stations. The NACCS analysis used a weight of 80 for all railroad stations and 50 for all Amtrak stations. Within this analysis, these two railroad station layers were merged into one dataset since ridership data allowed for them to be compared more objectively.

All Amtrak, Metropolitan Transit Authority (MTA) and Port Authority Trans-Hudson (PATH) systems have publicly-available, detailed ridership data on a station-by-station basis. The maximum weight (80) was assigned to the station with the greatest ridership (Times Square – 42nd Street) and all subsequent stations were assigned decreasing values based upon the ridership at each station. The MTA Broad Channel Station received the lowest weight of 50. Note that the Amtrak stations (excluding NYC Penn Station and Newark Penn Station) when ranked with the other railroad stations fell within the range of weights (60-39) around the weight (50) that had been originally assigned within the NACCS.

Railroad systems such as Long Island Railroad (LIRR), Metro-North Railroad (MNR), New Jersey Transit (NJT), and light rail lines have ridership data available, but the data is not on the same level of detail as the MTA/PATH data and is not available by station system-wide. A median value of 65 was used for these railroad stations. When the various railroad station ridership datasets were combined, duplicates for larger, cross-connecting stations (i.e., NYC Penn Station) were collapsed into a single station and the ridership was summed.

Figure 10 shows the result of ridership weighting with a log normalization scale applied. Note the maximum weight was set to 80 based on the relative importance compared other infrastructure assets (hospitals, airports, etc.).

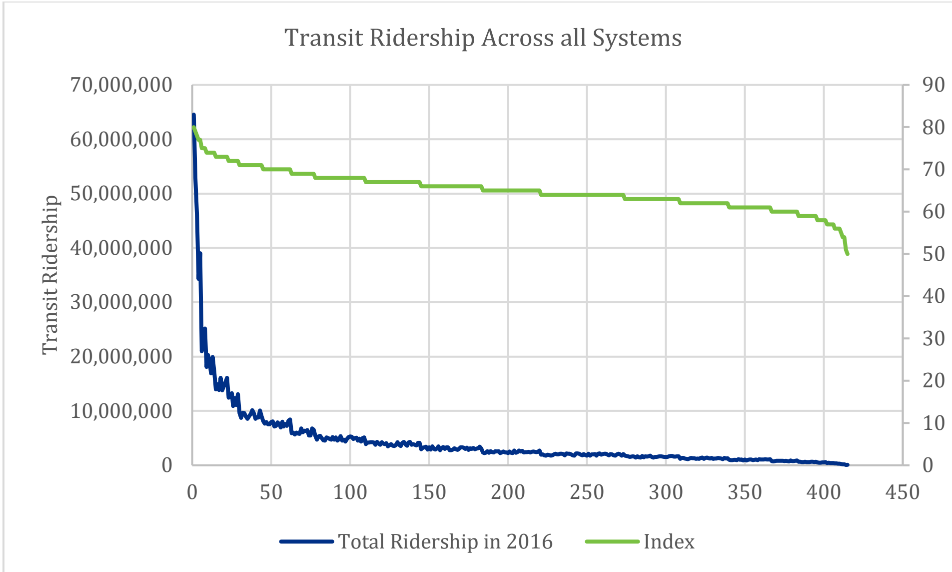


Figure 10 - Transit Ridership

The following steps were used to create the INFRA POINT raster.

1. Add a distance and weight field to each point feature class and populate the field based on **Table 4** in **Section 4.1.9**.
2. Buffer each feature class using the distance field to create a polygon buffer.
3. Convert each buffer feature class to raster using a 10-meter cell and the weight as the value field.
4. Mosaic all buffers together using the sum operation for the mosaic method.
5. Normalize the resulting raster by dividing by the max value by using the command:
    a. (RasterBuffer/RasterBuffer.maximum)*100

The final step in the infrastructure exposure is to create a composite exposure raster from the weighted points, lines and polygons.

4.1.3 Building Value

The building value exposure index represents the total replacement value of the built environment as defined by the FEMA Hazus dataset mapped to the Census Block level. The total replacement is the sum of Residential, Commercial, Industrial, Agriculture, Religion, Government and Education within each census block and is mapped to the field “Total Exposure”. The values range from $0 to $5,853,137,000. The values were normalized based on a log transformation and scaled to a maximum value of 100.

The source data was revised during the course of this study based on the release of new data on May 29, 2018 which resulted in refinements in the study area. In the latest Hazus 4.2 SP-1 released May 2018, valuations for all Hazus State databases (except Territories) have been updated from 2014 using the latest 2018 RS Means data. In addition, a more refined and accurate approach that utilized RS Means 2018 County adjustment factors for residential and nonresidential, as well as income ratios for adjusting single-family residential home valuations were included. As a result, significant changes occurred in New York and New Jersey.

Source: FEMA Hazus Building Stock 2018 released May 29, 2018. https://msc.fema.gov/portal/resources/hazus

Processing:

1. Extract the appropriate county building stock using the FEMA Hazus software by supplying the NYNJHATS study area boundary as the study area in Hazus.
2. Convert the Total Exposure to a value per square mile to calculate for density.
3. Add a new field "TotalExpDensity" (type: float) and calculate by using the command:
    a. !TotalExp/!shape.area@squaremile!
4. Apply the log transformation to the total density value. Add a new field "TotalExpLog" (type: float) and calculate by using the command:
    a. math.log10(!TotalExpDensity!)
5. Normalize the log total value density. Add a new field "TotalExpLogNorm" (type: float) and calculate by using the command:
    a. to !TotalExpLog!/max(!TotalExpLog!)*100
6. Convert the result to a raster using "TotalExpLogNorm" as the value field with a cell size of 10 meters.

4.1.4 Social Vulnerability

Similar to the metrics used by the NACCS, the social vulnerability exposure index was derived from Census Tracts using the following equation:

$$SoVI = \%Age_{65+} + \%Age_{5-} + \%Income_{subpoverty} + \%nonproficientEnglish$$

This dataset was updated to reflect the 2012 - 2016 5-year American Community Survey estimates.

Source: U.S. Census Tract 2012 - 2016 Detailed Tables: https://www.census.gov/geo/maps-data/data/tiger-data.html. See Census Tract Metadata.txt: https://www2.census.gov/geo/tiger/TIGER_DP/2015ACS/Metadata/TRACT_METADATA_2015.txt

Processing:

1. Download the NJ and NY Census Tract geodatabases with selected demographic and economic data for 2012 - 2016 detailed tables.
2. Use the Join Table tool on GEOID_Data to GEOID to the following tables/fields:
    a. Table: X01_AGE_AND_SEX
        - B01001e1: Total Population
        - B01001e3: Male under 5
        - B01001e27: Female under 5
        - B01001e20: Male 65 to 66
        - B01001e21: Male 67 to 69
        - B01001e22: Male 70 to 74
        - B01001e23: Male 75 to 79
        - B01001e24: Male 80 to 84

- B01001e25: Male 85 and over
- B01001e44: Female 65 to 66
- B01001e45: Female 67 to 69
- B01001e46: Female 70 to 74
- B01001e47: Female 75 to 79
- B01001e48: Female 80 to 84
- B01001e49: Female 85 and over

b. Table: X17_POVERTY
- B17001e1: Population
- B17001e2: Population in poverty past 12 months

c. Table: X16_LANGUAGE_SPOKEN_AT_HOME
- B16004e7: 5 to 17 years Speak Spanish English "not well"
- B16004e12: 5 to 17 years Speak other Info-European English "not well"
- B16004e17: 5 to 17 years Speak Asian English "not well"
- B16004e22: 5 to 17 years Speak Other English "not well"
- B16004e29: 18 to 64 years Speak Spanish English "not well"
- B16004e34: 18 to 64 years Speak other Info-European English "not well"
- B16004e39: 18 to 64 years Speak Asian English "not well"
- B16004e44: 18 to 64 years Speak Other English "not well"
- B16004e51: 65 and over Speak Spanish English "not well"
- B16004e56: 65 and over Speak other Info-European English "not well"
- B16004e61: 65 and over Speak Asian English "not well"
- B16004e66: 65 and over Speak Other English "not well"

3. Create and populate the following fields
   a. Rename B01001e1 field to Population
   b. Create field Age65P of type long and populate with the following python formula:
      !B01001e20!+!B01001e21!+!B01001e22!+!B01001e23!+!B01001e24!+!B01001e25!+!B01001e44!+ !B01001e45!+!B01001e46!+!B01001e47!+!B01001e48!+!B01001e49!
   c. Create field Age5U of type long and populate with the following python formula:
      !B01001e3!+!B01001e27!
   d. Create field PercAge65P of type float and populate with the following formula:
      *(!Age65P! / !Population!)*100*
   e. Create field PercAge6U of type float and populate with the following formula:
      *(!Age5U! / !Population!)*100*
   f. Create field Pov12M and calculate with the following formula:
      !B17001e2!
   g. Create field PercPov12M and calculate with the following formula:
      *(!Pov12M! / !Population!)*100*
   h. Create field EngNotWell and calculate with the following formula:
      !B16004e7! + !B16004e12! + !B16004e17! + !B16004e22! + !B16004e29! + !B16004e34! + !B16004e39! + !B16004e44! + !B16004e51! + !B16004e56! + !B16004e61! + !B16004e66!
   i. Create field PercEngNotWell and calculate with the following formula:
      *(!EngNotWell! / !Population!)*100*
4. Create and populate SoVI field
   a. Create field of "SoVI" (type: float) and populate with the following formula:
      !PercAge65P! + !PercAge5U! + !PercPov12M! +!PercNonEng
5. Convert the result to a raster using SoVI as the value field with a cell size of 10 meters.

4.1.5 Employment

The employment exposure index is used to represent the number of workers at a given location. The Census Transportation Planning Package (CTPP) product provides the self-reported work location for all workers, as measured by the American Community Survey, geocoded to the Census Tract level of geography. This dataset is intended to supplement the population data in that it represents the day-time population. It is estimated that the population on Manhattan doubles during the day due to commuters according to a report by Mitchell L. Moss and Carson Qing or the Rudin Center for Transportation Policy Management at the Wagner School of Public Services at New York University.
(https://wagner.nyu.edu/files/rudincenter/dynamic_pop_manhattan.pdf)

Source: Census Transportation Planning Package (CTPP) 2006 - 2010.
https://ctpp.transportation.org/ctpp-data-set-information/5-year-data/

Processing:

1. Download the census tracts for New York and New Jersey from the CTPP.
2. Merge the state datasets into one feature class.
3. Remove tracts outside of study area using the Select by Location tool with the NYNJHATS study area boundary.
4. F1 field represents the number of workers, rename F1 field to "workers".
5. F2 field represents the margin of error, rename F2 field to "error".
6. Calculate the worker density as workers per square mile.
7. Apply the log transformation to scale the data using the command:
    a. math.log10(!workerden!)
8. Use the maximum feature scaling to normalize to 0 - 100 using the command:
    a. !workdenlog!/max(!workdenlog!)
9. Convert the results to a raster using log normalized worker density with a cell size of 10 meters.

4.1.6 Cultural Resources

In the NACCS, the cultural resources index was combined with the environmental resources and habitat exposure indices. For the Enhanced Tier 2 GIS Analysis, separating the indices allows for transparency and flexibility in determining the final risk product. The cultural exposure index included locations of cultural and historic importance from the National Park Service's (NPS) National Registry of Historic Sites (NRHS). The cultural exposure index was first discussed in the NACCS Appendix C - Planning Appendix and in the analysis for the States of New York and New Jersey in the NACCS Appendix D - State and District of Columbia Analyses Appendix.

Source: NPS

Processing: All point layers -buildings, districts, objects, sites and structures - were buffered by 100 feet. Their polygon counterparts were downloaded from NPS, except for the Mott Avenue Control House from the buildings polygon layer. The purported property lines covered most of Manhattan along the East River.

4.1.7 Environmental Resources

The environmental resources exposure index was compiled from conservation datasets. The environmental exposure index was first discussed in the NACCS Appendix C - Planning Appendix and in the analysis for the States of New York and New Jersey in the NACCS Appendix D - State and District of Columbia Analyses Appendix. These areas are considered important to both the region's overall resilience with natural and nature-based features (NNBF) as well as the biodiversity of its flora and fauna. These layers included nature preserves from The Nature Conservancy (TNC), coastal barrier islands and rare, threatened and endangered species.

Source: TNC, US Fish and Wildlife Service, NY Natural Heritage (NYNH) and NJ Department of Environmental Protection (NJDEP)

Processing: All environmental layers were polygons. The NYNH significant natural communities' data layer was merged with the NYNH rare plants and animals and the NJDEP project landscape data to form one rare, threatened and endangered species polygon. Coastal barrier islands and TNC lands were also polygons; thus, the three layers were assigned weights, merged and then converted to raster.

4.1.8 Habitat

The habitat exposure index was compiled based on land cover data. In particular, freshwater wetlands were identified within the study area due to their role as NNBFs and critical habitats. The habitat exposure index was first discussed in the NACCS Appendix C - Planning Appendix and in the analysis for the States of New York and New Jersey in the NACCS Appendix D - State and District of Columbia Analyses Appendix.

Source: USGS National Wetlands Inventory, Cornell University Geospatial Information Repository (CUGIR), NJ Office of GIS

Processing: Wetland data from three separate sources was categorized according to their classification and combined into five general categories:

1. Forested wetland
    - Atlantic White Cedar
    - Coniferous wooded
    - Deciduous wooded
    - Mixed wooded
    - Severely burned vegetation
    - Wooded swamp
2. Scrub-shrub wetland
    - Coniferous scrub/shrub
    - Deciduous scrub/shrub
    - Formerly agricultural
    - Herbaceous
    - Managed wetland in built-up maintained recreational area
    - Managed wetland in maintained lawn greenspace
    - Mixed scrub/shrub
    - Phragmites dominated interior wetlands
    - Phragmites dominated urban area
    - Wetland rights-of-way

3. Freshwater/estuarine emergent marsh
   - Freshwater tidal marsh
   - Unvegetated flats
   - Freshwater emergent wetland
   - Freshwater pond
   - Lake
4. Freshwater forested/shrub wetland
   - Freshwater forested/shrub wetland
5. Riverine wetland
   - Estuarine and marine deep water
   - Estuarine and marine wetland
   - Riverine

These polygons were merged, assigned weights and converted to raster with a cell size of 10 meters.

4.1.9 Summary of Exposure Weights

The data used in this study was a combination of the NACCS data and updates for newer or more localized data sets. **Table 4** below lists the individual data layers that comprise the exposure datasets retrieved as discussed in **Section 3** and outlined above in **Section 4.1.1 to 4.1.8**.

Table 4 - Exposure Data Layers

Exposure Category	Layer	Data Type	Processing Description	Weight
Population Density	Population Density Grid	Raster	Log normalized	0 - 100
Infrastructure	Airport Boundaries	Polygon	N/A	100
	All Places of Worship	Points	1/4 mile buffer	0
	Amtrak Stations	Points	1/2 mile buffer	50
	Bus	Line	1/4 mile buffer	30
	Cellular Towers	Points	100 ft buffer	30
	Channel	Polygon	N/A	60
	Colleges/Universities	Point	1/4 mile buffer	65
	Communication Centers	Point	1/4 mile buffer	50
	Electric Generating Units	Point	1/4 mile buffer	100
	EMS	Point	1/2 mile buffer	100
	Ferry Terminals	Point	1/2 mile buffer	30
	Fire Stations	Point	1/2 mile buffer	100
	Gas Stations	Point	1/4 mile buffer	65
	Hospitals	Point	1/2 mile buffer	100
	Highways	Line	Rural Interstate- 60 ft buffer	70
			Rural Principal Arterial- 60 ft buffer	
			Rural Minor Arterial- 30 ft buffer	
			Rural Major Collector- 30 ft buffer	
			Urban Interstate- 90 ft buffer	
			Urban Freeway or Expressway- 90 ft buffer	
			Urban Principal Arterial- 60 ft buffer	

Exposure Category	Layer	Data Type	Processing Description	Weight
			Urban Minor Arterial- 30 ft buffer	
			Urban Local- 30 ft buffer	
	Hurricane Evacuation Routes	Line	30 ft buffer	100
	Intermodal Terminal Facilities	Point	1/4 mile buffer	60
Infrastructure	Law Enforcement Location	Point	1/4 mile buffer	80
	Local Emergency Operation Centers	Point	1/2 mile buffer	100
	National Shelter System	Point	1/2 mile buffer	65
	Natural Gas Compressor Stations	Point	1/4 mile buffer	50
	Natural Gas Receipt and Delivery Points	Point	1/4 mile buffer	30
	Nuclear Power Plants	Point	1/2 mile buffer	100
	Nursing Homes	Point	1/2 mile buffer	80
	Oil and Natural Gas Interconnects	Point	1/4 mile buffer	15
	Oil Refineries	Point	1/4 mile buffer	65
	Pharmacies	Point	1/4 mile buffer	50
	POL Terminals / Storage Facilities / Tank Farms	Point	1/4 mile buffer	50
	Ports	Point	1/4 mile buffer	50
	Railroad	Line	30 ft buffer	70
	Railroad Stations	Point	1/2 mile buffer	80
	Railroad Yards	Point	1/2 mile buffer	65
	Receiving Hospitals	Point	1/2 mile buffer	90
	Road and Railroad Bridges	Point	1/4 mile buffer	65
	Road and Railroad Tunnels	Line	30 ft buffer	65
	Public Schools	Point	1/2 mile buffer	50
	Private Schools	Point	1/2 mile buffer	50
	Service Providers	Point	1/2 mile buffer	50
	State Emergency Operation Centers	Point	1/2 mile buffer	100
	Strategic Petroleum Reserves	Point	1/4 mile buffer	50
	Substations	Point	1/4 mile buffer	65
	Transmission Lines	Line	30 ft buffer	60
	Urgent Care Facilities	Point	1/4 mile buffer	65
	Wastewater Treatment Plants	Point	1/4 mile buffer	90
	Water Treatment Facilities	Point	1/4 mile buffer	90
Building Value	HAZUS Raster Normalized to 100	Polygon	Log normalized on building value per sq. mi	0 - 100
Social Vulnerability	Social Vulnerability	Raster	Log normalized	0 - 100
Employment	CTPP Workers by Census Tract	Raster	Log normalized worker density	0 - 100
Cultural	Cultural Resource Building Polygon	Polygon	N/A	85
	Cultural Resource Building Point	Polygon	Converted to polygon, 100 ft buffer	85
	Cultural Resource District Point	Polygon	Converted to polygon, 100 ft buffer	85
	Cultural Resource District Polygon	Polygon	N/A	85
	Cultural Resource Object Point	Polygon	Converted to polygon, 100 ft buffer	85

Exposure Category	Layer	Data Type	Processing Description	Weight
	Cultural Resource Site Polygon	Polygon	N/A	85
	Cultural Resource Site Polygon	Polygon	Converted to polygon, 1000 ft buffer	85
	Cultural Resource Structure Polygon	Polygon	N/A	85
	Cultural Resource Structure Point	Polygon	Converted to polygon, 100 ft buffer	85
Environmental	Coastal Barrier Islands under CBRA	Polygon	N/A	91
	Rare, Threatened and Endangered Species	Polygon	N/A	89
	The Nature Conservancy Conservation Areas	Polygon	N/A	73
Habitat	Forested Wetland	Polygon	N/A	80
	Scrub- Shrub Wetland	Polygon	N/A	73
	Freshwater/Estuarine Emergent Marsh	Polygon	N/A	30
	Freshwater Forested/Shrub Wetland	Polygon	N/A	30
	Riverine Wetlands	Polygon	N/A	61
	Wetlands (NWI)	Polygon	N/A	0

4.2 Flooding Methodology

Development of floodplain extents is the basis of coastal flood vulnerability. This study used three coastal flooding scenarios: the 10 percent flood, 1 percent flood and the 0.1 percent flood (i.e., 10-year, 100-year and 1,000-year events) as summarized in **Table 5**. The 1 percent flood values include three (3) feet of water level. The addition of 3 feet to the 100-year flooding elevation seeks to reduce uncertainty about project performance with different sea level change scenarios, associated wave runup and compliance with building regulations and zoning requirements. These three scenarios were combined into a composite vulnerability raster and assigned a value according to the probability of occurrence. The values were adjusted up by a factor of 10 after a sensitivity run proved that the final risk values were very small. The ratio of probability among the events remained the same.

Table 5 - Flooding Event and Probability

FLOOD EVENT	PROBABILITY
10 percent flood	1/10
1 percent flood + 3 feet	1/100 + 3 feet
0.1 percent flood	1/1000

4.2.1 ADCIRC Node Data

This section outlines the process for delineating and incorporating flooding-event elevation data from the ADCIRC model developed as part of the NACCS. The flooding event elevations for this study were based on the most representative ADCIRC node at each of the 34 study shoreline or tributary segments. These points were decided upon by USACE with a concurrent study using the same data.

The nodes were then manually assigned to each representative study segment. In some cases, multiple nodes were assigned to a single segment, such as the Hudson River, due to the length of the segment and differences in flood elevation. **Figure 11** shows the relationship between the nodes and the study segments. This relationship was used to define the boundaries of the representative node to use in determining the flood inundation extents.

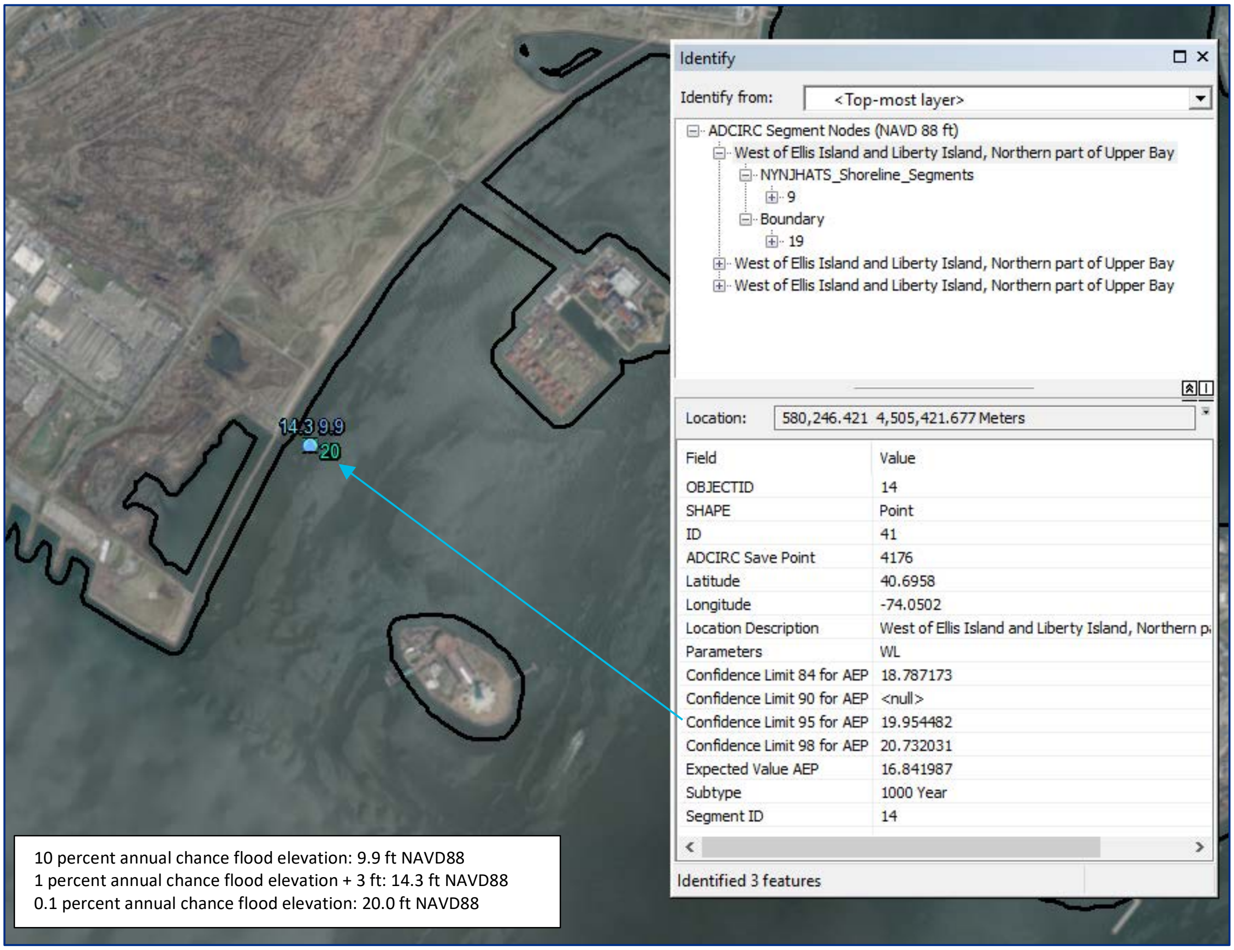


Figure 11 - ADCIRC Node and Study Segment Links

4.2.2. Datum Conversion

The ADCIRC node elevation datum is in mean sea level (MSL) in meters. The ground surface elevation data is in NAVD88 meters. Prior to developing the flood inundation extents, a common datum is needed. NOAA's VDATUM conversion tool[1] was used to convert the ADCIRC nodes from MSL meters into NAVD88 meters. The average conversion rate for the study is -0.036 meters. There are two special cases in which the conversion tool did not provide coverage, specifically along the Passaic River. NOAA Tides and Currents was used to determine the datum conversion. **Table 6** is a sample of the datum conversion values, the complete table is found in the GIS deliverable.

[1] https://vdatum.noaa.gov/vdatumweb/

Table 6 - Sample Datum Conversion at Various ADCIRC points

ADCIRC SAVE POINT *	LATITUDE	LONGITUDE	CONVERSION (MSL TO NAVD88 METERS)	SOURCE
3789	40.4478	-74.0039	-0.0708	Calculated using VDATUM
11740	40.4943	-74.2453	-0.0293	Calculated using VDATUM
13809	40.5361	-74.1386	-0.0478	Calculated using VDATUM
4004	40.5915	-74.2025	-0.0362	Calculated using VDATUM
3967	40.5776	-74.2114	-0.0342	Calculated using VDATUM
11754	40.6772	-74.1407	-0.0416	Calculated using VDATUM
4206	40.7144	-74.1211	-0.0343	Calculated using VDATUM
7412	40.7867	-74.1467	-0.014	NOAA Tides and Currents Station: 8530591, BELLEVILLE, PASSAIC
4281	40.7655	-74.0892	-0.0618	Calculated using VDATUM
7976	41.0346	-73.9085	0.104	Calculated using VDATUM

4.3.3 Floodplain Development

The floodplain development process involved mapping the inundation extent from the ADCIRC nodes using detailed topographic information. The source of the topography data is described in **Section 3.2**.

Processing:

1. Define the boundary for each study segment and ADCIRC node. Perform this task by considering natural features that may lead to a change in flood elevation. **Figure 12** shows the selected ADCIRC node and related study segments polygons. The extent of the darker blue polygon was drawn to represent the wider channel of the Upper New York Bay. The narrower areas of the Kill van Kull and Hudson are represented by different nodes.

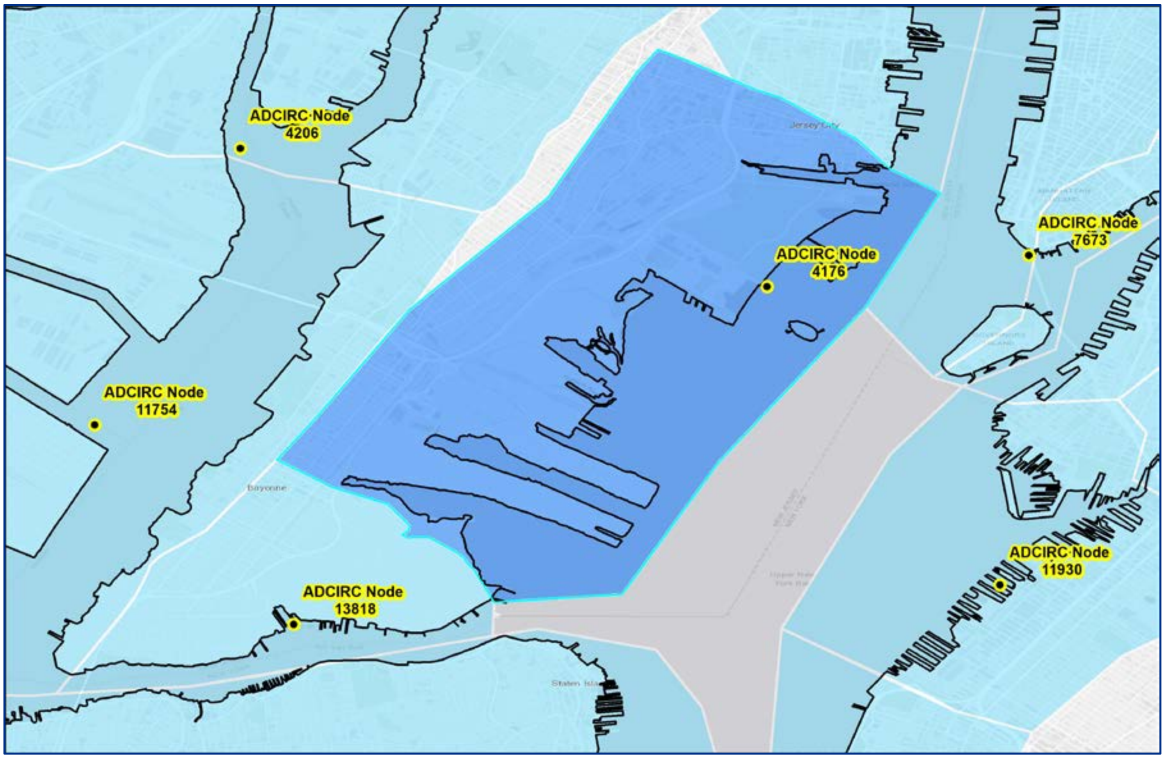


Figure 12 - ADCIRC Node and Study Segment Polygons

2. Assign the ADCIRC node flood event elevations to the boundaries. This is performed for all three events.
3. A python script was used to develop the inundation extents. The primary components of the script are as follows:
    a. Loop through each event (10 percent flood, 1 percent flood +3 ft, 0.1 percent flood)
    b. Convert the ADCIRC boundary to a raster with the event elevation as the value.
    c. Perform greater than function where the water surface raster is greater than the ground.
    d. Automatically fill in holes fewer than 5,000 m^2. Small holes were filled in to show that there is still risk associated with a small high ground area surrounded by flooding.
    e. Automatically bring back smaller holes with an aspect ratio of 25% (100m in length/25m in width). This is done using the minimum bounding geometry tool to calculate the minimum bounding length and width or the irregularly shaped polygons. These holes often represent elevated roadways.
    f. Smooth boundaries using the Majority Filter and Boundary Clean methods using the Esri Spatial Analyst toolbox.
    g. Convert the raster to a polygon for manual cleanup.
    h. Manually remove disconnected flooding where no hydraulic connection is apparent in either the LiDAR or aerial imagery.
4. Add a value field and assign values from Table 5.
5. Convert the results to a raster with 10-meter cell size using the probability value.
6. Mosaic all three rasters into one with maximum as the mosaic operator.

4.3.4 Flooding Extent with FWOPC Projects

There are several CSRM projects that could affect the plan selection process because they are of large enough scale to affect the benefit-cost analysis for this study. The projects are expected to have permits and funding for construction secured by July 2020, indicating that these projects are most likely to be implemented. These projects are considered the Future without Project condition (FWOPC). Accounting for these projects in the vulnerability index is important to ensure that the composite risk reflects the current and near future reality, especially in cases when the project is completed after topographic data was collected.

USACE provided the project extents and structure crest elevation in a shapefile format. Two separate methods were used to incorporate the project into the flooding extents. Method 1 was applied when the project extents clearly lined up with high ground in the topographic data. The processing for this method was done by manually clipping out the flooding based on a visual inspection of the ground surface and the project extents. Method 2 was applied when there was some uncertainty on the influence of the project, such as a gap between the structure crest and high ground. This process for this method involved incorporating the project extents into the DEM using the project crest height as the risk management elevation.

The flooding was reprocessed using the steps detailed in **Section 4.3.3.**

Passaic Tidal Newark Flanking Project

The Passaic Tidal Newark Flanking project is a seawall at 14 ft NAVD88 (**Figure 13**). The extents of the project tie into the existing rail bed. This project manages risk against the 10 percent flood event at (10.2 ft NAVD88) but not the 1 percent flood + 3 feet (17.8 ft NAVD88) and 0.1 percent flood (19 ft NAVD88) events. Method 1 was applied and the inundation extents were manually adjusted based on the project extent shapefile and existing topography.

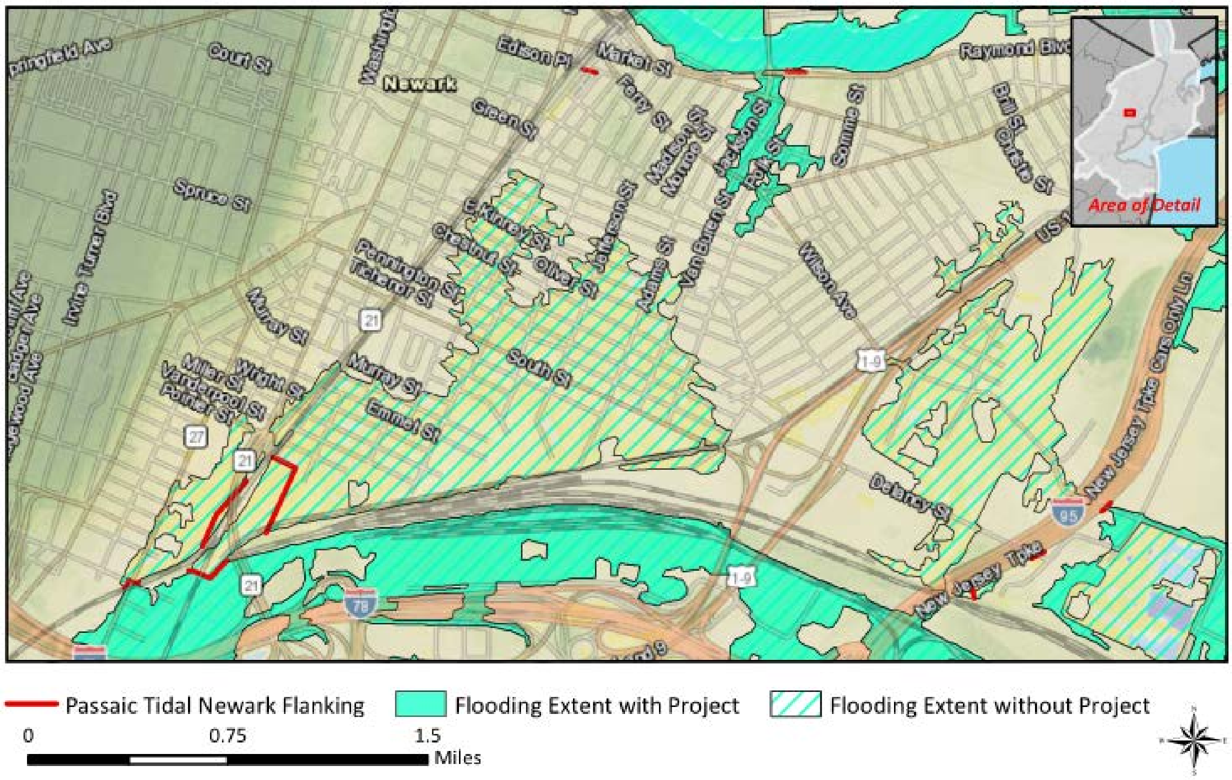


Figure 13 - Passaic Tidal Newark Flanking

Port Monmouth CSRM Project

The Port Monmouth Road project is a dune and levee system at 16 ft NAVD88 (**Figure 14**). The project manages risk from the 10 percent flood event (9.8 ft NAVD88) but not the 1 percent flood +3 feet (17.1 ft NAVD88) and 0.1 percent flood (19.3 ft NAVD88) events. Method 1 was applied and the inundation extents were manually adjusted based on the project extent shapefile and existing topography.

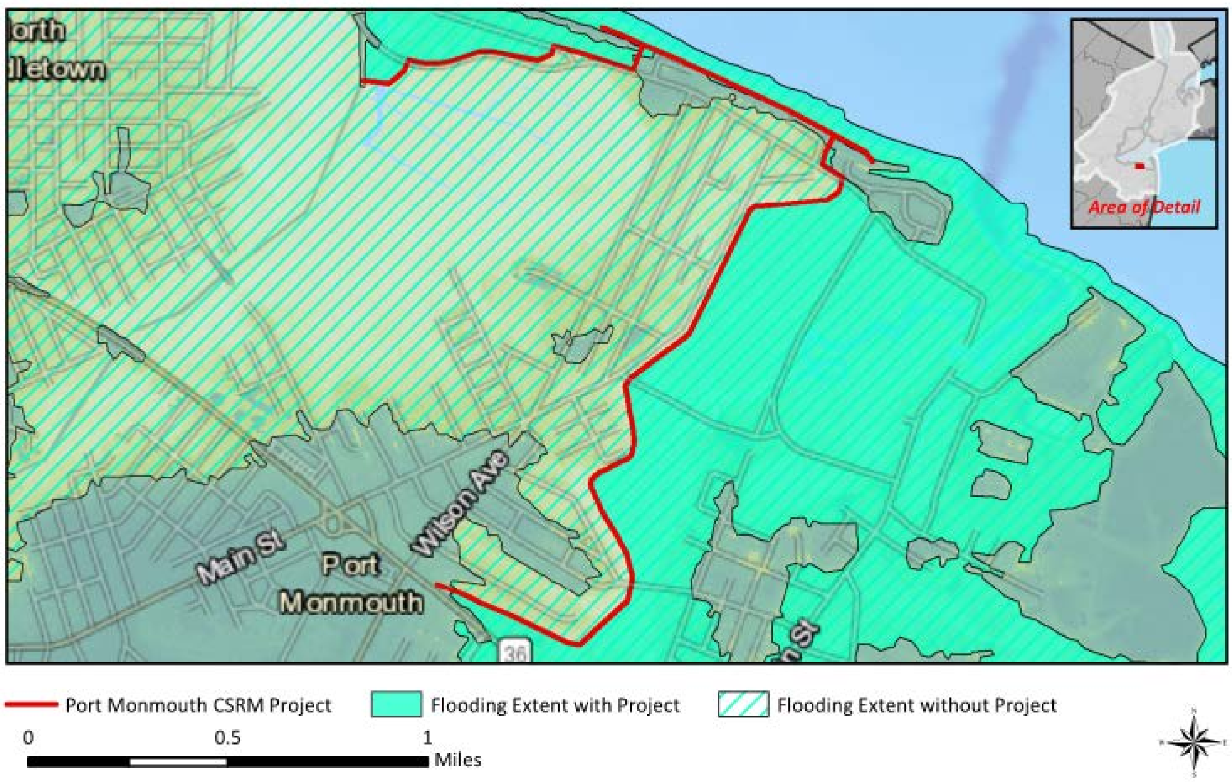


Figure 14 - Port Monmouth Road CSRM Project

South Shore Staten Island (SSSI) CSRM Project

The SSSI CSRM project is a sand-covered, buried seawall at 19.4 ft NAVD88, an earthen levee at 16.9 ft NAVD88 and a floodwall at 19.4 ft NAVD88 (**Figure 15**). The project manages risk from the 10 percent flood event (10.3 ft NAVD88) and the 1 percent flood + 3 feet event (18 ft NAVD88) but not the 0.1 percent flood event (21.1 ft NAVD88). Method 1 was applied and the inundation extents were manually adjusted based on the project extent shapefile and existing topography.

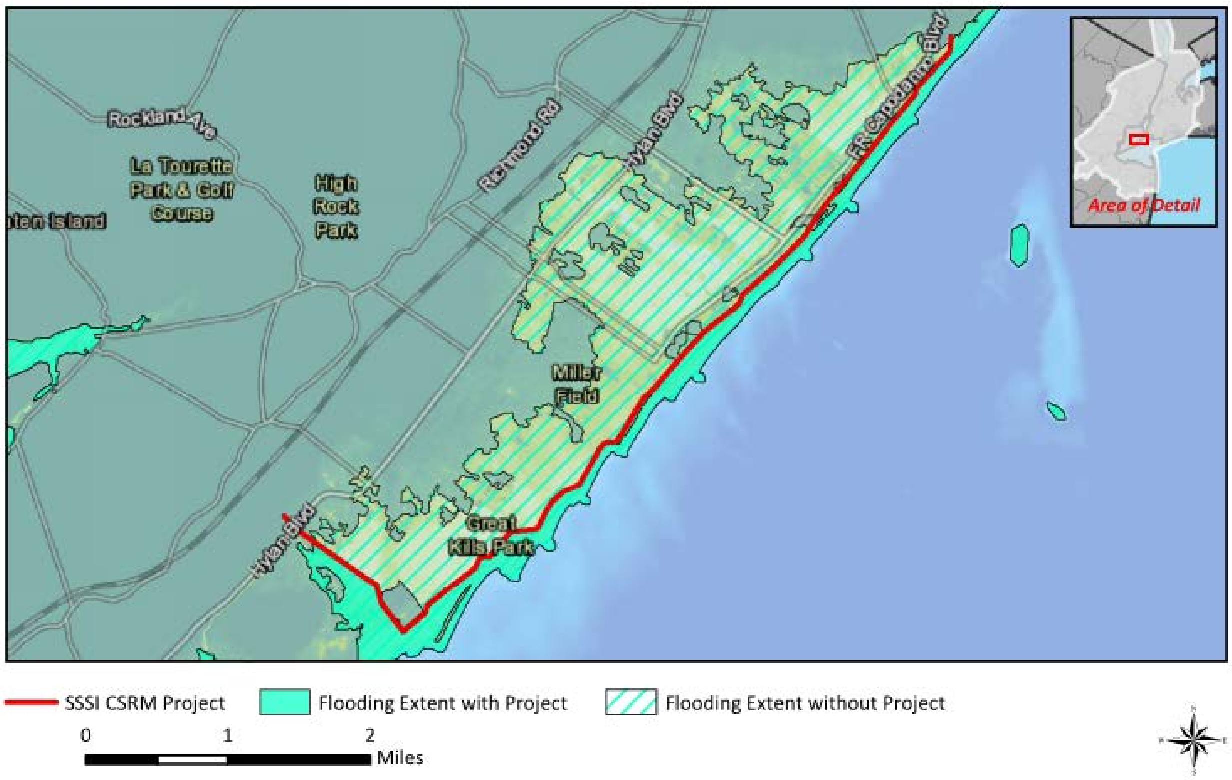


Figure 15 - SSSI CSRM Project

Coney Island CSRM project

The Coney Island CSRM project is a sand-covered, buried seawall at 12 ft NAVD88 (**Figure 16**). The project manages risk from the 10 percent flood event (9.7 ft NAVD88) but not the 1 percent flood + 3 feet event (16.9 ft NAVD88) and 0.1 percent flood event (19.3 ft NAVD88). The seawall crest was reflected in the topography; therefore, no changes were made to the flooding.

Figure 16 - Coney Island CSRM Project

Rockaway CSRM Project

The Rockaway CSRM project is a sand-covered, buried seawall at 18 ft NAVD88 (**Figure 17**). The project manages risk from the 10 percent flood event (9.6 ft NAVD88) and the 1 percent flood + 3 feet event (17 ft NAVD88) but not the 0.1 percent flood event (19.6 ft NAVD88). Method 2 was applied and the structure was incorporated into the DEM. The flood extents script was rerun with the modified DEM to reflect the changes in flooding. This method was used because the flooding impacts both the north and south side of the peninsula.

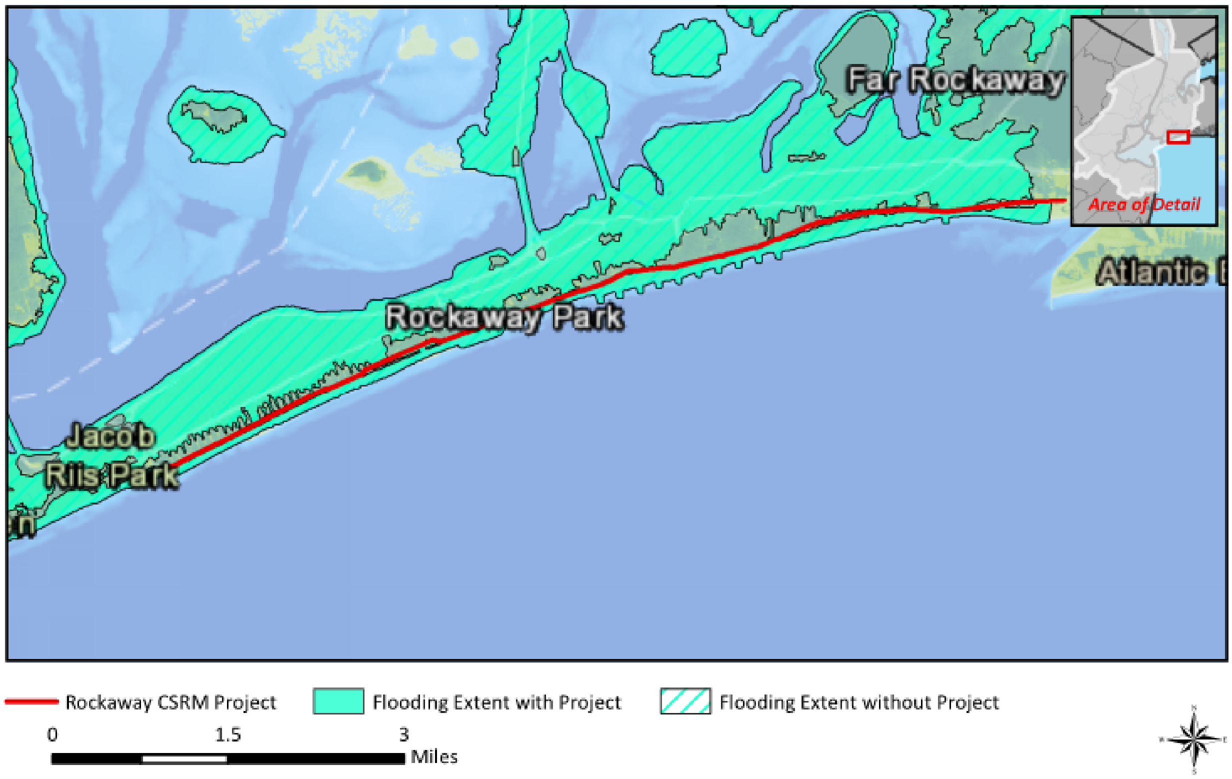


Figure 17 - Rockaway CSRM Project

Keansburg Seawall Project

The Keansburg CSRM project is a sand-covered, buried seawall at 14 ft NAVD88 (**Figure 18**). The project manages risk from the 10 percent flood event (9.8 ft NAVD88) but not the 1 percent flood + 3 feet event (17.1 ft NAVD88) and 0.1 percent flood event (19.3 ft NAVD88). Method 1 was applied and the inundation extents were manually adjusted based on the project extent shapefile and existing topography.

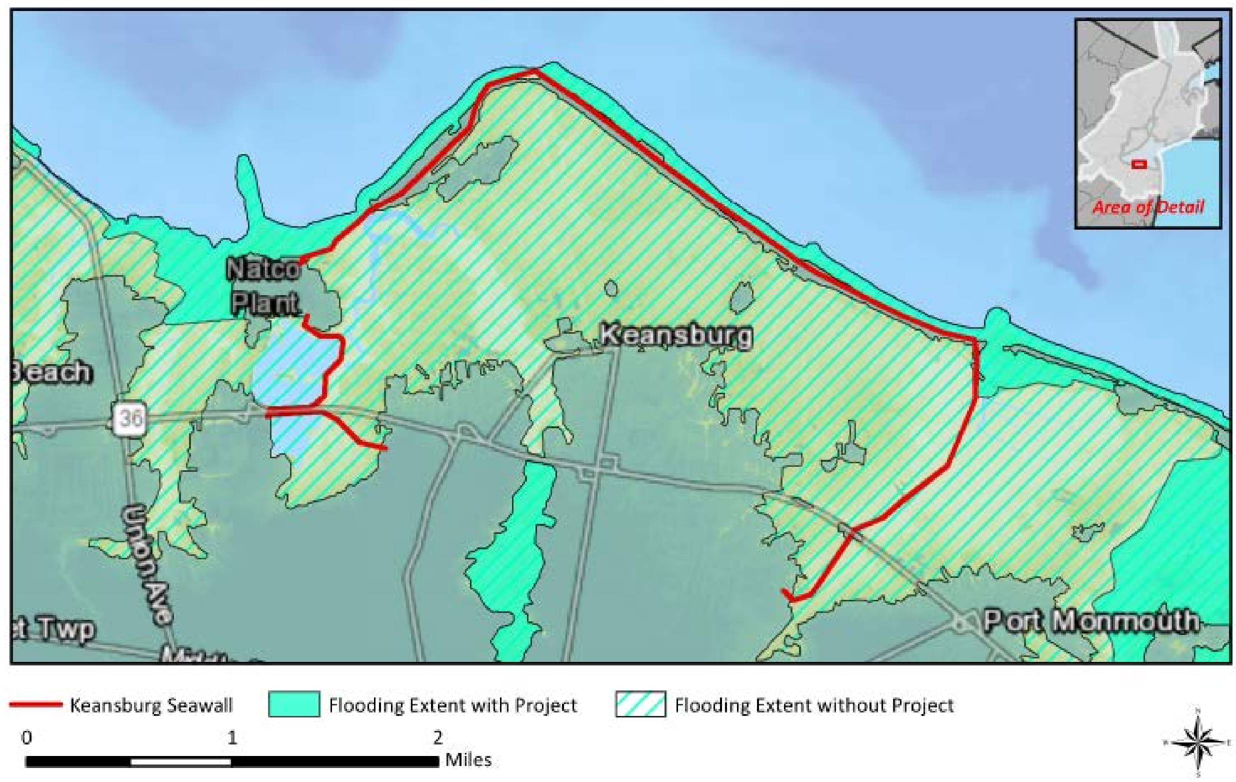


Figure 18 - Keansburg Seawall

Laurence Harbor CSRM Project

The Lawrence Harbor CSRM project is a seawall at 13 ft NAVD88 (**Figure 19**). The project manages risk from the 10 percent flood event (10.8 ft NAVD88) but not the 1 percent flood + 3 feet event (18.7 ft NAVD88) and 0.1 percent flood event (21.9 ft NAVD88). Method 1 was applied and the inundation extents were manually adjusted based on the project extent shapefile and existing topography.

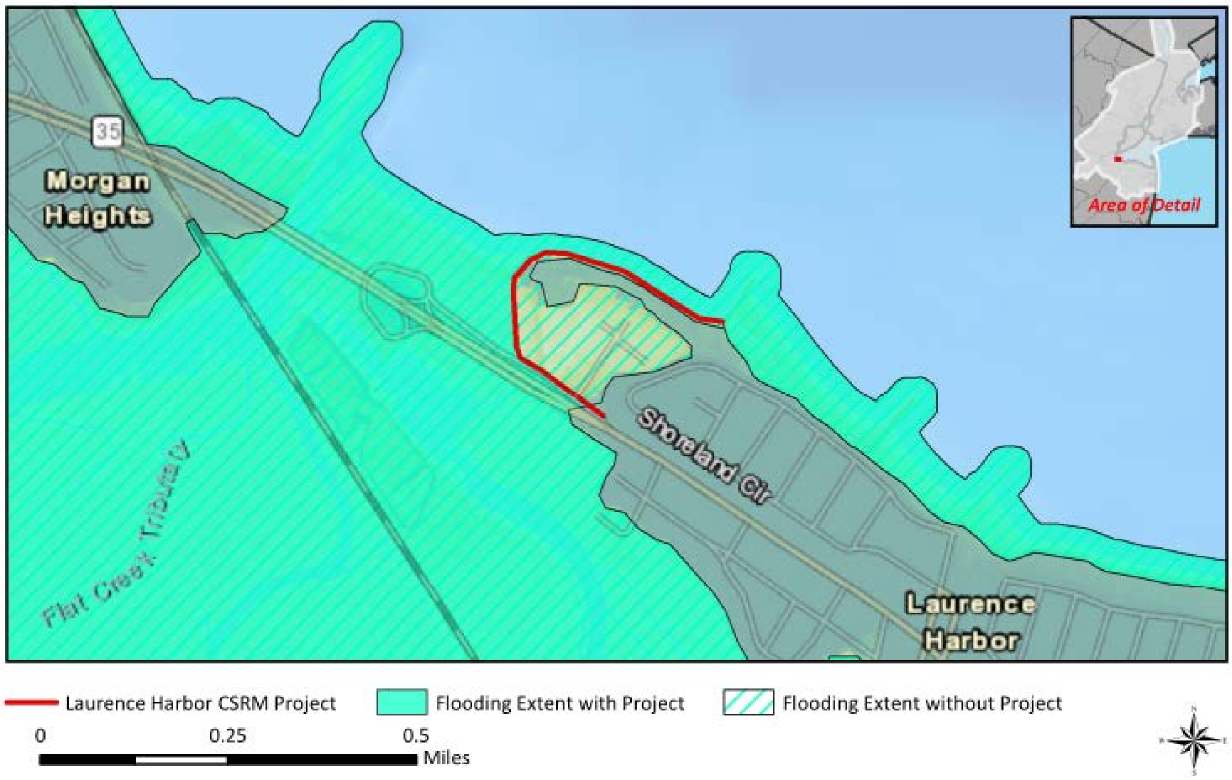


Figure 19 - Laurence Harbor

Union Beach CSRM Project

The Union Beach CSRM project is a seawall at 12 ft NAVD88 (**Figure 20**). The project manages risk from the 10 percent flood event (9.8 ft NAVD88) but not the 1 percent flood + 3 feet event (17.1 ft NAVD88) and 0.1 percent flood event (19.3 ft NAVD88). Method 1 was applied and the inundation extents were manually adjusted based on the project extent shapefile and existing topography.

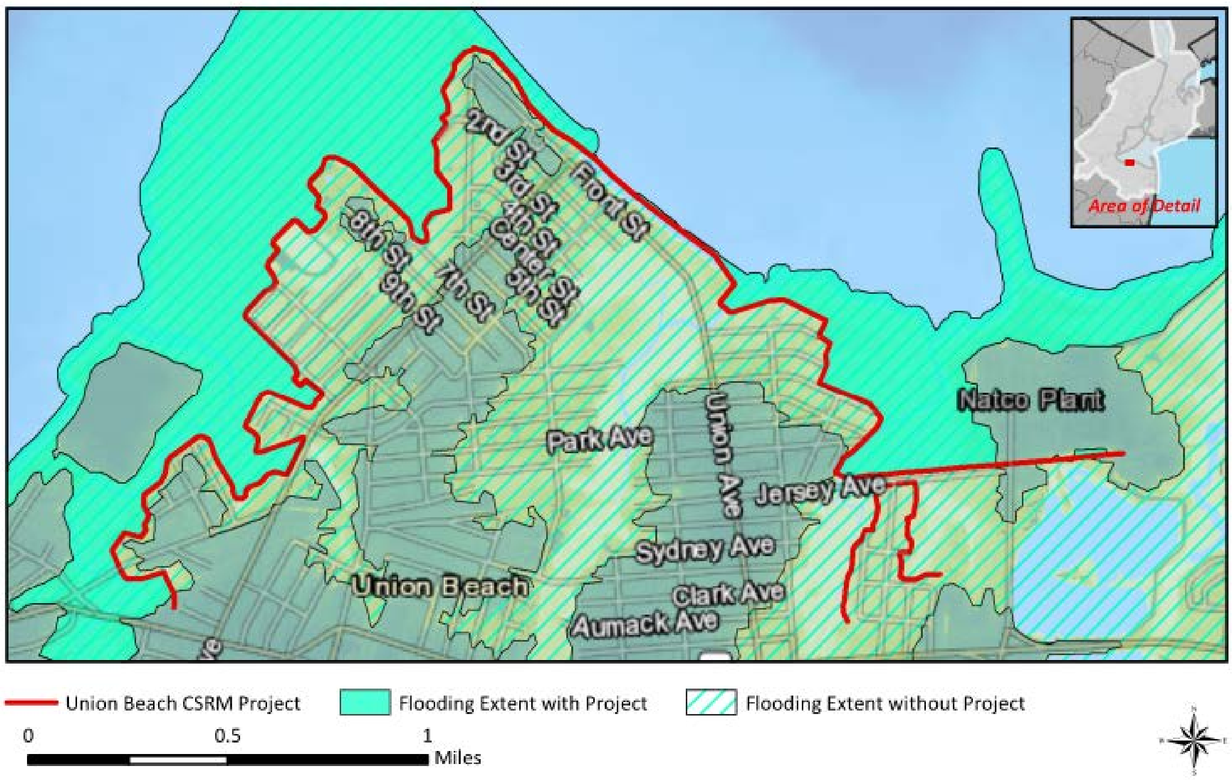


Figure 20 - Union Beach Floodwall

Passaic Valley Sewerage Commission Floodwall Project

The Passaic Valley Sewerage Commission project is a proposed floodwall connecting to an existing berm (**Figure 21**). Award for construction is expected in 2019. The western portion of the project is at 17 ft NAVD88. The eastern portion is at 19ft NAVD88. The project manages risk from the 10 percent flood event (10.2 ft NAVD88). The eastern portion of the project also manages risk from the 1 percent flood + 3 feet event (17.6 ft NAVD88) and the 0.1 percent flood event (18.8 ft NAVD88). Method 1 was applied and the inundation extents were manually adjusted based on the project extent shapefile and existing topography.

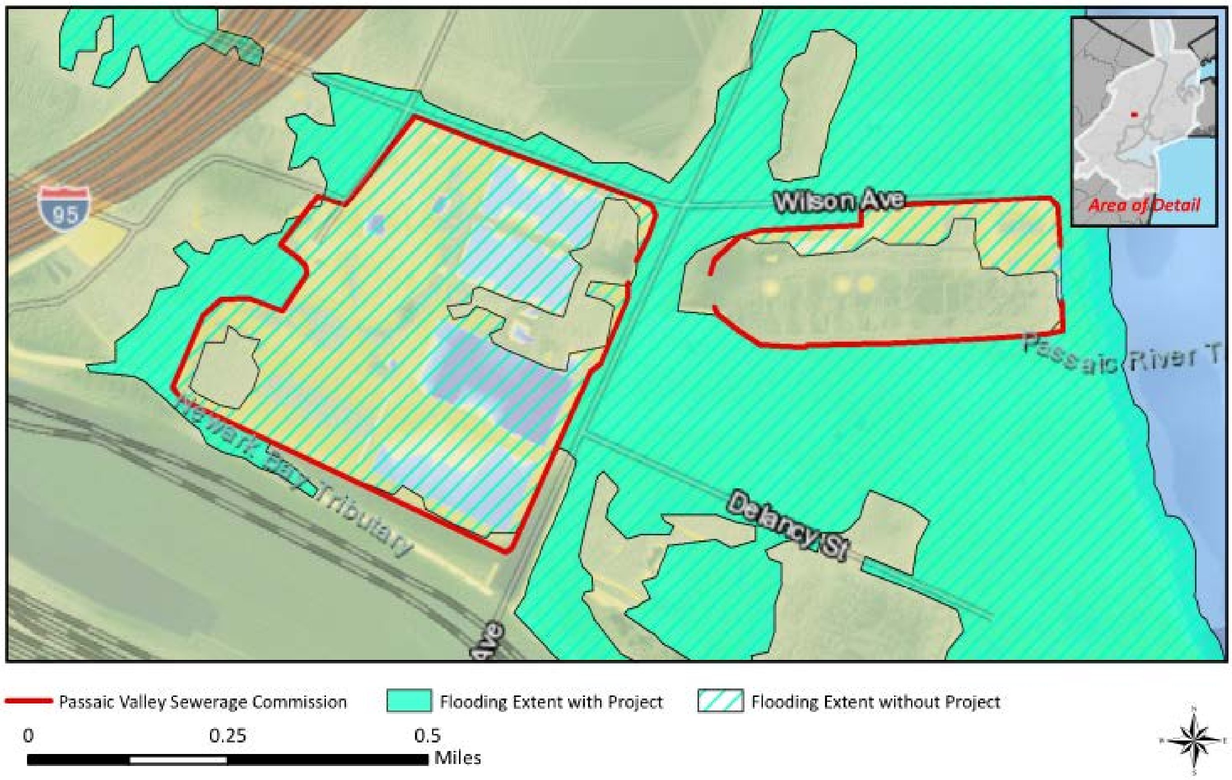


Figure 21 - Passaic Valley Sewerage Commission Floodwall

East Side Coastal Resiliency and Two Bridges Projects

The East Side Coastal Resiliency + Two Bridges projects include floodwalls, levees, deployable gates and interior drainage management at 16.5 ft NAVD88 (**Figure 22**). Construction is anticipated to begin in Spring 2019. The project manages risk from the 10 percent flood event (9.9 ft NAVD88), but not the 1 percent flood + 3 feet event (17.1 ft and 17.2 ft NAVD88) or the 0.1 percent flood event (19.5 ft and 19.7 ft NAVD88). Method 1 was applied and the inundation extents were manually adjusted based on the project extent shapefile and existing topography.

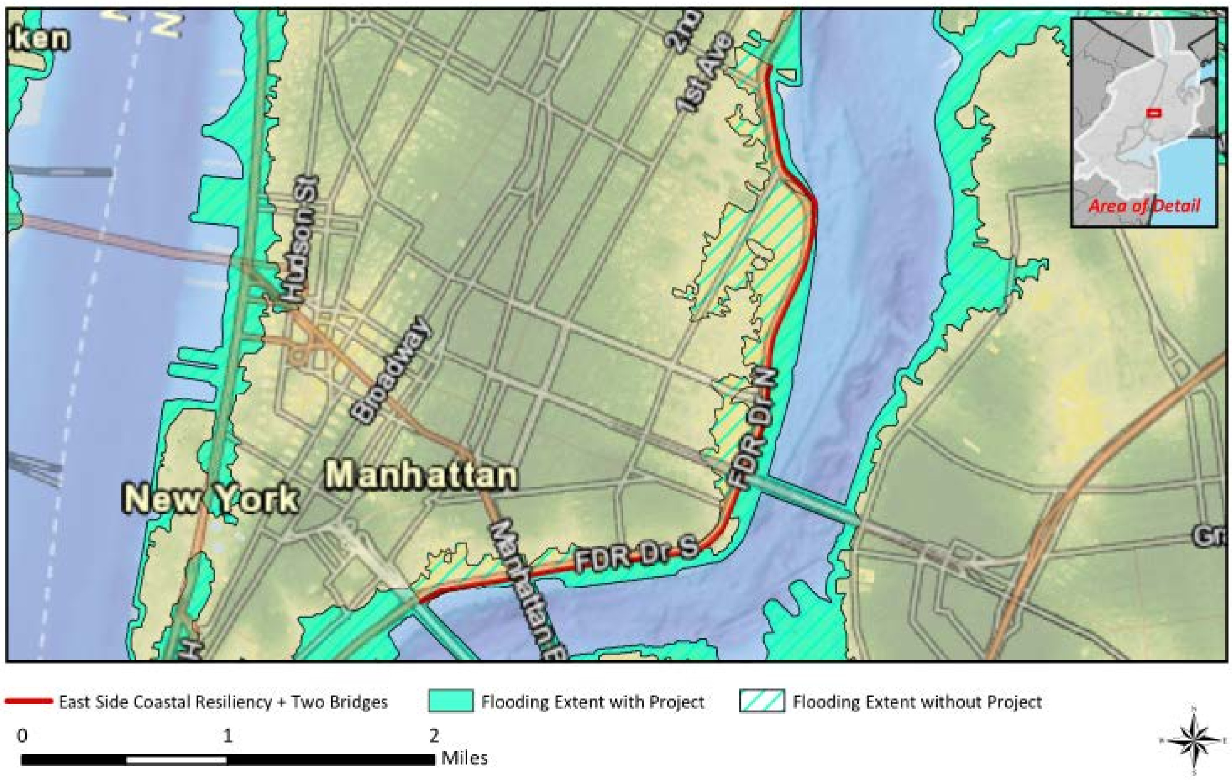


Figure 22 - East Side Coastal Resiliency and Two Bridge Projects

This page intentionally left blank.

Section 5

Composite Index Results

The results of the analysis are described in this section. The final stage of the analysis is to apply the index weights and perform the raster math to derive the composite risk raster as described in the following equation.

$$Risk = Vulnerability \times \sum_{i}^{n} Exposure \times Weight$$

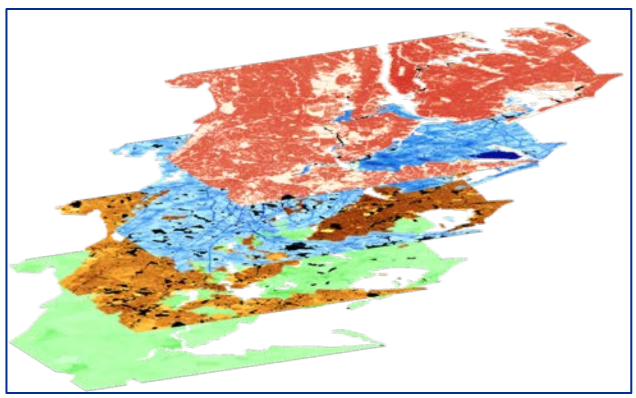
The weights are subjective in nature; therefore, a “slider tool” was developed in ArcMap Desktop to allow the user to modify the weights of the exposure indices and compare and contrast various weighting scenarios. For details on the slider tool, refer to Appendix A the “NYNJHATS Enhanced Tier 2 GIS Analysis - Slider Application” document.

5.1 Composite Exposure Index

The total composite exposure is the weighted sum of all eight exposure indices. The default weights in **Table 7** were used to develop figures in this section. Due to the size and shape of the NYNJHATS study area, **Figure 23** represents the New York-New Jersey Harbor area. **Figure 24** and **Figure 25** represent the Hudson River area. **Appendix B** contains the exposure indices for each of the eight categories for the New-York New Jersey Harbor and Hudson River area.

Table 7 - Exposure Index Weights

CATEGORY	WEIGHT
Population Density	25%
Infrastructure	25%
Building Value	20%
Social Vulnerability	10%
Employment	10%
Cultural	4%
Environmental	3%
Habitat	3%
TOTAL	**100%**



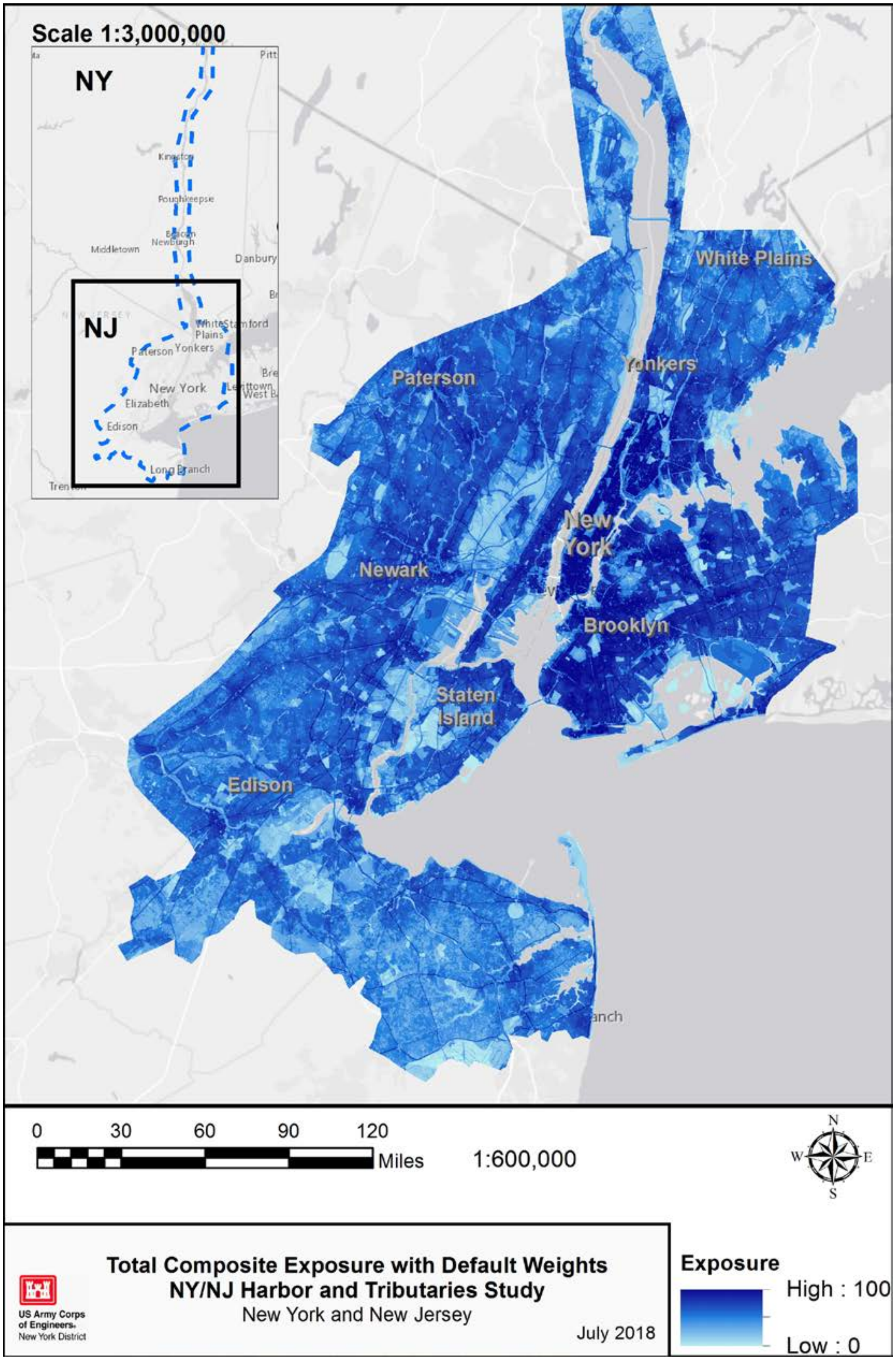


Figure 23 - Total Composite Exposure Index in NY-NJ Harbor

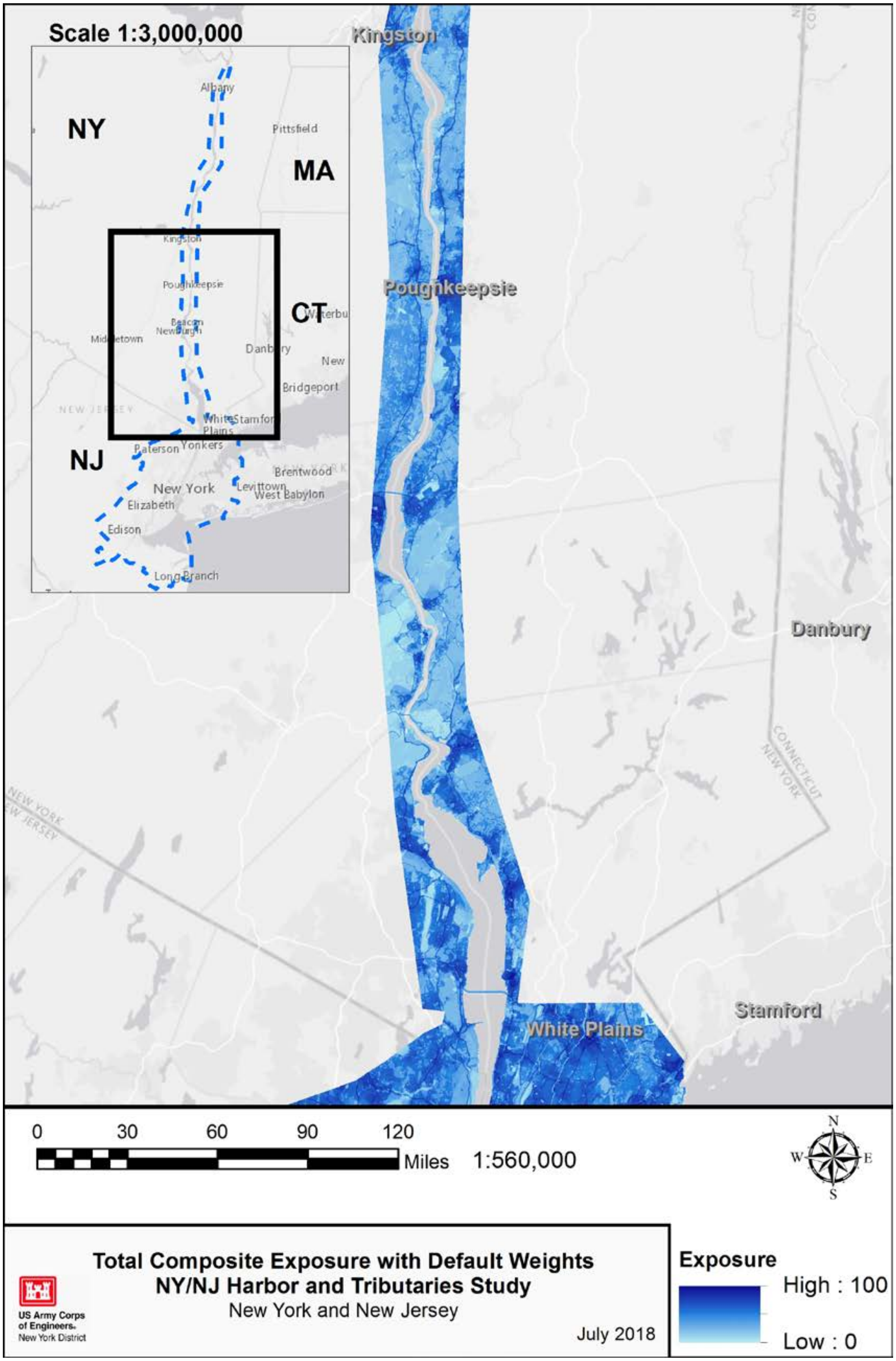


Figure 24 - Total Composite Exposure Index along the Lower Hudson River

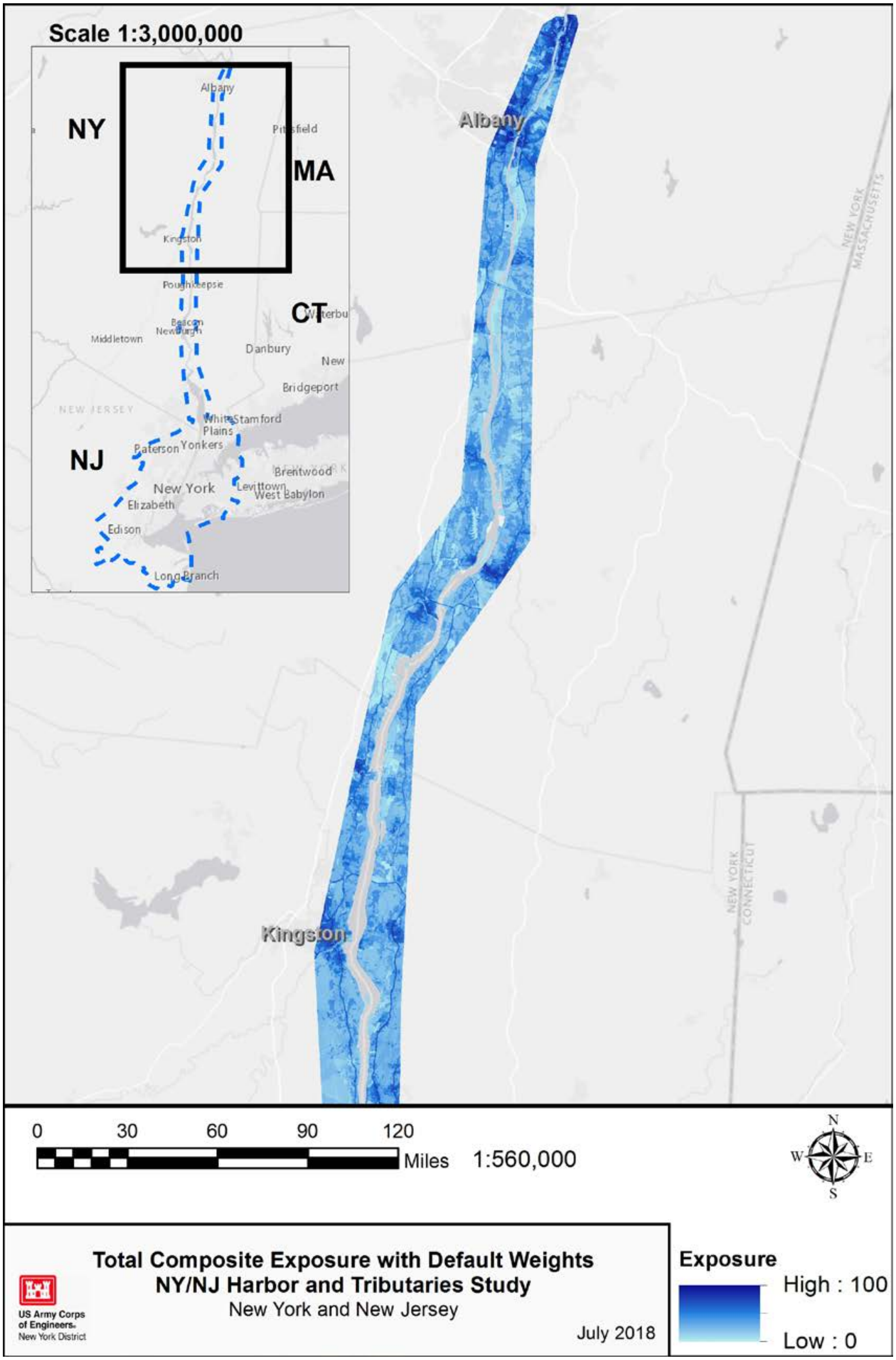


Figure 25 - Total Composite Exposure Index along the Upper Hudson River

5.2 Composite Vulnerability Index

The vulnerability index is the combination of the 10 percent, 1 percent + 3 feet and 0.1 percent annual chance (i.e., 10-year, 100-year + 3 ft, 1,000-year) flood events. Two indices were developed: a current day vulnerability index and a FWOPC vulnerability index, which includes the CSRM projects described in **Section 4.3.4**. The FWOPC index was used in **Figure 26**, **Figure 27** and **Figure 28.**

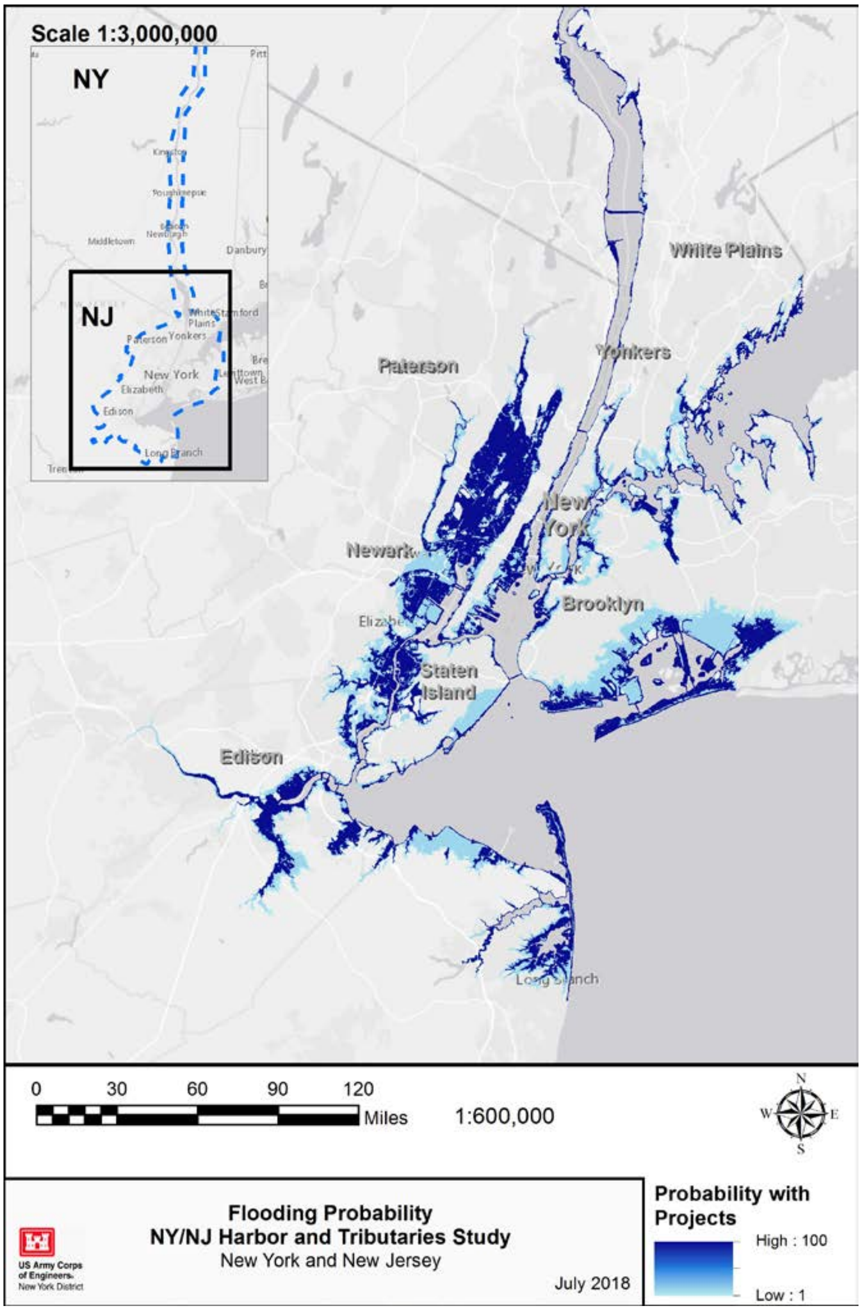


Figure 26 – Composite Vulnerability Index in New York - New Jersey Harbor (FWOPC)

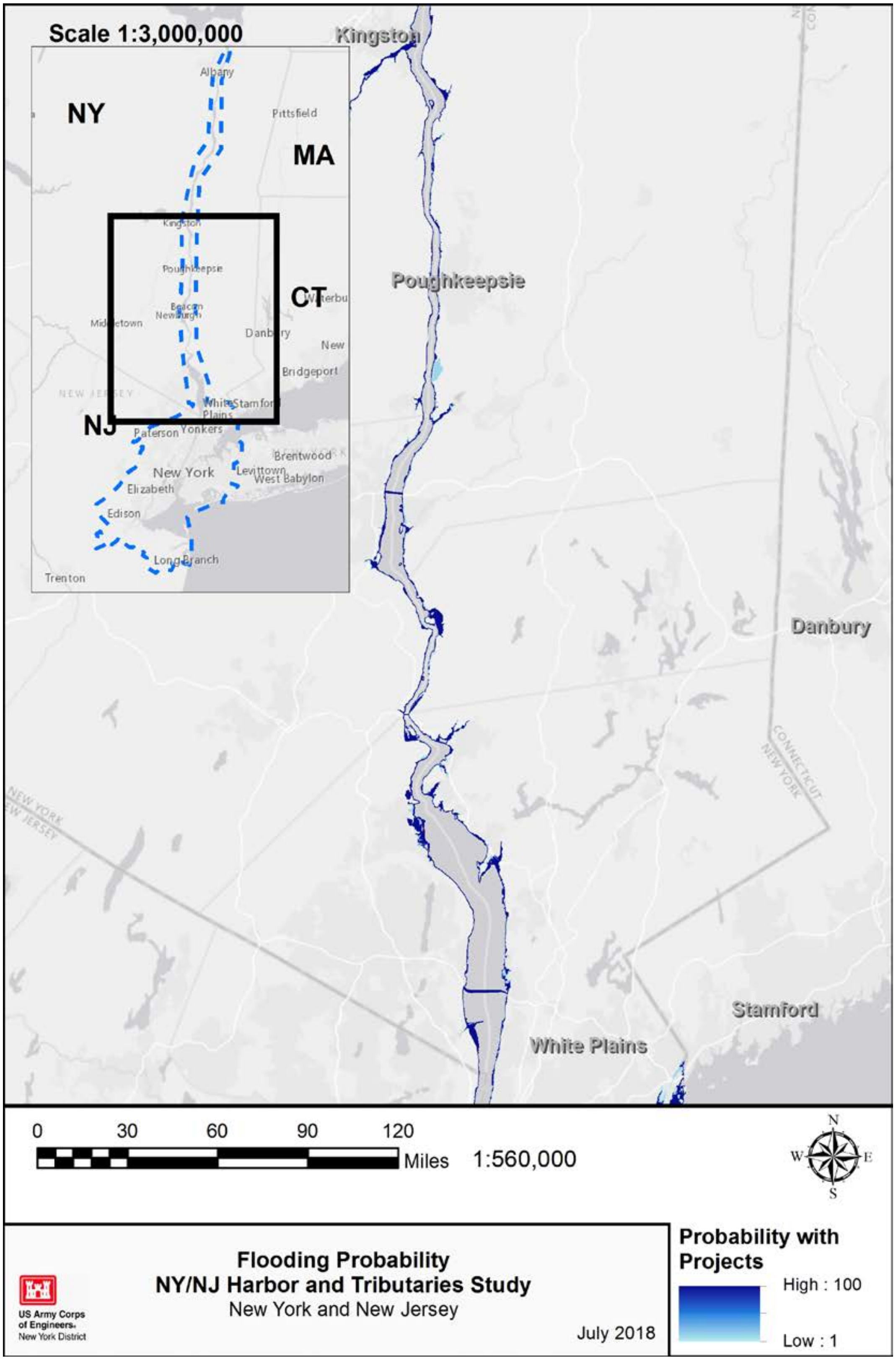


Figure 27 – Composite Vulnerability Index along the Lower Hudson River (FWOPC)

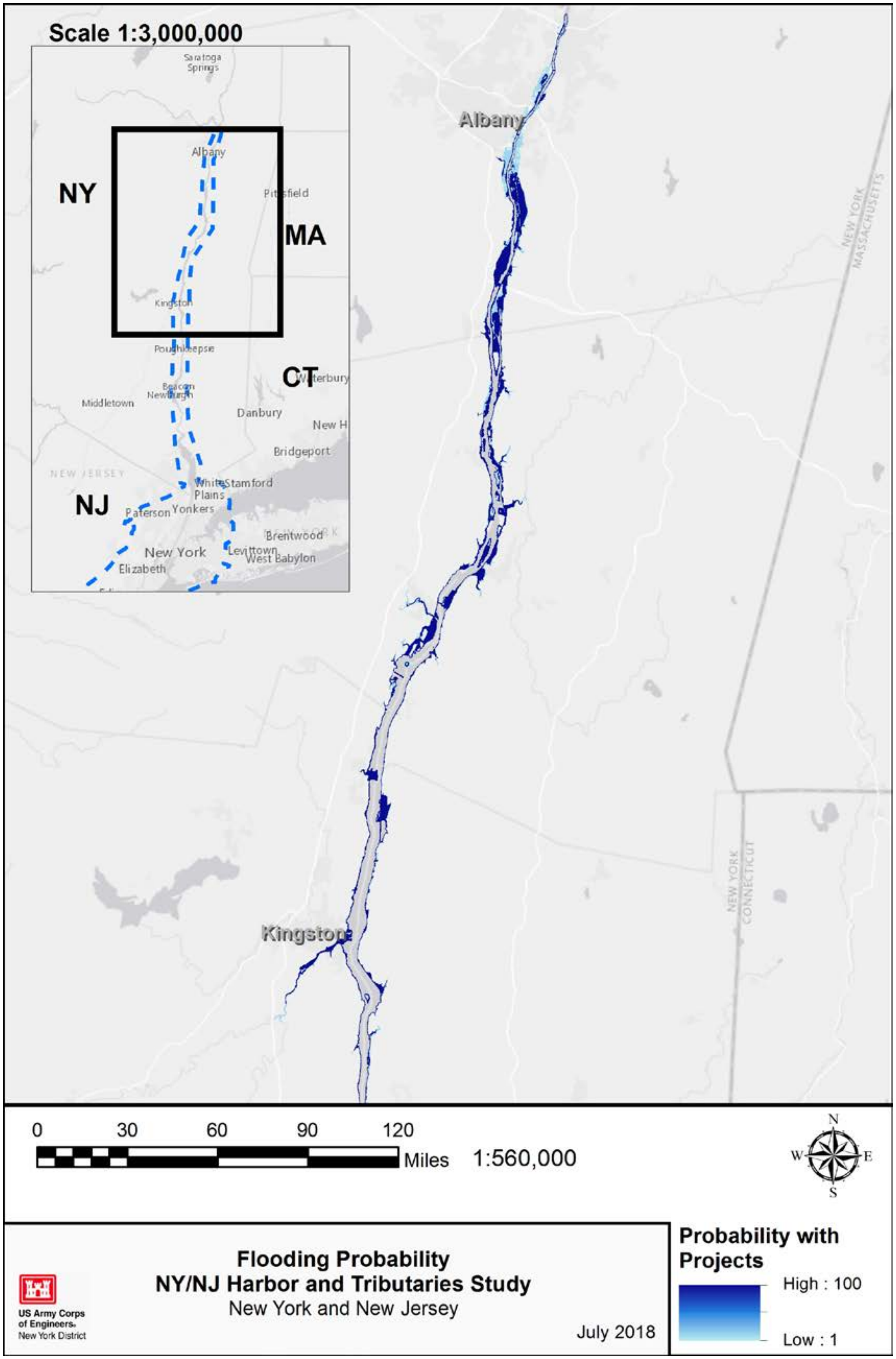


Figure 28 – Composite Vulnerability Index along the Upper Hudson River (FWOPC)

5.3 Composite Risk Index

The composite risk index is the multiplication of the composite exposure index with the vulnerability index. The FWOPC vulnerability index was used to create **Figure 29**, **Figure 30** and **Figure 31**. **Appendix C** contains the composite risk indices for each of the 34 study segments.

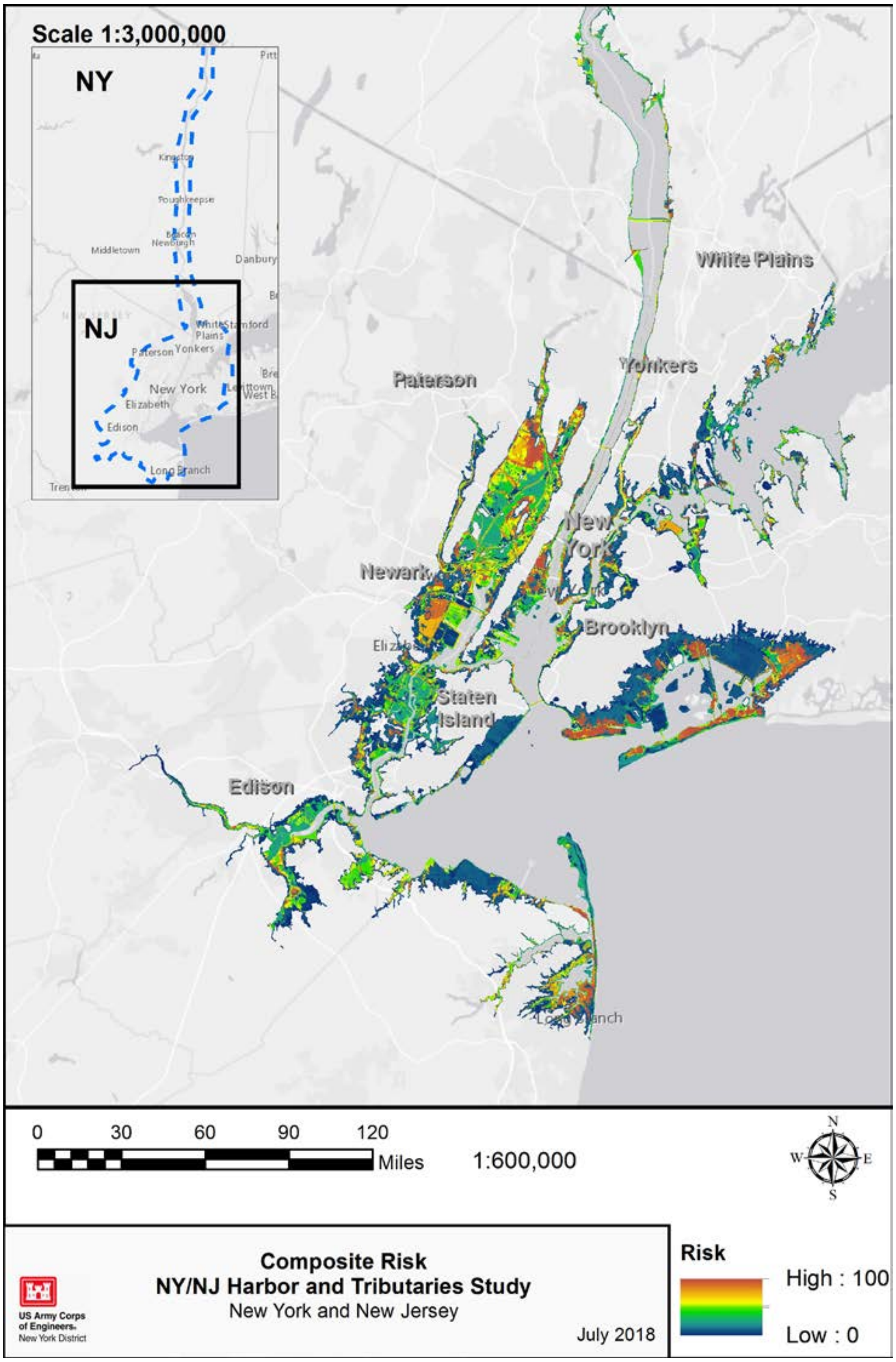


Figure 29 - Composite Risk Index in New York - New Jersey Harbor (FWOPC)

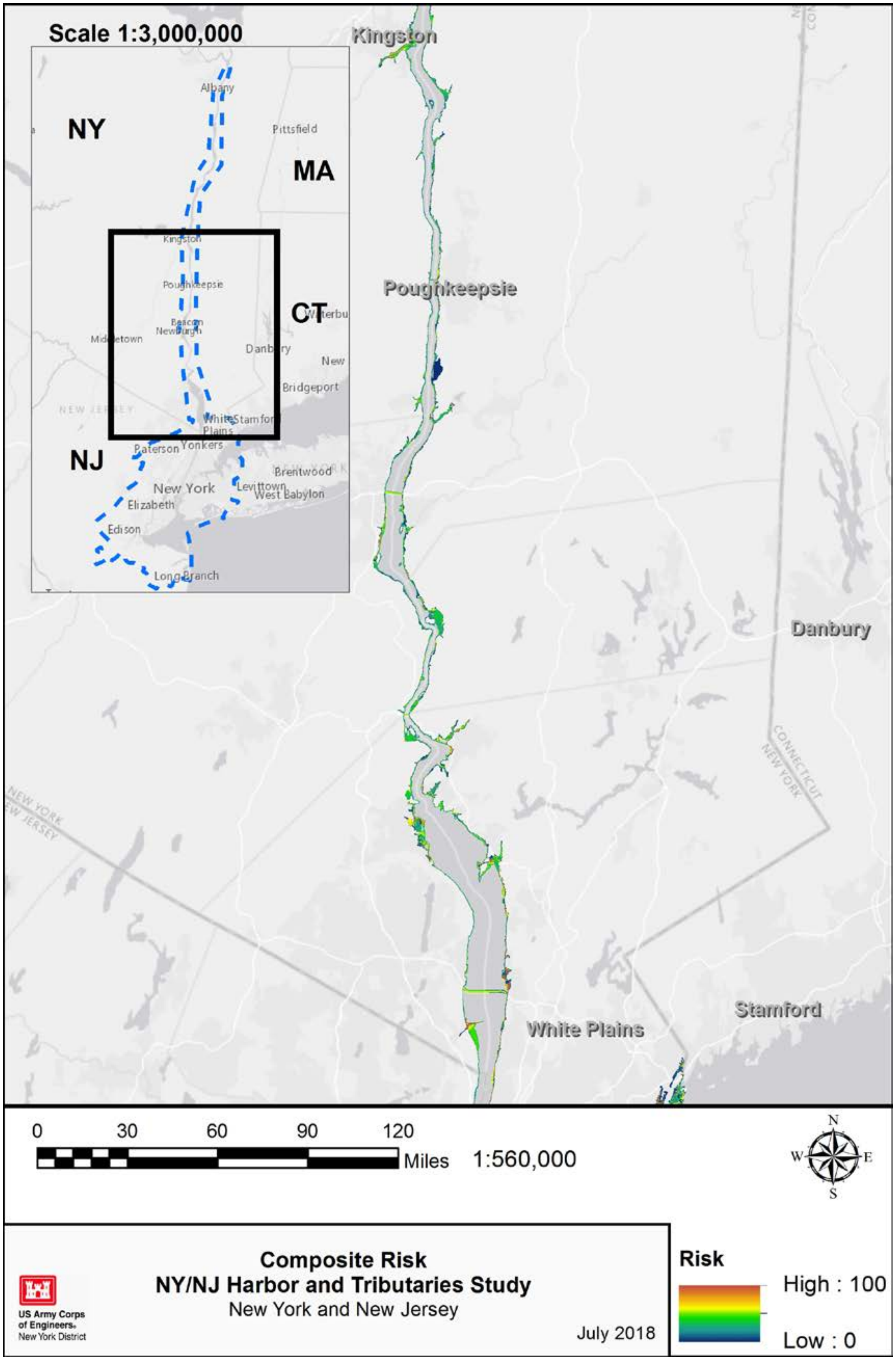


Figure 30 - Composite Risk Index along the Lower Hudson River

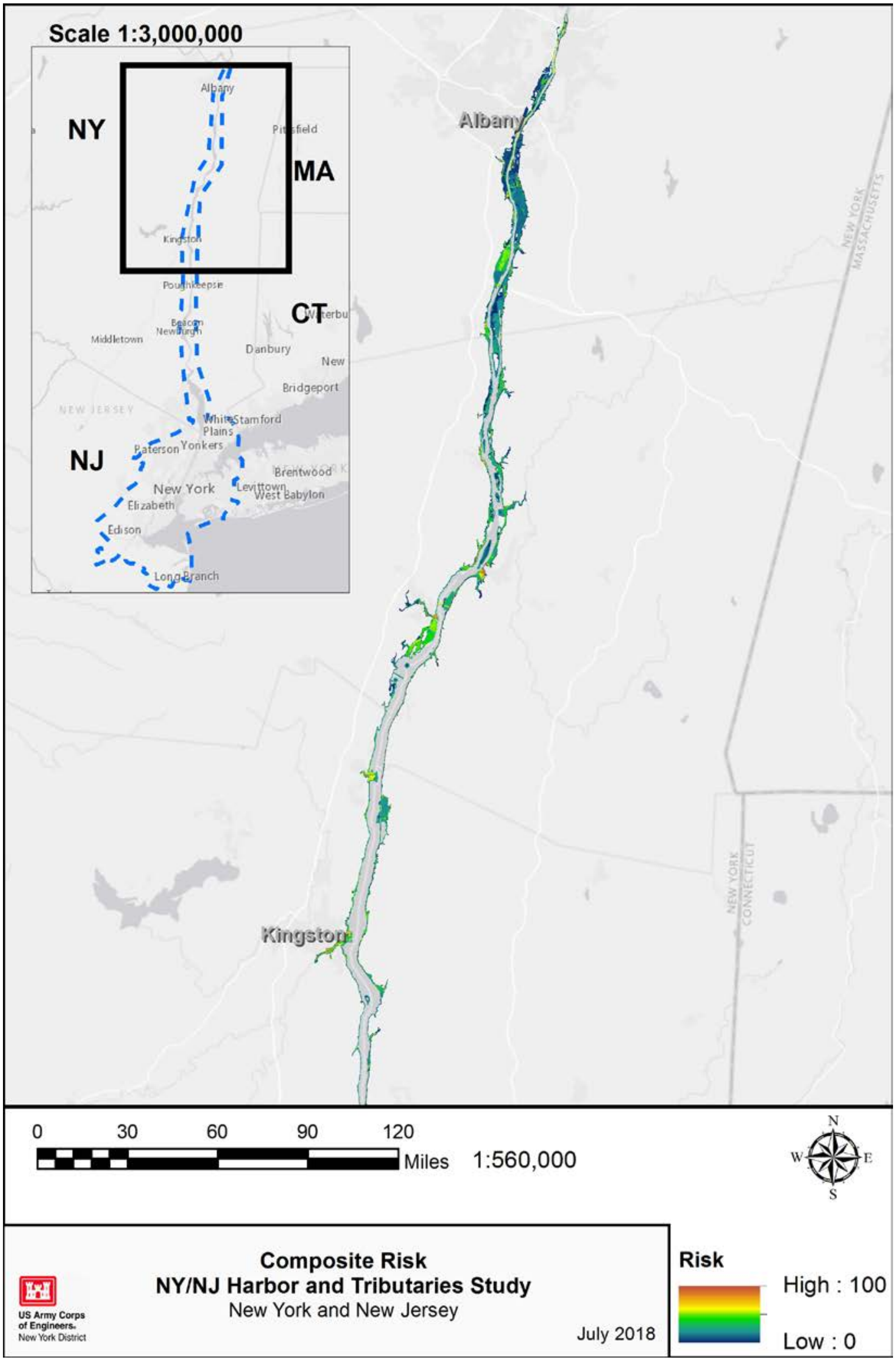


Figure 31 - Composite Risk Index along the Upper Hudson River

5.4 Areas of High Risk

Using the default weights as described in **Section 4.1** and the projects in the FWOPC as described in **Section 4.3.4**, the composite risk index was produced. This product can be used to determine which areas are considered high risk, evaluated as part of this study. With projects implemented along the shoreline of the NYNJHATS area, residual risk will always remain. Residual risk is the flood risk to people and assets after all implementation efforts to reduce risk are completed. It is important to identify residual risk to account for extreme flood extents associated with a catastrophic event. Often, flood risk management measures do not reduce risk associated with an extreme event. As observed with the incorporation of projects into the vulnerability index for the FWOPC, few projects manage risk to a catastrophic event.

As such, a preliminary review of the composite risk for each study segment was conducted. Using a risk score greater than or equal to 75 on a scale of 100 (equivalent to the top 1%), the following areas are identified as high risk. The risk to these identified areas are subject to change given the preferences of USACE and local sponsors to define the importance and relative scaling of exposure indices to each other. This is an attempt to generally quantify the risk on a comparative basis to inform decision-making in the future. **Appendix C** contains the composite risk indices for each of the 34 study segments.

Table 8 High Risk Areas by Segment

SEGMENT	AREA	APPENDIX C REFERENCE
Shrewsbury Line	Sea Bright and Long Branch neighborhoods	C-2
NJ - Raritan & Sandy Hook Shoreline	Port Monmouth neighborhood	C-3
Raritan Line	Near Journey Mill Rd and Bordertown Ave and Perth Amboy rail yard	C-4
NJ - Shoreline along Arthur Kill	Woodbridge neighborhood	C-8
Hackensack Line	Hackensack - Little Ferry near Teterboro Airport	C-12
NJ - Shoreline along Hudson River	Jersey City and South Hoboken	C-15
NYC - Manhattan shoreline along Hudson River	Lower Manhattan - Hudson River Park	C-19
NYC - Manhattan shoreline along East River	Lower Manhattan - Carey Tunnel to Brooklyn Bridge	C-20
NYC - Manhattan shoreline along East River	Manhattan near Queens Midtown Tunnel	C-20
NYC - Manhattan shoreline along Harlem River	Manhattan - Yorkville, East Harlem and Strivers Row	C-21
NYC - Queens shoreline along East River	Queens near Queens Midtown Tunnel	C-27

SEGMENT	AREA	APPENDIX C REFERENCE
NYC - Brooklyn along East River	Brooklyn - between the Brooklyn Bridge and Manhattan Bridge	C-29
NYC - Brooklyn - Lower Bay, Coney Island/Creek shoreline	Coney Island	C-32
NYC - Queens Shoreline and Islands In Jamaica Bay	Rockaway Park	C-34

5.5 Conclusions

Building upon the efforts completed by the NACCS, the current 2017-2018 effort enhanced existing data and processes to evaluate current and future risk within the NYNJHATS study area. This study and report describes in discrete steps the sources of data and processes in which the Enhanced Tier 2 GIS Analysis was completed. The improvements for this study include:

- Using available exposure data from nationwide, regional and local datasets.
- Factoring use statistics into the development of weights for infrastructure data where information was accurate and consistent enough to warrant. Airport passenger data and railroad station ridership statistics were utilized to improve the weighting of infrastructure within those data layers.
- Incorporating data not previously included in the NACCS to enhance the final risk product, notably building replacement value and employment data.
- Incorporating specific preferences to weights on an exposure category basis and an index basis. The use of the on-the-fly tool to allows for comparison of different weighting preferences.
- Assigning each exposure index its own weight. This simplifies the risk equation, enables transparent review of weights and clarifies the impact of weighting on the final risk product.
- Incorporating CSRM projects that have modified and will modify the ground surface along shorelines since Hurricane Sandy in the NYNJHATS study area.
- Utilizing ADCIRC storm surge modeling to determine inundation extents for typical and extreme flooding events.

Throughout the course of this study, a few potential enhancements were noted. The short list below captures these enhancement for consideration in future analysis.

- Improvements to Building Value - using FEMA's dasymetric HAZUS dataset allows for the elimination of bare land and would provide a more granular dataset that represents the built environment. Additionally, further research on outliers, such as the Bay Plaza Shopping Center in Bronx, NY need to be conducted to mitigate potentially erroneous data.

- Improvements to Vulnerability - the vulnerability index could be further discretized by including additional flood frequencies such as the 4 percent, 2 percent and 1 percent annual chance events (i.e., 25-, 50- and 100-year events). This would produce a smoother vulnerability grid, provide greater detail and ramping of risk in the zone between the 10 percent and 1 percent +3 feet zones.

- Improvements to Social Vulnerability - the social vulnerability grid was produced at the Census Tract level for consistency with the NACCS. Increasing the resolution of the social vulnerability grid will provide greater detail and granularity.

- Improvements to Population - the population data is based on the 2010 Census data. The 2010 Census data is the only dataset at the block level, which is the finest grain dataset. The ACS five-year estimates are available at the Block Group level and this data was considered for use within this effort, but decreased resolution of data was a concern. For a future effort, the ACS five-year estimates may better represent the data if applied to the blocks using a dasymetric process. Additionally, the 2020 Census data will be available at the end of 2020.

- Improvements to Infrastructure - similar to the ridership weighting, several other datasets could be enhanced by evaluating the exposure weight based on usage. For example, hospitals could be weighted based on number of beds or average annual patients. This data would need to be acquired for all hospitals or assets in the study area and consistency of data collection/quality would need to be demonstrated. In addition, the buffer areas could be expanded to account for the service area of the more important datasets, such as medical centers and evacuation shelters.

- Scenario Planning for Large Scale Projects - the large-scale projects such as those being considered for the Tentatively Selected Plan, could be incorporated into the vulnerability raster. Data on the scope, scale and extent of these projects would need to be acquired. When multiple future projects are incorporated, the result could be used in scenario planning to evaluate the optimal risk reduction strategies.

- Accessibility of Results - the results for this analysis are available through the “Slider Tool”. The tool is currently available through ArcGIS Desktop. The analysis results and slider tool could be migrated to a web map, making the data more accessible to the stakeholders.

This page intentionally left blank.

Section 6

References

American Community Survey (2012). Census Transportation Planning Package (CTPP) 2006 - 2010. Available at https://ctpp.transportation.org/ctpp-data-set-information/5-year-data/. Accessed July 2018.

FEMA (2018). FEMA Hazus Building Stock. Available at https://msc.fema.gov/portal/resources/hazus. Accessed July 2018.

Moss, M. and C. Qing (2012). The Dynamic Population of Manhattan. Available at https://wagner.nyu.edu/files/rudincenter/dynamic_pop_manhattan.pdf . Accessed July 2018.

Port Authority of New York and New Jersey (2017). Airport Traffic Report. Available at https://www.panynj.gov/airports/pdf-traffic/ATR2017.pdf. Accessed June 2018.

USACE (2015a). North Atlantic Coast Comprehensive Study Main Report. Available at http://www.nad.usace.army.mil/Portals/40/docs/NACCS/NACCS_main_report.pdf. Accessed July 2018.

USACE (2015b). North Atlantic Coast Comprehensive Study Appendix C: Planning Analyses. Available at http://www.nad.usace.army.mil/Portals/40/docs/NACCS/NACCS_Appendix_C.pdf. Accessed July 2018.

USACE (2015c). North Atlantic Coast Comprehensive Study Appendix D: State and District of Columbia Analyses. Available at http://www.nad.usace.army.mil/Portals/40/docs/NACCS/NACCS_Appendix_D.pdf. Accessed July 2018.

US Census (2010). TIGER Products. Available at https://www.census.gov/geo/maps-data/data/tiger.html. Accessed July 2018.

US Census (2015). Census Tract Detailed Tables. Available at https://www.census.gov/geo/maps-data/data/tiger-data.html. Accessed July 2018.

Appendix A

Slider Tool Documentation

NYNJHATS Enhanced Tier 2 GIS Analysis - Slider Application

This guide provides details on how to use the GIS-based "Slider Tool" in conjunction with the NYNJHATS Enhanced Tier 2 Study. The primary purpose of the tool is to allow the user to interactively change the weights or influence of the individual exposure rasters. The Risk tool allows the user to then calculate and compare the associated levels of risk based on these different weights.

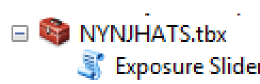
The primary components of the tool are as follows:

- NYNJHATS_Slider.mxd – ESRI ArcGIS Map Document with the exposure layers and flood layer loaded
- NYNJHATS Toolbox – ArcToolbox with the Exposure Slider script and the Risk script
- NYNJHATS_Exposure.gdb – Geodatabase with the exposure raster datasets and the results of the tool
- Scripts Folder – Folder containing the scripts and template layer and graph files

Using the Exposure Slider Application

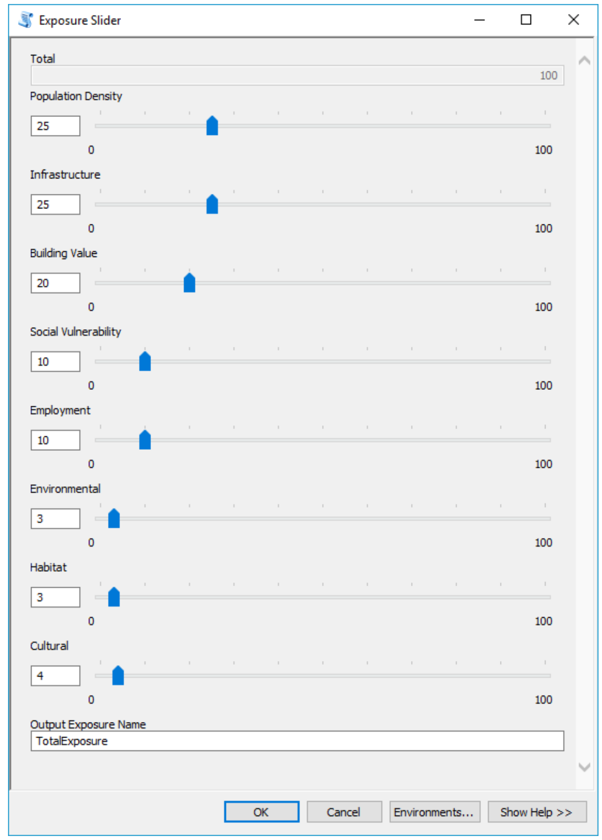
To use the slider tool, open the NYNJHATS_Slider map document within ArcGIS (version 10.3 or later) and follow the steps below.

- Open the "Catalog" window with ArcMap and locate the NYNJHATS toolbox



- Open the “Exposure Slider” tool
- Adjust the weights accordingly and modify the Output Exposure Name. The tool will not run successfully if a new Output Exposure Name has not been created.
- If the Total is more or less than 100, the tool will display an error, adjust the weights to equal 100
- Click OK, the tool may take a few minutes to complete

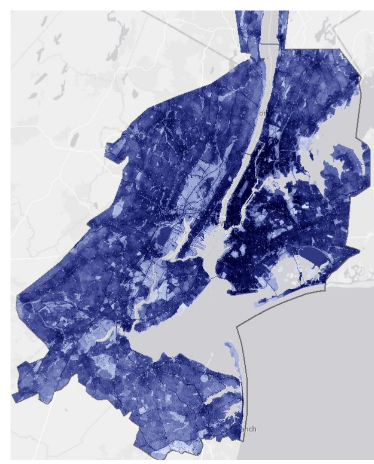
The tool will automatically output the Total Exposure raster to the MXD. This tool can be run multiple times to compare the effects of different weights on the Total Exposure values.

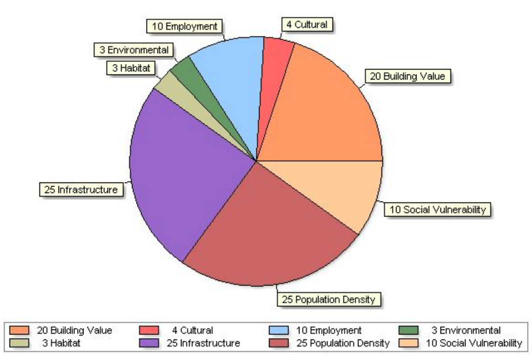


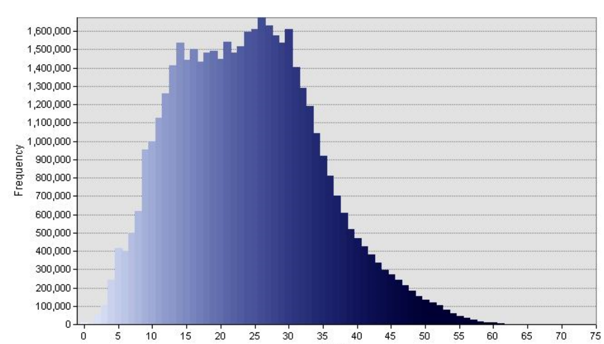
Understanding Total Exposure Outputs

The tool will produce:

- The Total Exposure Raster
- A pie chart to display the selected weight distribution used to create the raster
- A histogram displaying the distribution of total exposure values throughout the study area

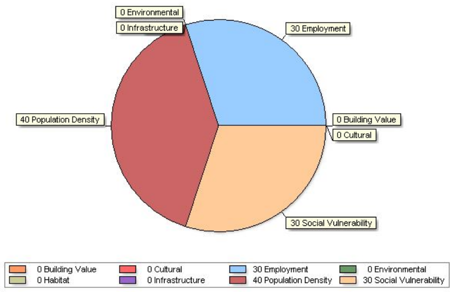


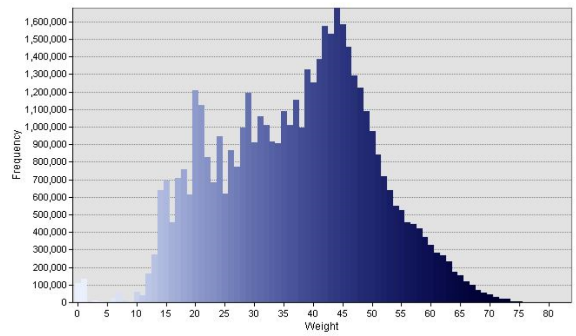




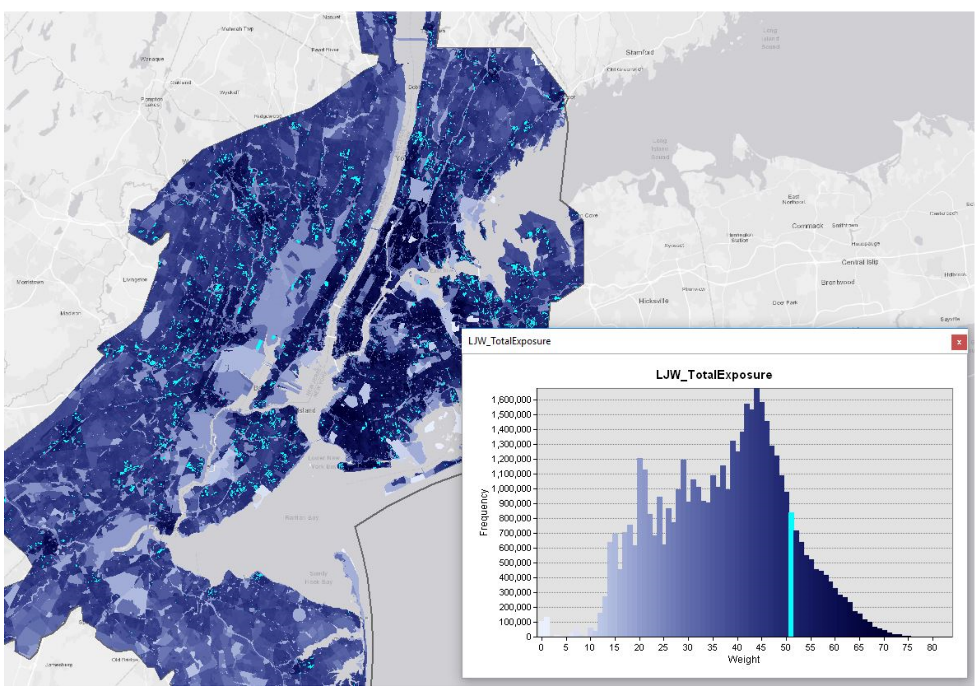
The images above are based on the pre-set weight distribution; however, the tool can be run with any variation of weights equal to 100.

For example, the pie chart below shows a possible weight distribution that emphasizes population density, social vulnerability and employment. The corresponding histogram demonstrates the distribution of exposure levels at this specific weighting.



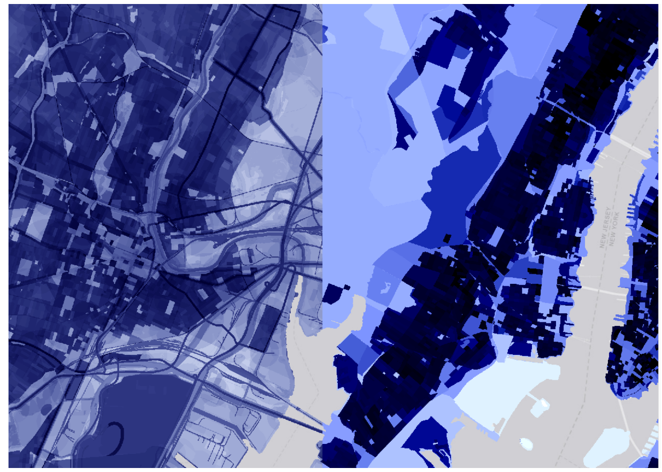


- To identify the locations of each of these exposure values on the map, click on an individual bar in the histogram as shown below.



Comparing Total Exposure Outputs

The user may also compare multiple total exposure scenarios using “Swipe” tool in ArcGIS.



- If the “Effects” toolbar is not already added to the map, go to the “Customize” menu drop down, hover over “Toolbars” and select it
- Turn on both layers in the Table of Contents
- Select the Swipe tool from the toolbar 
- Hold down the mouse and move the cursor across the screen to view the raster image below and compare the different Total Exposure rasters in detail.

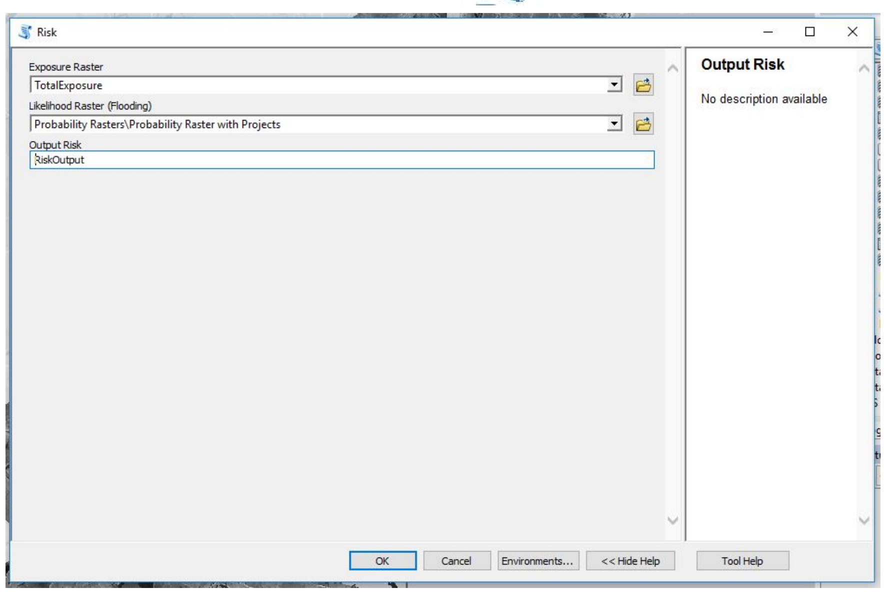
Using the Risk Application

The Risk script allows the user to calculate and compare the levels of risk associated with the 10-, 100-, and 1000-year flood event. The tool calculates risk based on the total exposure value multiplied by the likelihood of flooding for each cell in the raster.

To use the Risk tool, keep the NYNJHATS_Slider map document open and follow the steps below.

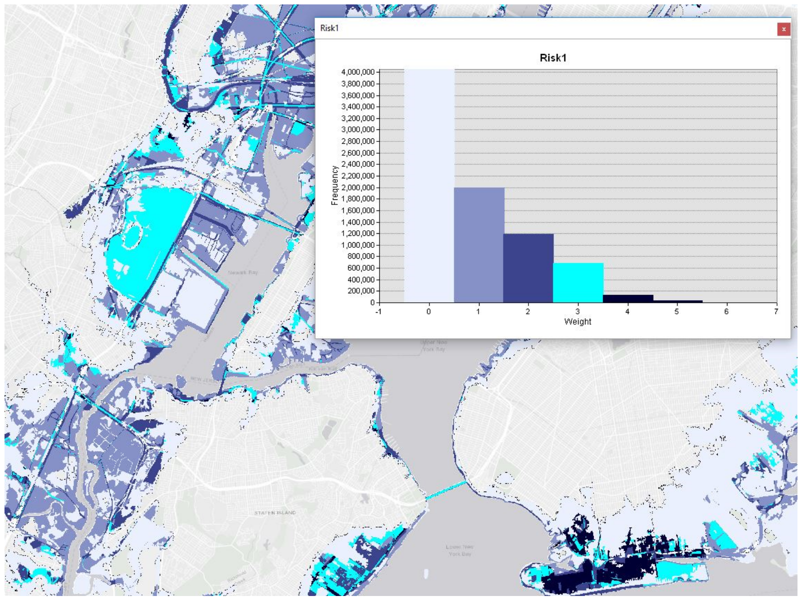
- Open the “Catalog” window with ArcMap and locate the NYNJHATS toolbox again

- Open the “Risk” tool
- Select the Total Exposure raster created from the slider tool.
- Select the preferred Probability raster. Choose between the Probability Raster with Projects incorporated into it or the original.
- Create an Output name.
- Click OK, the tool may take 1 minute to complete



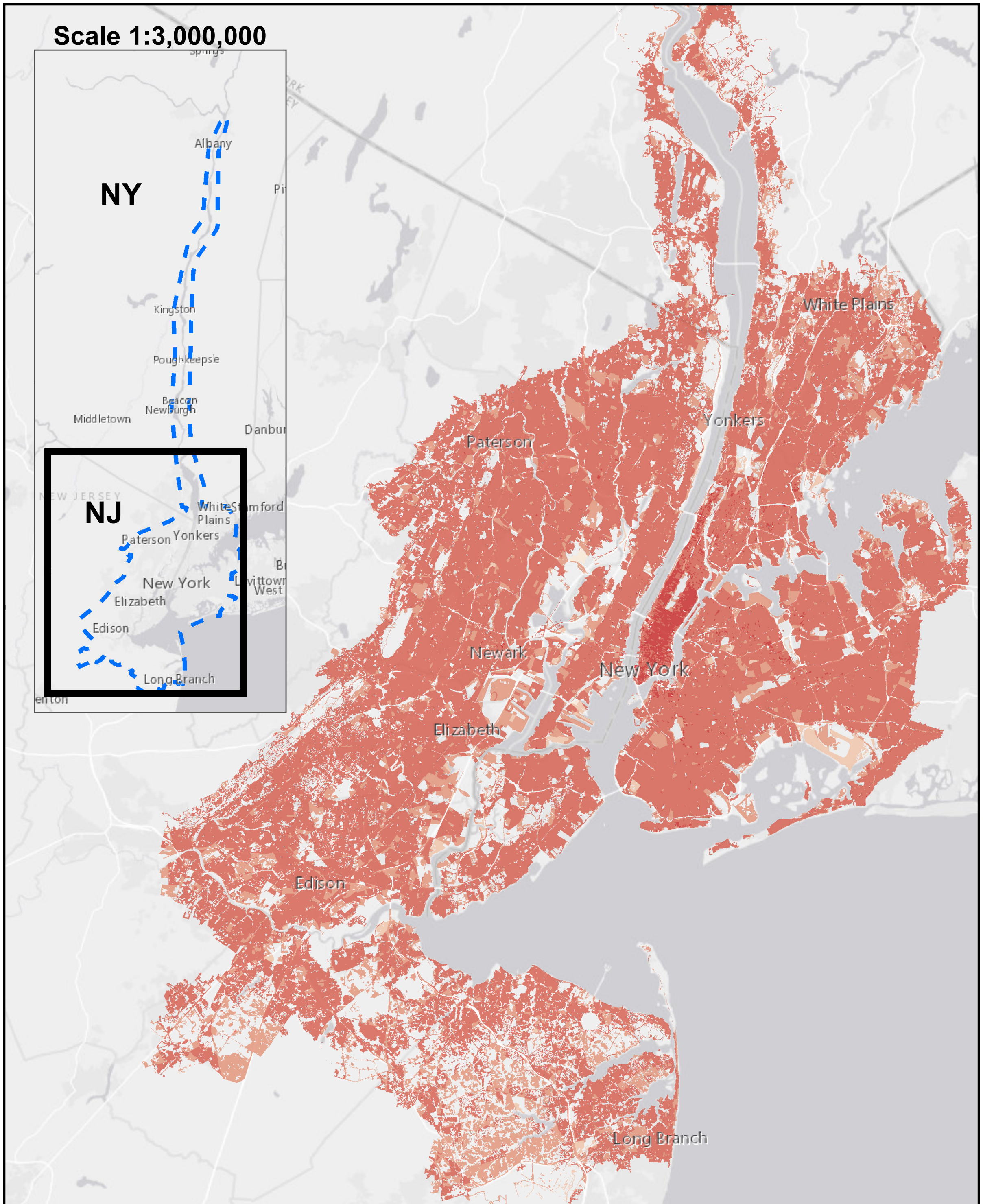
The tool will automatically output:

- A Total Risk raster
- A histogram of the distribution of risk levels
- To identify the locations of each of these risk values on the map, click on an individual bar in the histogram as shown below



Appendix B

Composite Exposure Indices



0 30 60 90 120
Miles 1:600,000

N W E S

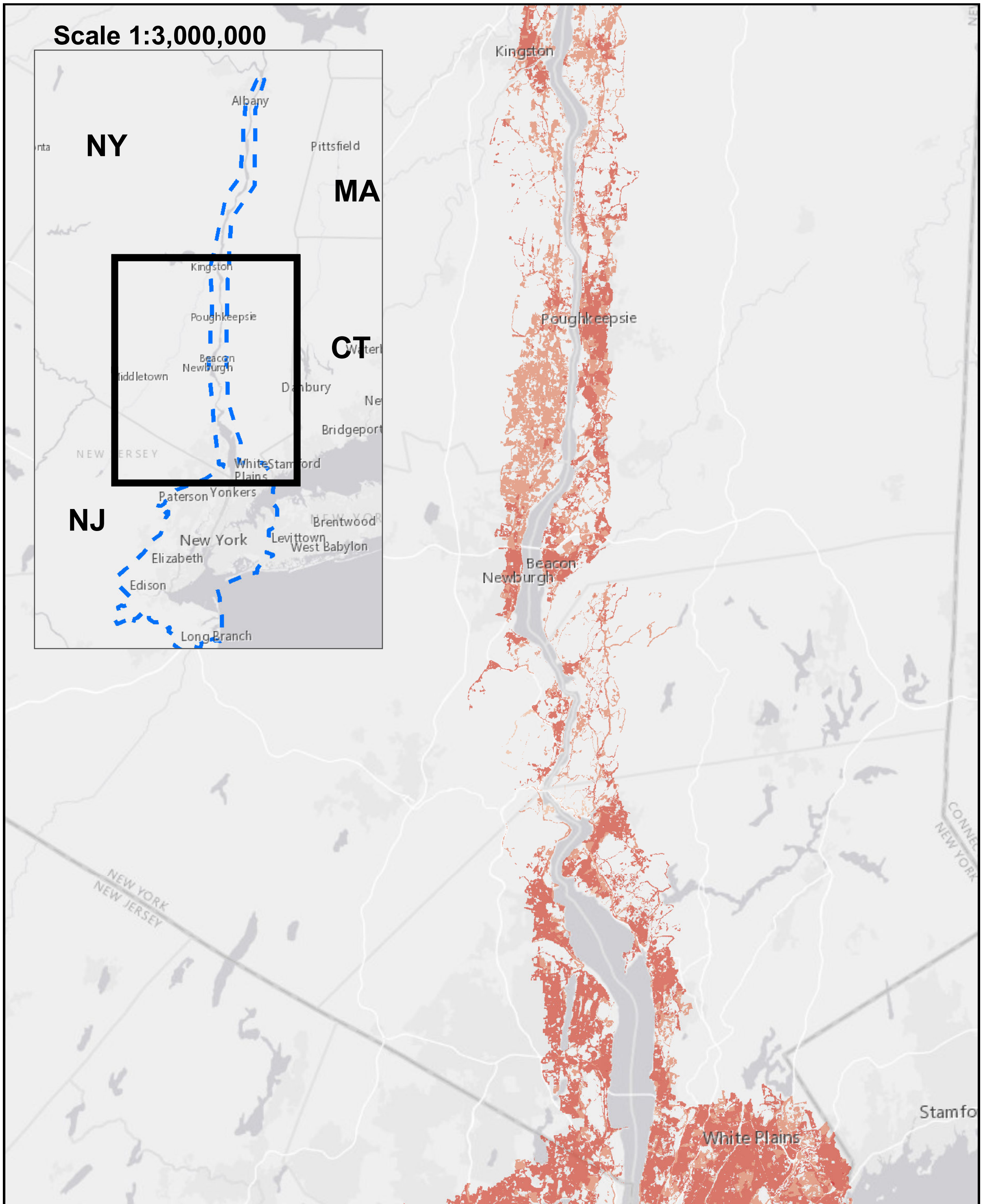
Exposure

- 0 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100

US Army Corps of Engineers
New York District

Building Value
NY/NJ Harbor and Tributaries Study
New York and New Jersey

July 2018



0 30 60 90 120 Miles 1:560,000

N W E S

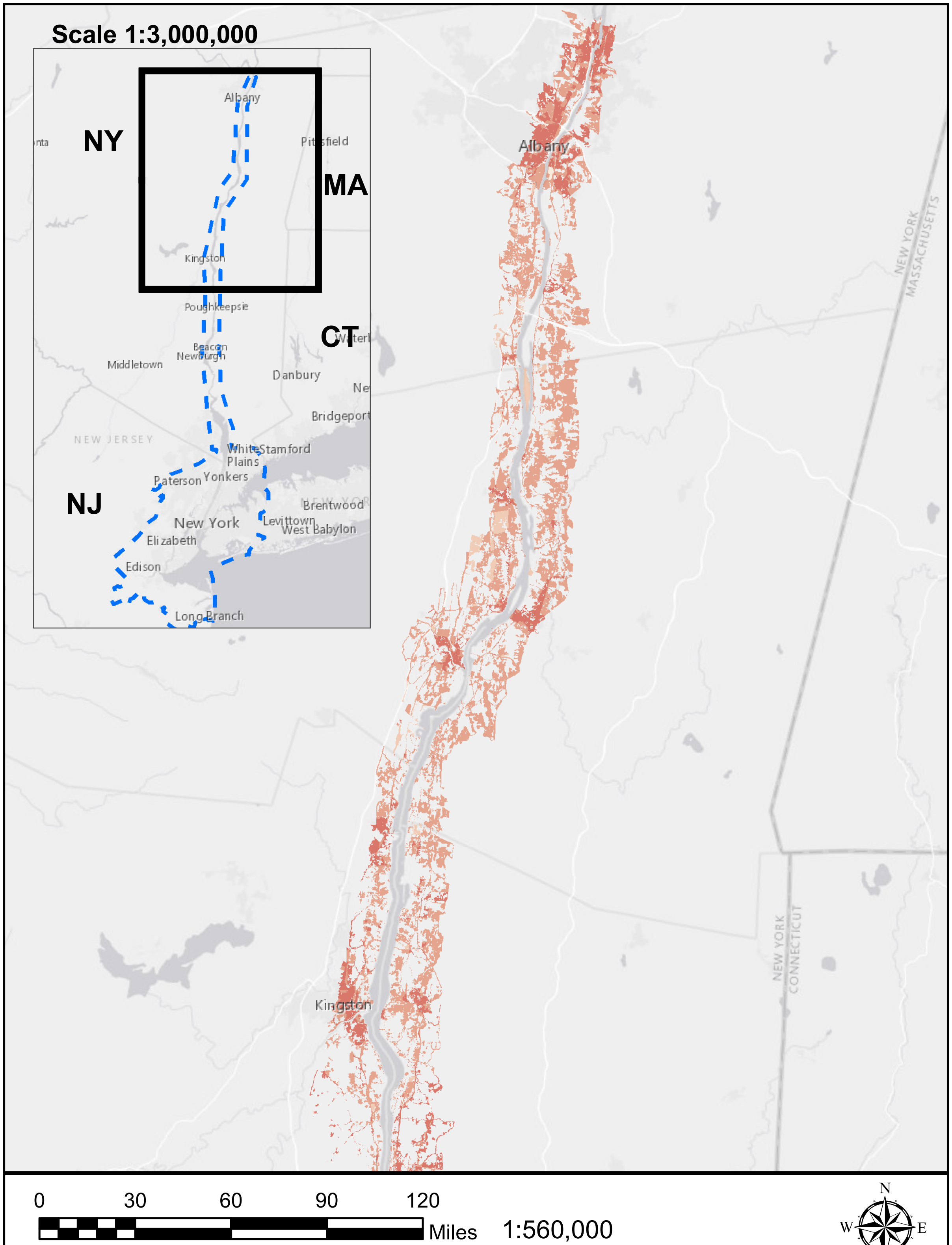
Exposure

- 0 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100

US Army Corps of Engineers
New York District

Building Value
NY/NJ Harbor and Tributaries Study
New York and New Jersey

July 2018



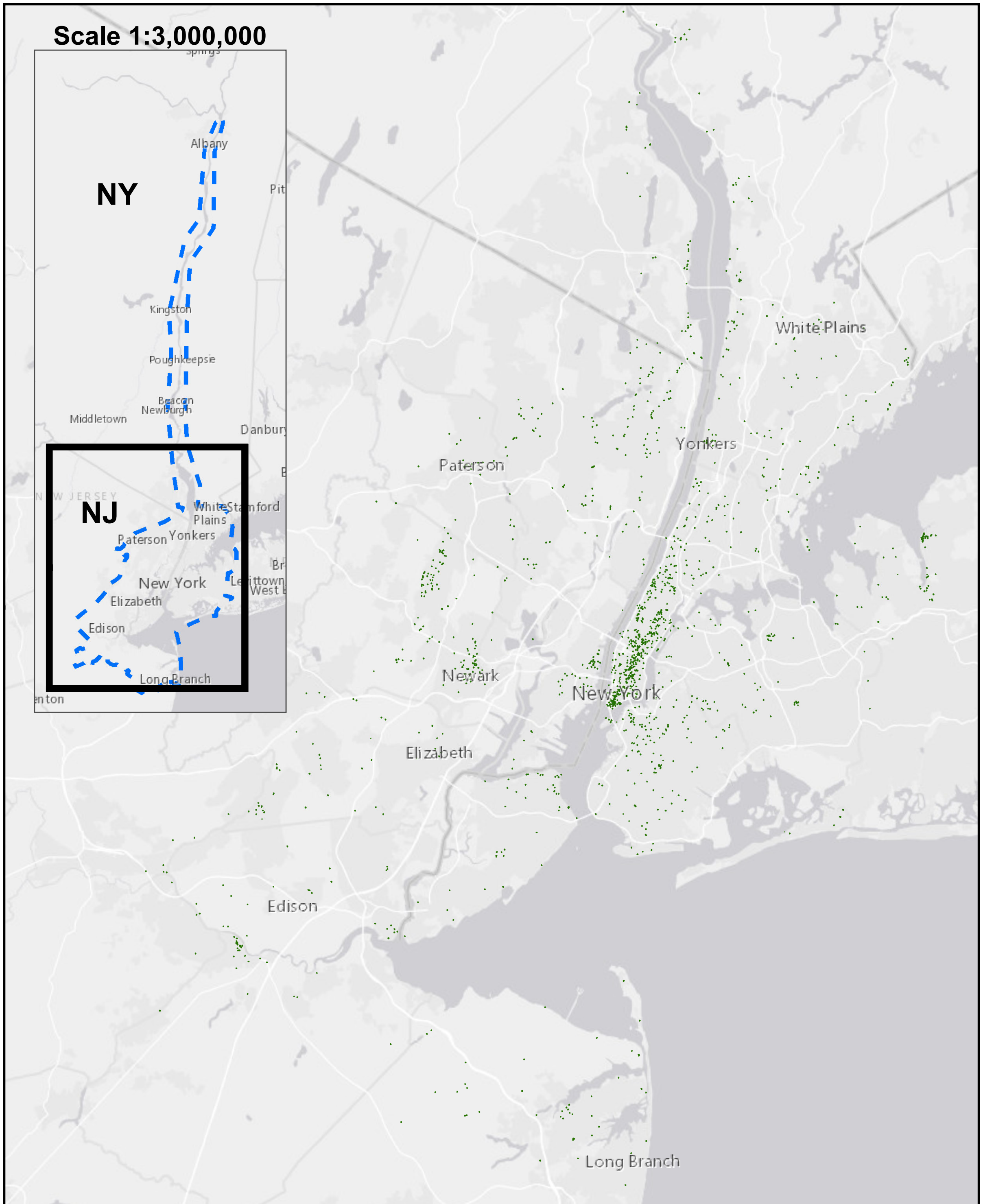
Exposure

- 0 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100

US Army Corps of Engineers
New York District

Building Value
NY/NJ Harbor and Tributaries Study
New York and New Jersey

July 2018



0 30 60 90 120 Miles 1:600,000

N W E S

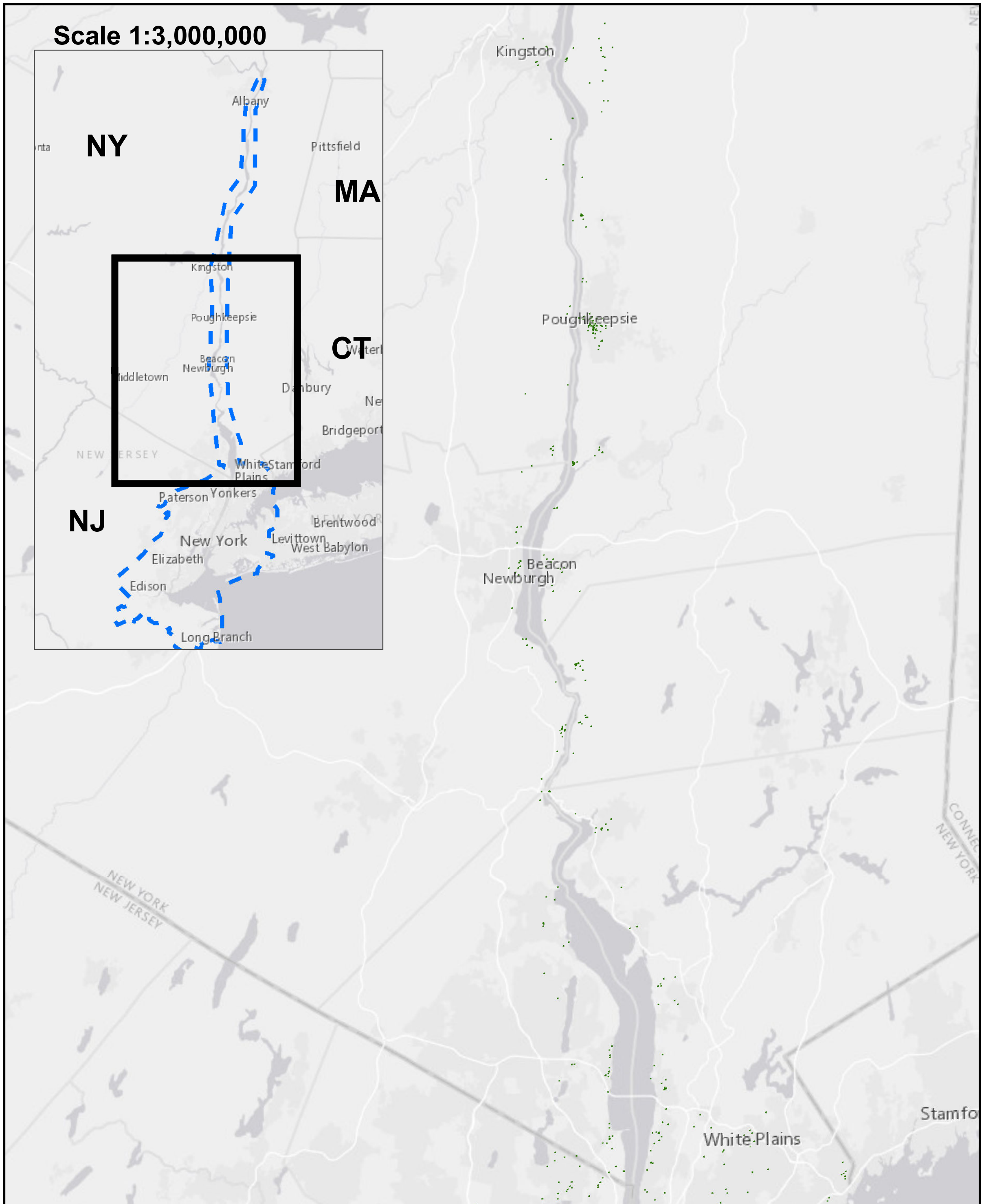
Exposure

85

US Army Corps of Engineers
New York District

Cultural Resources
NY/NJ Harbor and Tributaries Study
New York and New Jersey

July 2018



0 30 60 90 120 Miles

1:560,000

N W E S

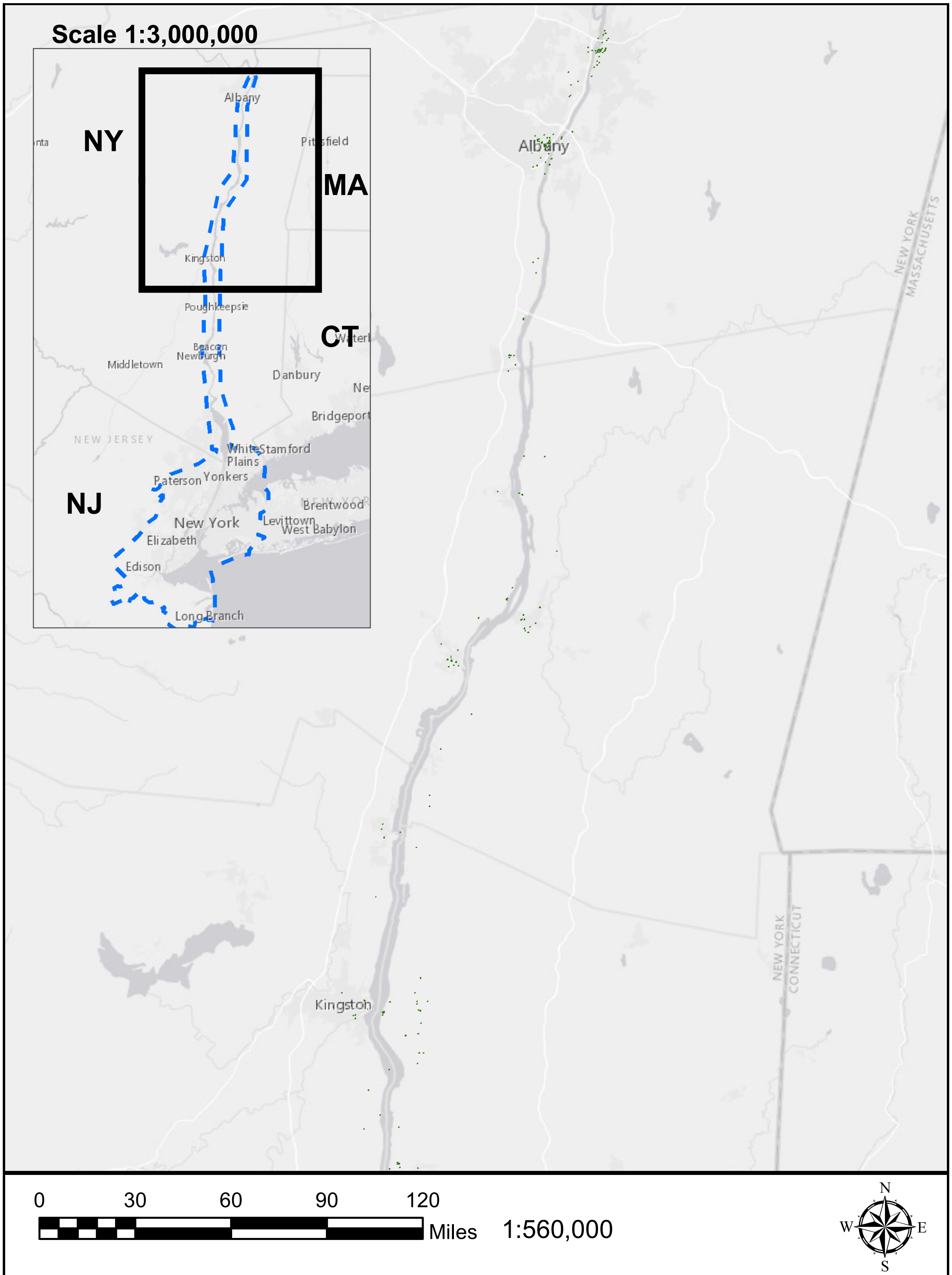
Exposure

85

US Army Corps of Engineers
New York District

Cultural Resources
NY/NJ Harbor and Tributaries Study
New York and New Jersey

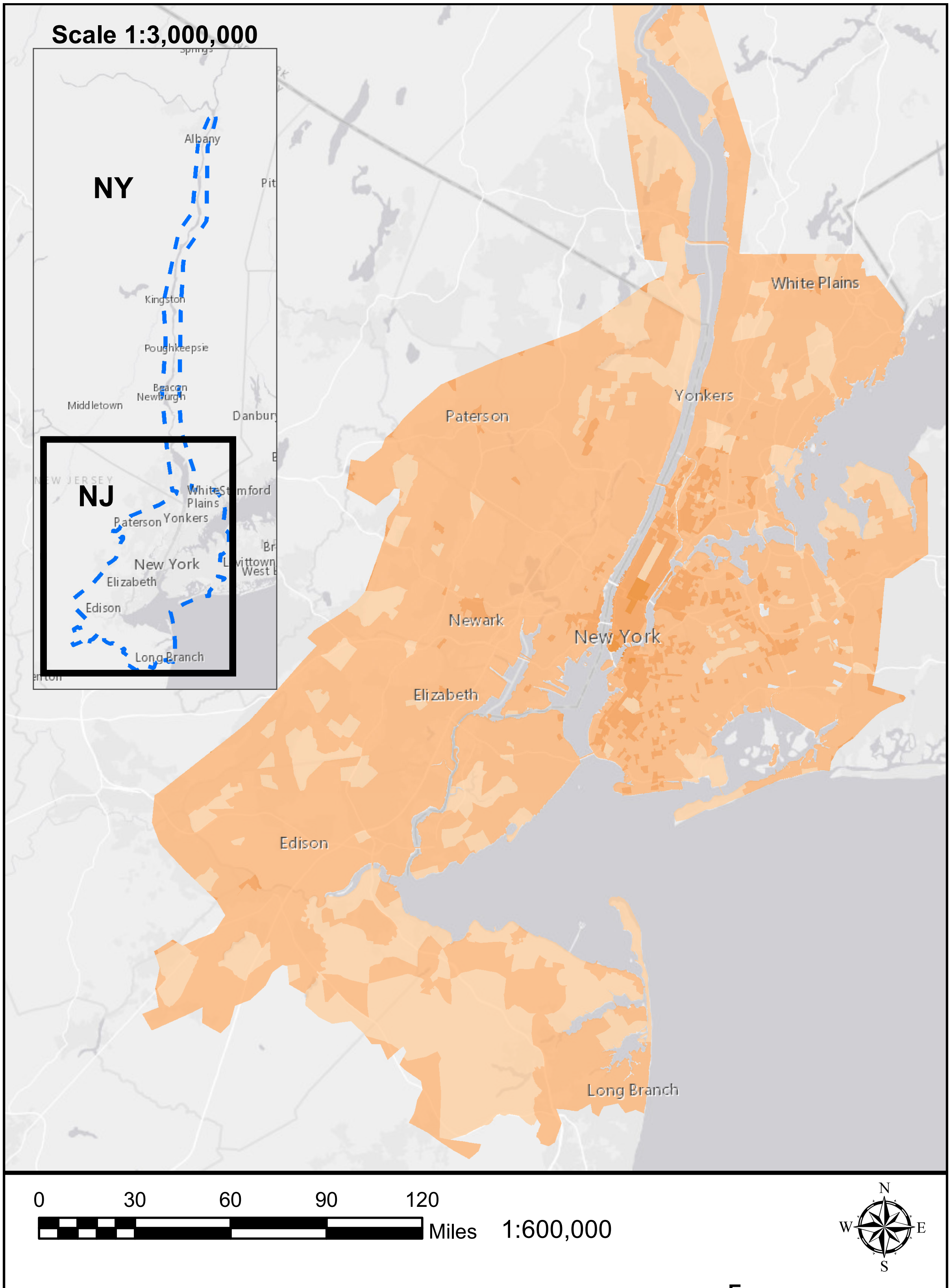
July 2018



Cultural Resources
NY/NJ Harbor and Tributaries Study
New York and New Jersey

US Army Corps of Engineers
New York District

July 2018



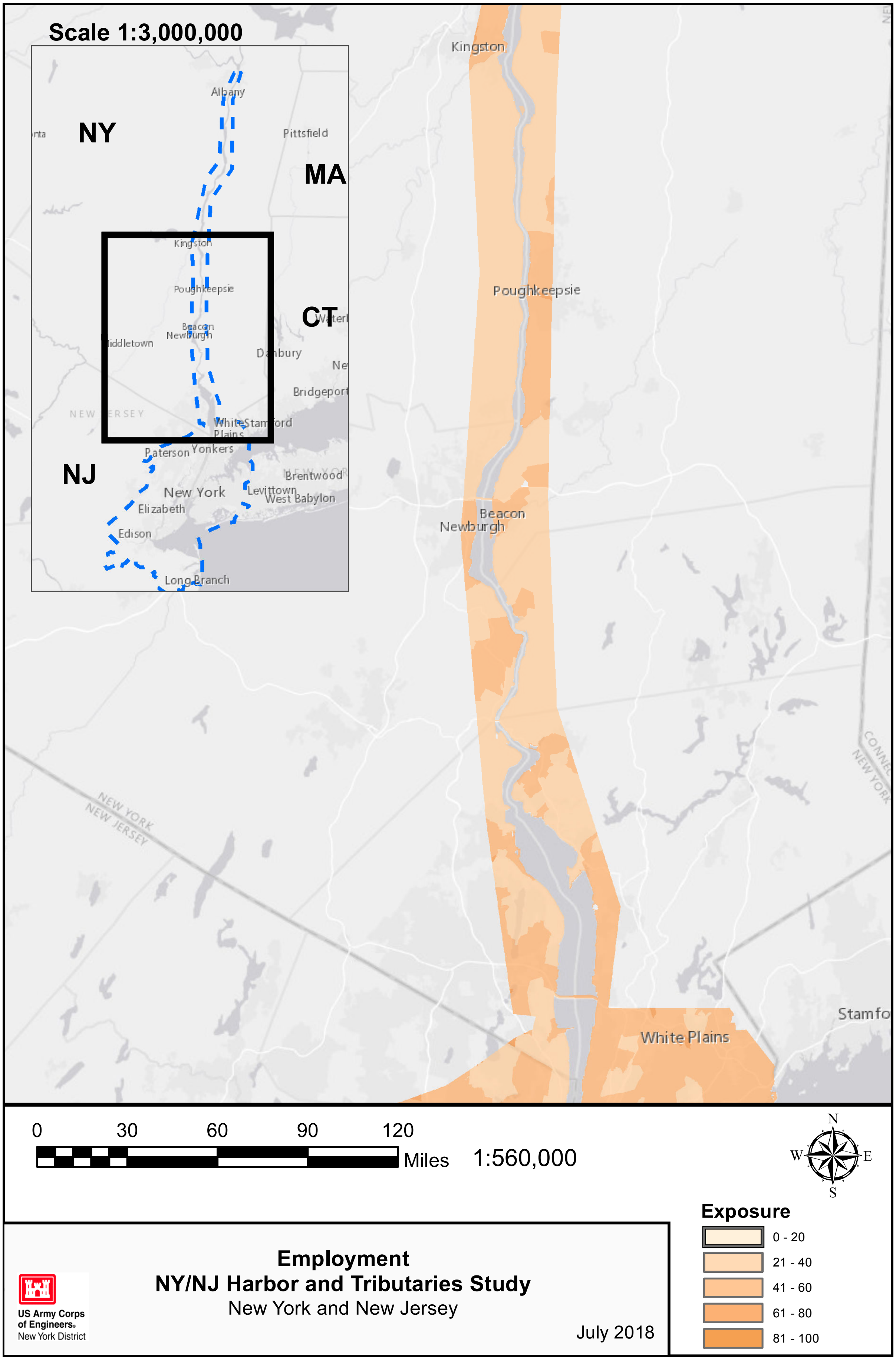
Exposure

- 0 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100

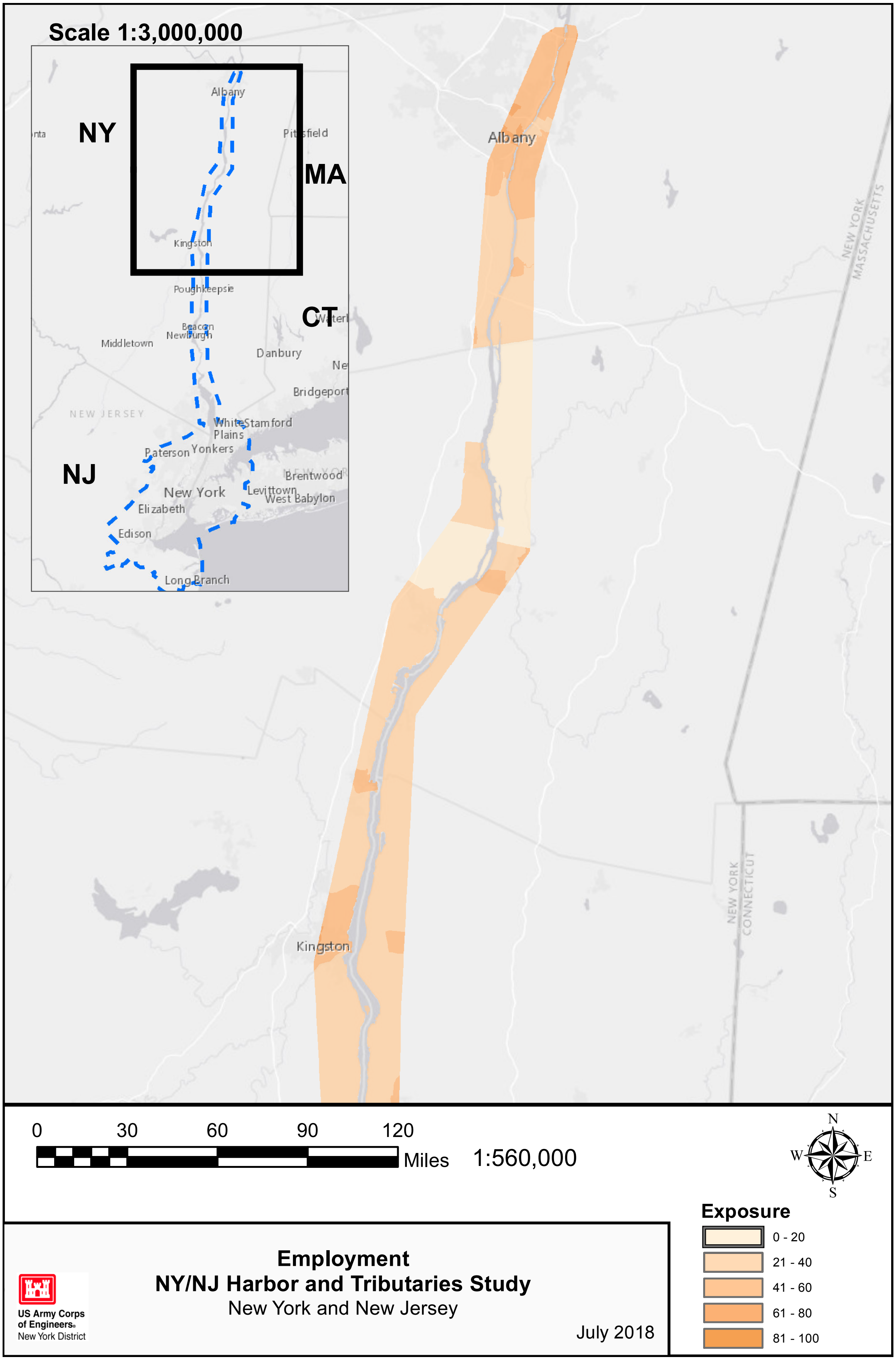
US Army Corps of Engineers®
New York District

Employment
NY/NJ Harbor and Tributaries Study
New York and New Jersey

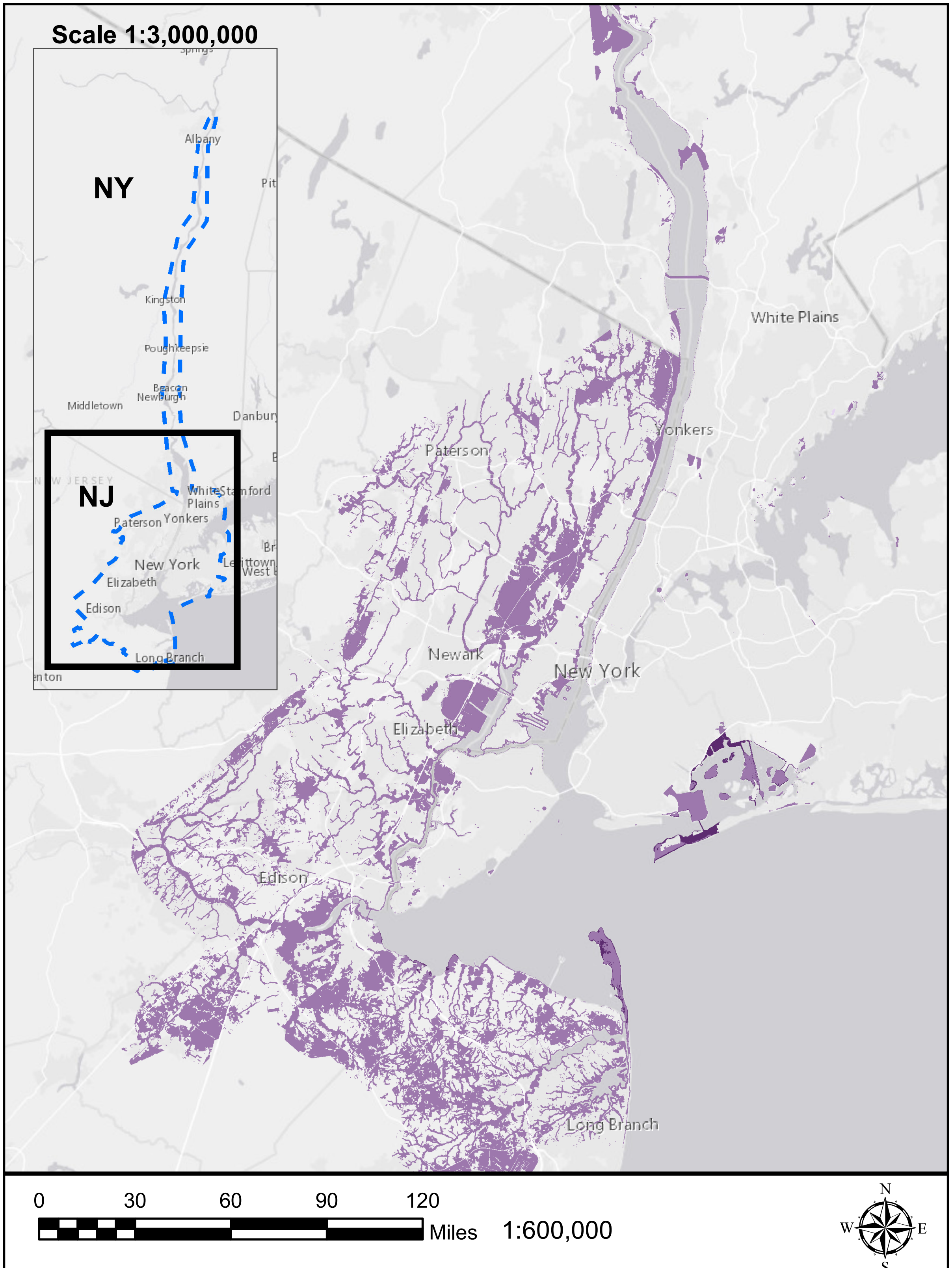
July 2018



Employment
NY/NJ Harbor and Tributaries Study
New York and New Jersey
July 2018



Scale 1:3,000,000
NY
MA
CT
NJ
Albany
Pittsfield
Kingston
Poughkeepsie
Beacon
Newburgh
Middletown
Danbury
Bridgeport
NEW JERSEY
White Plains
Stamford
Paterson
Yonkers
Brentwood
New York
Levittown
West Babylon
Elizabeth
Edison
Long Branch
Albany
Kingston
NEW YORK
MASSACHUSETTS
NEW YORK
CONNECTICUT
0 30 60 90 120
Miles
1:560,000
N
W
E
S
Exposure
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
Employment
NY/NJ Harbor and Tributaries Study
New York and New Jersey
July 2018
US Army Corps of Engineers
New York District



Environmental

NY/NJ Harbor and Tributaries Study

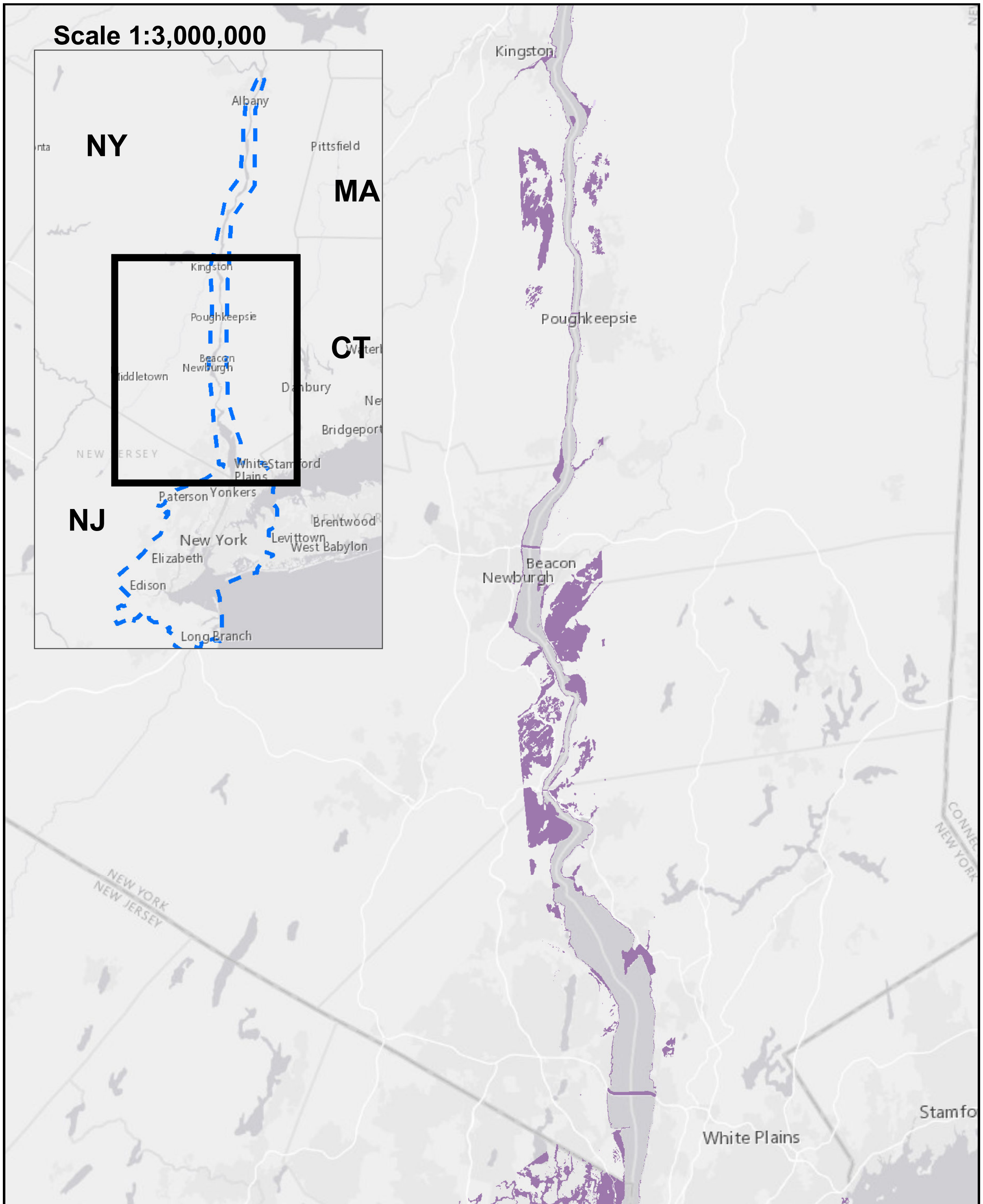
New York and New Jersey

US Army Corps of Engineers
New York District

July 2018

Exposure

- 73
- 89
- 91



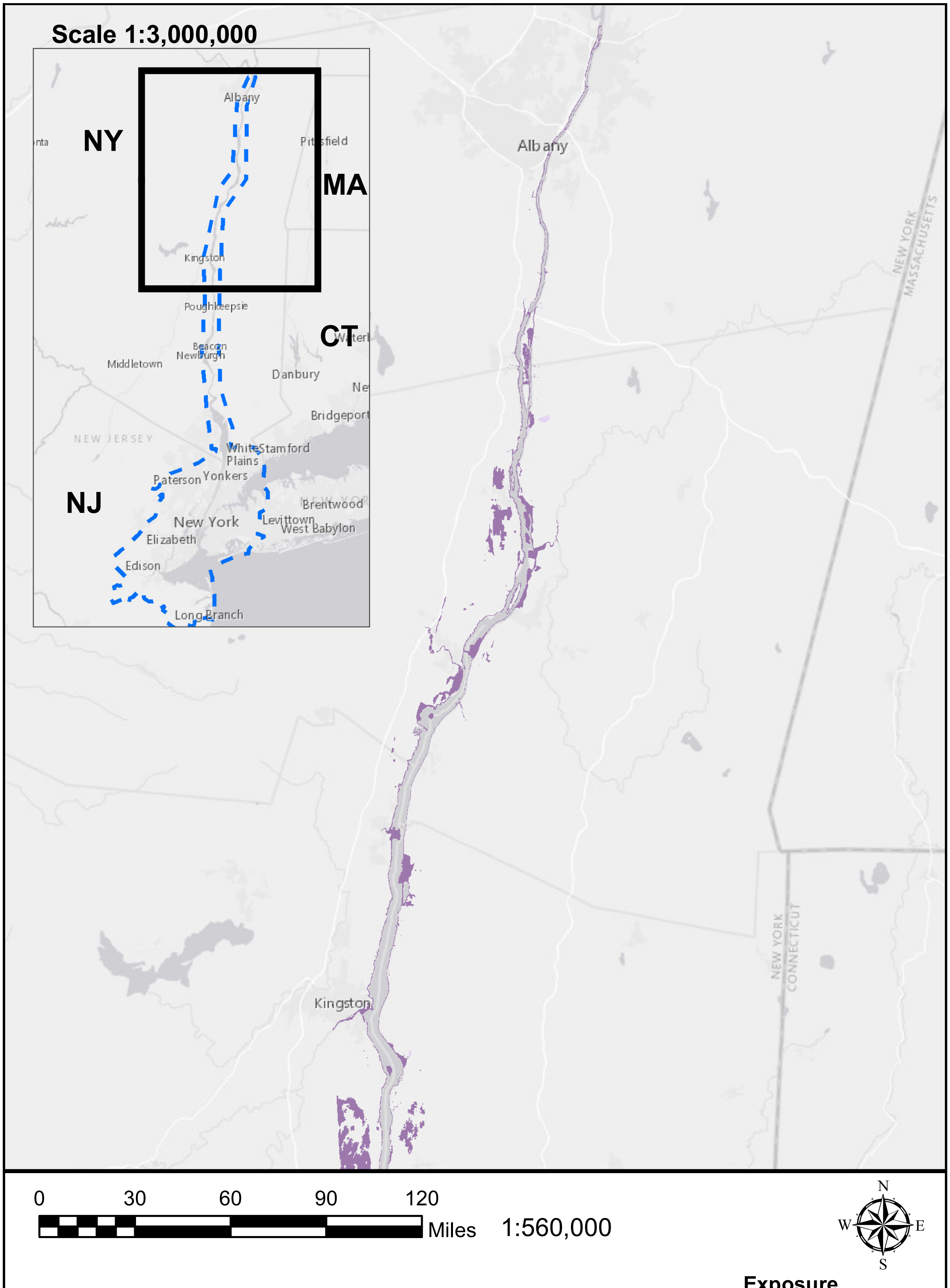
Exposure

	73
	89
	91

US Army Corps of Engineers
New York District

Environmental
NY/NJ Harbor and Tributaries Study
New York and New Jersey

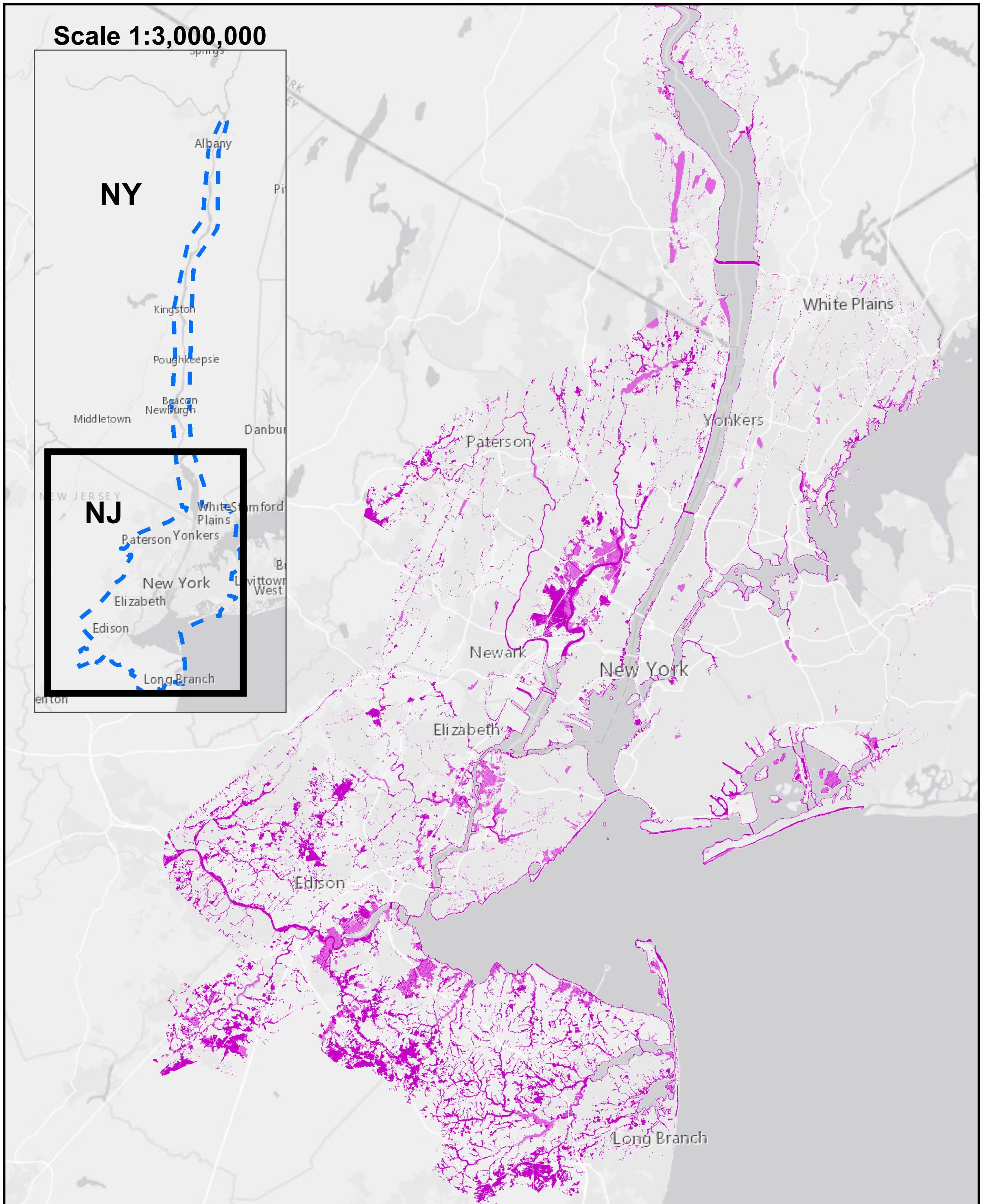
July 2018



Environmental
NY/NJ Harbor and Tributaries Study
New York and New Jersey

US Army Corps of Engineers
New York District

July 2018



0 30 60 90 120 Miles 1:600,000

N W E S

Exposure

High : 80

Low : 0

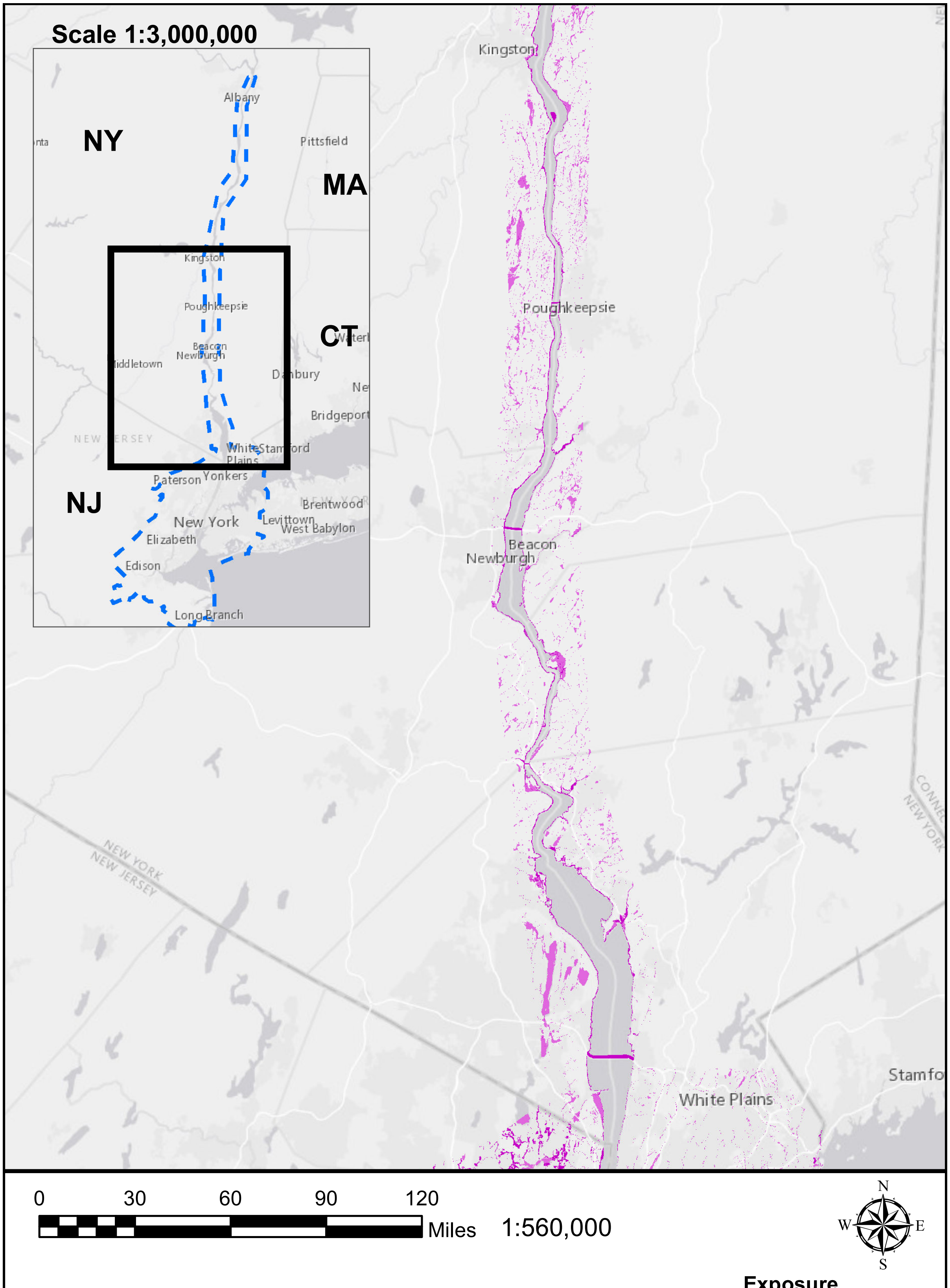
US Army Corps of Engineers® New York District

Habitat

NY/NJ Harbor and Tributaries Study

New York and New Jersey

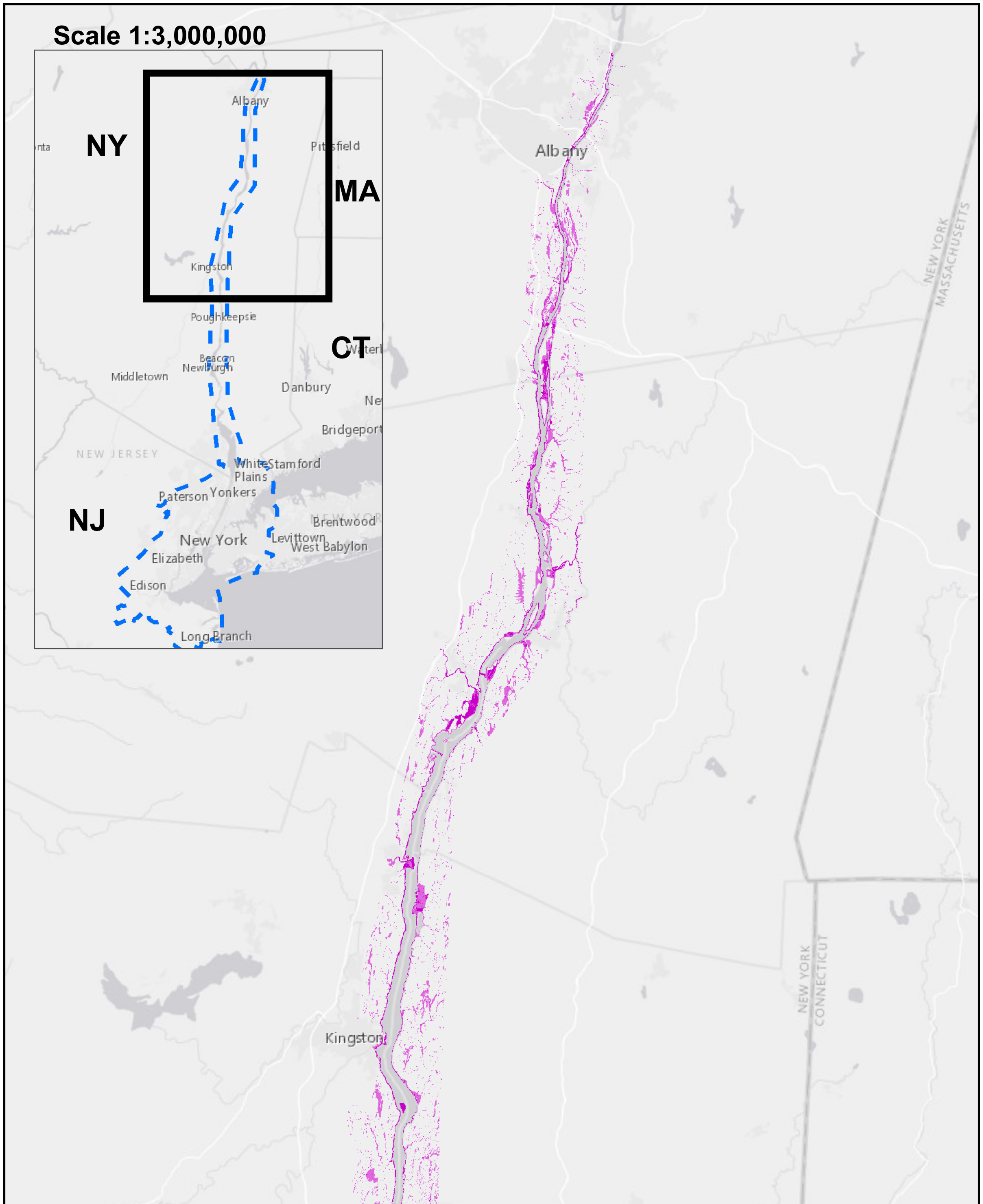
July 2018



Building Value
NY/NJ Harbor and Tributaries Study
New York and New Jersey

US Army Corps of Engineers
New York District

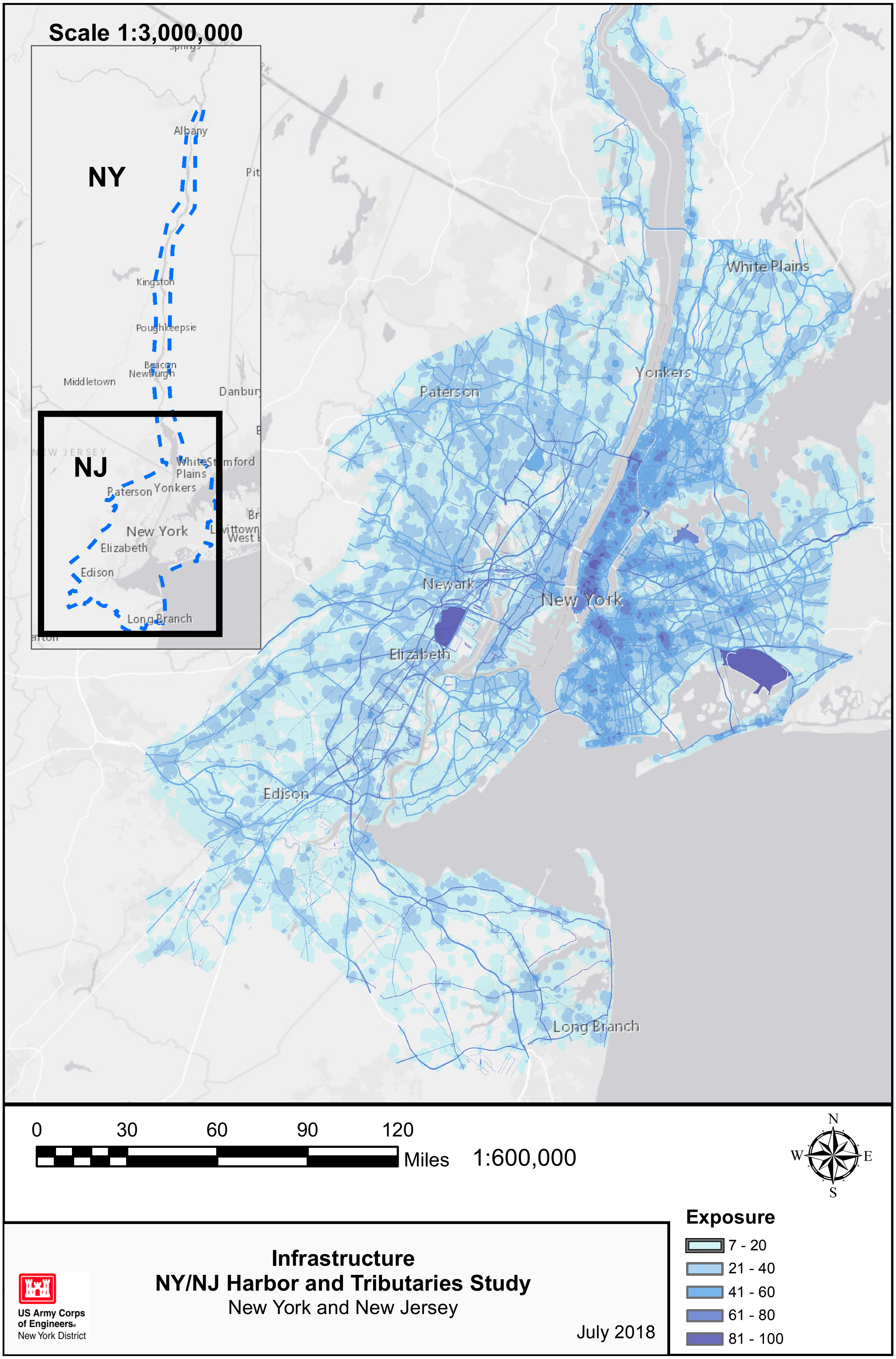
July 2018

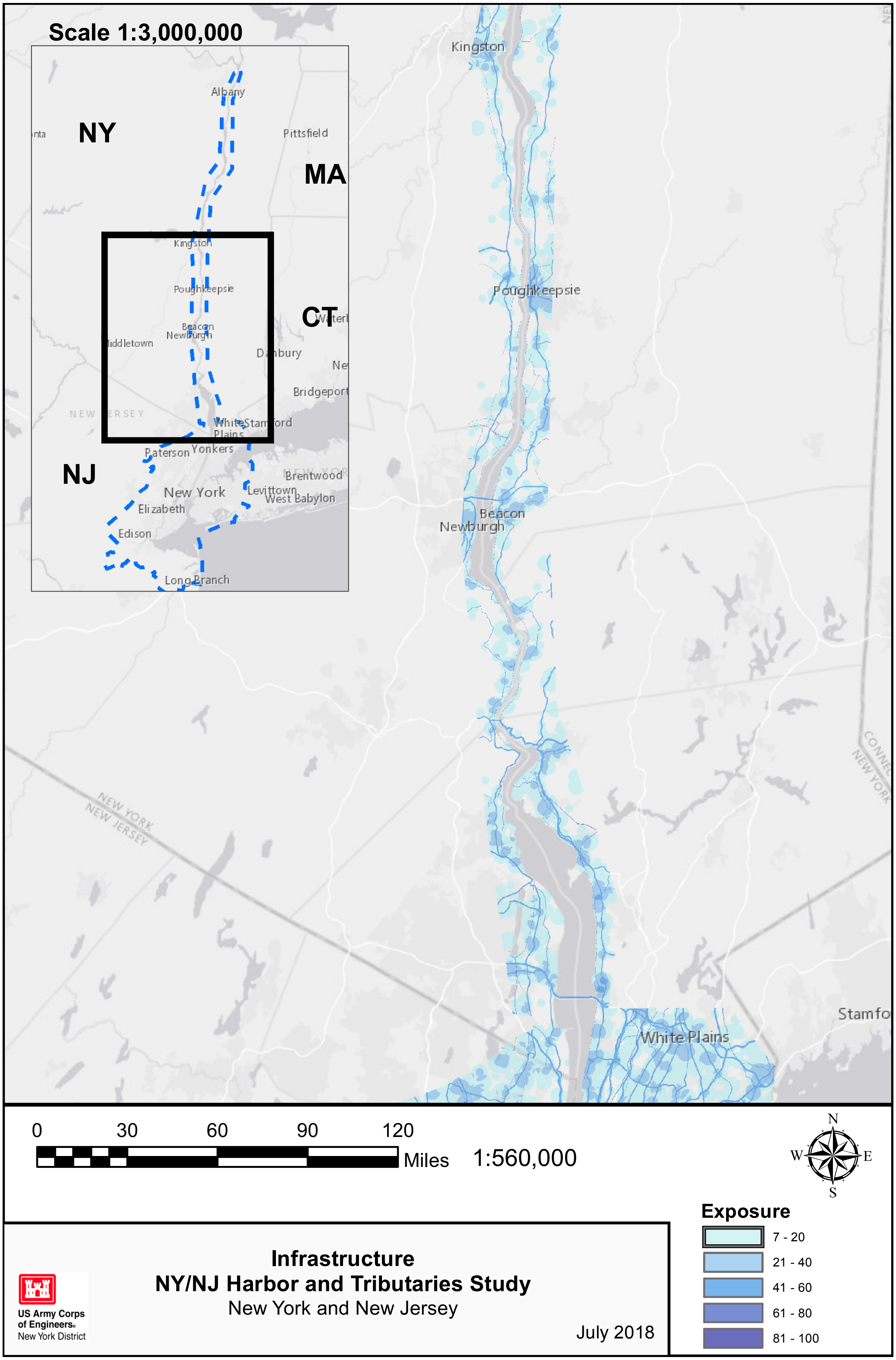


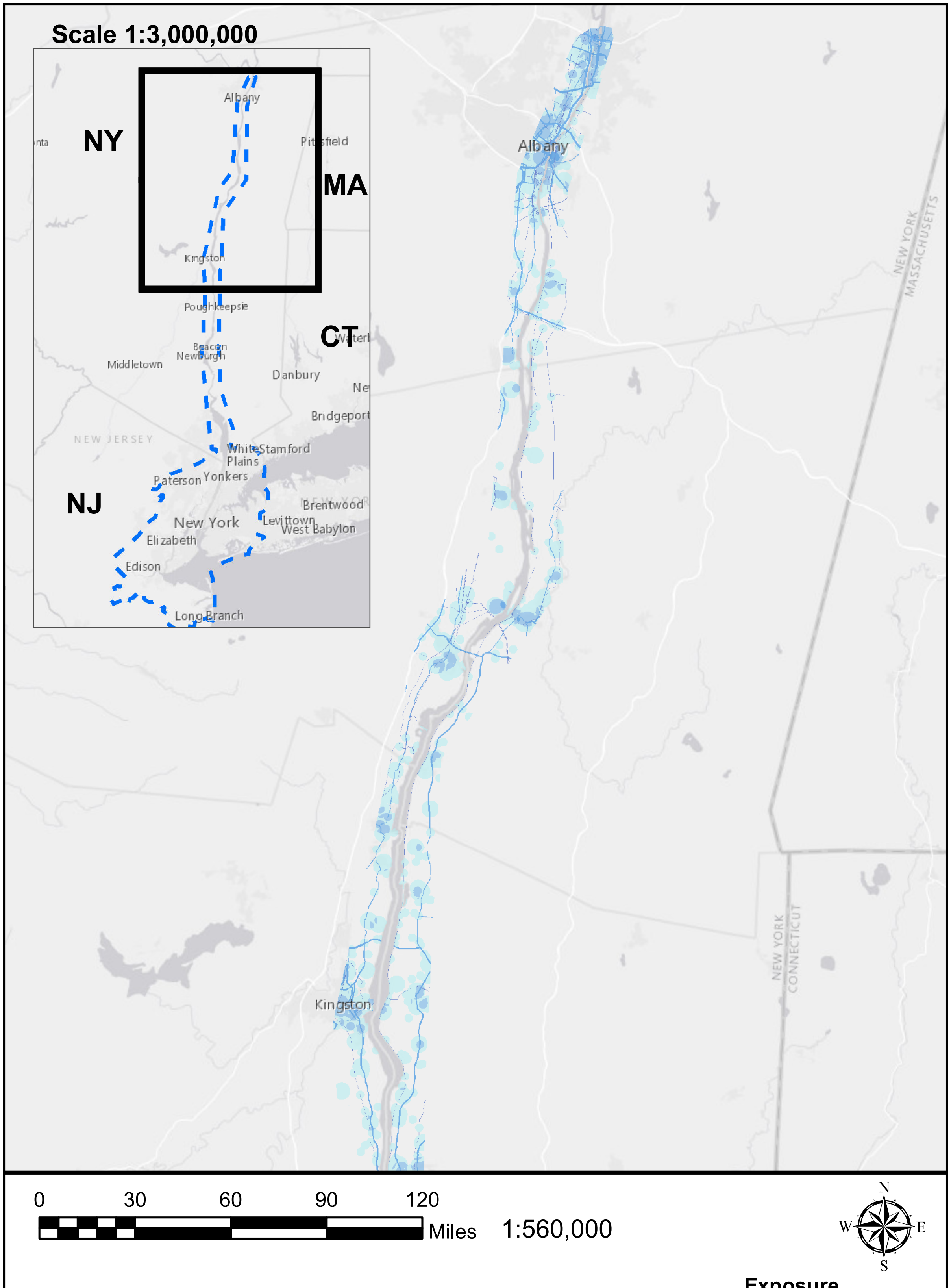
Building Value
NY/NJ Harbor and Tributaries Study
New York and New Jersey

US Army Corps of Engineers
New York District

July 2018


Scale 1:3,000,000
NY
Albany
Kingston
Poughkeepsie
Beacon
Newburgh
Middletown
Danbury
NEW JERSEY
NJ
White Plains
Stamford
Paterson
Yonkers
New York
Elizabeth
Edison
Long Branch
White Plains
Yonkers
Paterson
Newark
New York
Elizabeth
Edison
Long Branch
0
30
60
90
120
Miles
1:600,000
N
W
E
S
Exposure
7 - 20
21 - 40
41 - 60
61 - 80
81 - 100
Infrastructure
NY/NJ Harbor and Tributaries Study
New York and New Jersey
July 2018
US Army Corps of Engineers
New York District


Scale 1:3,000,000
NY
MA
CT
NJ
Albany
Pittsfield
Kingston
Poughkeepsie
Beacon
Newburgh
Middletown
Danbury
Bridgeport
NEW JERSEY
White Plains
Stamford
Paterson
Yonkers
Brentwood
New York
Levittown
West Babylon
Elizabeth
Edison
Long Branch
NEW YORK
NEW JERSEY
CONNECTICUT
NEW YORK
0
30
60
90
120
Miles
1:560,000
N
W
E
S
Exposure
7 - 20
21 - 40
41 - 60
61 - 80
81 - 100
US Army Corps of Engineers
New York District
Infrastructure
NY/NJ Harbor and Tributaries Study
New York and New Jersey
July 2018



US Army Corps of Engineers
New York District

Infrastructure
NY/NJ Harbor and Tributaries Study
New York and New Jersey

July 2018

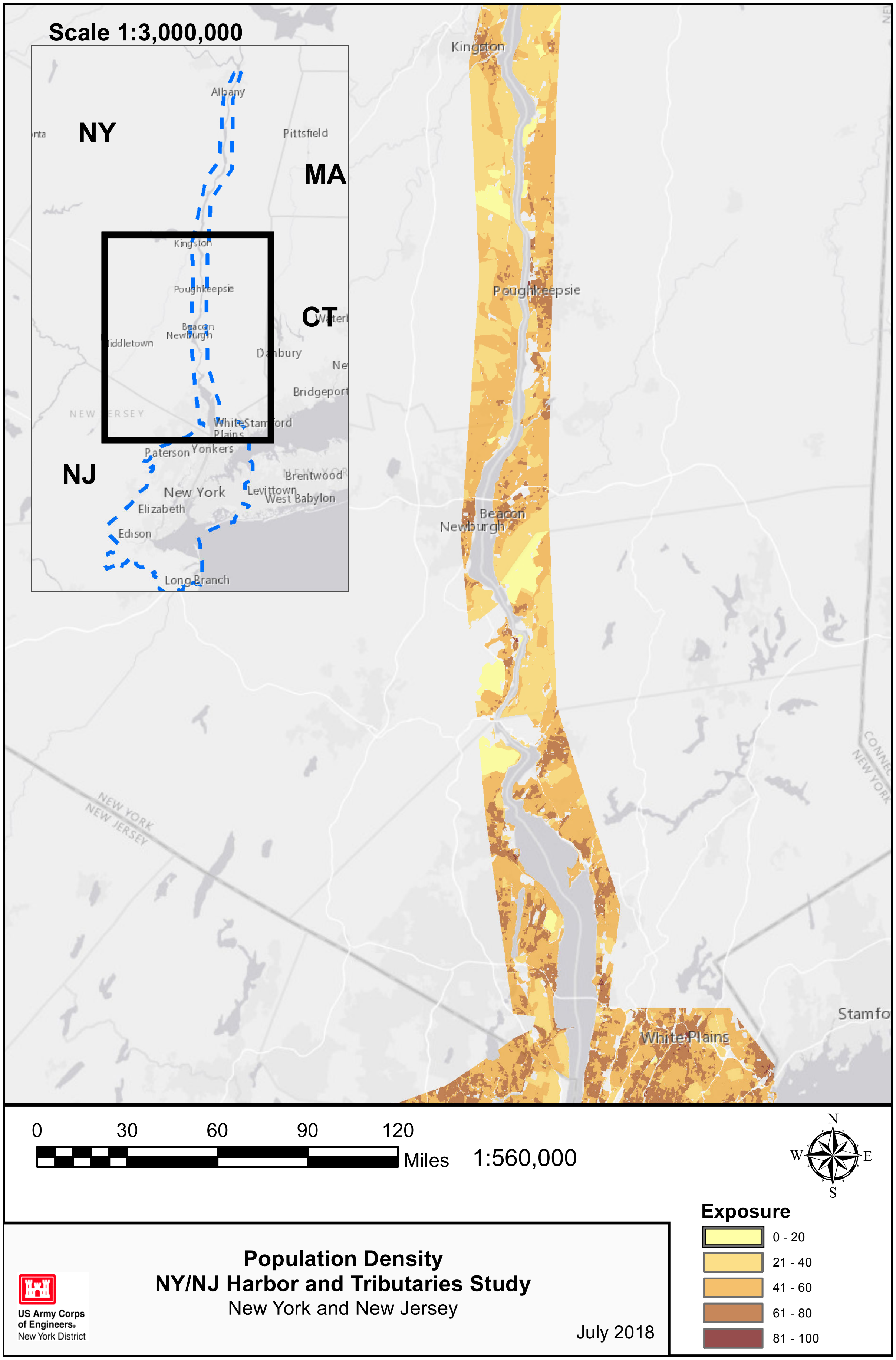
Exposure

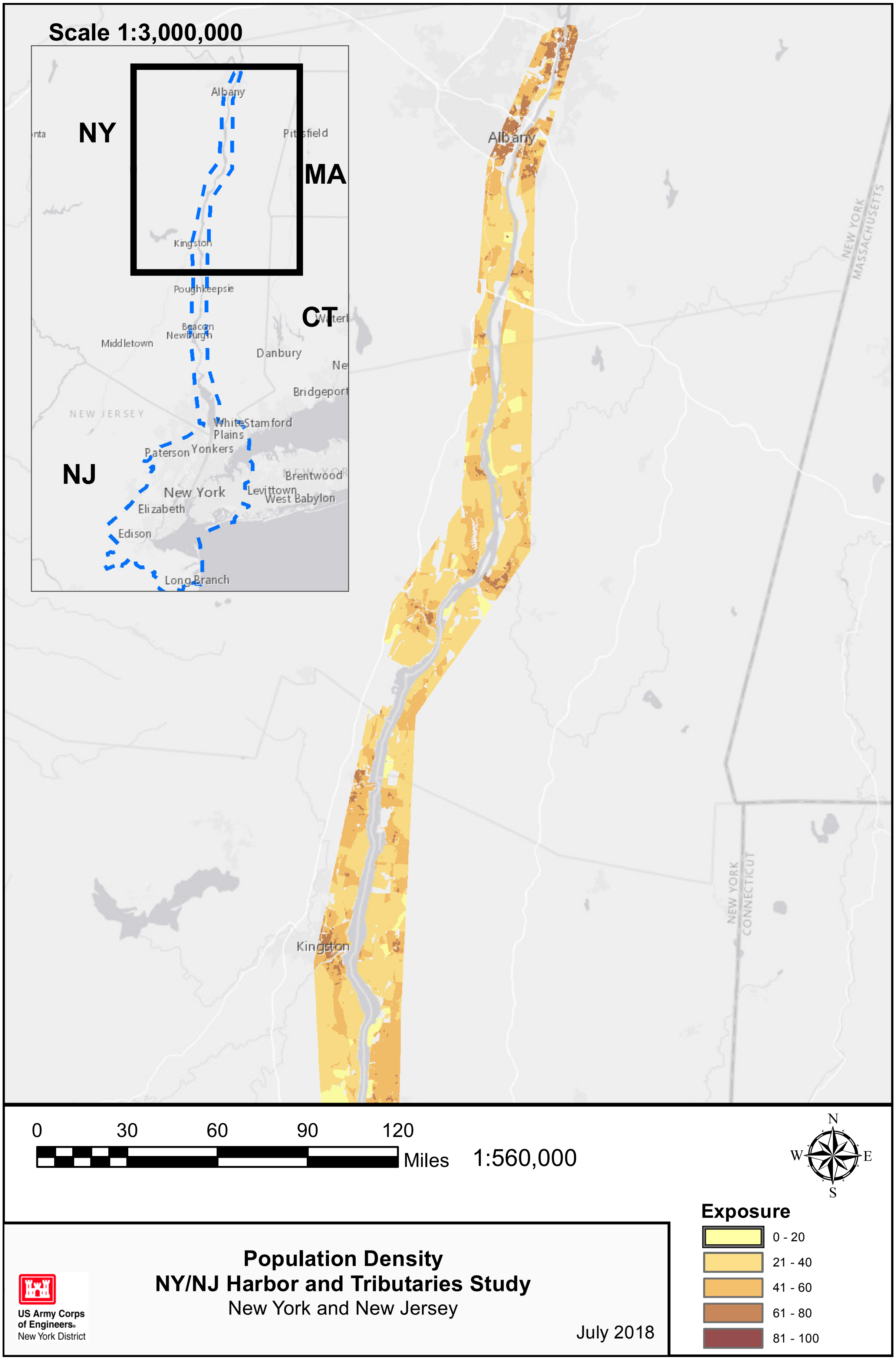
- 0 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100

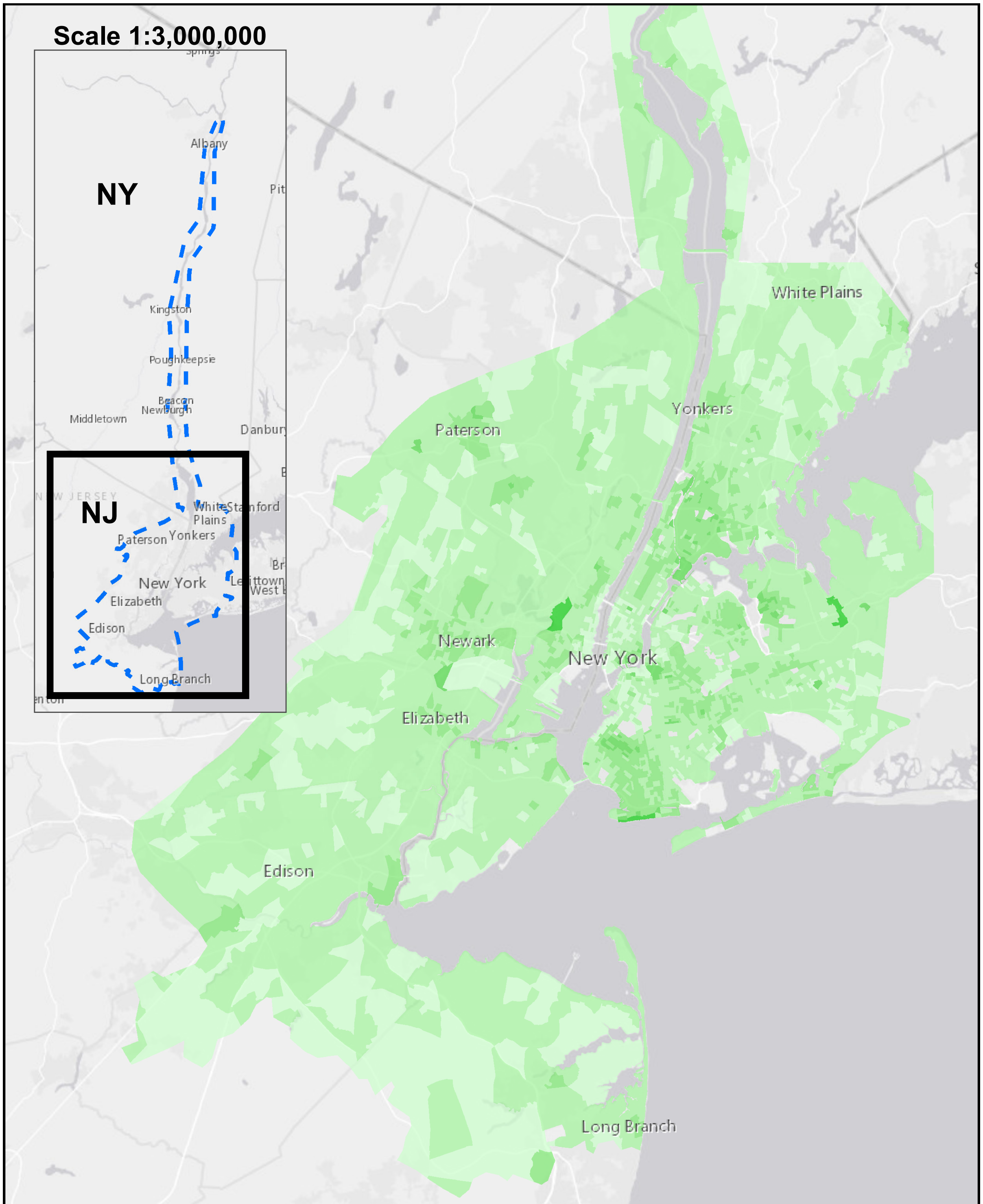
US Army Corps of Engineers®
New York District

Population Density
NY/NJ Harbor and Tributaries Study
New York and New Jersey

July 2018


Scale 1:3,000,000
NY
MA
CT
NJ
Albany
Pittsfield
Kingston
Poughkeepsie
Beacon
Newburgh
Danbury
Bridgeport
White Plains
Stamford
Paterson
Yonkers
New York
Elizabeth
Edison
Brentwood
Levittown
West Babylon
Long Branch
NEW YORK
NEW JERSEY
0 30 60 90 120
Miles
1:560,000
N
S
E
W
Exposure
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
Population Density
NY/NJ Harbor and Tributaries Study
New York and New Jersey
July 2018
US Army Corps of Engineers
New York District


Scale 1:3,000,000
NY
MA
CT
NJ
Albany
Pittsfield
Kingston
Poughkeepsie
Beacon
Newburgh
Middletown
Danbury
Bridgeport
NEW JERSEY
White Plains
Stamford
Paterson
Yonkers
Brentwood
New York
Levittown
West Babylon
Elizabeth
Edison
Long Branch
NEW YORK
MASSACHUSETTS
CONNECTICUT
0 30 60 90 120
Miles
1:560,000
N
S
W
E
Exposure
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
Population Density
NY/NJ Harbor and Tributaries Study
New York and New Jersey
July 2018
US Army Corps of Engineers
New York District



0 30 60 90 120 Miles

1:600,000

N W E S

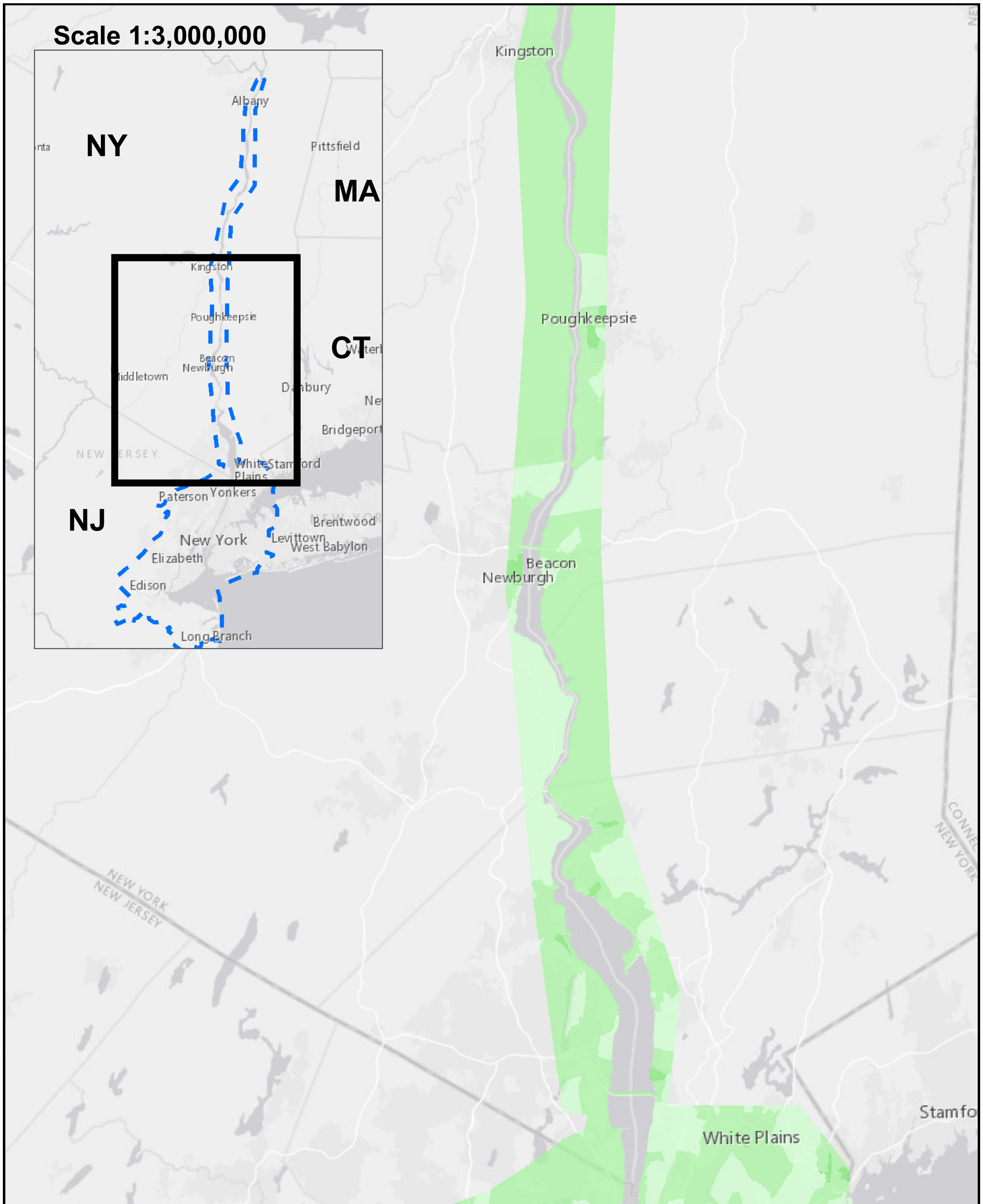
Exposure

- 1 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100

US Army Corps of Engineers
New York District

Social Vulnerability
NY/NJ Harbor and Tributaries Study
New York and New Jersey

July 2018



0 30 60 90 120 Miles

1:560,000

N W E S

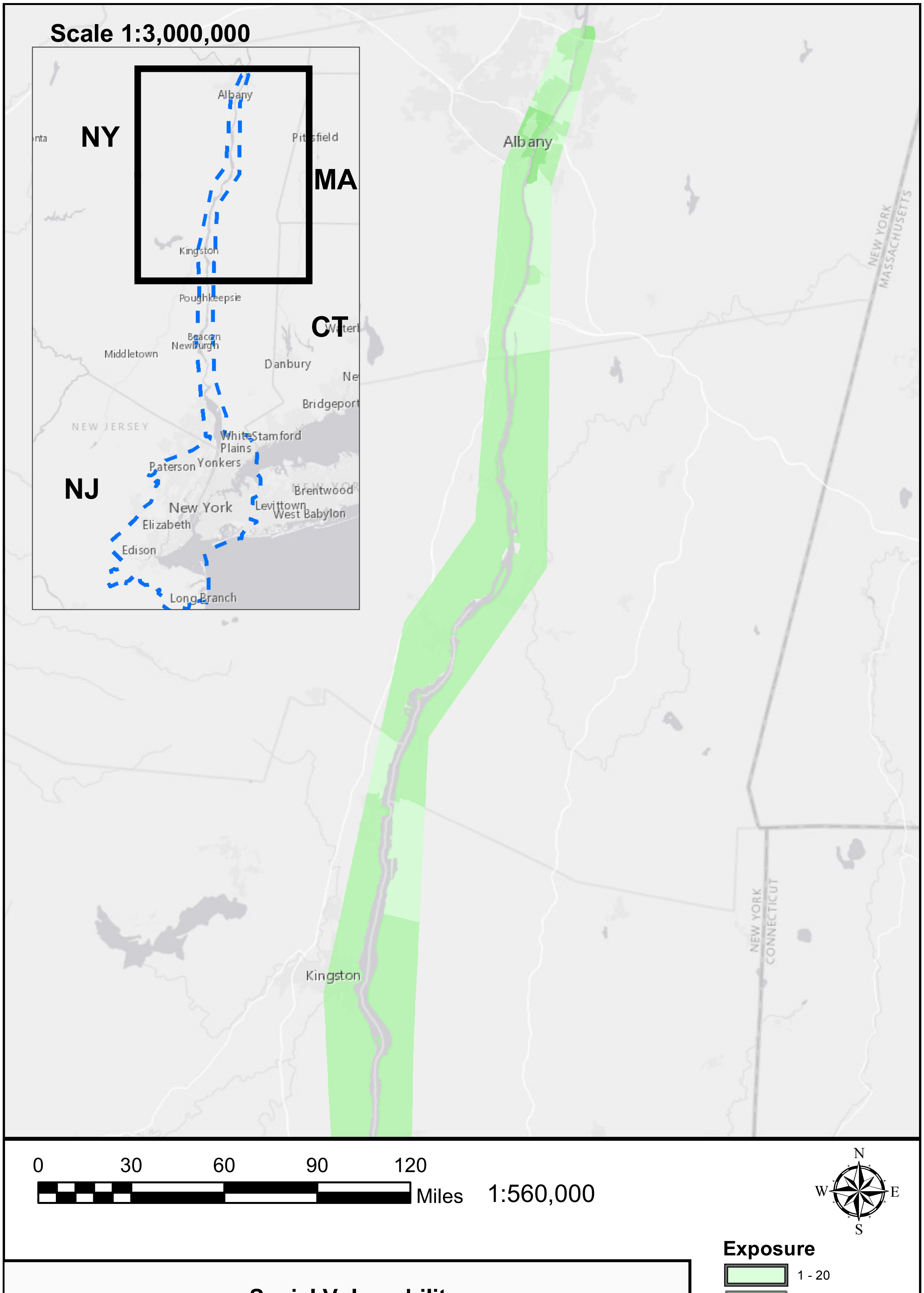
Exposure

- 1 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100

US Army Corps of Engineers® New York District

Social Vulnerability
NY/NJ Harbor and Tributaries Study
New York and New Jersey

July 2018



Exposure

	1 - 20
	21 - 40
	41 - 60
	61 - 80
	81 - 100

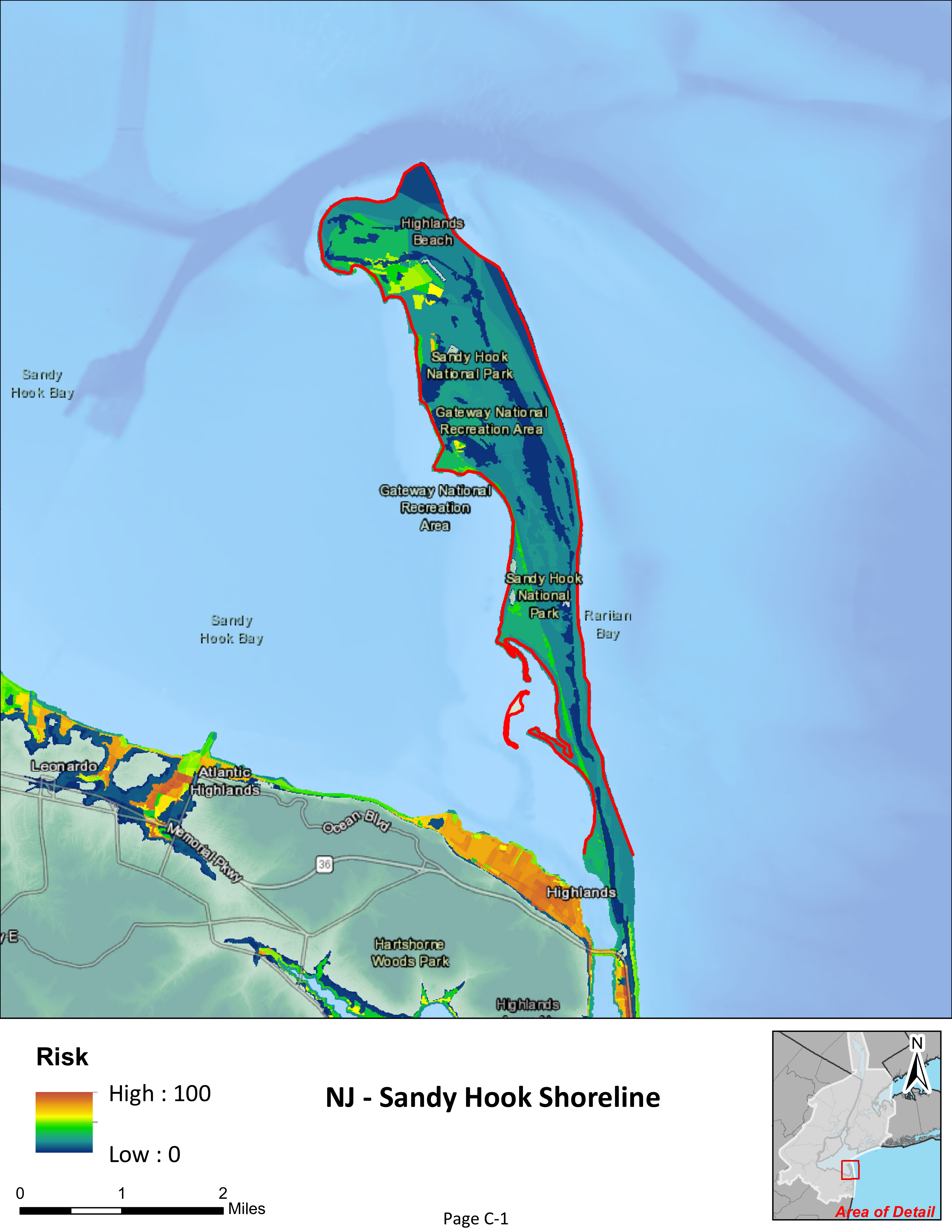
US Army Corps of Engineers
New York District

Social Vulnerability
NY/NJ Harbor and Tributaries Study
New York and New Jersey

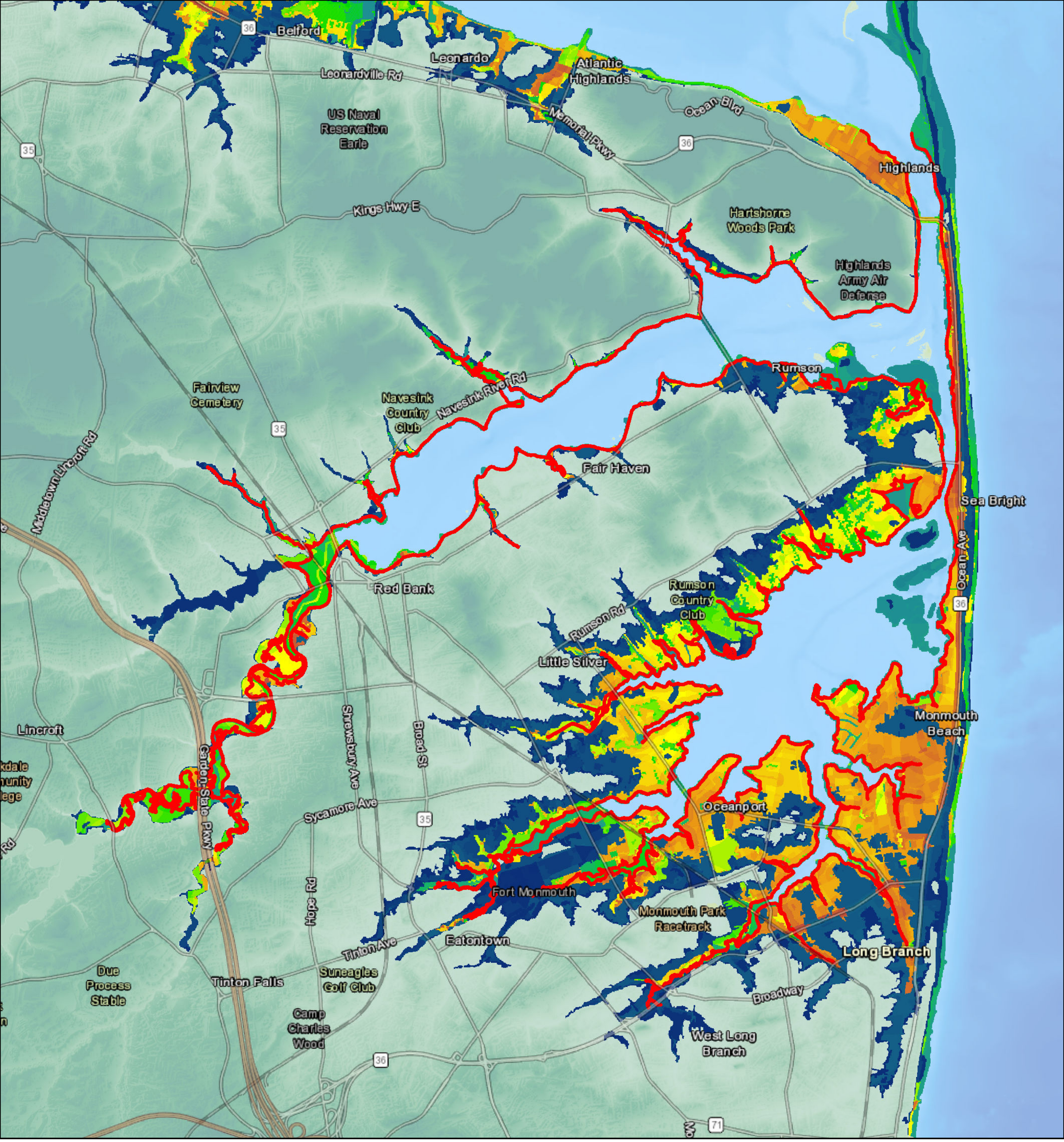
July 2018

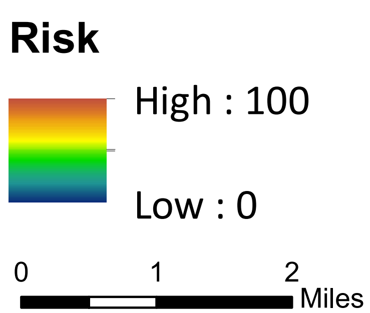
Appendix C

Composite Risk Indices

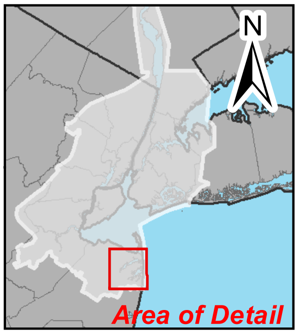


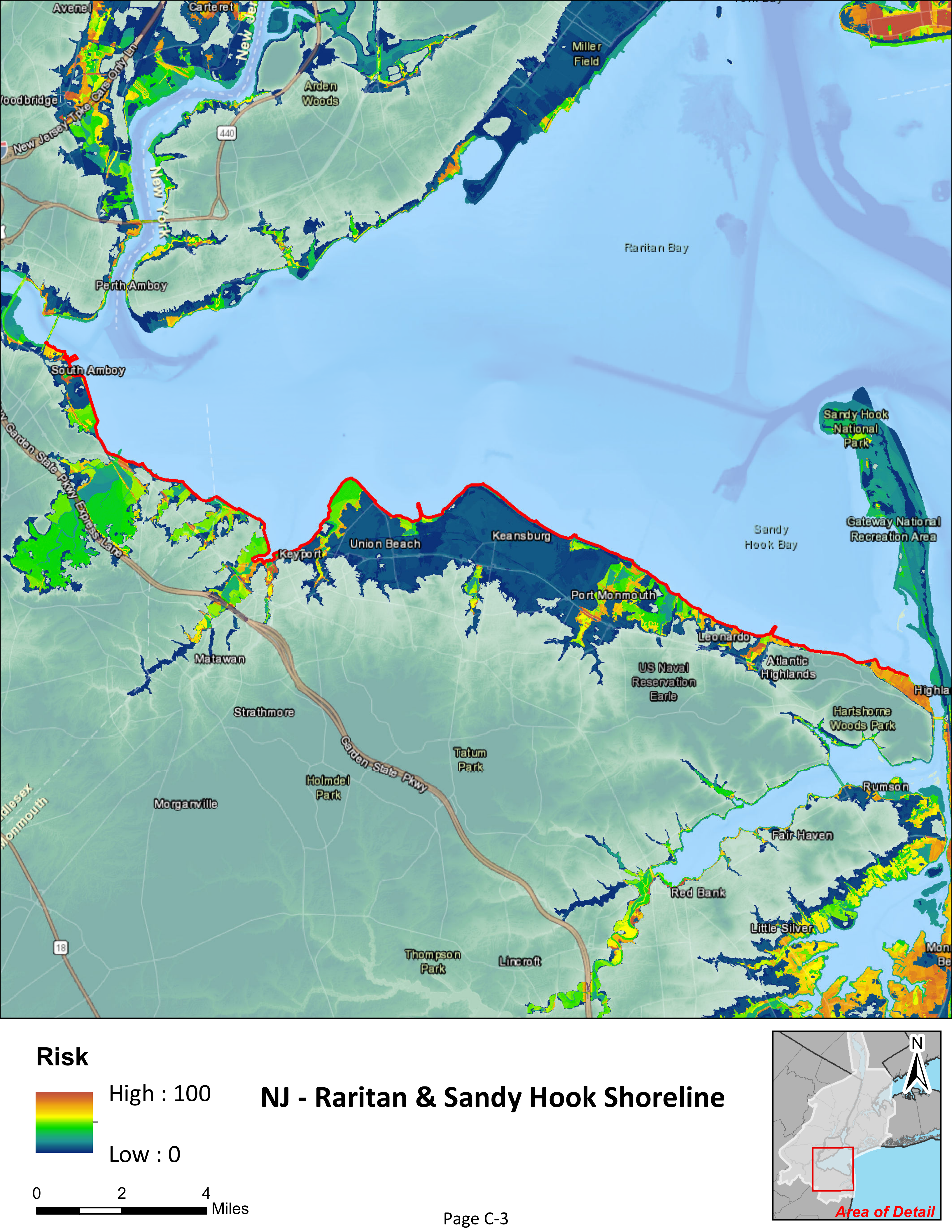
NJ - Sandy Hook Shoreline



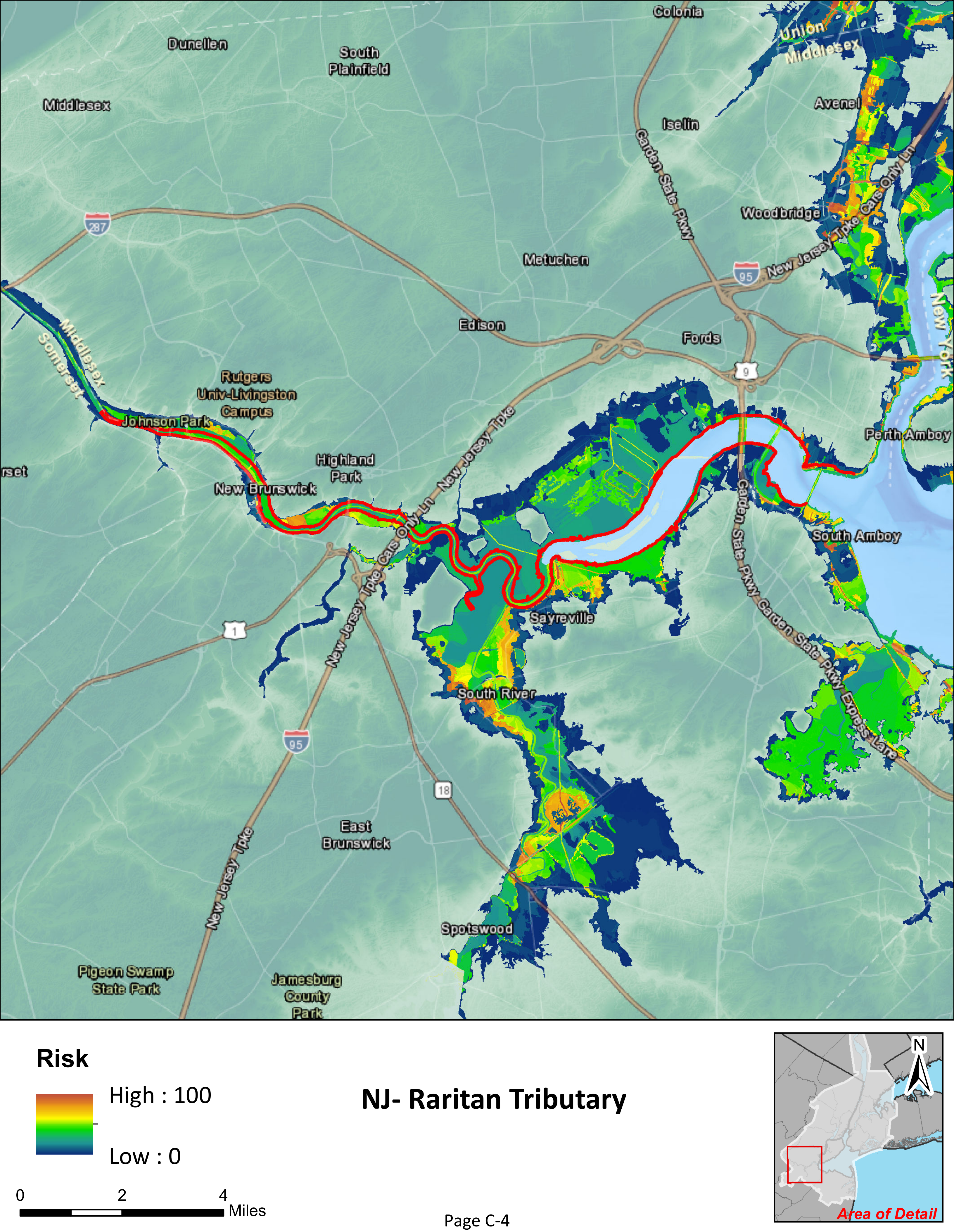


NJ- Shrewsbury Tributary

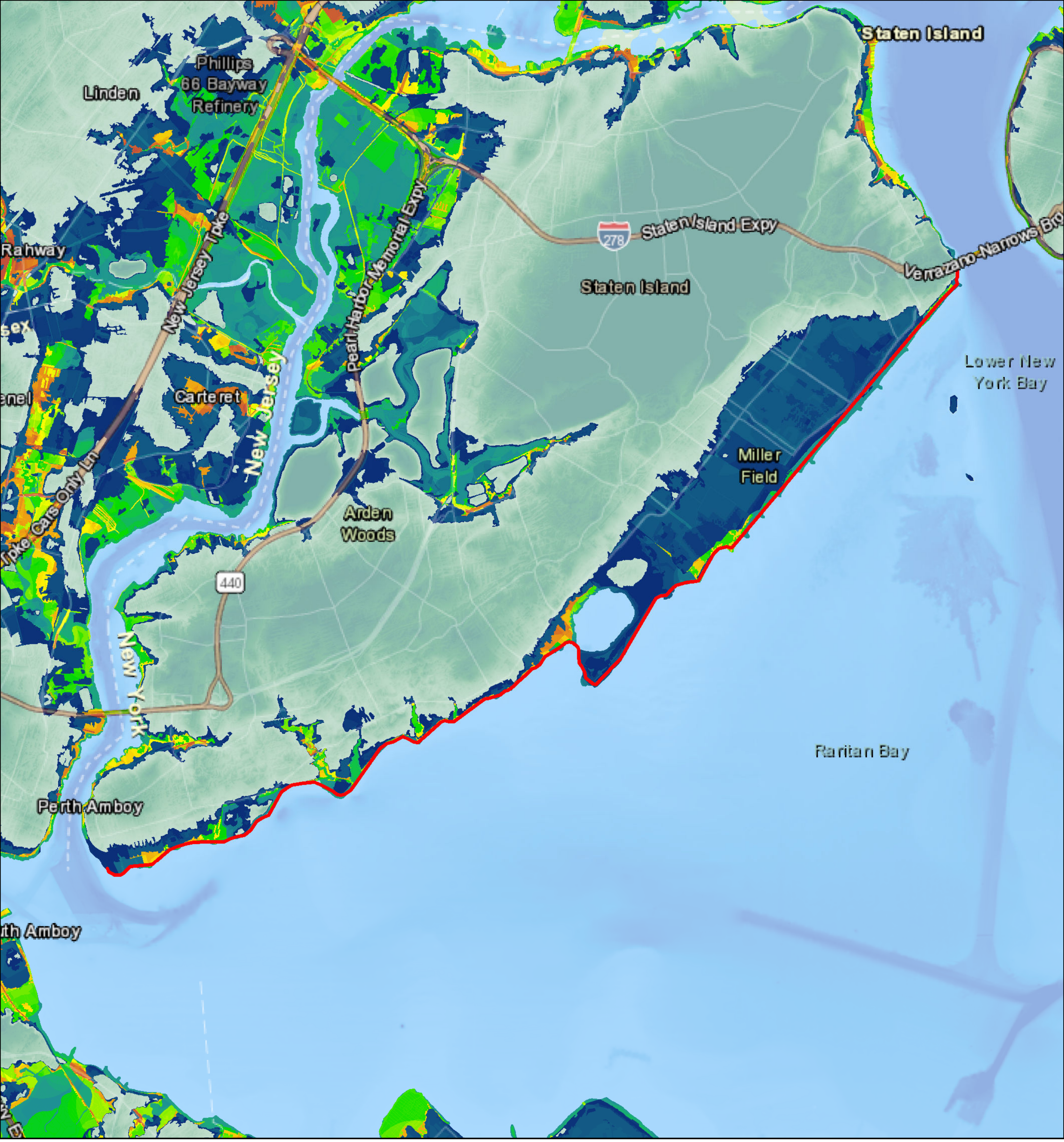




NJ - Raritan & Sandy Hook Shoreline



NJ- Raritan Tributary



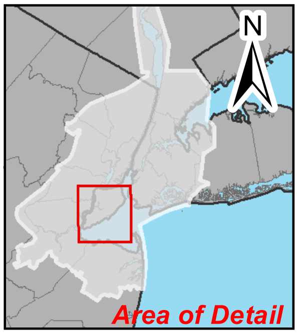
Risk

High : 100

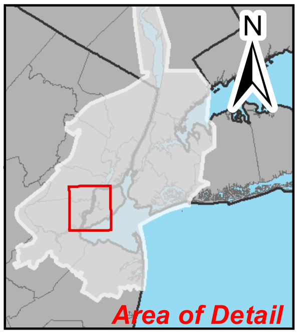
Low : 0

0 1.5 3 Miles

NYC - South Shore of Staten Island



NYC - Western Shore of Staten Island



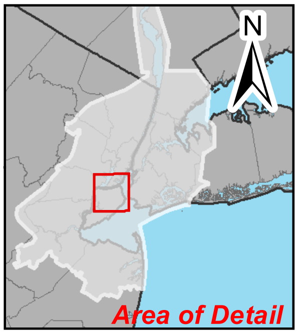
Risk

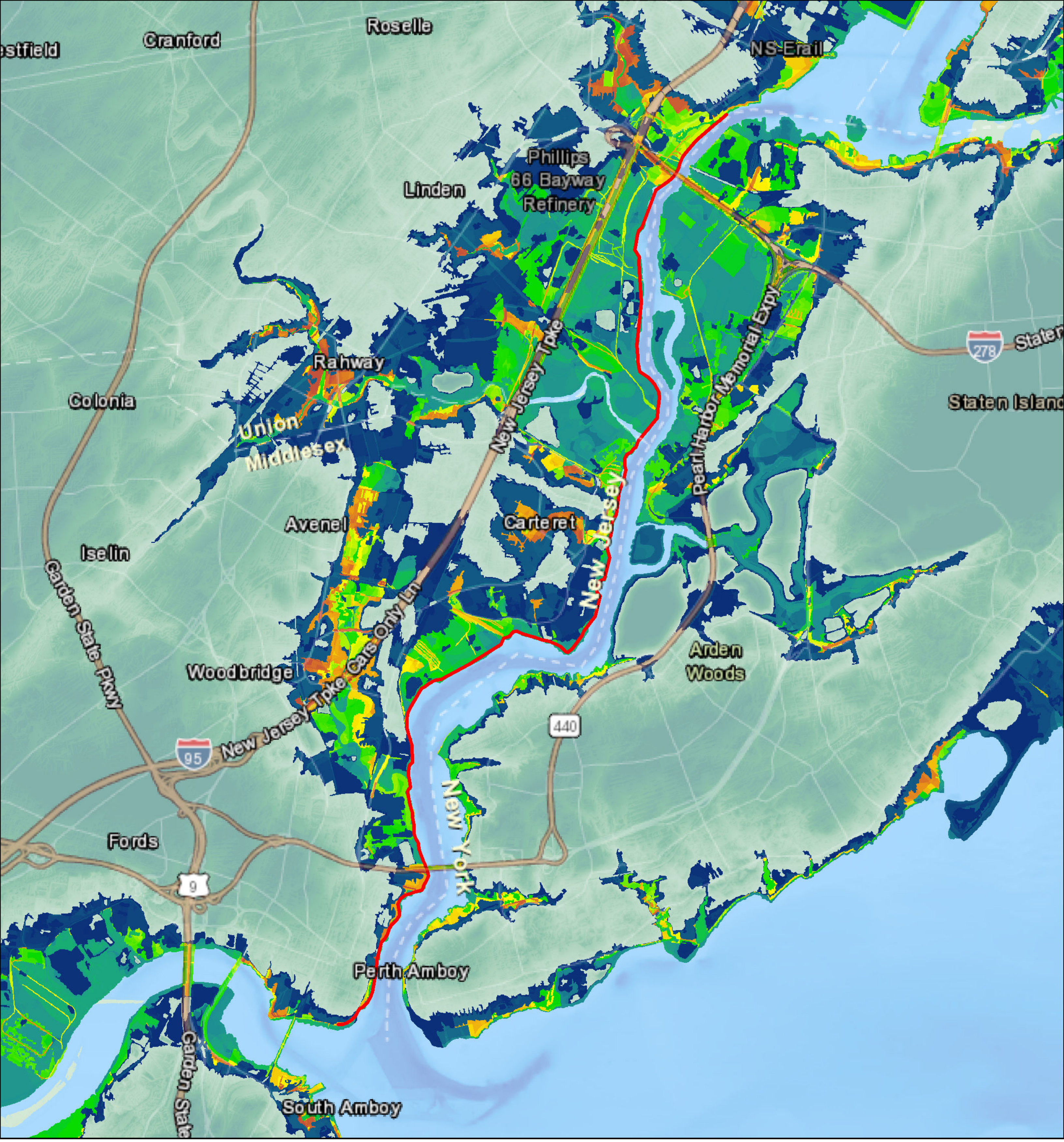
High : 100

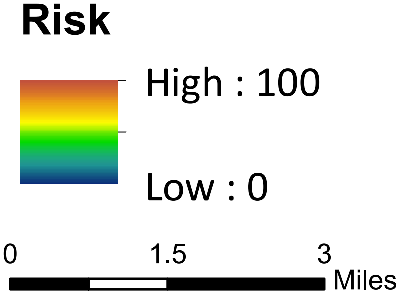
Low : 0

0 1 2 Miles

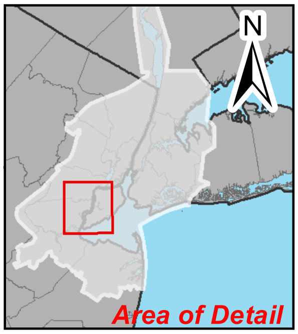
NYC - Northern Shore of Staten Island

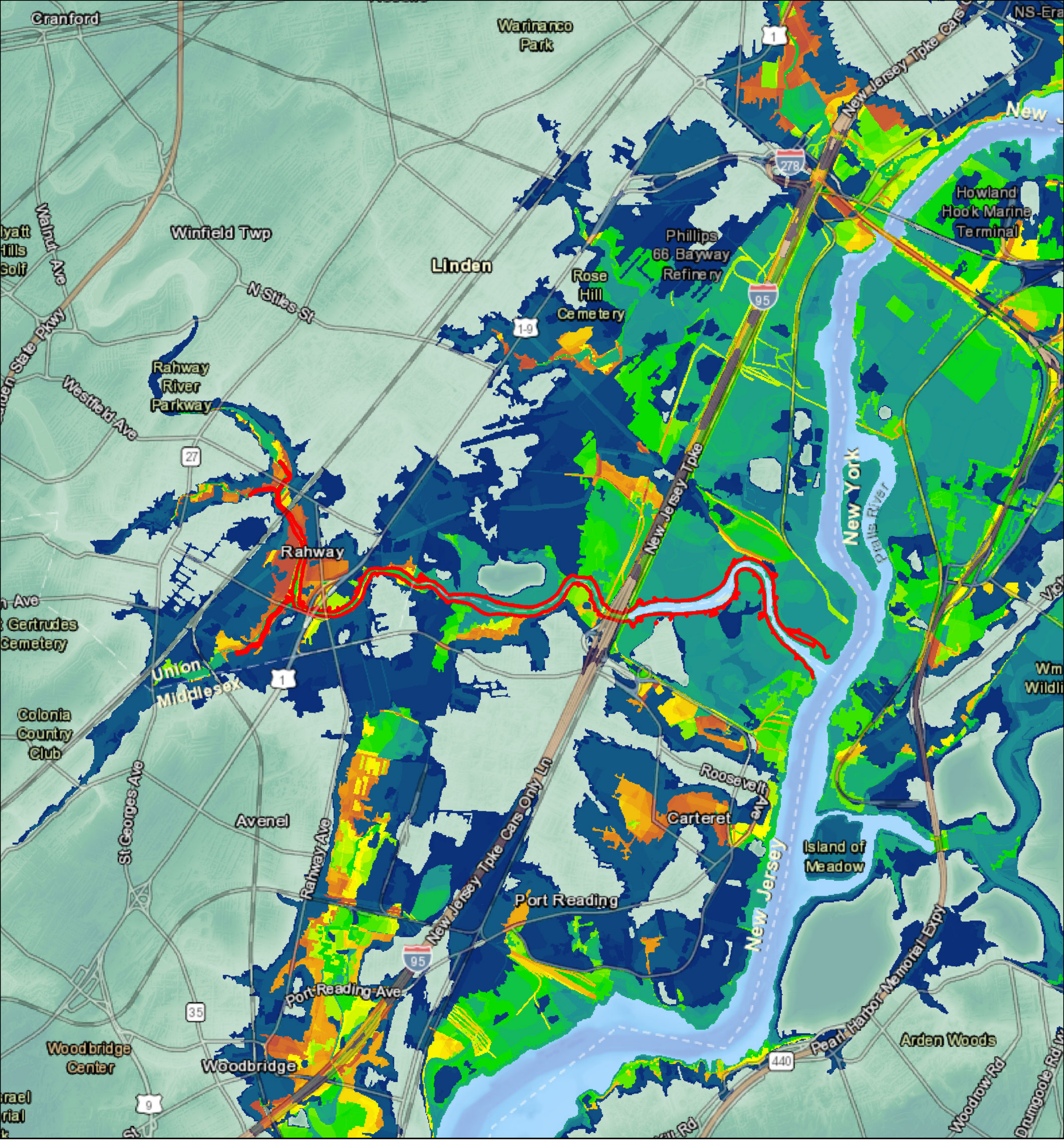






NJ - Shoreline along Arthur Kill





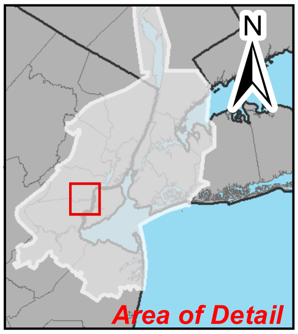
Risk

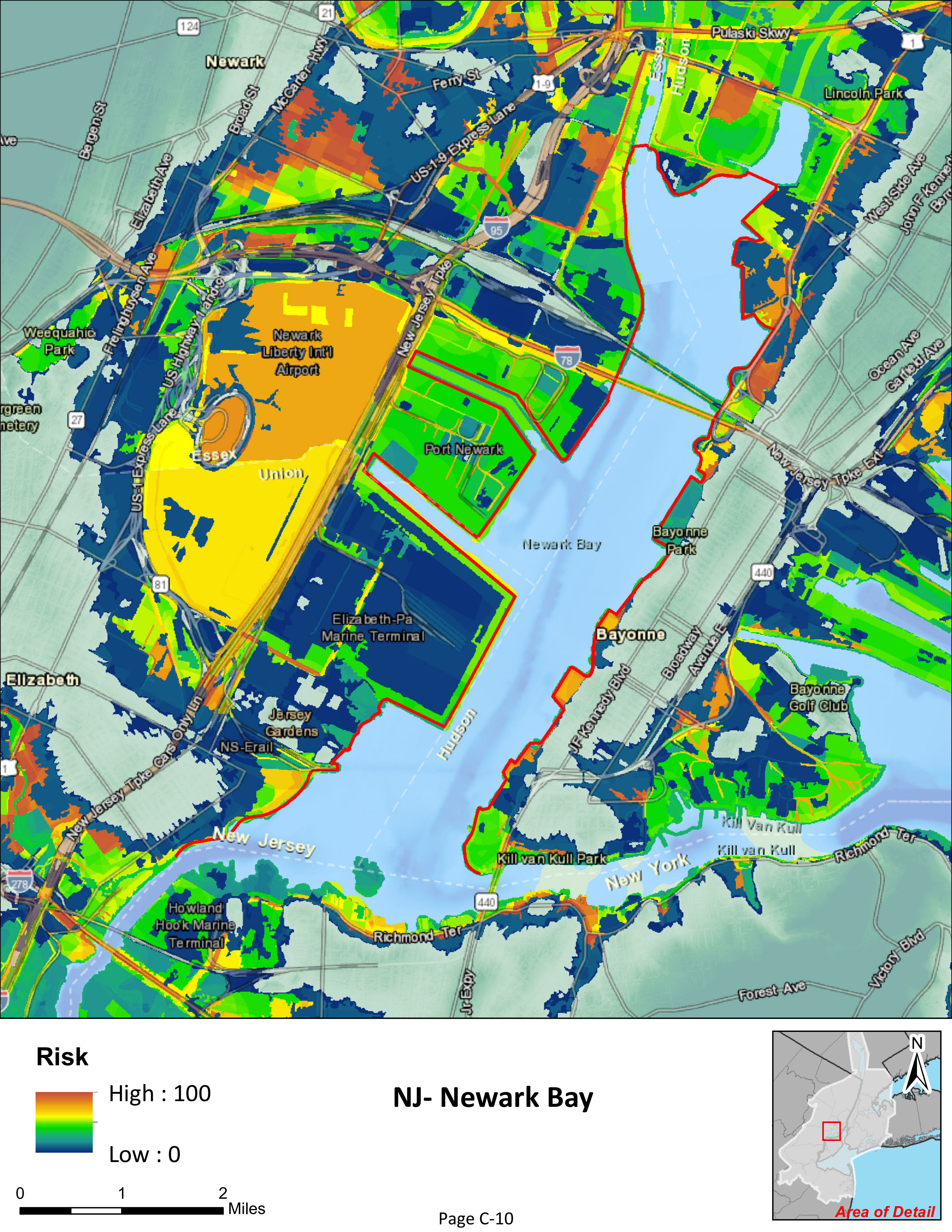
High : 100

Low : 0

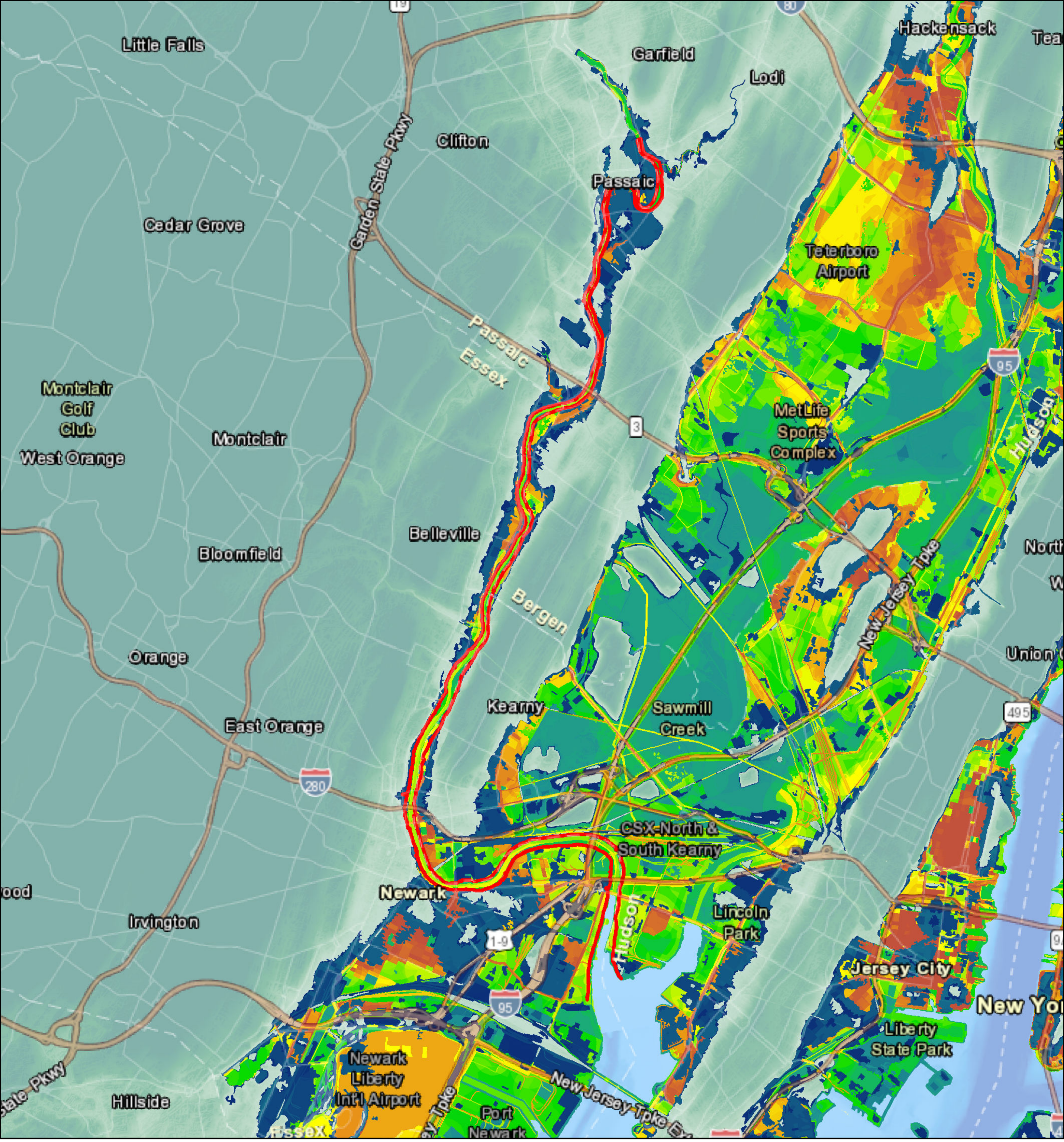
NJ- Rahway Tributary

0 1 2 Miles





NJ- Newark Bay



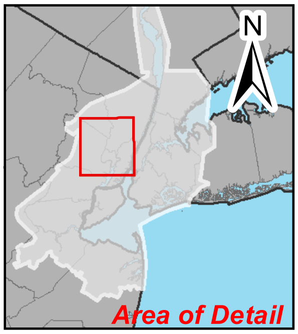
Risk

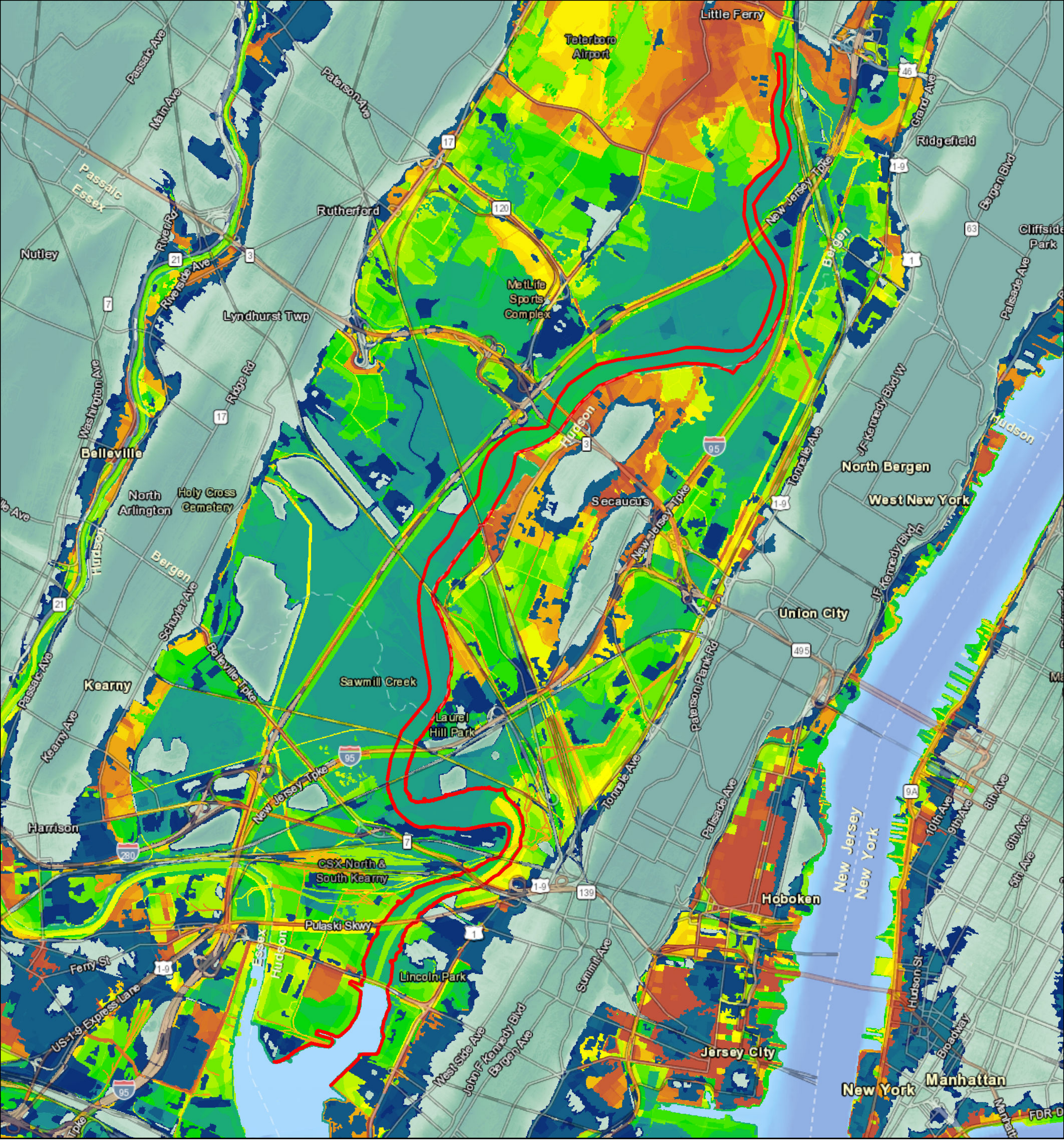
High : 100

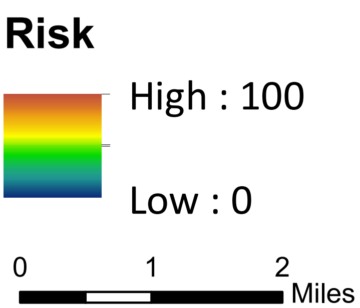
Low : 0

NJ- Passaic Tributary

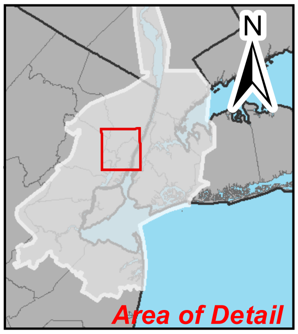
0 1.5 3 Miles







NJ- Hackensack Tributary



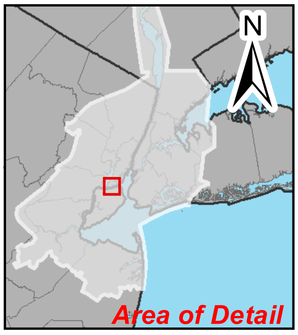
Risk

High : 100

Low : 0

0 0.5 1 Miles

NJ - Shoreline along Kill Van Kull



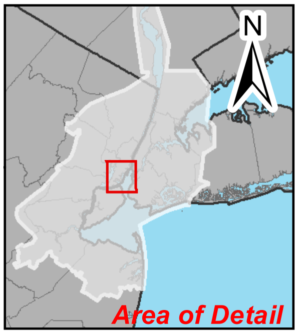
Risk

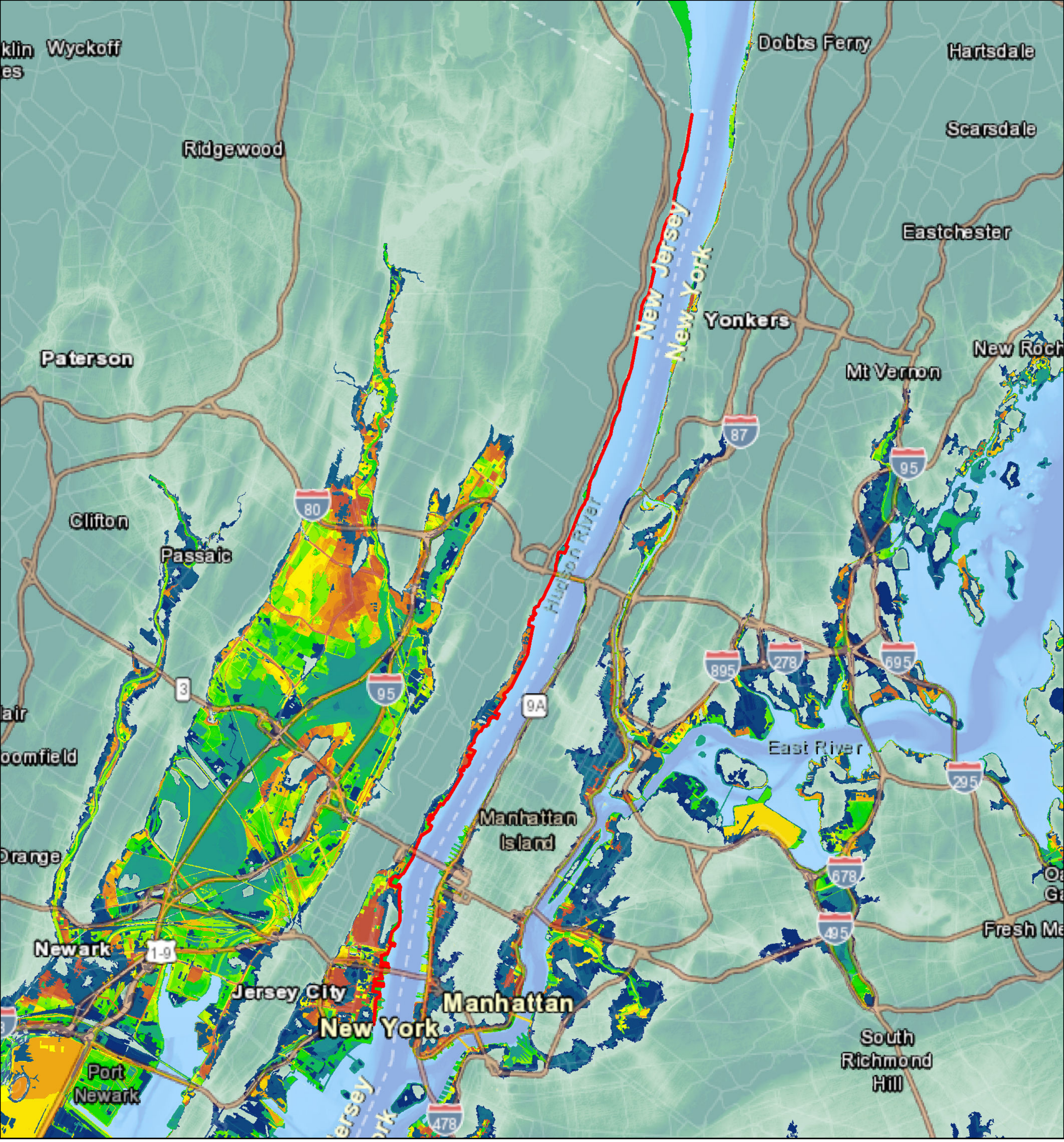
High : 100

Low : 0

NJ - Shoreline along Upper Bay

0 1 2 Miles





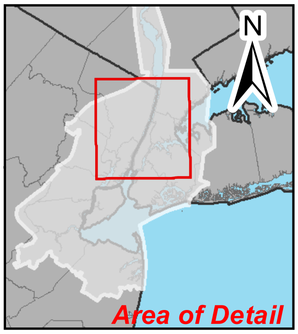
Risk

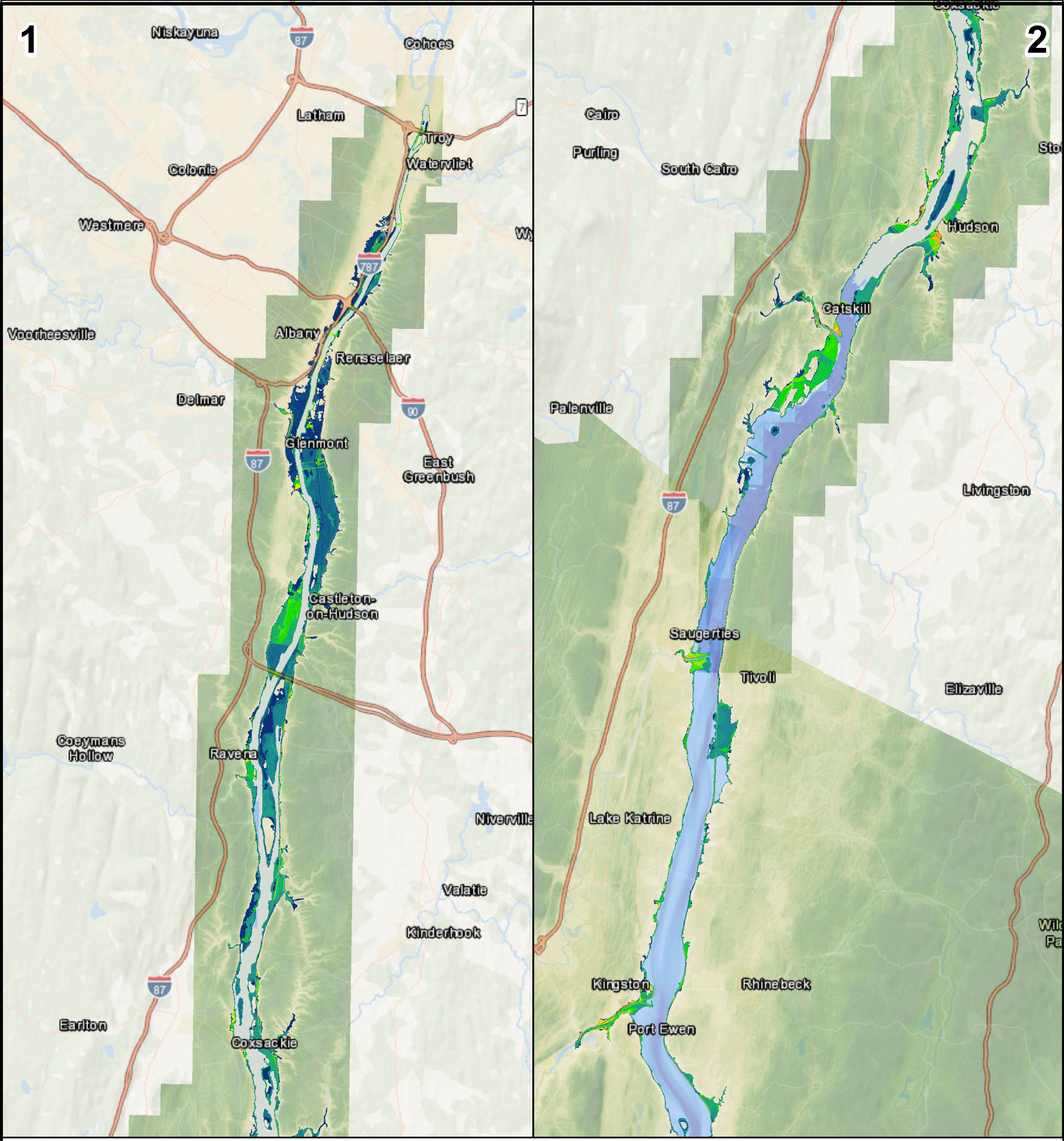
High : 100

Low : 0

0 3 6 Miles

NJ - Shoreline along Hudson River



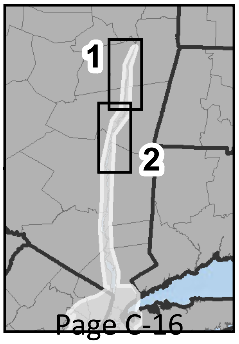


NY- Shoreline along Hudson River (Albany)

Risk

High : 100

Low : 0



NY- Shoreline along Hudson River (Greene and Columbia)

N
W E
S

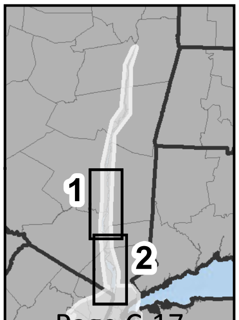
0 5 10 Miles

NY- Shoreline along Hudson River (Ulster and Dutchess)

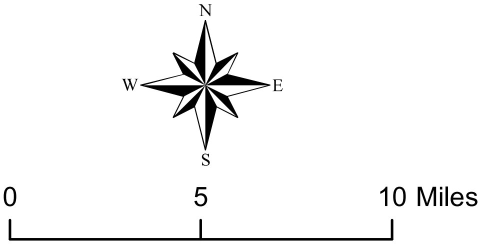
Risk

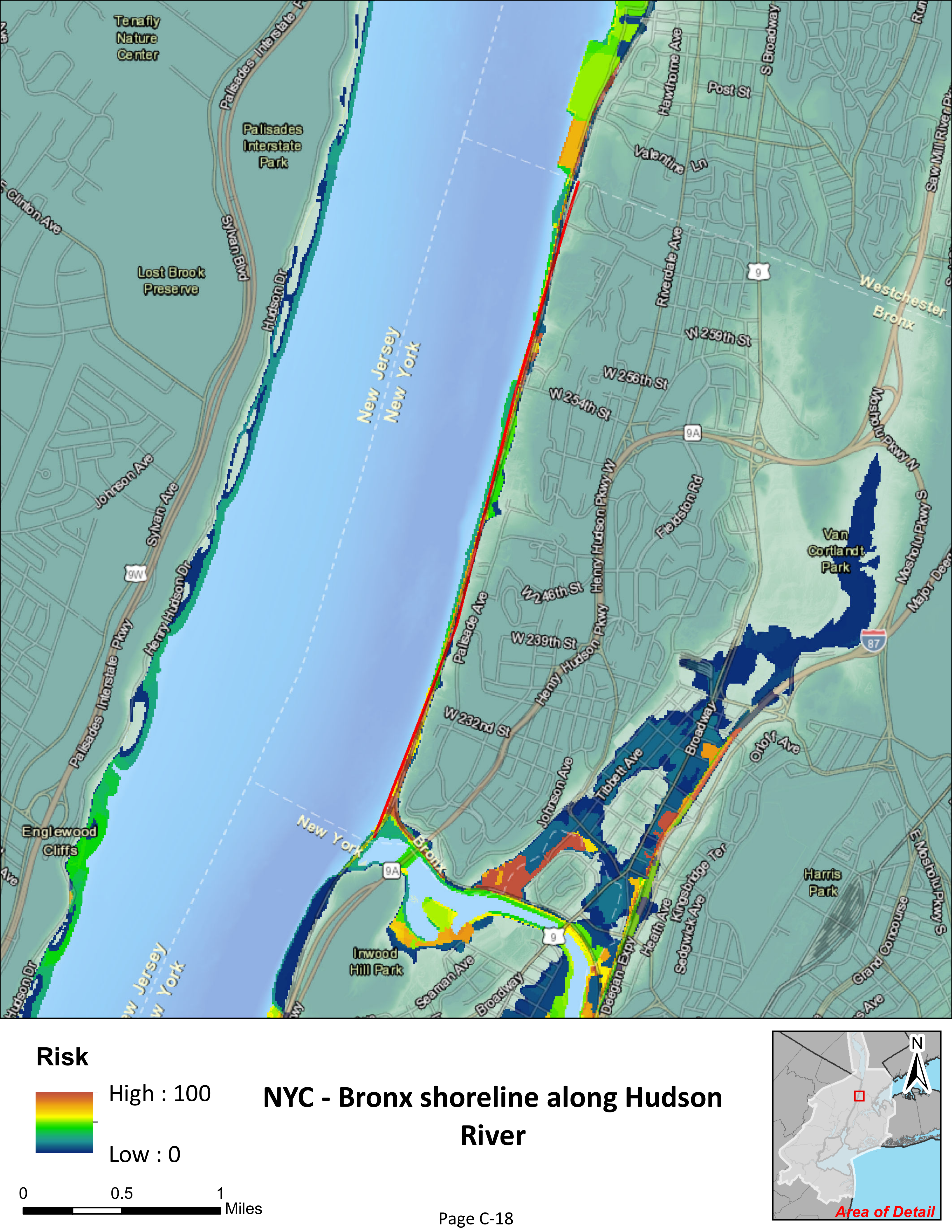
High : 100

Low : 0

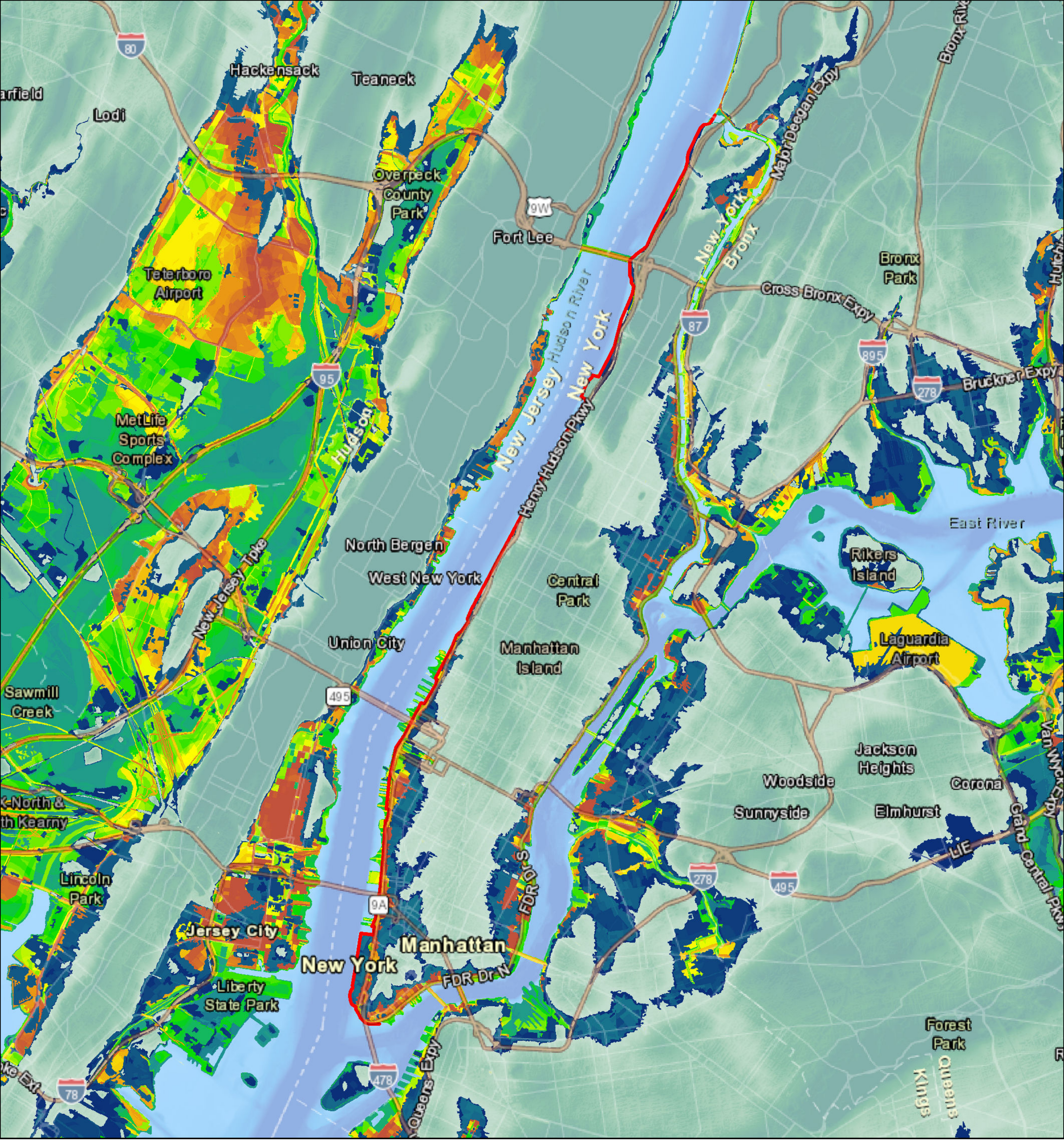


NY- Shoreline along Hudson River (Orange, Rockland, Putnam, and Westchester)





NYC - Bronx shoreline along Hudson River



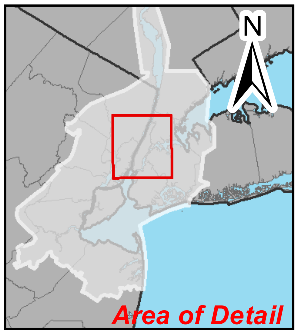
Risk

High : 100

Low : 0

0 2 4 Miles

NYC - Manhattan shoreline along Hudson River



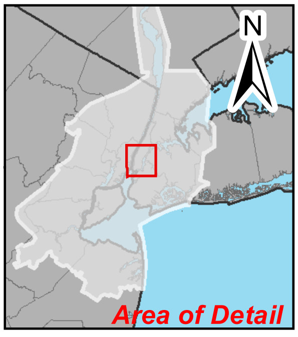
Risk

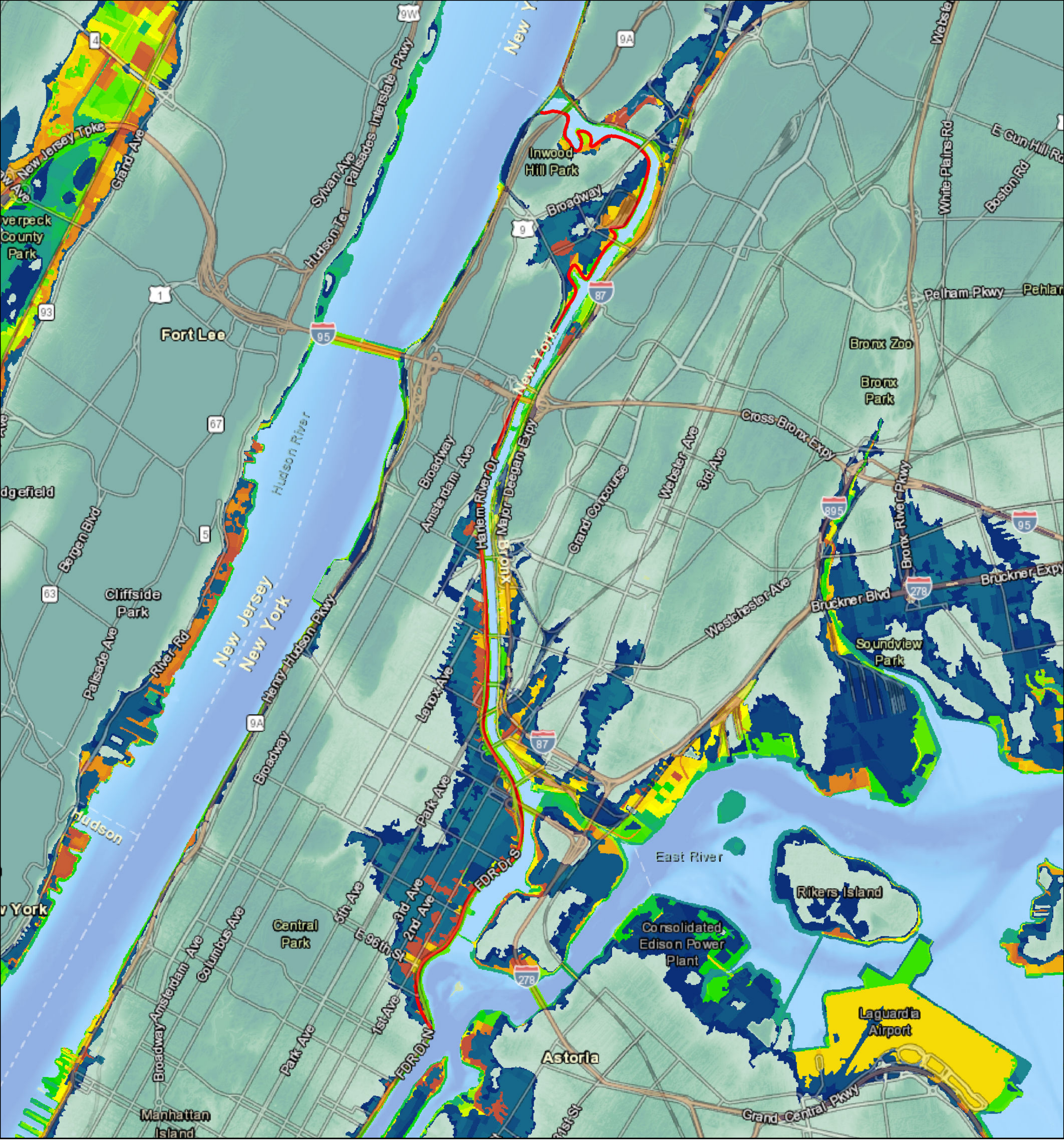
High : 100

Low : 0

0 1 2
Miles

NYC - Manhattan shoreline along East River





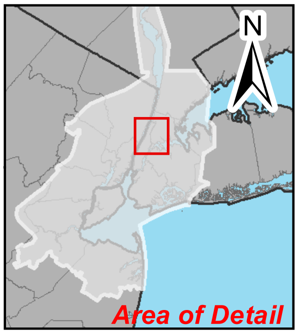
Risk

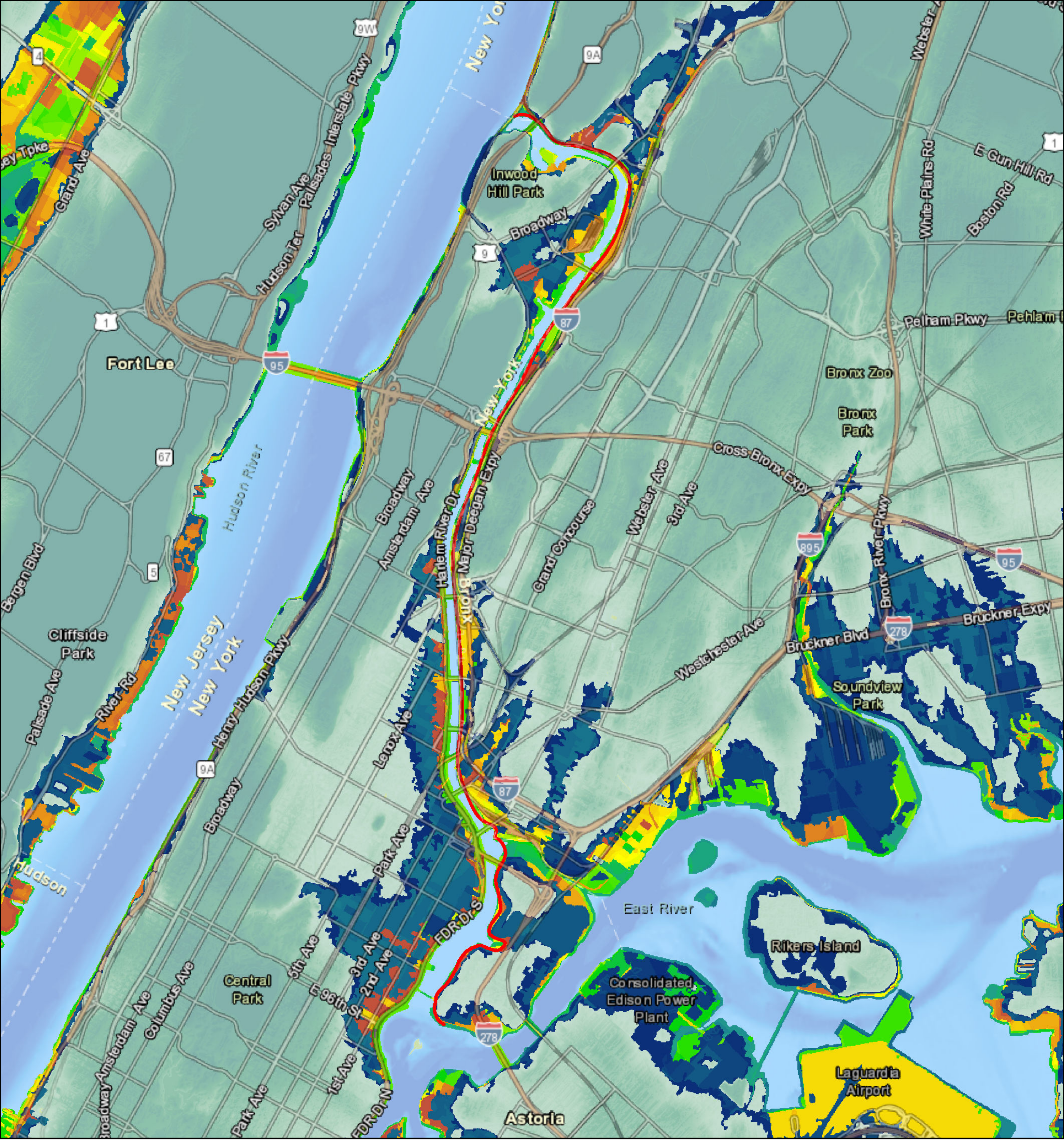
High : 100

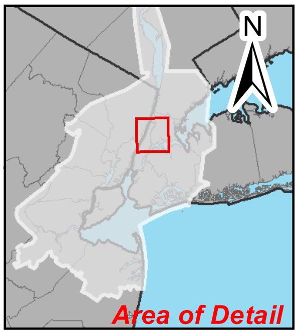
Low : 0

0 1 2 Miles

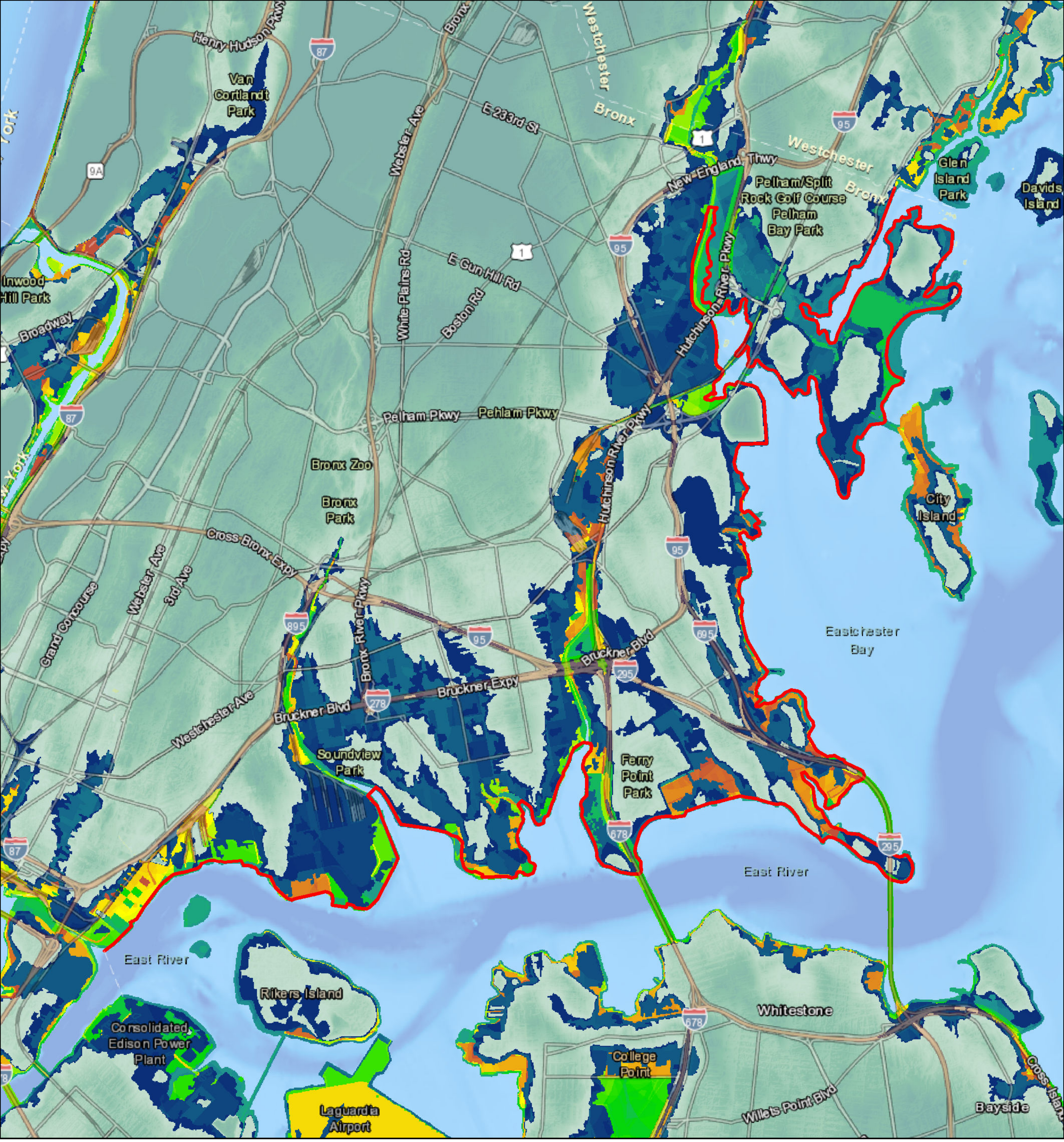
NYC - Manhattan shoreline along Harlem River







NYC - Bronx shoreline along Harlem River



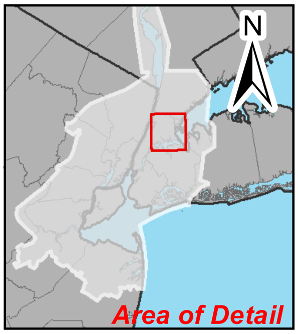
Risk

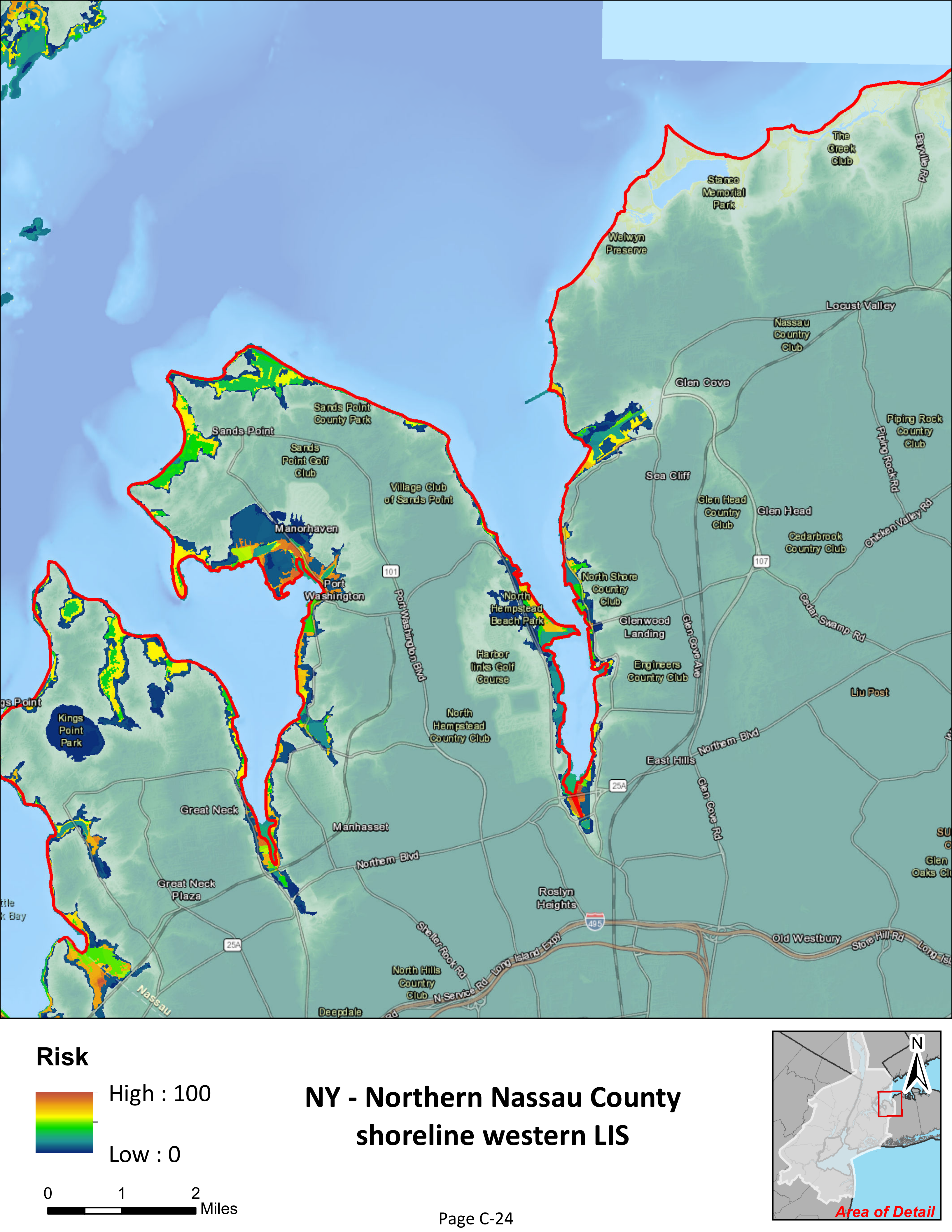
High : 100

Low : 0

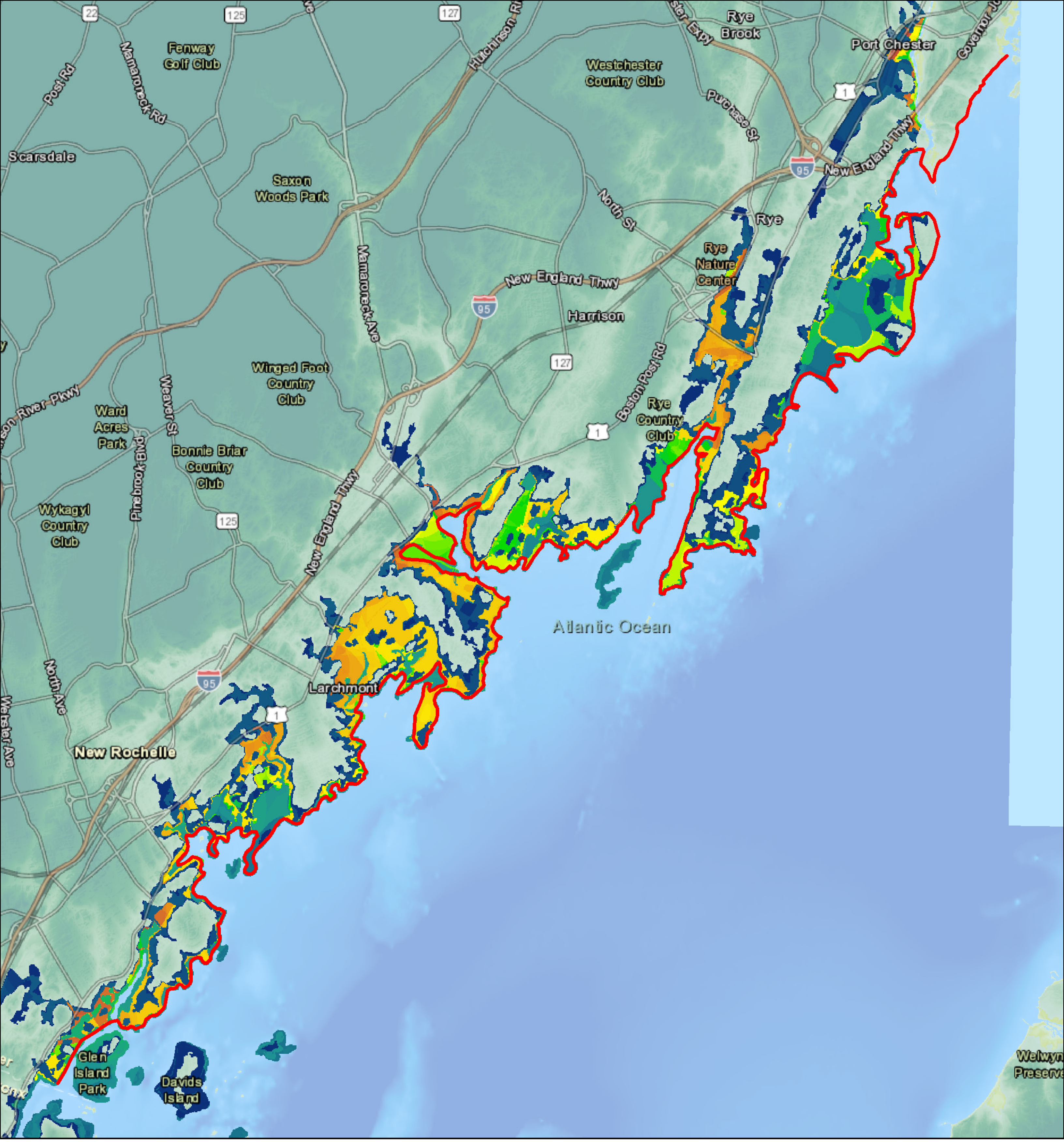
0 1 2 Miles

NYC - Bronx shoreline along western LIS





NY - Northern Nassau County shoreline western LIS



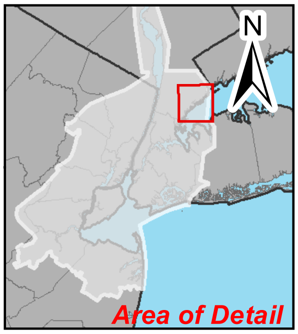
Risk

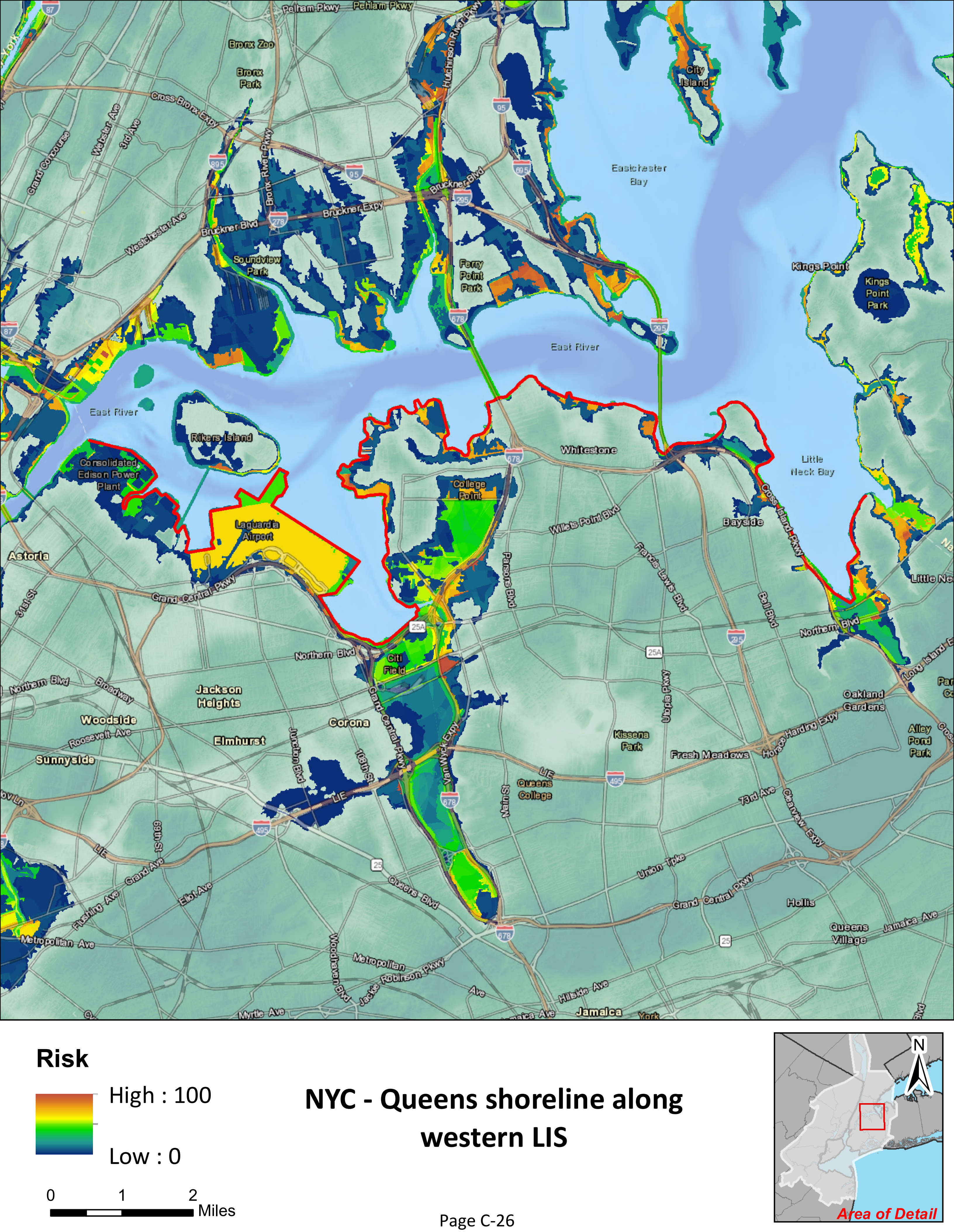
High : 100

Low : 0

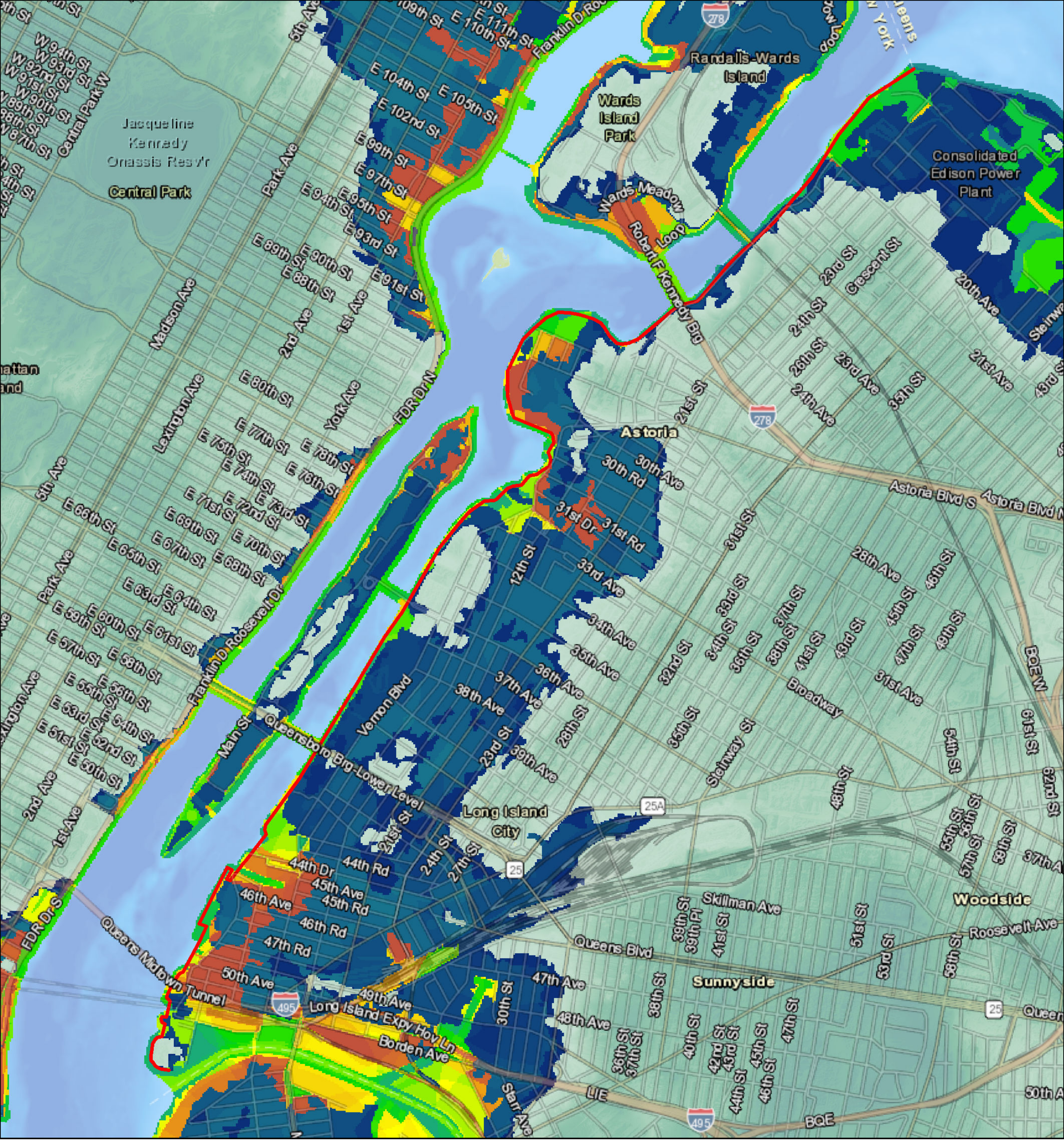
0 1 2 Miles

NY - Eastern Westchester County along western LIS





NYC - Queens shoreline along western LIS



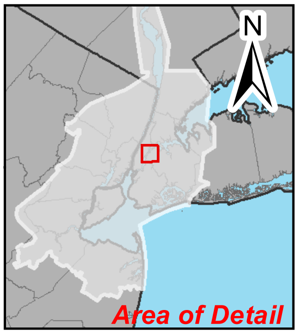
Risk

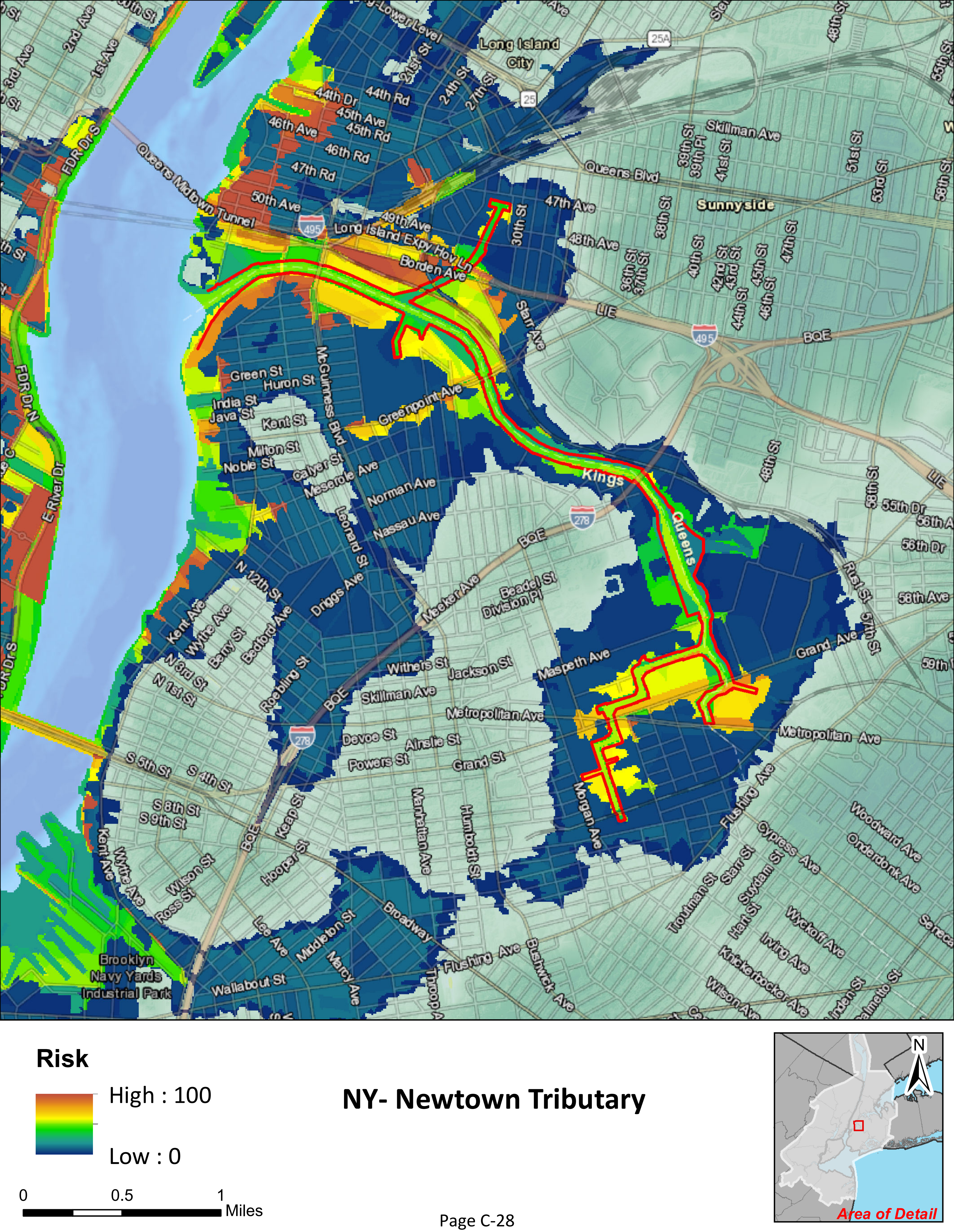
High : 100

Low : 0

0 0.55 1.1 Miles

NYC - Queens shoreline along East River





NY- Newtown Tributary

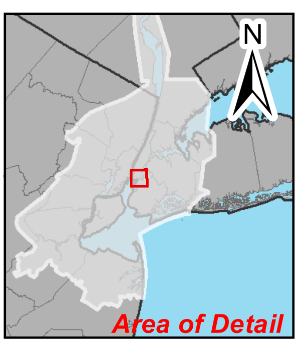
Risk

High : 100

Low : 0

NYC - Brooklyn along East River

0 0.55 1.1 Miles



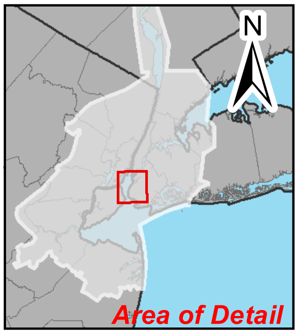
Risk

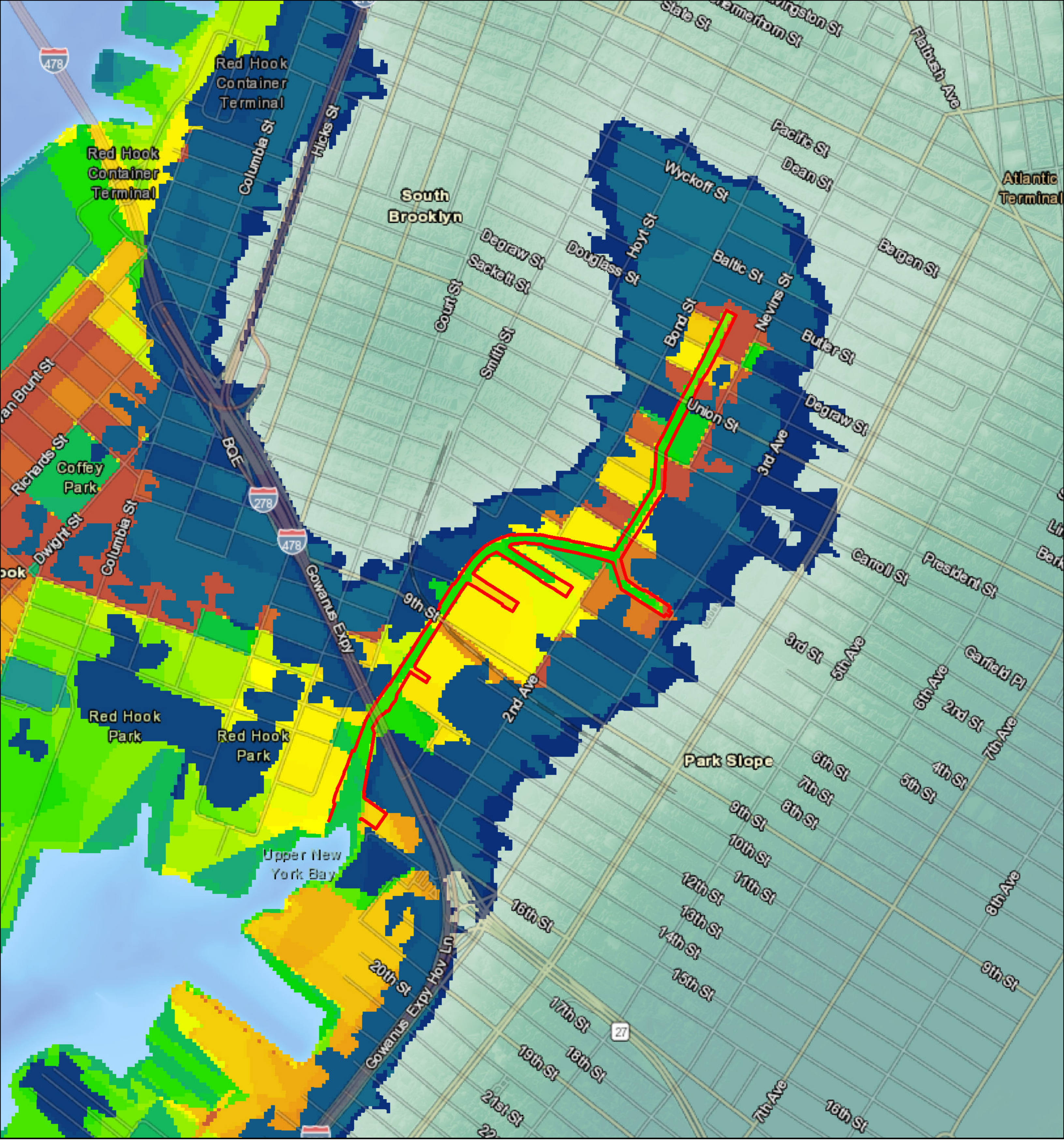
High : 100

Low : 0

0 1 2 Miles

NYC - Brooklyn shoreline along Upper Bay





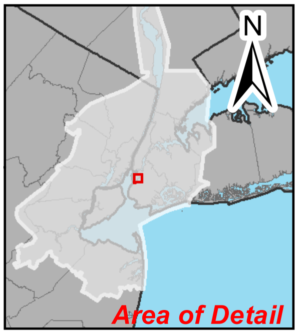
Risk

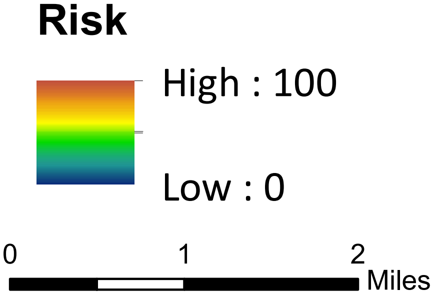
High : 100

Low : 0

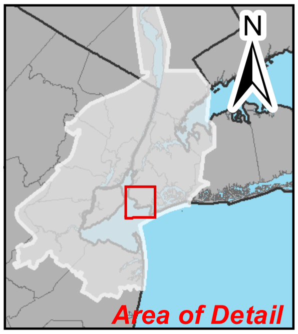
0 0.25 0.5 Miles

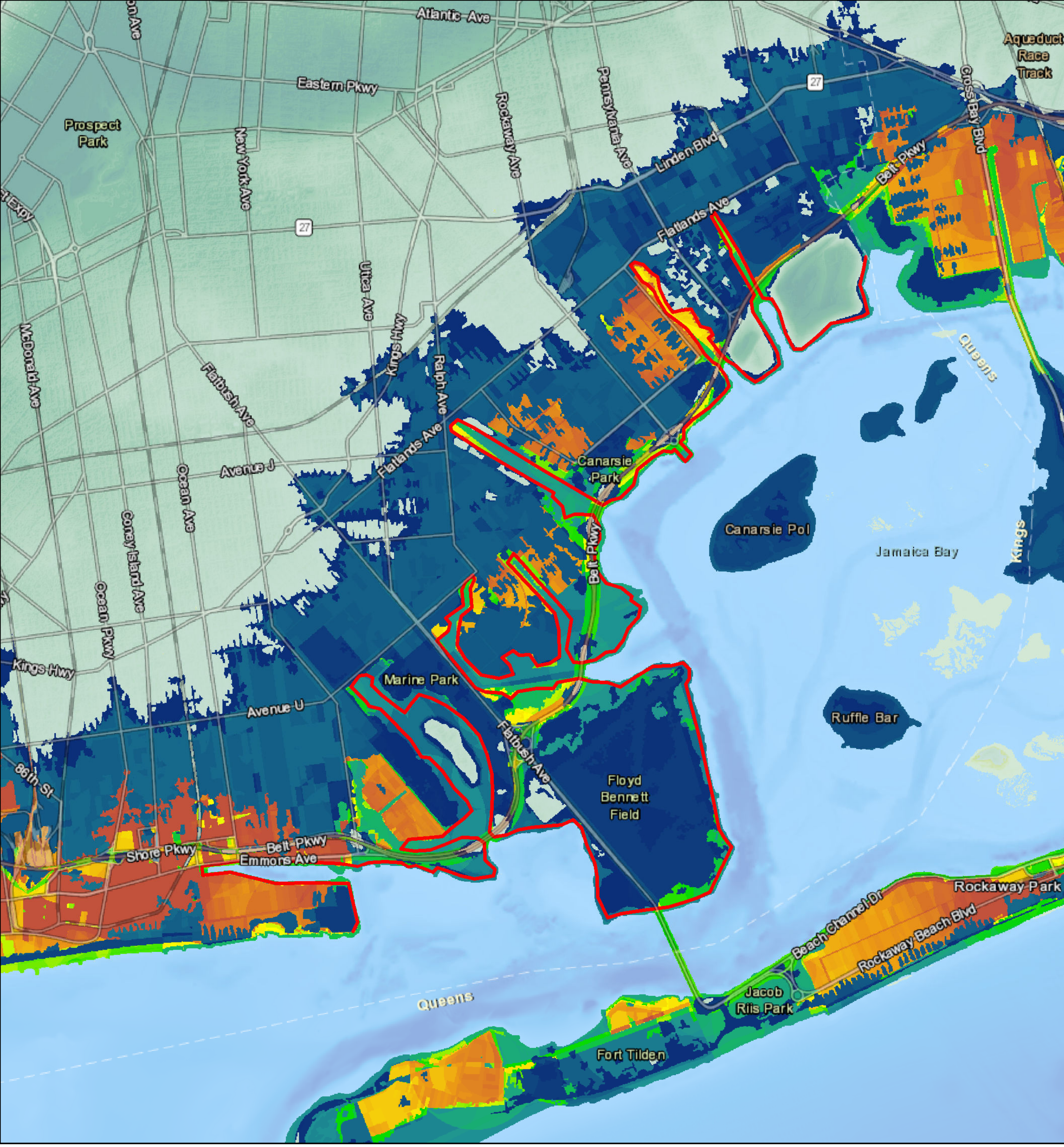
NY- Gowanus Tributary





NYC - Brooklyn - Lower Bay, Coney Island/Creek shoreline





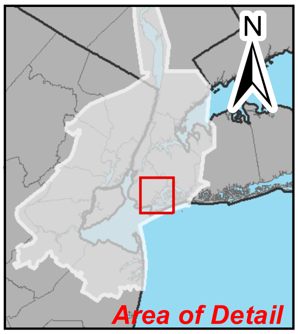
Risk

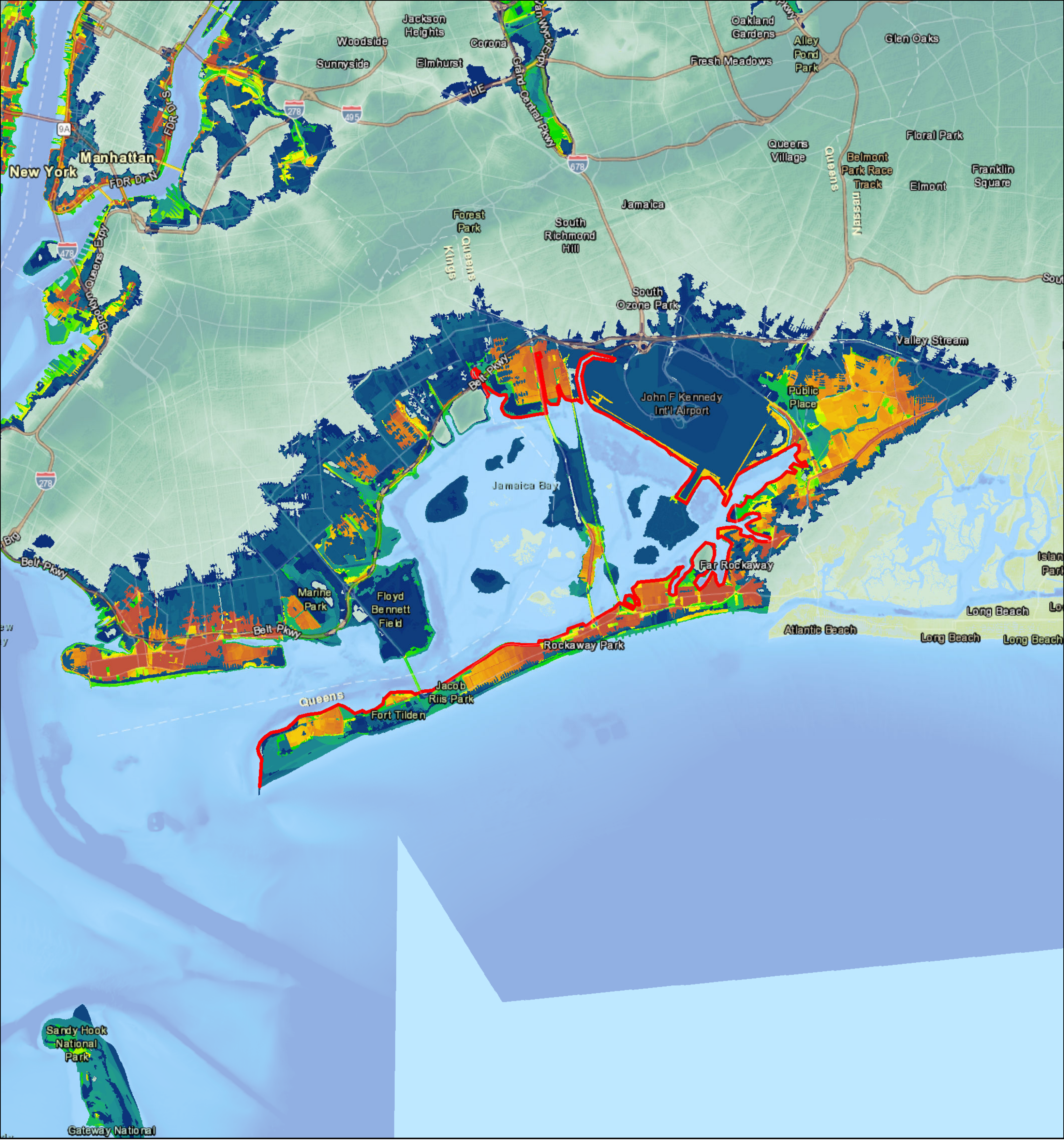
High : 100

Low : 0

0 1 2 Miles

NYC - Brooklyn shoreline in Jamaica Bay





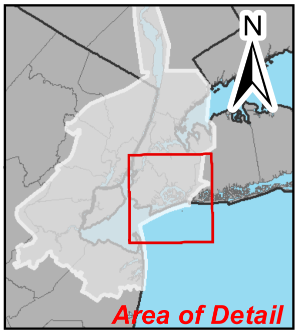
Risk

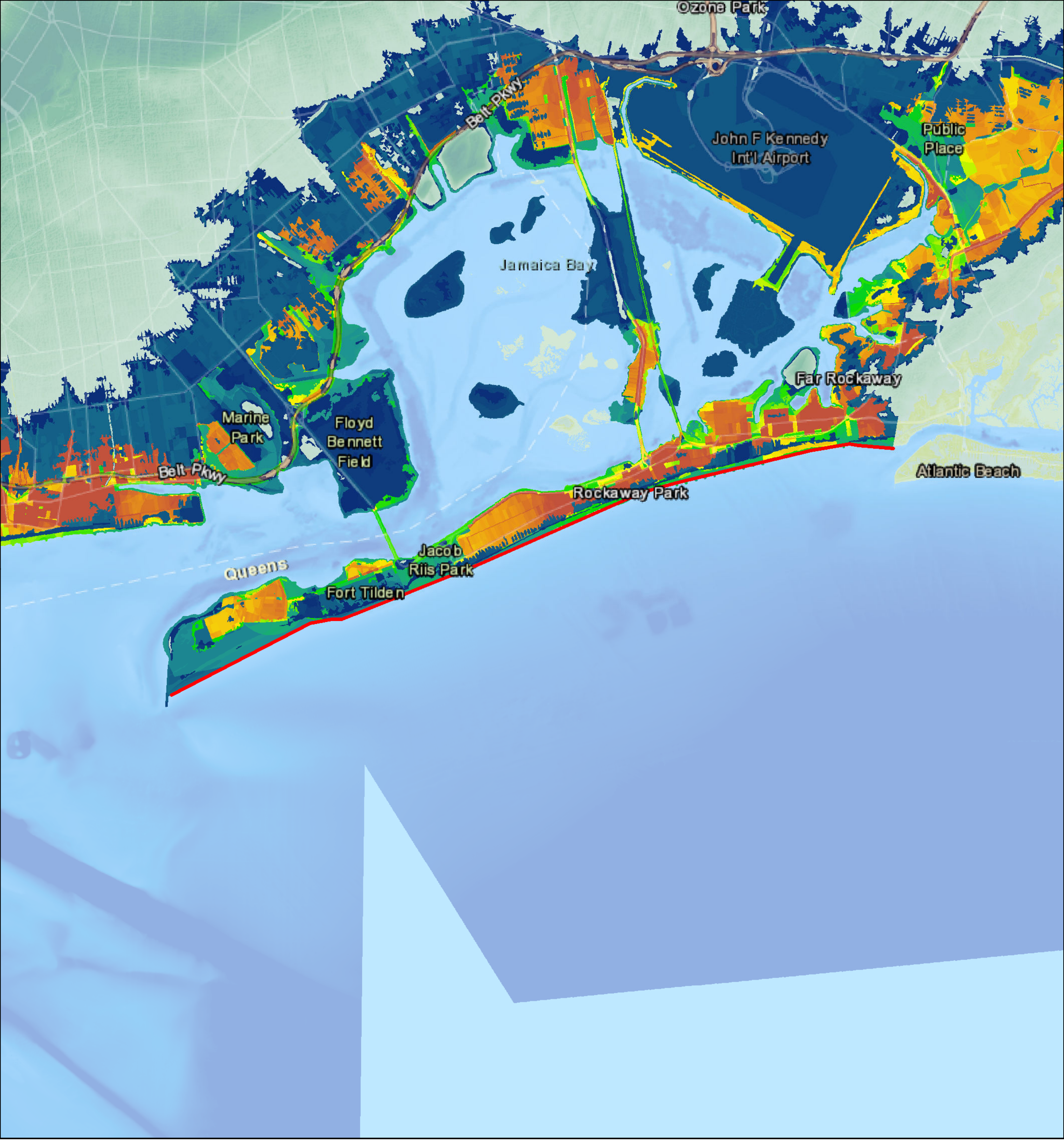
High : 100

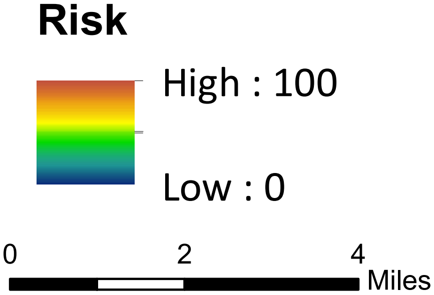
Low : 0

0 2.5 5 Miles

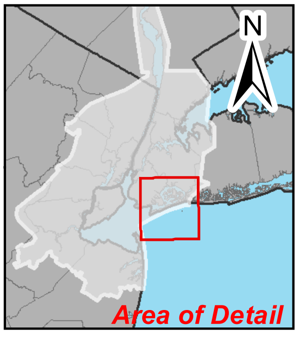
NYC - Queens shoreline & islands in Jamaica Bay







NYC - Queens Rockaway Peninsula shoreline



cdmsmith.com

United States Army Corps of Engineers (USACE)
New York – New Jersey Harbor and Tributaries Study (NYNJHATS)
Enhanced Tier 2 GIS Analysis – Report Addendum
February 2019

Background

The *New York-New Jersey Harbor and Tributaries Coastal Storm Risk Management Feasibility Study Support for Enhanced Tier 2 GIS Analysis Final Report* (NYNJHATS GIS report) was written to provide readers with GIS knowledge and experience enough detail so that all the steps of the analysis could be understood and replicated, if necessary. This addendum provides a brief overview of the development of the New York – New Jersey Harbor and Tributaries Study Enhanced Tier 2 GIS Analysis and explains how the analysis was applied to evaluate the currently proposed study alternatives and features. This addendum should be read for the context and basic development of the details in the NYNJHATS GIS report.

The analysis is based off the framework developed by the 2015 US Army Corps of Engineers (USACE) North Atlantic Comprehensive Coastal Study (NACCS), which was focused on the Northeast region of the United States from Maine to Virginia. The NACCS applied a tiered step-by-step approach where Tier 1 utilized National scale datasets and Tier 2 built upon what had been accomplished by the Tier 1 effort yet also incorporated more detailed State scale datasets.

The NACCS effort has led to multiple focus area studies such as the NYNJHATS. At the start of the study there were many discussions about the possible development of a Tier 3 analysis as had been conceptualized during the NACCS, where data on a local level would be integrated into the analysis. During conversations regarding a Tier 3 analysis for NYNJHATS, the Project Delivery Team (PDT) was concerned that the study, which spans two states, was too expansive for a Tier 3 analysis as envisioned in the NACCS. The PDT decided to move forward an Enhanced Tier 2 GIS Analysis, which looked to refine and build upon what had been done with the NACCS Tier 2 effort, to maintain comparability of data sets across the study area. Tier 3 analyses can be conducted on subsets of the study area in future rounds of plan formulation for the study, as warranted. The USACE New York District contracted with Gahagan & Bryant Associates/CDM Smith to develop and run this analysis.

Composite Exposure Index

The tiered approach employed within the NACCS framework assessed exposure and vulnerability to determine risk (where exposure multiplied by vulnerability equals risk). Spatial data layers used for the Tier 1 and 2 work were updated where possible and combined with new layers where identified. These individual data layers were organized into categories, and weighted based upon the preferences of the study's sponsors and partners, namely the New Jersey Department of Environmental Protection, the New York State Department of Environmental Conservation, and the City of New York in collaboration with the PDT. Each category comprised an exposure index which characterized a relative exposure to flood hazard. For the NYNJHATS analysis eight indices were created (Population Density, Infrastructure, Building Value, Social Vulnerability, Employment, Cultural, Environmental, and Habitat). Each of these indices were produced, weighted by importance relative to one another, and then combined to create a composite exposure index.

Composite Vulnerability Index

At the time the NACCS Tier 1 and Tier 2 analyses were being completed, a concurrent effort of modeling storm surge was in progress. Thus, for the Tier 1 and 2 analyses, surrogate flooding extents and probability of flooding were assigned. There were three floodplain inundation scenarios: Category 4 Maximum of Maximum (MOM) envelope of high water from the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model, 1 percent flood plus three feet, and the 10 percent flood. In total, three grids of inundation extent were created. The bands correspond with the flooding source to the 10 percent inundation extent, the 10 percent to the 1 percent plus three feet extent and the 1 percent plus three (3) feet to the Category 4 MOM inundation extent. The 1 percent plus three feet extent was defined as the Category 2 MOM because at the study area scale, some areas did not have Federal Emergency Management Agency (FEMA) 1 percent flood mapping.

The NYNJHATS looked to build upon the NACCS by making use of the modeling efforts that were in production during the Tier 1 and 2 efforts. ADvanced CIRCulation (ADCIRC) modeling output produced by USACE Engineer Research and Development Center (ERDC) during the NACCS was utilized to determine flooding extents for typical and extreme flooding events. To be conservative a decision was made by the PDT early in the GIS Analysis development to make use of the 95% confidence level ADCIRC data. Like the NACCS analyses three bands were defined. However, these bands were defined using the ADCIRC data and representing the following: 1) a storm event up to a 10 percent flood, 2) a storm event ranging from a 10 percent flood to a 1 percent flood +3 feet, and 3) an event ranging from a 1 percent flood +3 feet to a 0.1 percent flood. These flooding extents represent the vulnerable places within the study area which are likely to be subjected to coastal flooding.

Inundation Extent	NACCS (SLOSH)	NYNJHATS (ADCIRC)
High frequency event	10 percent flood	10 percent flood
Screening event	1 percent flood + 3 feet	1 percent flood + 3 feet
Extreme event	Category 4 MOM	0.1 percent flood

Composite Risk Index

For the purposes of the GIS analysis the risk of a coastal storm event is the consequence or exposure of an area multiplied by the probability of flooding or vulnerability of that area. (Exposure) x (Vulnerability) = (Risk).

To calculate the composite risk for the analysis each of the exposure indexes are assigned a weight to create a Composite Exposure Index. The Enhanced Tier 2 GIS Analysis included the development of two ArcGIS tools effectively allowing users to run the analysis with variable weighting options. An "Exposure Slider" tool provides users the ability to adjust combinations of weighting factors to each of the composite exposure indexes thereby creating a total composite exposure index based upon which indices the user values most. A "Risk" tool then provides the users the ability to multiply the total composite exposure index by the vulnerability (characterized through three potential flooding bands) to create a total composite risk index.

Enhanced Tier 2 GIS Analysis Report

The report with all its appendices is included within this document. Please note the analysis explained within the Enhanced Tier 2 GIS Report and all the maps and graphics produced for that report make use of a "default" exposure weighting established by the PDT and includes all three vulnerability/flooding bands. The default exposure weights were distributed as follows: Population Density 25%, Infrastructure 25%, Building Value 20%, Social Vulnerability 10%, Employment 10%, Cultural 4%, Environmental 3%, and Habitat 3%.

Final Exposure Weighting Option Employed in Evaluation Analysis

Throughout the development of the NYNJHATS Enhanced Tier 2 GIS Analysis the PDT coordinated with the Sponsors and Partners (States of New York and New Jersey as well as the City of New York). It was made clear to the sponsors and partners that data and weights being integrated into the composite exposure indices (Population Density, Infrastructure, Building Value, Social Vulnerability, Employment, Cultural, Environmental, and Habitat) should reflect resources that they prioritized for coastal flood risk management.

During discussions as to the development of the composite exposure indices and the weights that would be applied to each of indices, representatives from the State of New York expressed concern the weighting of environmental and habitat indices could result in structural coastal storm risk management features (barriers or seawalls) isolating natural habitats from rivers, bays, and oceans, thereby negatively impacting these resources (ex: restricted sediment movement during storms).

The PDT proceeded with the development of a stand-alone Environmental and Habitat exposure index so that the effect of changing the weight on these factors upon the exposure index could be more easily discerned through adjustments on the Exposure Slider tool.

Following the completion of GIS risk analysis tool development and the report, a decision was made by the sponsors and partners to make use of a version of the GIS analysis which applied a combination of exposure weights referred to as "Option 2". In this option the Environmental Exposure Index and the Habitat Exposure Index are both weighted as zero. The weighting in this option is distributed to the other six indices as such: Population Density 25%, Infrastructure 30%, Building Value 20%, Social Vulnerability 10%, Employment 10%, and Cultural 5%. It is this

"Option 2" exposure weighting and the GIS composite risk results which are used to evaluate the alternatives and features currently proposed.

Final Vulnerability/Flooding Probability Employed in Evaluation Analysis
The Enhanced Tier 2 GIS Analysis as developed and presented within the report includes three vulnerability (flooding extent) bands (10 percent flood, 1 percent flood +3ft, and 0.1 percent flood) but the GIS analysis used to evaluate study alternatives and features only contain two bands (10 percent flood and 1 percent flood +3ft) because for the sake of evaluating alternatives and features none of the structures were designed to address a 0.1 percent flood event. It was also realized that for consistency in comparing the GIS Analysis with the Economic Analysis the 0.1 percent flood probability band should be removed since the HEC-FDA work did not incorporate a 0.1 percent flood event.

GIS Risk Analysis Statistics
The areas protected and unprotected by each of the alternatives and features were digitized based upon the vulnerability/flooding extent and used within the GIS software to produce statistical data on the GIS risk analysis output. The output of the GIS Risk Analysis is presented statistically within tables 1 through 7 within this addendum.

A number of statistics were created to represent all the protected and unprotected areas but the key statistic used for evaluation purposes is the "SUM" number. The "SUM" statistic equates to the cumulative sum of all 10x10 meter cell values falling within the flooding extent of the 100-yr +3ft event and that are protected by a feature, protected by an alternative, or unprotected.

Tables 1 through 5 present the statistics for all the protected and unprotected areas by alternative and feature where each table represents an alternative. Table 6 presents the statistics for all the features regardless of what alternative(s) they are associated with as well as an estimated cost for each feature as supplied by USACE Cost Engineering and the GIS value ("SUM" statistic) per feature cost. Table 7 simply summarizes the feature costs, GIS value, and GIS value per feature cost.

GIS Risk Analysis Maps
The output of the GIS Risk Analysis is presented graphically in map format within figures 1 through 46. Figures 1 and 2 present the GIS Risk Analysis throughout the study area where figure 1 covers the portion of the study area surrounding the NY/NJ Harbor and figure 2 covers the portion of the study along the Hudson River. Figures 3 through 46 present the GIS Risk Analysis "with-project" and "without-project" for each of the twenty-two proposed study features. It should be noted that all of the "with-project" figures have had the at-risk areas removed from the map to reflect the protected area behind that study feature.

NYNJHATS Alternative 2

NYNJHATS Enhanced Tier 2 GIS Risk Analysis - Option 2 Exposure Weighing, Vulnerability = 10-yr and 100-yr +3ft

Summary - Protected vs Unprotected for Alternative 2

	Protection	COUNT	AREA	% AREA	MIN	MAX	RANGE	MEAN	STD	SUM		VARIETY	MAJORITY	MINORITY	MEDIAN
	Protected	7151328	715132800	94.79%	0	100	100	17.83	18.4	127530840	94.83%	98	5	100	8
	Unprotected	393134	39313400	5.21%	0	85	85	17.69	17	6953401	5.17%	79	5	76	9
	SUM		**754446200**	**100.00%**						**134484241**	**100.00%**				

Breakdown by Feature - Protected vs Unprotected for Alternative 2

Feature	Protection	COUNT	AREA	% AREA	MIN	MAX	RANGE	MEAN	STD	SUM		VARIETY	MAJORITY	MINORITY	MEDIAN
None	Unprotected	393134	39313400	5.21%	0	85	85	17.69	17	6953401	5.17%	79	5	76	9
Combined - SHR & TNB Barrier	Protected	7097595	709759500	94.08%	0	100	100	17.89	18.5	126960097	94.41%	98	5	100	8
Pelham Barrier	Protected	53733	5373300	0.71%	0	73	73	10.62	11.5	570743	0.42%	64	5	24	6
	SUM		**754446200**	**100.00%**						**134484241**	**100.00%**				

COUNT - The number of raster 10x10 meter cells within that zone.

AREA - The area of that zone in square meters.

% AREA - Percentage of each zone in reference to the entire risk raster.

MINIMUM— Determines the smallest value of all cells in the value raster that belong to the same zone as the output cell.

MAXIMUM— Determines the largest value of all cells in the value raster that belong to the same zone as the output cell.

RANGE— Calculates the difference between the largest and smallest value of all cells in the value raster that belong to the same zone as the output cell.

MEAN— Calculates the average of all cells in the value raster that belong to the same zone as the output cell.

STD— Calculates the standard deviation of all cells in the value raster that belong to the same zone as the output cell.

SUM— Calculates the total value of all cells in the value raster that belong to the same zone as the output cell.

VARIETY— Calculates the number of unique values for all cells in the value raster that belong to the same zone as the output cell.

MAJORITY— Determines the value that occurs most often of all cells in the value raster that belong to the same zone as the output cell.

MINORITY— Determines the value that occurs least often of all cells in the value raster that belong to the same zone as the output cell.

MEDIAN— Determines the median value of all cells in the value raster that belong to the same zone as the output cell.

NYNJHATS Alternative 3a

NYNJHATS Enhanced Tier 2 GIS Risk Analysis - Option 2 Exposure Weighing, Vulnerability = 10-yr and 100-yr +3ft

Summary - Protected vs Unprotected for Alternative 3a

	Protection	COUNT	AREA	% AREA	MIN	MAX	RANGE	MEAN	STD	SUM	% SUM	VARIETY	MAJORITY	MINORITY	MEDIAN
	Protected	5610430	561043000	74.36%	0	100	100	18.74	19.09	105136712	78.18%	98	5	100	9
	Unprotected	1934032	193403200	25.64%	0	90	90	15.174	15.82	29347529	21.82%	88	5	90	8
	SUM		**754446200**	**100.00%**						**134484241**	**100.00%**				

Breakdown by Feature - Protected vs Unprotected for Alternative 3a

Feature	Protection	COUNT	AREA	% AREA	MIN	MAX	RANGE	MEAN	STD	SUM	% SUM	VARIETY	MAJORITY	MINORITY	MEDIAN
None	Unprotected	1934032	193403200	25.64%	0	90	90	15.174	15.82	29347529	21.82%	88	5	90	8
Combined - AK & Verrazano & TNB Barrier	Protected	4367713	436771300	57.89%	0	100	100	18.676	17.82	81573363	60.66%	98	5	100	11
Jamaica Bay Barrier	Protected	1188984	118898400	15.76%	0	98	98	19.338	23.32	22992606	17.10%	97	5	97	6
Pelham Barrier	Protected	53733	5373300	0.71%	0	73	73	10.622	11.53	570743	0.42%	64	5	24	6
	SUM		**754446200**	**100.00%**						**134484241**	**100.00%**				

COUNT - The number of raster 10x10 meter cells within that zone.
AREA - The area of that zone in square meters.
% AREA - Percentage of each zone in reference to the entire risk raster.
MINIMUM— Determines the smallest value of all cells in the value raster that belong to the same zone as the output cell.
MAXIMUM— Determines the largest value of all cells in the value raster that belong to the same zone as the output cell.
RANGE— Calculates the difference between the largest and smallest value of all cells in the value raster that belong to the same zone as the output cell.
MEAN— Calculates the average of all cells in the value raster that belong to the same zone as the output cell.
STD— Calculates the standard deviation of all cells in the value raster that belong to the same zone as the output cell.
SUM— Calculates the total value of all cells in the value raster that belong to the same zone as the output cell.
VARIETY— Calculates the number of unique values for all cells in the value raster that belong to the same zone as the output cell.
MAJORITY— Determines the value that occurs most often of all cells in the value raster that belong to the same zone as the output cell.
MINORITY— Determines the value that occurs least often of all cells in the value raster that belong to the same zone as the output cell.
MEDIAN— Determines the median value of all cells in the value raster that belong to the same zone as the output cell.

NYNJHATS Alternative 3b															
NYNJHATS Enhanced Tier 2 GIS Risk Analysis - Option 2 Exposure Weighing, Vulnerability = 10-yr and 100-yr +3ft															
Summary - Protected vs Unprotected for Alternative 3b															
	Protection	**COUNT**	**AREA**	**% AREA**	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**	**% SUM**	**VARIETY**	**MAJORITY**	**MINORITY**	**MEDIAN**
	Protected	4082496	408249600	54.11%	0	100	100	19.8	20.1	80851843	60.12%	98	5	100	9
	Unprotected	3461966	346196600	45.89%	0	97	97	15.49	15.8	53632398	39.88%	96	5	97	8
	SUM		**754446200**	**100.00%**						**134484241**	**100.00%**				

Breakdown by Feature - Protected vs Unprotected for Alternative 3b															
Feature	**Protection**	**COUNT**	**AREA**	**% AREA**	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**	**% SUM**	**VARIETY**	**MAJORITY**	**MINORITY**	**MEDIAN**
None	Unprotected	3461966	346196600	45.89%	0	97	97	15.49	15.8	53632398	39.88%	96	5	97	8
Combined - AK & KVK Barrier	Protected	2407446	240744600	31.91%	0	95	95	20.39	18.1	49081076	36.50%	93	2	95	13
Astoria SBM	Protected	15634	1563400	0.21%	0	59	59	7.614	9.56	119039	0.09%	28	2	16	2
Bronx River Westchester Creek Barrier	Protected	75803	7580300	1.00%	0	86	86	11.91	16.1	903181	0.67%	77	5	68	5
East Harlem SBM	Protected	33884	3388400	0.45%	2	88	86	18.2	22.6	616552	0.46%	65	7	23	7
Flushing Creek Barrier	Protected	82762	8276200	1.10%	0	78	78	18.36	15.1	1519410	1.13%	74	23	56	16
Gowanus Canal Barrier	Protected	10983	1098300	0.15%	2	74	72	18.45	19.5	202633	0.15%	55	7	31	7
Stony Point Perimeter - Polygon	Protected	1851	185100	0.02%	3	44	41	25.69	19.8	47559	0.04%	7	44	3	44
Stony Point SBM	Protected	637	63700	0.01%	3	53	50	44.91	13	28608	0.02%	10	49	45	49
Jamaica Bay Barrier	Protected	1188984	118898400	15.76%	0	98	98	19.34	23.3	22992606	17.10%	97	5	97	6
Long Island City Astoria SBM	Protected	18785	1878500	0.25%	1	72	71	11.51	15.8	216218	0.16%	63	6	11	6
New Jersey along Hudson River SBM	Protected	72468	7246800	0.96%	0	97	97	30	26.6	2174377	1.62%	95	6	10	21
New York City West Side SBM	Protected	38122	3812200	0.51%	1	100	99	25.53	27.3	973332	0.72%	81	7	100	8
Newtown Creek Barrier	Protected	71865	7186500	0.95%	0	98	98	15.51	18.6	1114451	0.83%	84	4	98	6
Ossining SBM	Protected	1310	131000	0.02%	0	76	76	13.68	17.4	17919	0.01%	22	1	19	10
Pelham Barrier	Protected	53733	5373300	0.71%	0	73	73	10.62	11.5	570743	0.42%	64	5	24	6
Tarrytown SBM	Protected	3649	364900	0.05%	3	75	72	31.76	26.7	115882	0.09%	34	3	41	36
Yonkers North SBM	Protected	2575	257500	0.03%	1	83	82	35.81	25.2	92211	0.07%	38	69	34	43
Yonkers South SBM	Protected	2005	200500	0.03%	1	82	81	32.94	17.1	66046	0.05%	26	34	50	34
	SUM		**754446200**	**100.00%**						**134484241**	**100.00%**				

COUNT - The number of raster 10x10 meter cells within that zone.
AREA - The area of that zone in square meters.
% AREA - Percentage of each zone in reference to the entire risk raster.
MINIMUM— Determines the smallest value of all cells in the value raster that belong to the same zone as the output cell.
MAXIMUM— Determines the largest value of all cells in the value raster that belong to the same zone as the output cell.
RANGE— Calculates the difference between the largest and smallest value of all cells in the value raster that belong to the same zone as the output cell.
MEAN— Calculates the average of all cells in the value raster that belong to the same zone as the output cell.
STD— Calculates the standard deviation of all cells in the value raster that belong to the same zone as the output cell.
SUM— Calculates the total value of all cells in the value raster that belong to the same zone as the output cell.
VARIETY— Calculates the number of unique values for all cells in the value raster that belong to the same zone as the output cell.
MAJORITY— Determines the value that occurs most often of all cells in the value raster that belong to the same zone as the output cell.
MINORITY— Determines the value that occurs least often of all cells in the value raster that belong to the same zone as the output cell.
MEDIAN— Determines the median value of all cells in the value raster that belong to the same zone as the output cell.

NYNJHATS Alternative 4															
NYNJHATS Enhanced Tier 2 GIS Risk Analysis - Option 2 Exposure Weighing, Vulnerability = 10-yr and 100-yr +3ft															
Summary - Protected vs Unprotected for Alternative 4															
	Protection	**COUNT**	**AREA**	**% AREA**	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**	**% SUM**	**VARIETY**	**MAJORITY**	**MINORITY**	**MEDIAN**
	Protected	2674725	267472500	35.45%	0	100	100	21.007	21.28	56189182	41.78%	98	5	100	9
	Unprotected	4869737	486973700	64.55%	0	97	97	16.078	16.3	78295059	58.22%	96	5	97	8
	SUM	**7544462**	**754446200**	**100.00%**						**134484241**	**100.00%**				
Breakdown by Feature - Protected vs Unprotected for Alternative 4															
Feature	**Protection**	**COUNT**	**AREA**	**% AREA**	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**	**% SUM**	**VARIETY**	**MAJORITY**	**MINORITY**	**MEDIAN**
None	Unprotected	4869737	486973700	64.55%	0	97	97	16.078	16.3	78295059	58.22%	96	5	97	8
Astoria SBM	Protected	15634	1563400	0.21%	0	59	59	7.6141	9.555	119039	0.09%	28	2	16	2
Bronx River Westchester Creek Barrier	Protected	75803	7580300	1.00%	0	86	86	11.915	16.11	903181	0.67%	77	5	68	5
East Harlem SBM	Protected	33884	3388400	0.45%	2	88	86	18.196	22.61	616552	0.46%	65	7	23	7
Flushing Creek Barrier	Protected	82762	8276200	1.10%	0	78	78	18.359	15.14	1519410	1.13%	74	23	56	16
Gowanus Canal Barrier	Protected	10983	1098300	0.15%	2	74	72	18.45	19.5	202633	0.15%	55	7	31	7
Hackensack River Barrier	Protected	999675	99967500	13.25%	0	91	91	24.426	18.38	24418415	18.16%	90	8	91	21
Stony Point Perimeter - Polygon	Protected	1851	185100	0.02%	3	44	41	25.694	19.83	47559	0.04%	7	44	3	44
Stony Point SBM	Protected	637	63700	0.01%	3	53	50	44.911	12.99	28608	0.02%	10	49	45	49
Jamaica Bay Barrier	Protected	1188984	118898400	15.76%	0	98	98	19.338	23.32	22992606	17.10%	97	5	97	6
Long Island City Astoria SBM	Protected	18785	1878500	0.25%	1	72	71	11.51	15.81	216218	0.16%	63	6	11	6
New Jersey Hudson River SBM	Protected	72468	7246800	0.96%	0	97	97	30.005	26.61	2174377	1.62%	95	6	10	21
New York City West Side SBM	Protected	38122	3812200	0.51%	1	100	99	25.532	27.34	973332	0.72%	81	7	100	8
Newtown Creek Barrier	Protected	71865	7186500	0.95%	0	98	98	15.508	18.57	1114451	0.83%	84	4	98	6
Ossining SBM	Protected	1310	131000	0.02%	0	76	76	13.679	17.4	17919	0.01%	22	1	19	10
Pelham Barrier	Protected	53733	5373300	0.71%	0	73	73	10.622	11.53	570743	0.42%	64	5	24	6
Tarrytown SBM	Protected	3649	364900	0.05%	3	75	72	31.757	26.7	115882	0.09%	34	3	41	36
Yonkers North SBM	Protected	2575	257500	0.03%	1	83	82	35.81	25.22	92211	0.07%	38	69	34	43
Yonkers South SBM	Protected	2005	200500	0.03%	1	82	81	32.941	17.1	66046	0.05%	26	34	50	34
	SUM		**754446200**	**100.00%**						**134484241**	**100.00%**				

COUNT - The number of raster 10x10 meter cells within that zone.

AREA - The area of that zone in square meters.

% AREA - Percentage of each zone in reference to the entire risk raster.

MINIMUM— Determines the smallest value of all cells in the value raster that belong to the same zone as the output cell.

MAXIMUM— Determines the largest value of all cells in the value raster that belong to the same zone as the output cell.

RANGE— Calculates the difference between the largest and smallest value of all cells in the value raster that belong to the same zone as the output cell.

MEAN— Calculates the average of all cells in the value raster that belong to the same zone as the output cell.

STD— Calculates the standard deviation of all cells in the value raster that belong to the same zone as the output cell.

SUM— Calculates the total value of all cells in the value raster that belong to the same zone as the output cell.

VARIETY— Calculates the number of unique values for all cells in the value raster that belong to the same zone as the output cell.

MAJORITY— Determines the value that occurs most often of all cells in the value raster that belong to the same zone as the output cell.

MINORITY— Determines the value that occurs least often of all cells in the value raster that belong to the same zone as the output cell.

MEDIAN— Determines the median value of all cells in the value raster that belong to the same zone as the output cell.

NYNJHATS Alternative 5

NYNJHATS Enhanced Tier 2 GIS Risk Analysis - Option 2 Exposure Weighing, Vulnerability = 10-yr and 100-yr +3ft

Summary - Protected vs Unprotected for Alternative 5

	Protection	COUNT	AREA	% AREA	MIN	MAX	RANGE	MEAN	STD	SUM	% SUM	VARIETY	MAJORITY	MINORITY	MEDIAN
	Protected	241295	24494400	3.25%	0	100	100	24.47	23.2	6020820	4.48%	98	7	100	14
	Unprotected	7303167	729951800	96.75%	0	98	98	17.61	18.1	128463421	95.52%	97	5	97	8
	SUM	**7544462**	**754446200**	**100.00%**						**134484241**	**100.00%**				

Breakdown by Feature - Protected vs Unprotected for Alternative 5

Feature	Protection	COUNT	AREA	% AREA	MIN	MAX	RANGE	MEAN	STD	SUM	% SUM	VARIETY	MAJORITY	MINORITY	MEDIAN
None	Unprotected	7303167	729951800	96.75%	0	98	98	17.61	18.1	128463421	95.52%	97	5	97	8
Astoria SBM	Protected	15634	1563400	0.21%	0	59	59	7.614	9.56	119039	0.09%	28	2	16	2
East Harlem SBM	Protected	33884	3388400	0.45%	2	88	86	18.2	22.6	616552	0.46%	65	7	23	7
Hackensack Perimeter Lower Area - Polygon	Protected	7499	749900	0.10%	9	54	45	27.12	6.21	203404	0.15%	22	30	20	30
Hackensack Perimeter Middle Area - Polygon	Protected	4502	450200	0.06%	2	63	61	26.18	7.5	117856	0.09%	28	29	13	26
Hackensack Perimeter Upper Area - Polygon	Protected	42023	4202300	0.56%	1	88	87	29.31	14.8	1231817	0.92%	70	24	76	28
Stony Point Perimeter - Polygon	Protected	1851	185100	0.02%	3	44	41	25.69	19.8	47559	0.04%	7	44	3	44
Stony Point SBM	Protected	637	63700	0.01%	3	53	50	44.91	13	28608	0.02%	10	49	45	49
Long Island City Astoria SBM	Protected	18785	1878500	0.25%	1	72	71	11.51	15.8	216218	0.16%	63	6	11	6
New Jersey along Hudson River SBM	Protected	72468	7246800	0.96%	0	97	97	30	26.6	2174377	1.62%	95	6	10	21
New York City West Side SBM	Protected	38122	3812200	0.51%	1	100	99	25.53	27.3	973332	0.72%	81	7	100	8
Ossining SBM	Protected	1310	131000	0.02%	0	76	76	13.68	17.4	17919	0.01%	22	1	19	10
Tarrytown SBM	Protected	3649	364900	0.05%	3	75	72	31.76	26.7	115882	0.09%	34	3	41	36
Yonkers North SBM	Protected	2575	257500	0.03%	1	83	82	35.81	25.2	92211	0.07%	38	69	34	43
Yonkers South SBM	Protected	2005	200500	0.03%	1	82	81	32.94	17.1	66046	0.05%	26	34	50	34
	SUM		**754446200**	**100.00%**						**134484241**	**100.00%**				

COUNT - The number of raster 10x10 meter cells within that zone.

AREA - The area of that zone in square meters.

% AREA - Percentage of each zone in reference to the entire risk raster.

MINIMUM— Determines the smallest value of all cells in the value raster that belong to the same zone as the output cell.

MAXIMUM— Determines the largest value of all cells in the value raster that belong to the same zone as the output cell.

RANGE— Calculates the difference between the largest and smallest value of all cells in the value raster that belong to the same zone as the output cell.

MEAN— Calculates the average of all cells in the value raster that belong to the same zone as the output cell.

STD— Calculates the standard deviation of all cells in the value raster that belong to the same zone as the output cell.

SUM— Calculates the total value of all cells in the value raster that belong to the same zone as the output cell.

VARIETY— Calculates the number of unique values for all cells in the value raster that belong to the same zone as the output cell.

MAJORITY— Determines the value that occurs most often of all cells in the value raster that belong to the same zone as the output cell.

MINORITY— Determines the value that occurs least often of all cells in the value raster that belong to the same zone as the output cell.

MEDIAN— Determines the median value of all cells in the value raster that belong to the same zone as the output cell.

Table 5

NYNJHATS Features																			
NYNJHATS Enhanced Tier 2 GIS Risk Analysis - Option 2 Exposure Weighing, Vulnerability = 10-yr and 100-yr +3ft																	Present Worth Costs		
Breakdown by Feature - Protected																	Total	Total	GIS Value (or SUM) Protected/Cost ($M)
Feature	**Protection**	**COUNT**	**AREA**	**% AREA**	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**	**% SUM**	**VARIETY**	**MAJORITY**	**MINORITY**	**MEDIAN**		**($B)**	**($M)**	
Combined - SHR & TNB Barrier	Protected	7097595	709759500	94.08%	0	100	100	17.89	18.5	126960097	94.41%	98	5	100	8		117.744	117,744	1,078
Combined - AK & Verrazano & TNB Barrier	Protected	4367713	436771300	57.89%	0	100	100	18.68	17.8	81573363	60.66%	98	5	100	11		36.140	36,140	2,257
Combined - AK & KVK Barrier	Protected	2407446	240744600	31.91%	0	95	95	20.39	18.1	49081076	36.50%	93	2	95	13		13.356	13,356	3,675
Hackensack River Barrier	Protected	999675	99967500	13.25%	0	91	91	24.43	18.4	24418415	18.16%	90	8	91	21		2.317	2,317	10,539
Jamaica Bay Barrier	Protected	1188984	118898400	15.76%	0	98	98	19.34	23.3	22992606	17.10%	97	5	97	6		9.863	9,863	2,331
New Jersey along Hudson River SBM	Protected	72468	7246800	0.96%	0	97	97	30	26.6	2174377	1.62%	95	6	10	21		2.935	2,935	741
Flushing Creek Barrier	Protected	82762	8276200	1.10%	0	78	78	18.36	15.1	1519410	1.13%	74	23	56	16		1.155	1,155	1,316
Hackensack Perimeter Upper Area - Polygon	Protected	42023	4202300	0.56%	1	88	87	29.31	14.8	1231817	0.92%	70	24	76	28		0.868	868	1,419
Newtown Creek Barrier	Protected	71865	7186500	0.95%	0	98	98	15.51	18.6	1114451	0.83%	84	4	98	6		1.191	1,191	936
New York City West Side SBM	Protected	38122	3812200	0.51%	1	100	99	25.53	27.3	973332	0.72%	81	7	100	8		2.650	2,650	367
Bronx River Westchester Creek Barrier	Protected	75803	7580300	1.00%	0	86	86	11.91	16.1	903181	0.67%	77	5	68	5		2.117	2,117	427
East Harlem SBM	Protected	33884	3388400	0.45%	2	88	86	18.2	22.6	616552	0.46%	65	7	23	7		2.371	2,371	260
Pelham Barrier	Protected	53733	5373300	0.71%	0	73	73	10.62	11.5	570743	0.42%	64	5	24	6		0.959	959	595
Long Island City Astoria SBM	Protected	18785	1878500	0.25%	1	72	71	11.51	15.8	216218	0.16%	63	6	11	6		0.255	255	848
Hackensack Perimeter Lower Area - Polygon	Protected	7499	749900	0.10%	9	54	45	27.12	6.21	203404	0.15%	22	30	20	30		1.691	1,691	120
Gowanus Canal Barrier	Protected	10983	1098300	0.15%	2	74	72	18.45	19.5	202633	0.15%	55	7	31	7		0.655	655	309
Astoria SBM	Protected	15634	1563400	0.21%	0	59	59	7.614	9.56	119039	0.09%	28	2	16	2		0.145	145	821
Hackensack Perimeter Middle Area - Polygon	Protected	4502	450200	0.06%	2	63	61	26.18	7.5	117856	0.09%	28	29	13	26		2.112	2,112	56
Tarrytown SBM	Protected	3649	364900	0.05%	3	75	72	31.76	26.7	115882	0.09%	34	3	41	36		0.339	339	342
Yonkers North SBM	Protected	2575	257500	0.03%	1	83	82	35.81	25.2	92211	0.07%	38	69	34	43		0.406	406	227
Yonkers South SBM	Protected	2005	200500	0.03%	1	82	81	32.94	17.1	66046	0.05%	26	34	50	34		0.403	403	164
Stony Point Perimeter - Polygon	Protected	1851	185100	0.02%	3	44	41	25.69	19.8	47559	0.04%	7	44	3	44		0.185	185	258
Stony Point SBM	Protected	637	63700	0.01%	3	53	50	44.91	13	28608	0.02%	10	49	45	49		0.171	171	168
Ossining SBM	Protected	1310	131000	0.02%	0	76	76	13.68	17.4	17919	0.01%	22	1	19	10		0.120	120	150
***Total Area (see other sheets)**			**754446200**		***Total SUM (see other sheets)**					**134484241**									

*** This sheet combines all features from all alternatives, therefore Total Area and Total SUM are not summations of the cells on this sheet but come from the other sheets which are consisitent by analysis.**

COUNT - The number of raster 10x10 meter cells within that zone.

AREA - The area of that zone in square meters.

% AREA - Percentage of each zone in reference to the entire risk raster.

MINIMUM— Determines the smallest value of all cells in the value raster that belong to the same zone as the output cell.

MAXIMUM— Determines the largest value of all cells in the value raster that belong to the same zone as the output cell.

RANGE— Calculates the difference between the largest and smallest value of all cells in the value raster that belong to the same zone as the output cell.

MEAN— Calculates the average of all cells in the value raster that belong to the same zone as the output cell.

STD— Calculates the standard deviation of all cells in the value raster that belong to the same zone as the output cell.

SUM— Calculates the total value of all cells in the value raster that belong to the same zone as the output cell.

VARIETY— Calculates the number of unique values for all cells in the value raster that belong to the same zone as the output cell.

MAJORITY— Determines the value that occurs most often of all cells in the value raster that belong to the same zone as the output cell.

MINORITY— Determines the value that occurs least often of all cells in the value raster that belong to the same zone as the output cell.

MEDIAN— Determines the median value of all cells in the value raster that belong to the same zone as the output cell.

Exposure Index Weighting for GIS Analyses			
Exposure Indices		**Option 2 Weighting %**	
Population Density		25	
Infrastructure		30	
Building Value		20	
Social Vulnerability		10	
Employment		10	
Environmental		0	
Habitat		0	
Cultural		5	
Total		**100**	
GIS Analyses Output by Alternative			
		GIS Analysis - Option 2 Weighting	
	Cost (millions)	**GIS Value (SUM) Protected**	**GIS Value/Million $**
Alternative 2	$118,100.00	127,530,840	1,080
Alternative 3a	$47,100.00	105,136,712	2,232
Alternative 3b	$43,000.00	80,851,843	1,880
Alternative 4	$32,000.00	56,189,182	1,756
Alternative 5	$14,800.00	5,904,938	399
GIS Analyses Output by Feature			
		GIS Analysis - Option 2 Weighting	
	Cost (millions)	**GIS Value (SUM) Protected**	**GIS Value/Million $**
Combined - SHR & TNB Barriers	$117,744	126960097	1,078
Combined - AK & Verrazano & TNB Barriers	$36,140	81573363	2,257
Combined - AK & KVK Barriers	$13,356	49081076	3,675
Hackensack River Barrier	$2,317	24418415	10,539
Jamaica Bay Barrier	$9,863	22992606	2,331
New Jersey along Hudson River SBM	$2,935	2174377	741
Flushing Creek Barrier	$1,155	1519410	1,316
Hackensack Perimeter Upper Area - Polygon	$868	1231817	1,419
Newtown Creek Barrier	$1,191	1114451	936
New York City West Side SBM	$2,650	973332	367
Bronx River Westchester Creek Barrier	$2,117	903181	427
East Harlem SBM	$2,371	616552	260
Pelham Barrier	$959.00	570743	595
Hackensack Perimeter Lower Area - Polygon	$255.00	216218	848
Long Island City Astoria SBM	$1,690.50	203404	120
Gowanus Canal Barrier	$655.00	202633	309
Hackensack Perimeter Middle Area - Polygon	$145.00	119039	821
Astoria SBM	$2,112.00	117856	56
Tarrytown SBM	$338.75	115882	342
Yonkers North SBM	$405.75	92211	227
Yonkers South SBM	$402.75	66046	164
Stony Point Perimeter - Polygon	$184.50	47559	258
Stony Point SBM	$170.50	28608	168
Ossining SBM	$119.75	17919	150

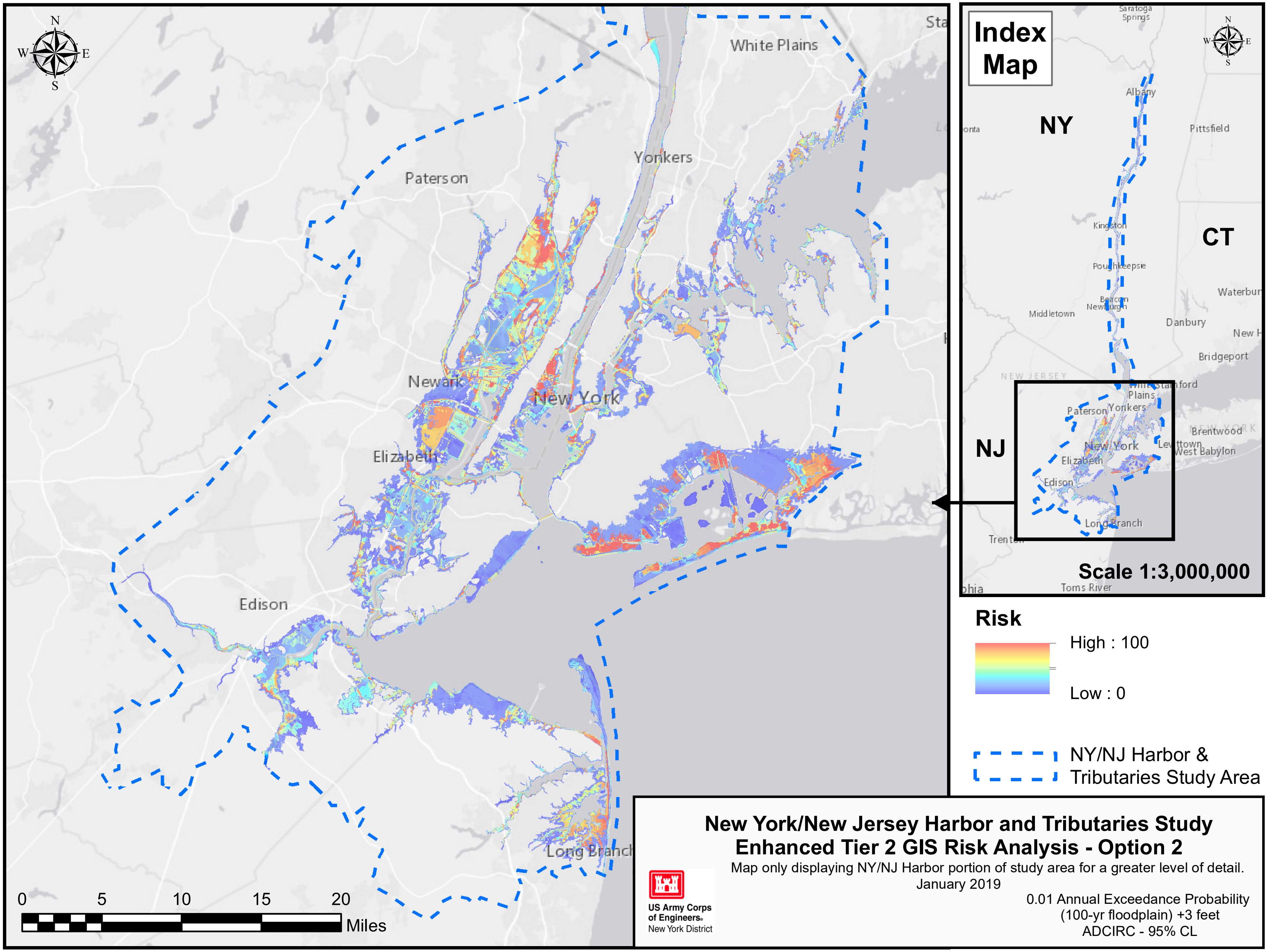
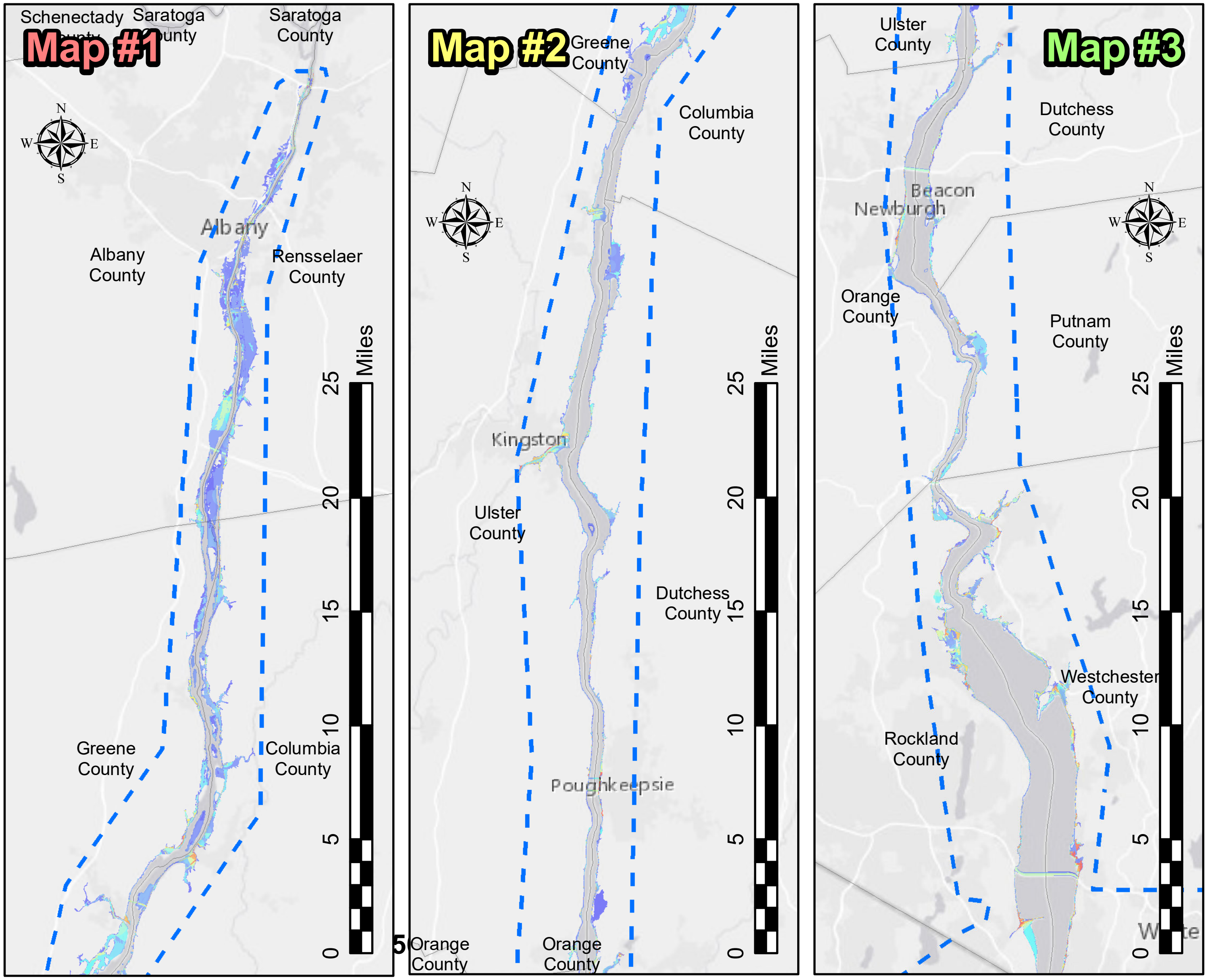
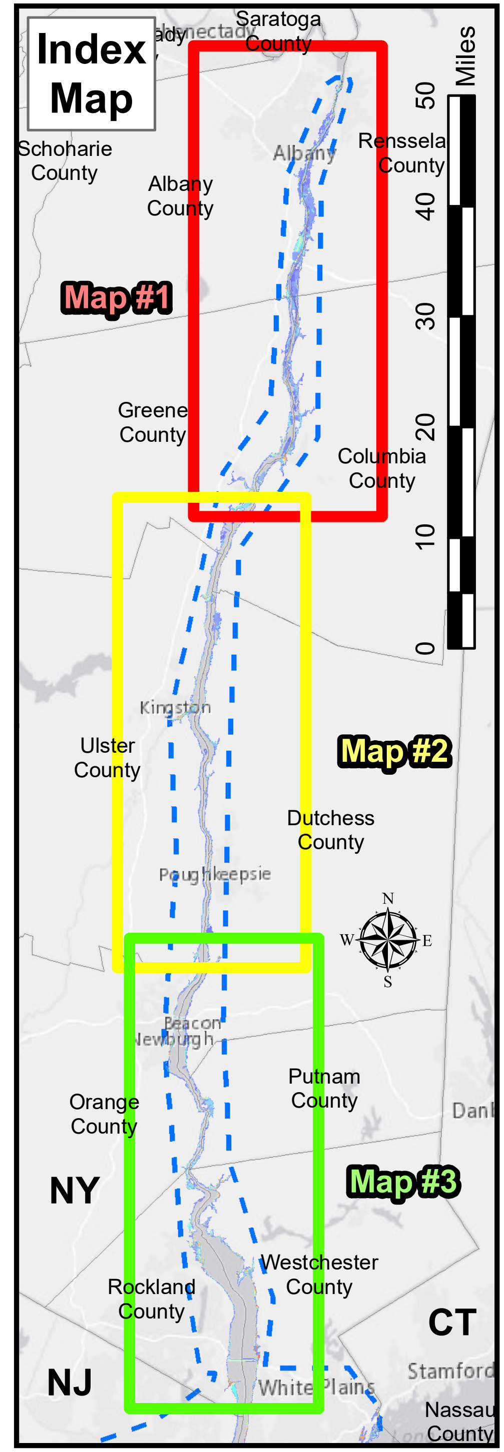


Figure 1
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum





New York/New Jersey Harbor and Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Map only displaying Hudson River portion of study area for a greater level of detail.

January 2019

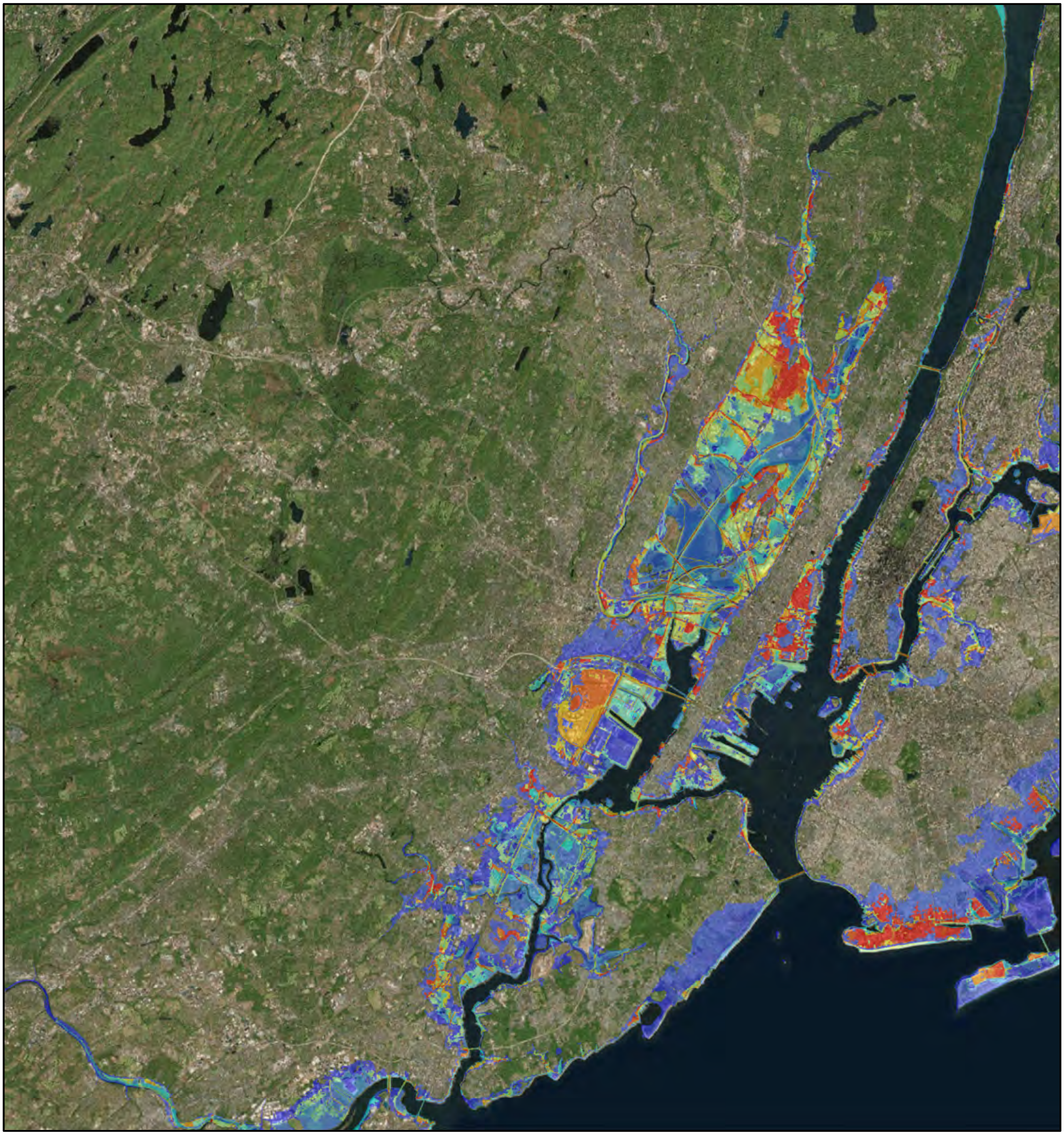
0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

Risk
High : 100
Low : 0

New York County Boundaries
NY/NJ Harbor & Tributaries Study Area

US Army Corps of Engineers
New York District

Figure 2
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

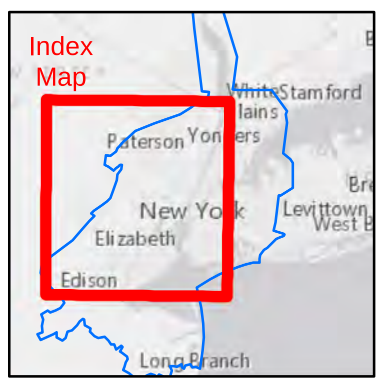
Future Without-Project Risk
Feature:
Arthur Kill & Kill Van Kull Barriers

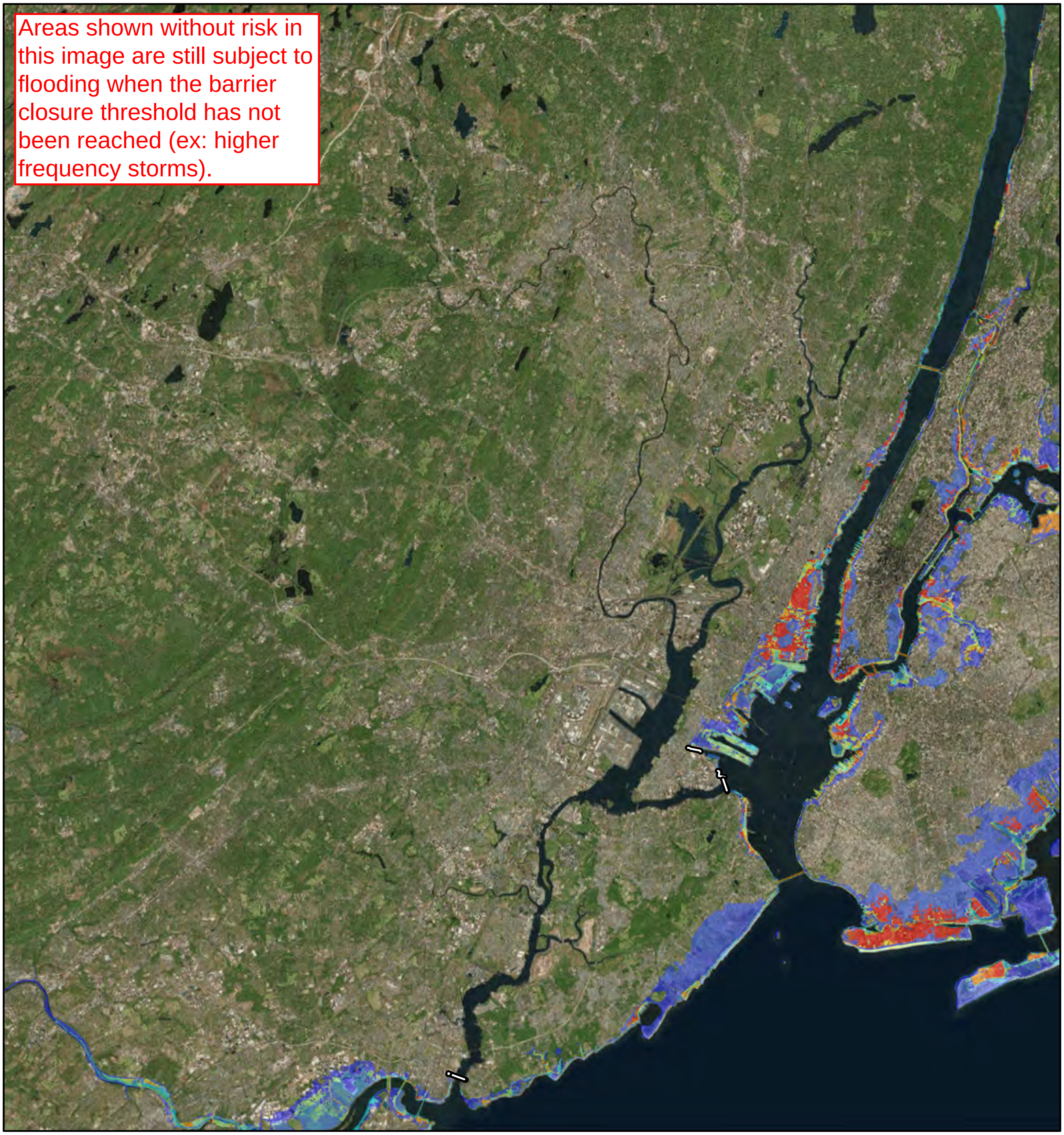
US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 10,000 20,000 30,000 40,000 50,000 Feet





Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

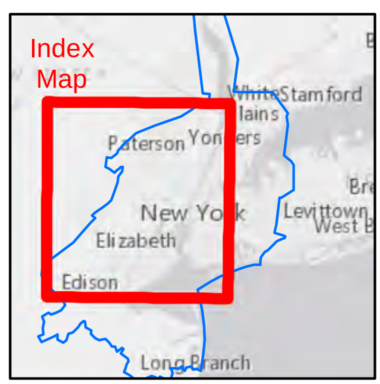
New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

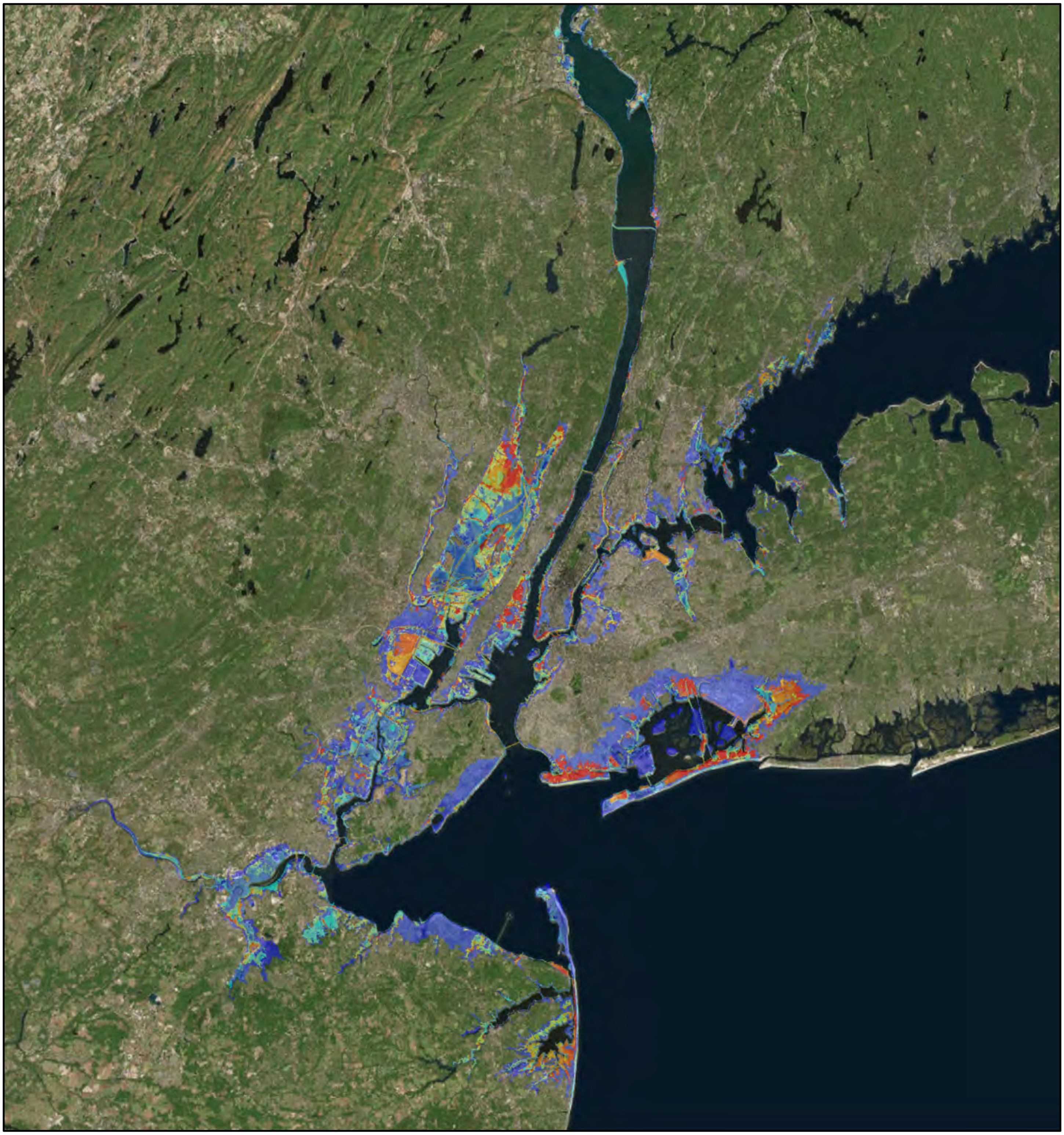
Future With-Project Risk
Feature:
Arthur Kill & Kill Van Kull Barriers

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 10,000 20,000 30,000 40,000 50,000 Feet





New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature: Arthur Kill, Throgs Neck, & Verrazzano Barriers

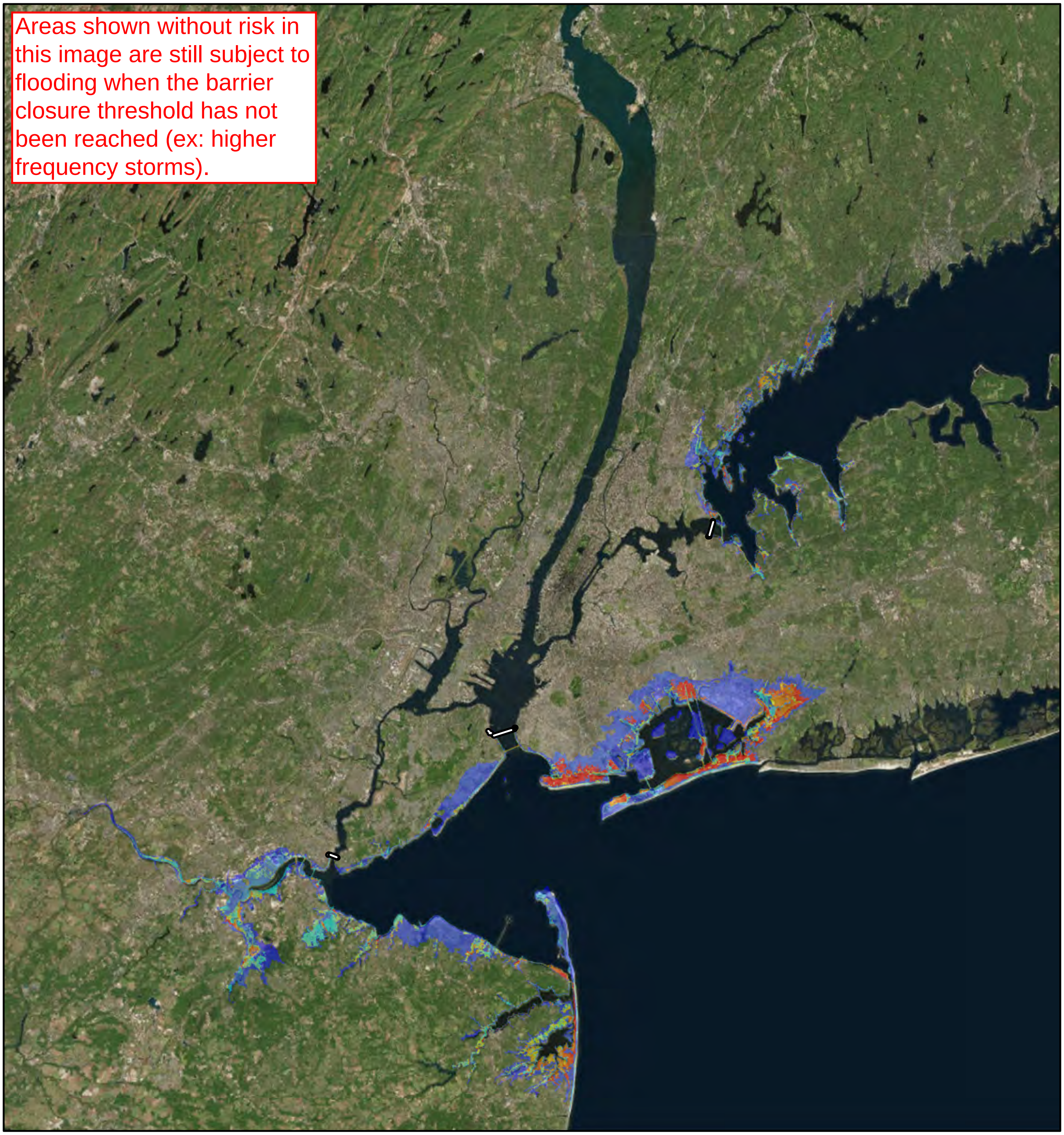
Risk
High : 100
Low : 0

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 18,000 36,000 54,000 72,000 90,000 Feet



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature: Arthur Kill, Throgs Neck, & Verrazzano Barriers

Risk
High : 98
Low : 0
Feature Alignment

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 18,000 36,000 54,000 72,000 90,000
Feet

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Risk

High : 100

Low : 0

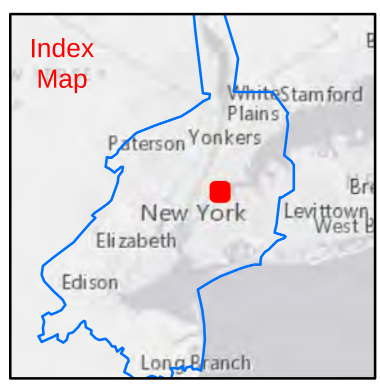
Future Without-Project Risk
Feature:
Astoria SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 540 1,080 1,620 2,160 2,700 Feet

N W E S

US Army Corps of Engineers
New York District



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Risk
High : 100
Low : 0
Feature Alignment

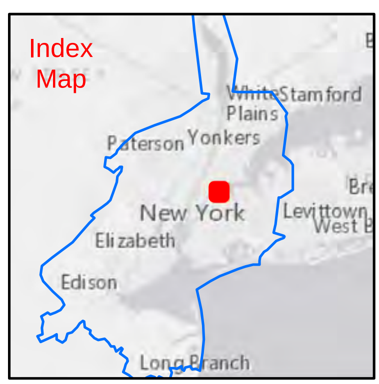
Future With-Project Risk
Feature:
Astoria SBM

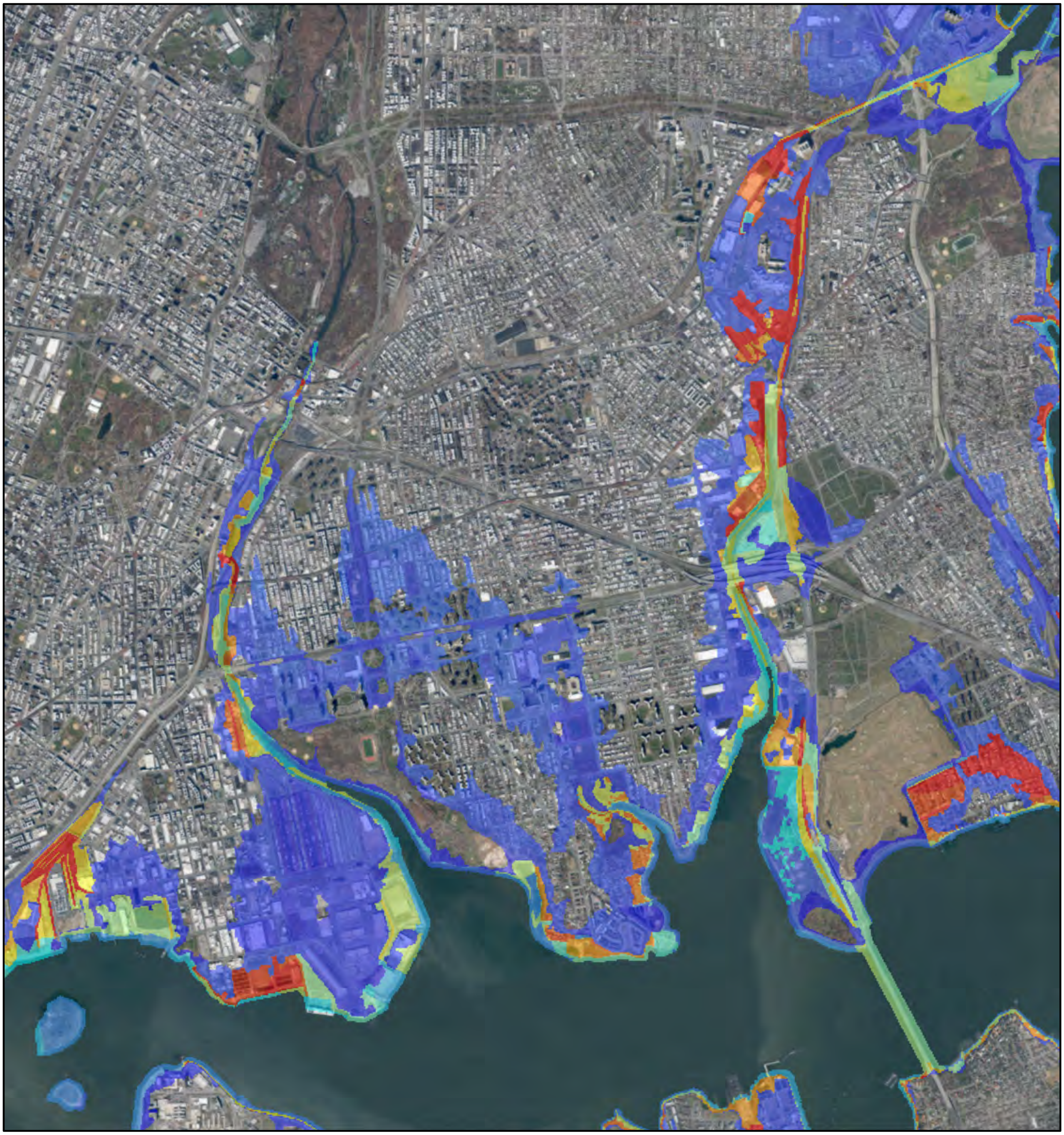
US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 540 1,080 1,620 2,160 2,700 Feet

N W E S





Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

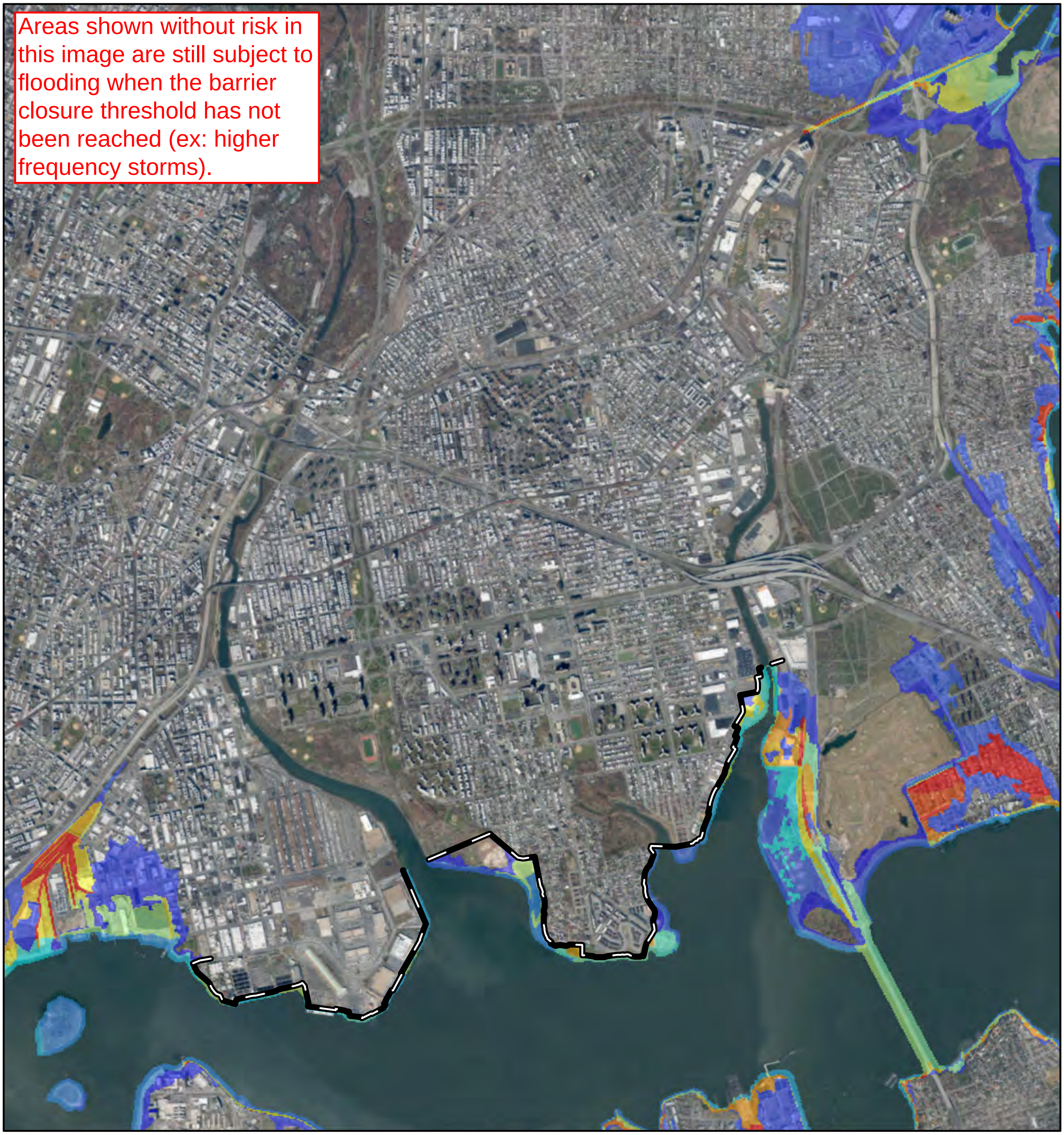
Future Without-Project Risk Features: Bronx River & Westchester Creek Barriers

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 1,300 2,600 3,900 5,200 6,500 Feet



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Risk
High : 100
Low : 0
Feature Alignment

Future With-Project Risk
Feature: Bronx River & Westchester Creek Barriers

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 1,300 2,600 3,900 5,200 6,500 Feet

US Army Corps of Engineers
New York District

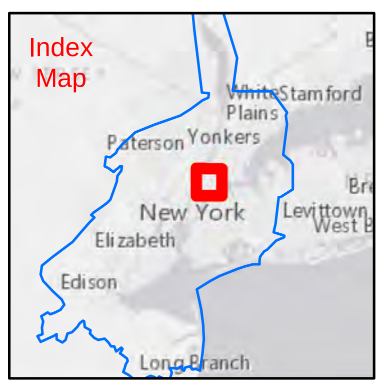
Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
East Harlem SBM



US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 1,400 2,800 4,200 5,600 7,000 Feet

Figure 11

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
East Harlem SBM

Risk
High : 100
Low : 0
Feature Alignment

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 1,400 2,800 4,200 5,600 7,000 Feet

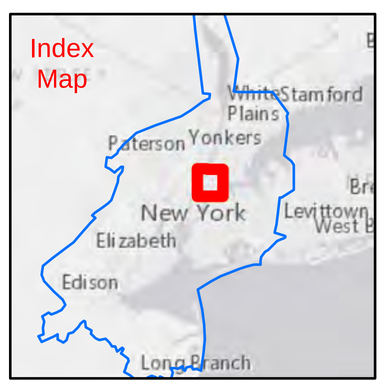
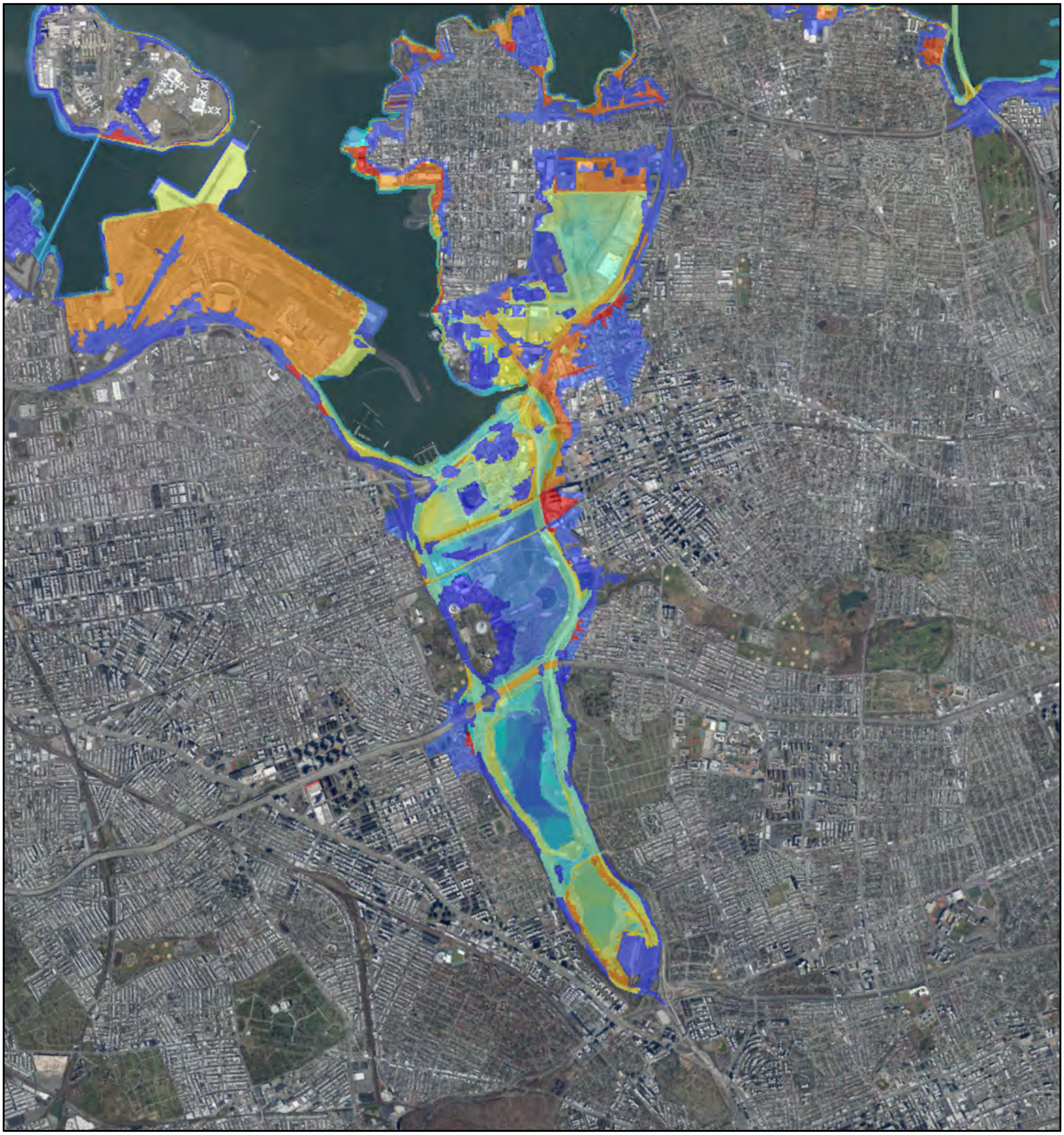


Figure 12
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

US Army Corps of Engineers®
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

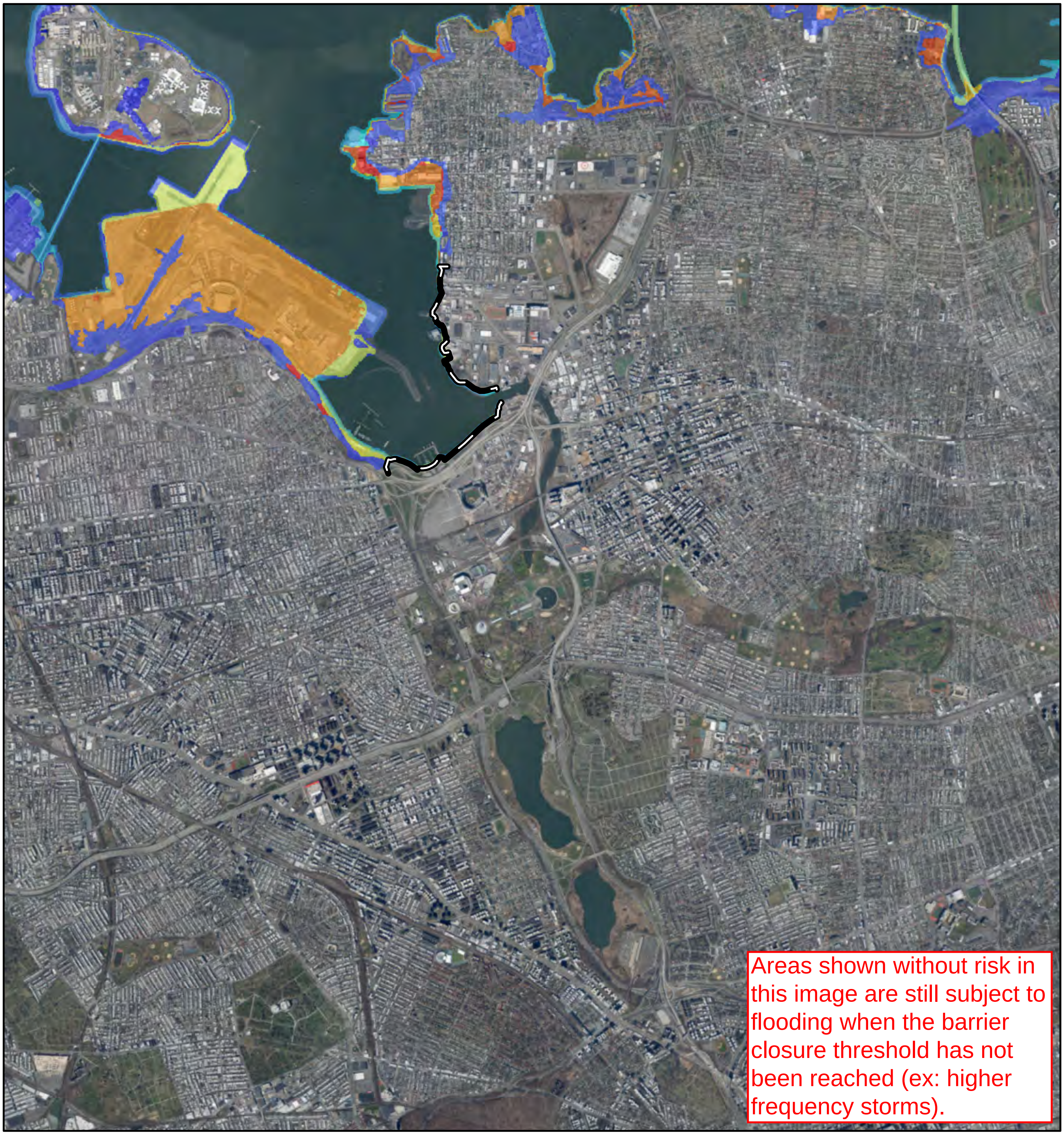
Future Without-Project Risk
Feature:
Flushing Creek Barrier

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N
W E
S

0 1,600 3,200 4,800 6,400 8,000
Feet

Figure 13
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk Feature: Flushing Creek Barrier

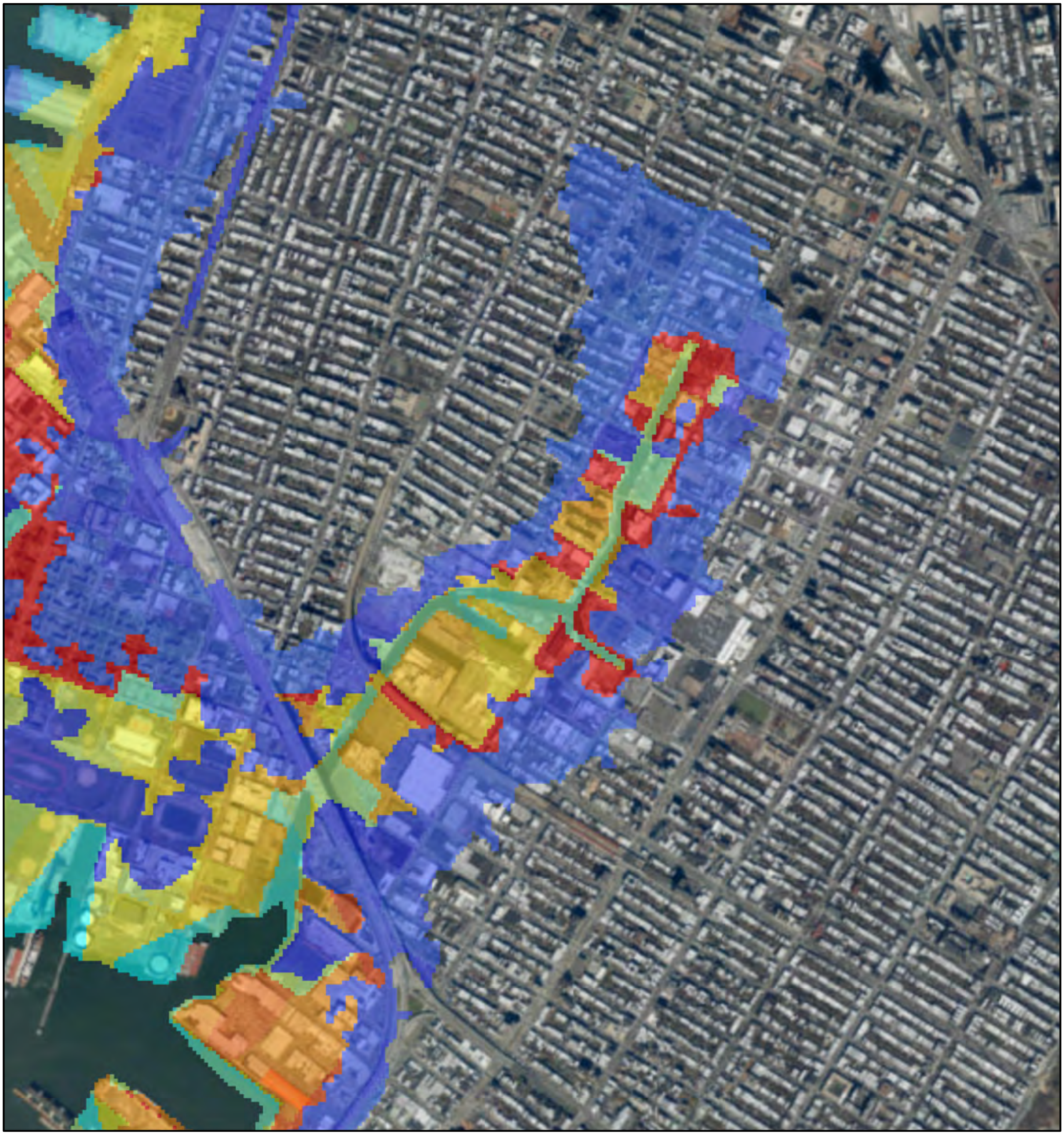
Risk
High : 100
Low : 0
Feature Alignment

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 1,600 3,200 4,800 6,400 8,000 Feet

N E S W



Risk
High : 100
Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Gowanus Canal Barrier

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 475 950 1,425 1,900 2,375 Feet

Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

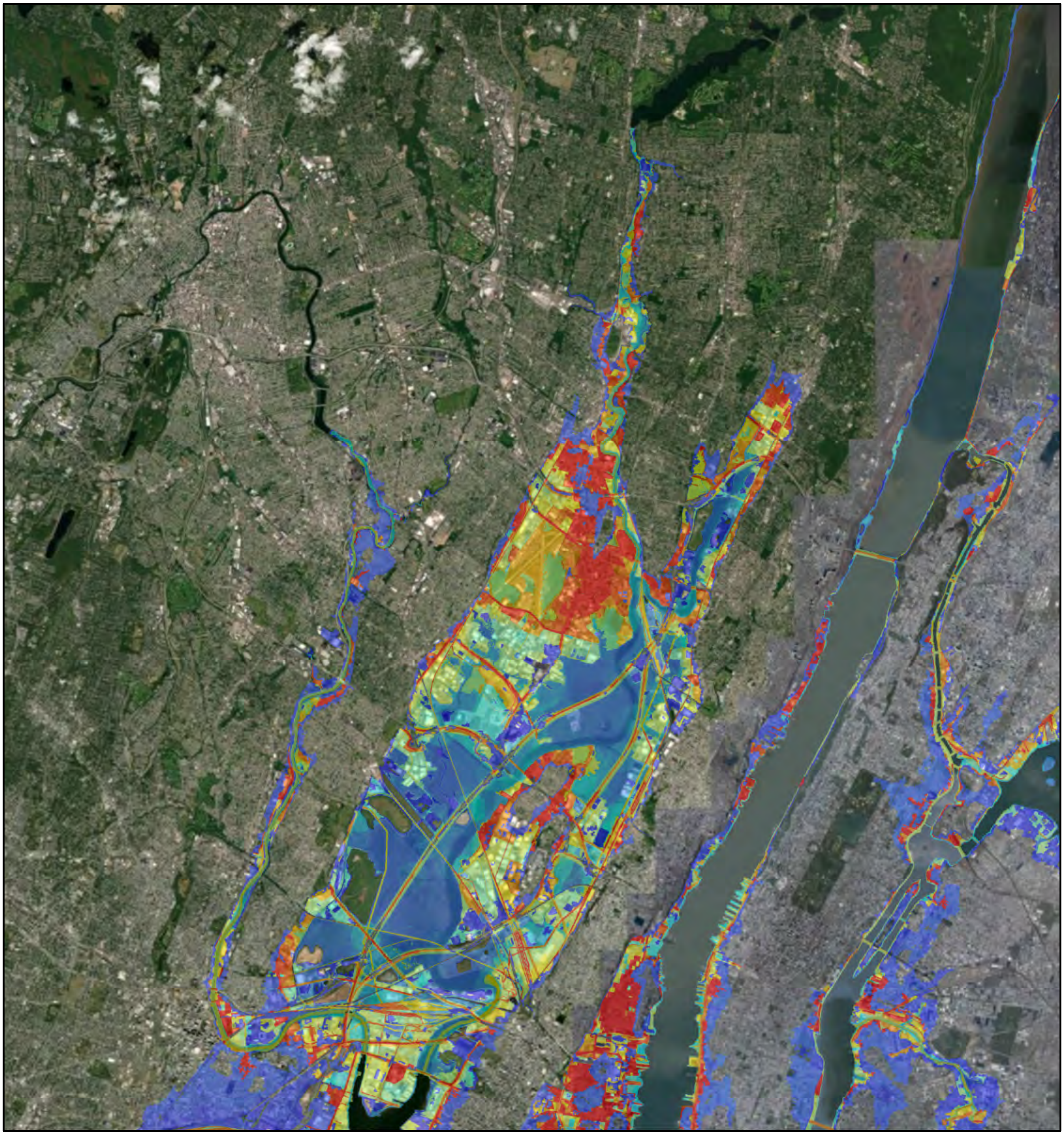
Future With-Project Risk Feature: Gowanus Canal Barrier

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 475 950 1,425 1,900 2,375 Feet

Figure 16
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Hackensack River Barrier

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 5,000 10,000 15,000 20,000 25,000 Feet

N W E S

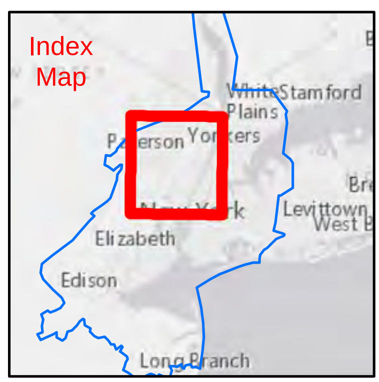
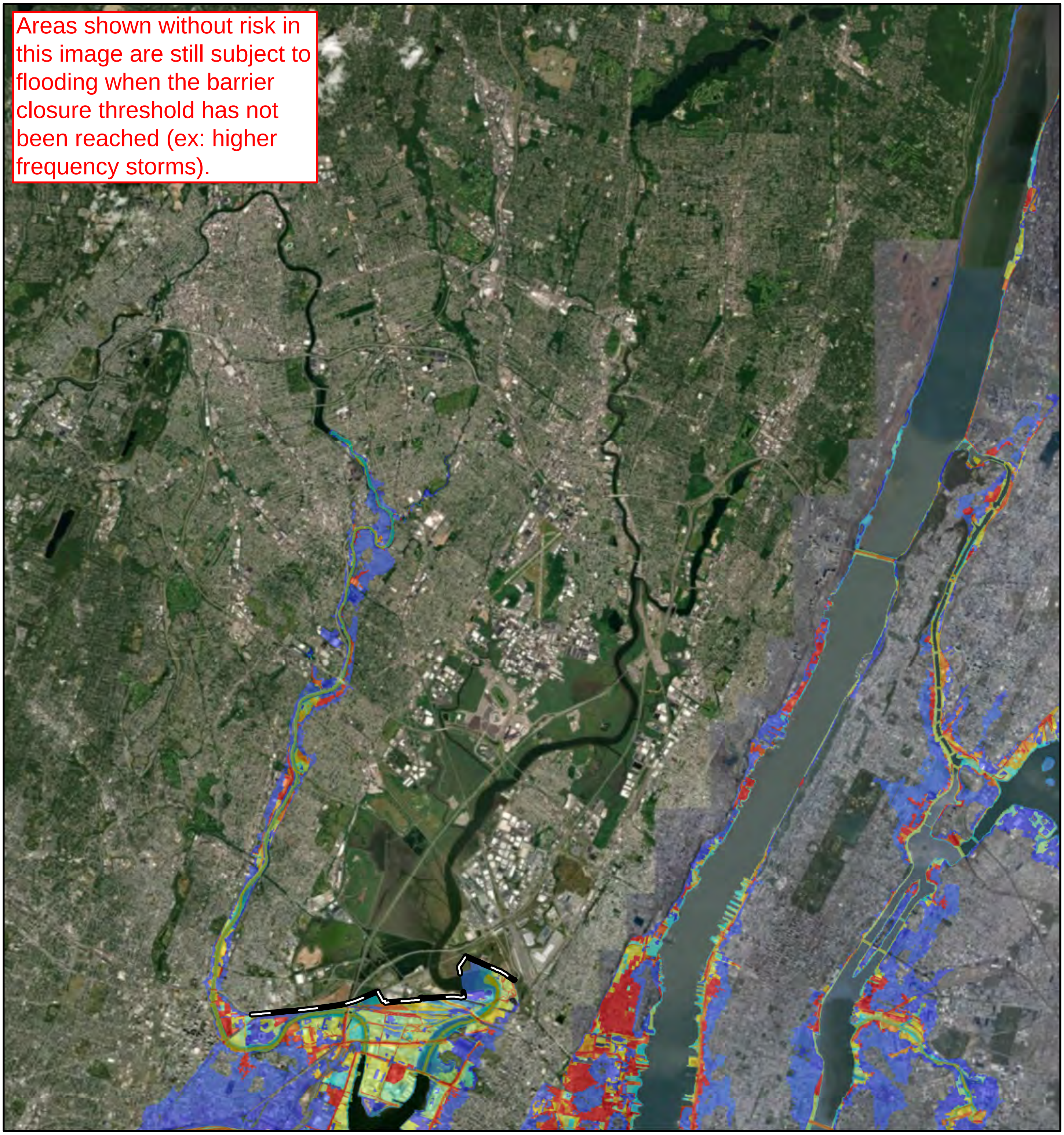


Figure 17
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Hackensack River Barrier

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 5,000 10,000 15,000 20,000 25,000 Feet

N W E S

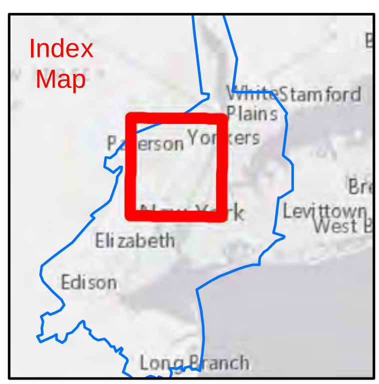
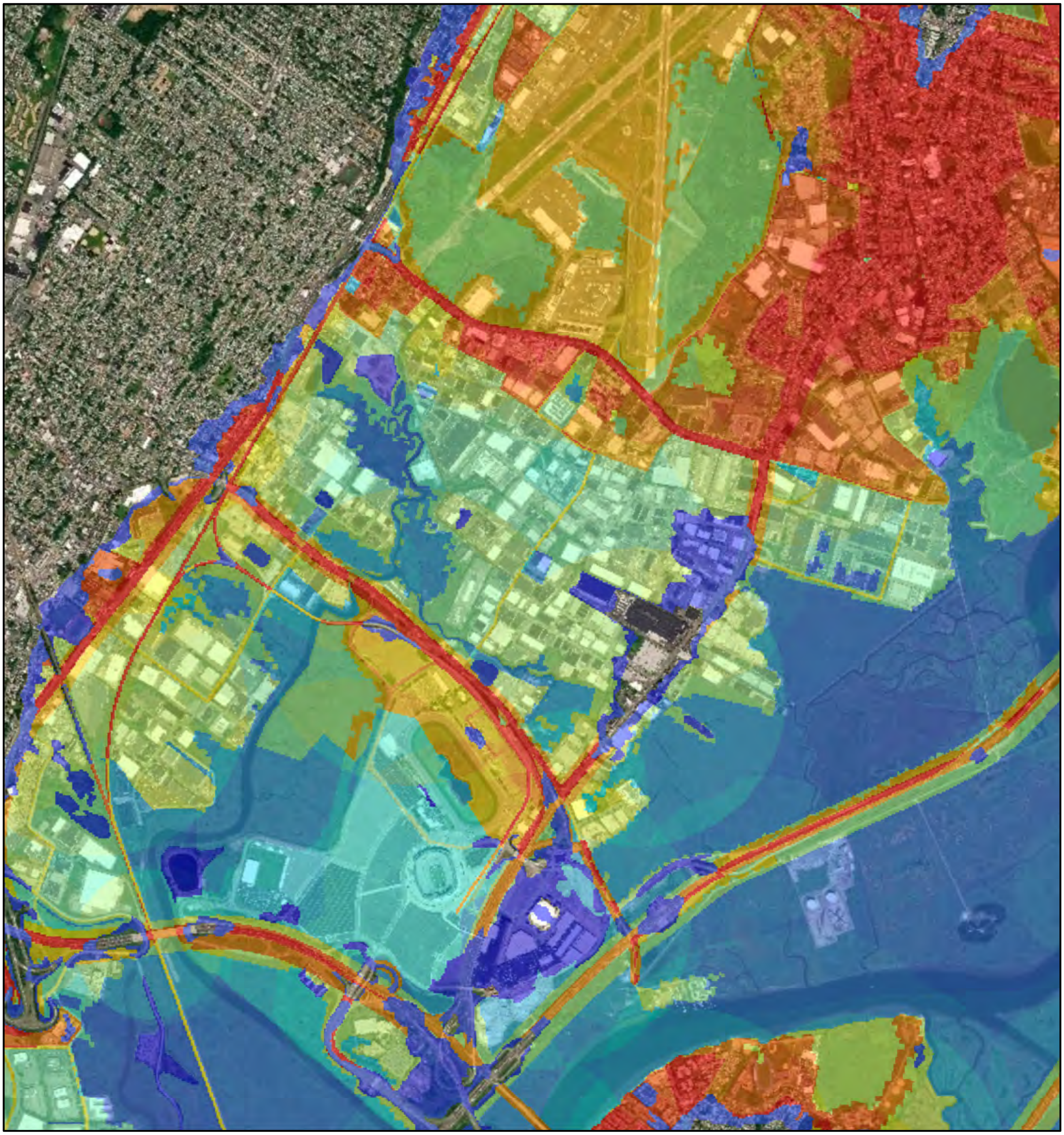


Figure 18
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Hackensack Perimeter

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 1,000 2,000 3,000 4,000 5,000
Feet

N
W E
S

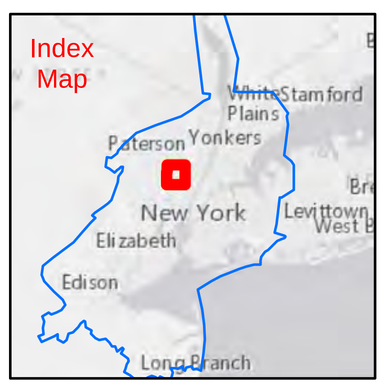
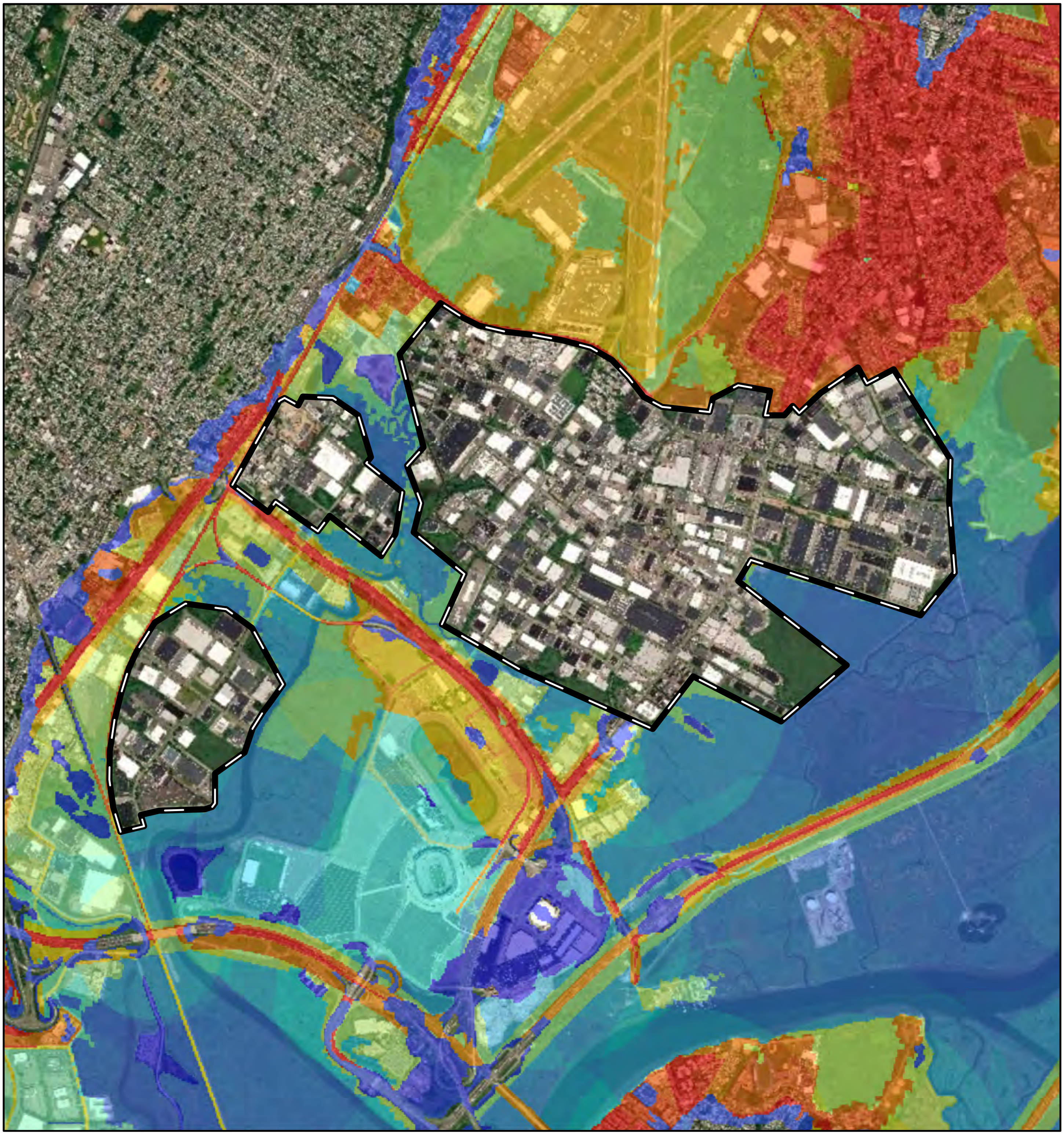


Figure 19
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Hackensack Perimeter

Risk
High : 100
Low : 0
Feature Alignment

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 1,000 2,000 3,000 4,000 5,000 Feet

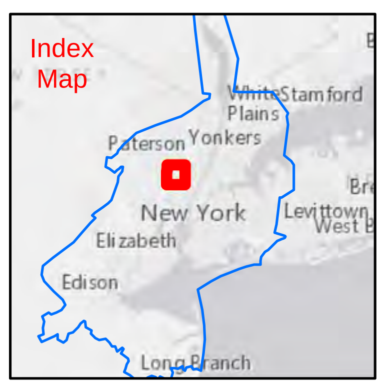
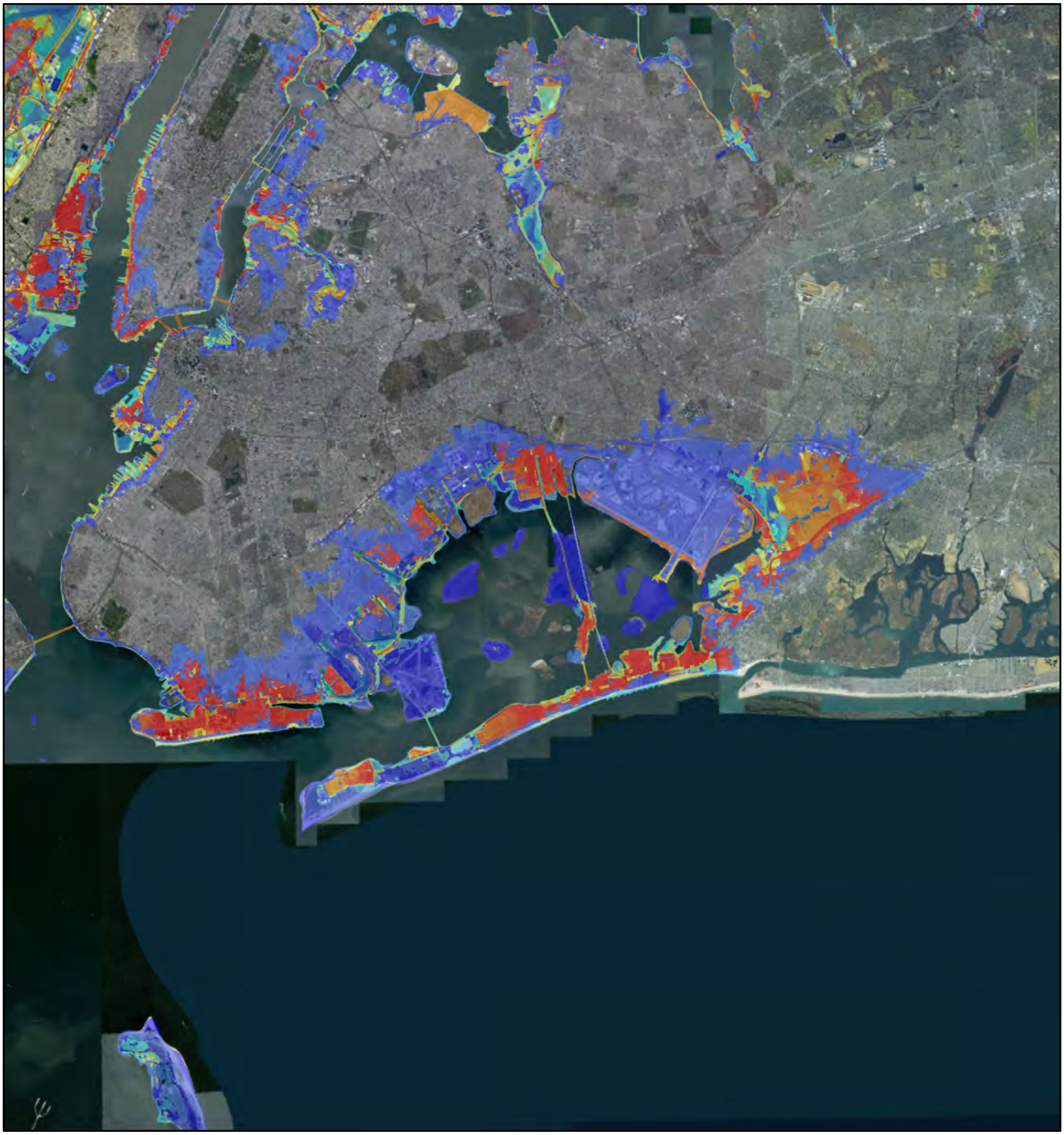


Figure 20
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

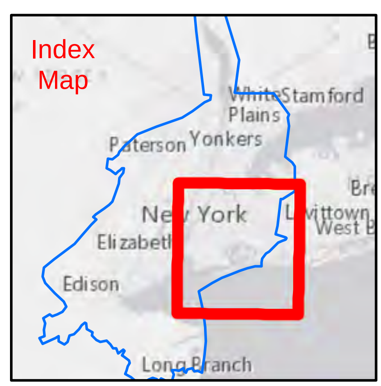
Future Without-Project Risk
Feature:
Jamaica Bay Barrier

N
W E
S

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 6,700 13,400 20,100 26,800 33,500 Feet



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Jamaica Bay Barrier

Risk
High : 100
Low : 0
Feature Alignment

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 6,700 13,400 20,100 26,800 33,500 Feet

N W E S

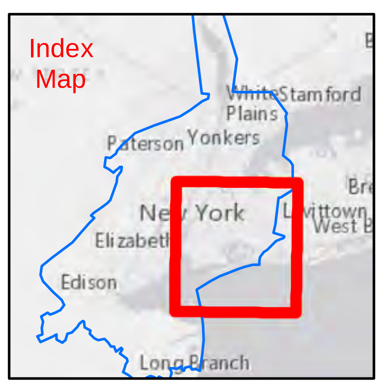


Figure 22
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum

Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Long Island City - Astoria SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 620 1,240 1,860 2,480 3,100 Feet

US Army Corps of Engineers
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Long Island City - Astoria SBM

Risk
High : 100
Low : 0
Feature Alignment

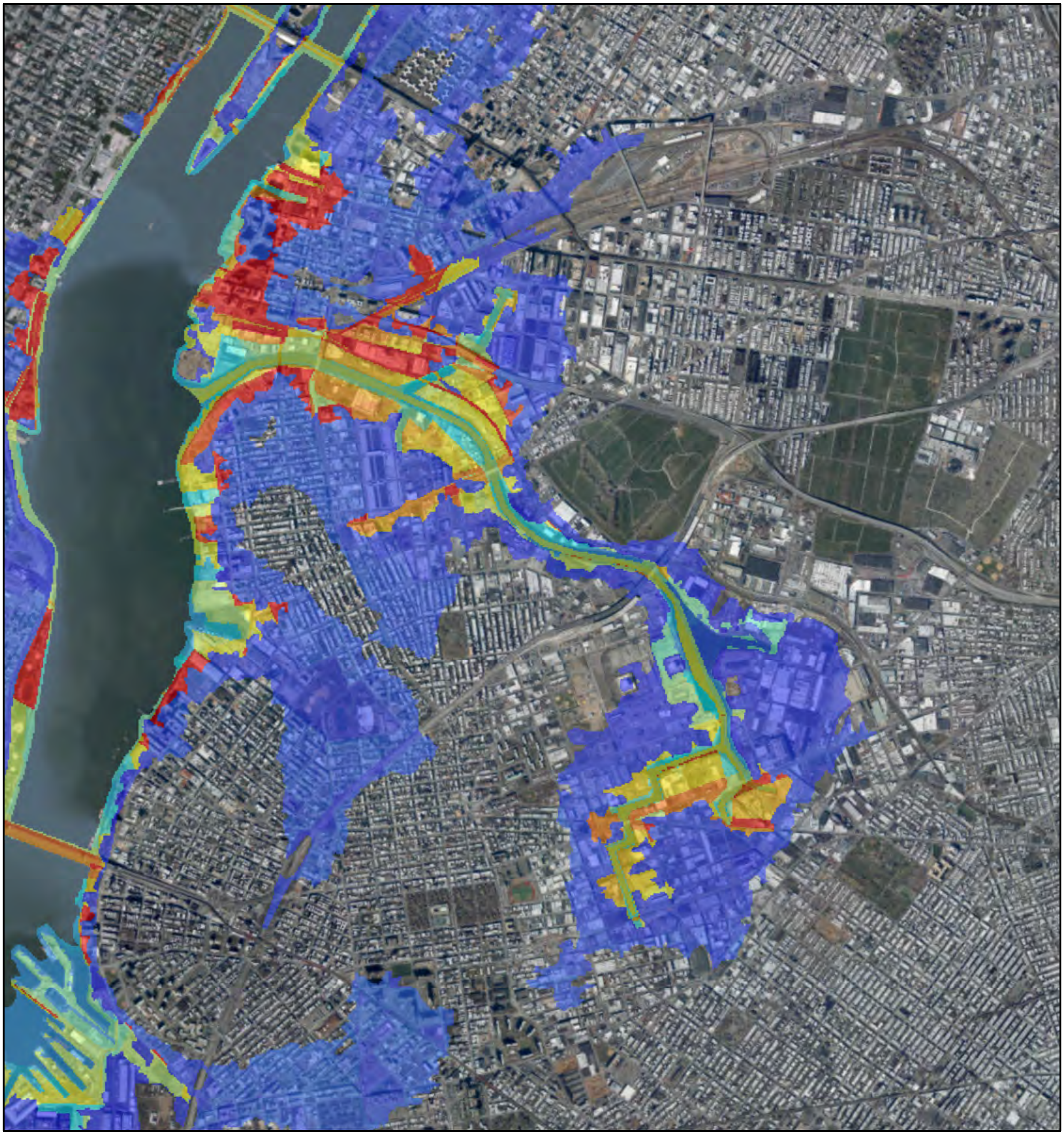
US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 620 1,240 1,860 2,480 3,100
Feet

Figure 24
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Newtown Creek Barrier

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 1,100 2,200 3,300 4,400 5,500 Feet

US Army Corps of Engineers
New York District

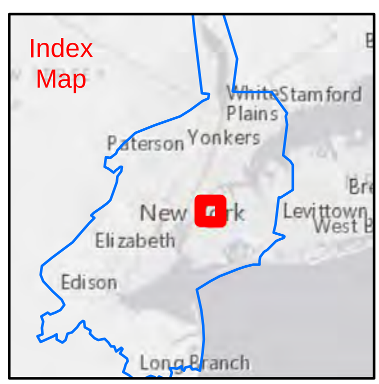
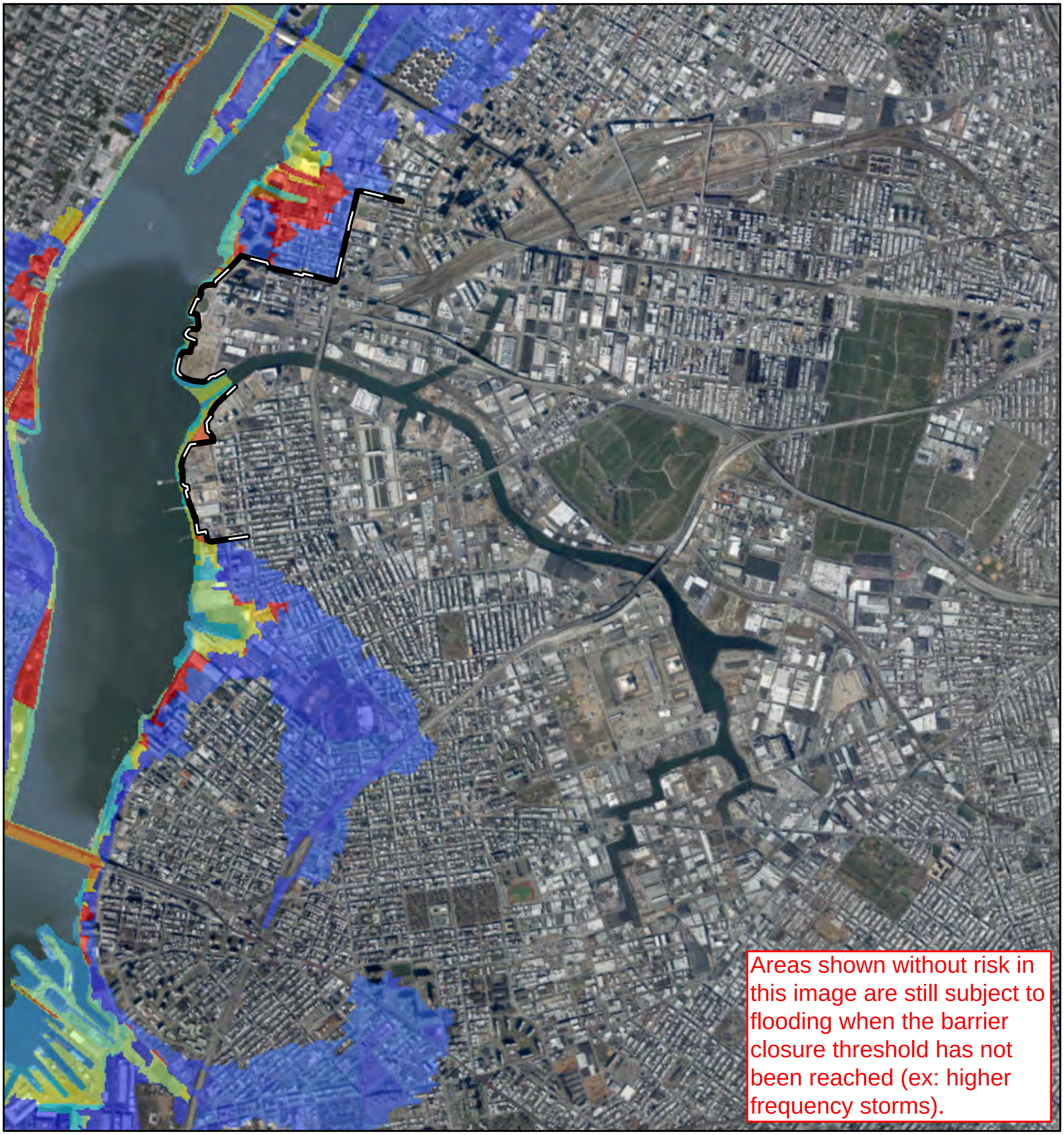


Figure 25



Risk
High : 100
Low : 0
Feature Alignment

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Newtown Creek Barrier

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 1,100 2,200 3,300 4,400 5,500 Feet

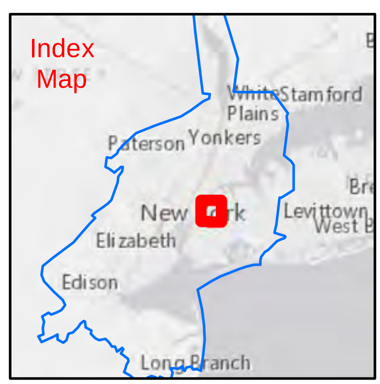
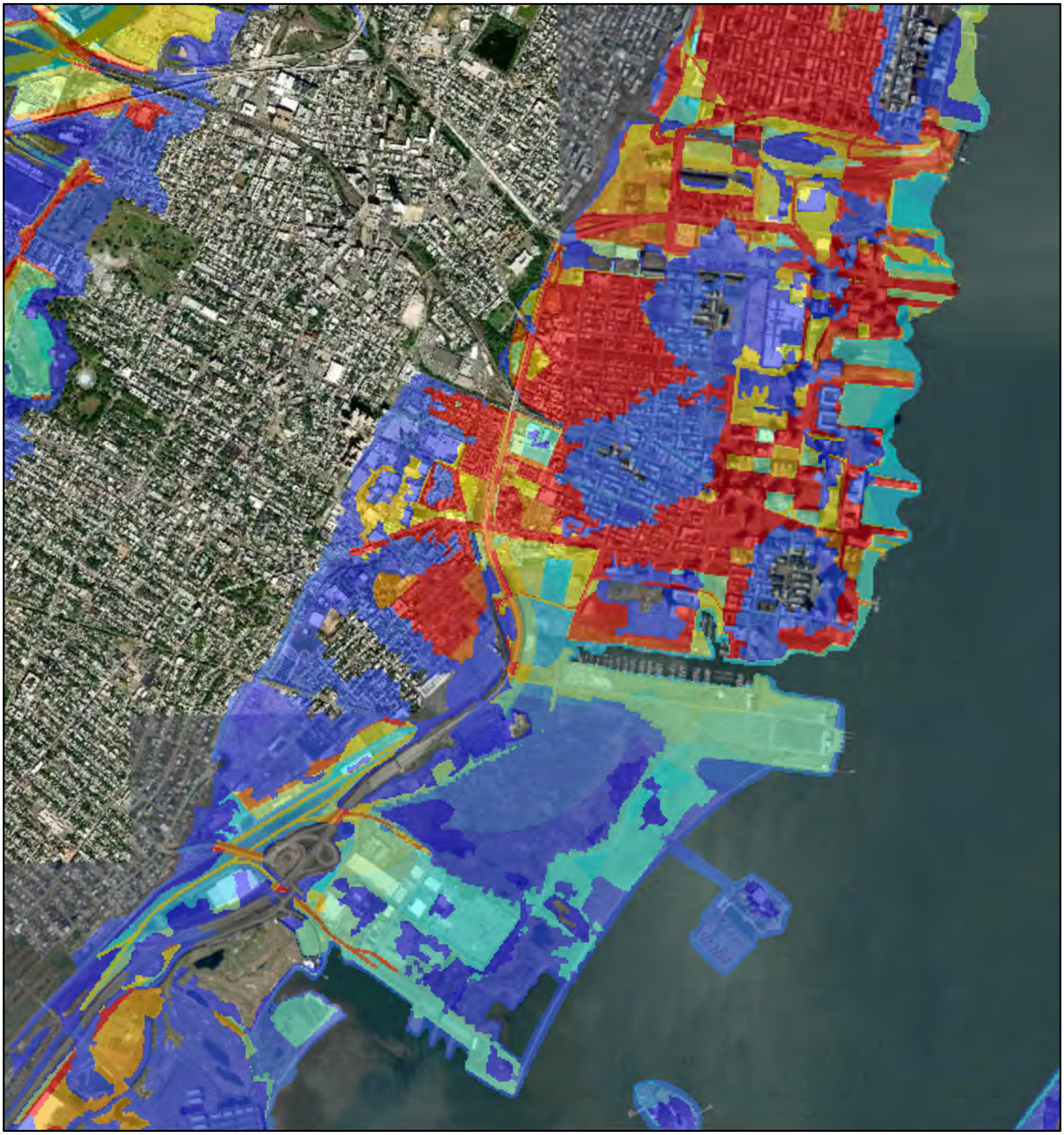


Figure 26
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

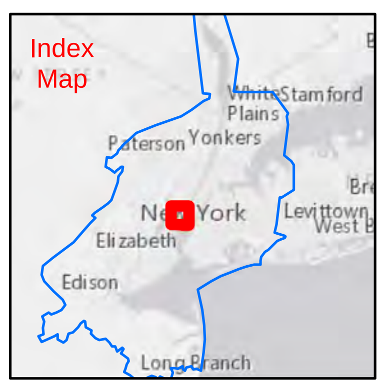
High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
New Jersey Hudson River SBM

N
W E
S



US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 975 1,950 2,925 3,900 4,875
Feet

Figure 27

Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
New Jersey Hudson River SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N
W E
S

0 975 1,950 2,925 3,900 4,875 Feet

Figure 28
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum

Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
New York City West Side SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 1,200 2,400 3,600 4,800 6,000 Feet

N W E S

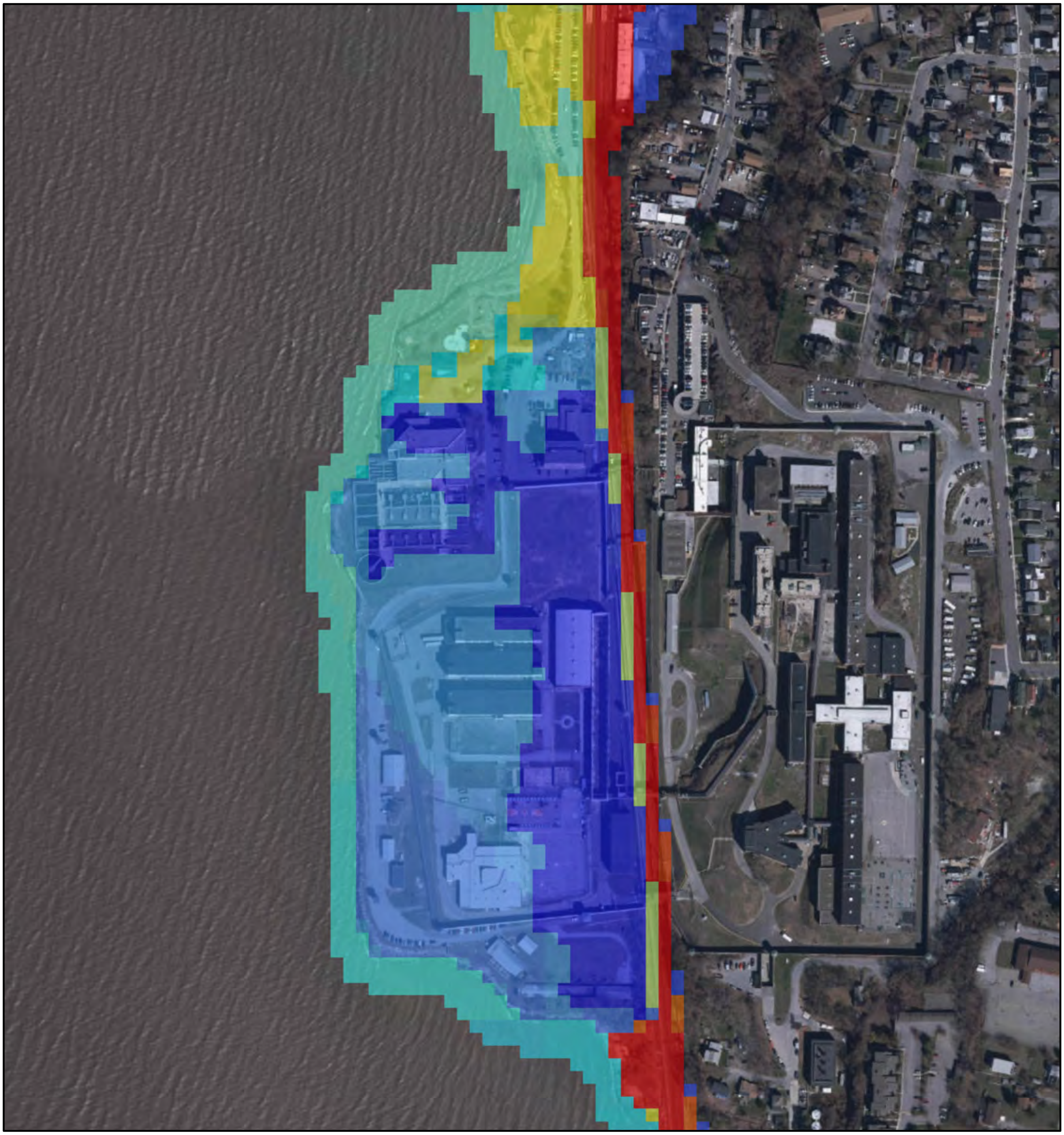
US Army Corps of Engineers
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
New York City West Side SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

Figure 30
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Ossining SBM

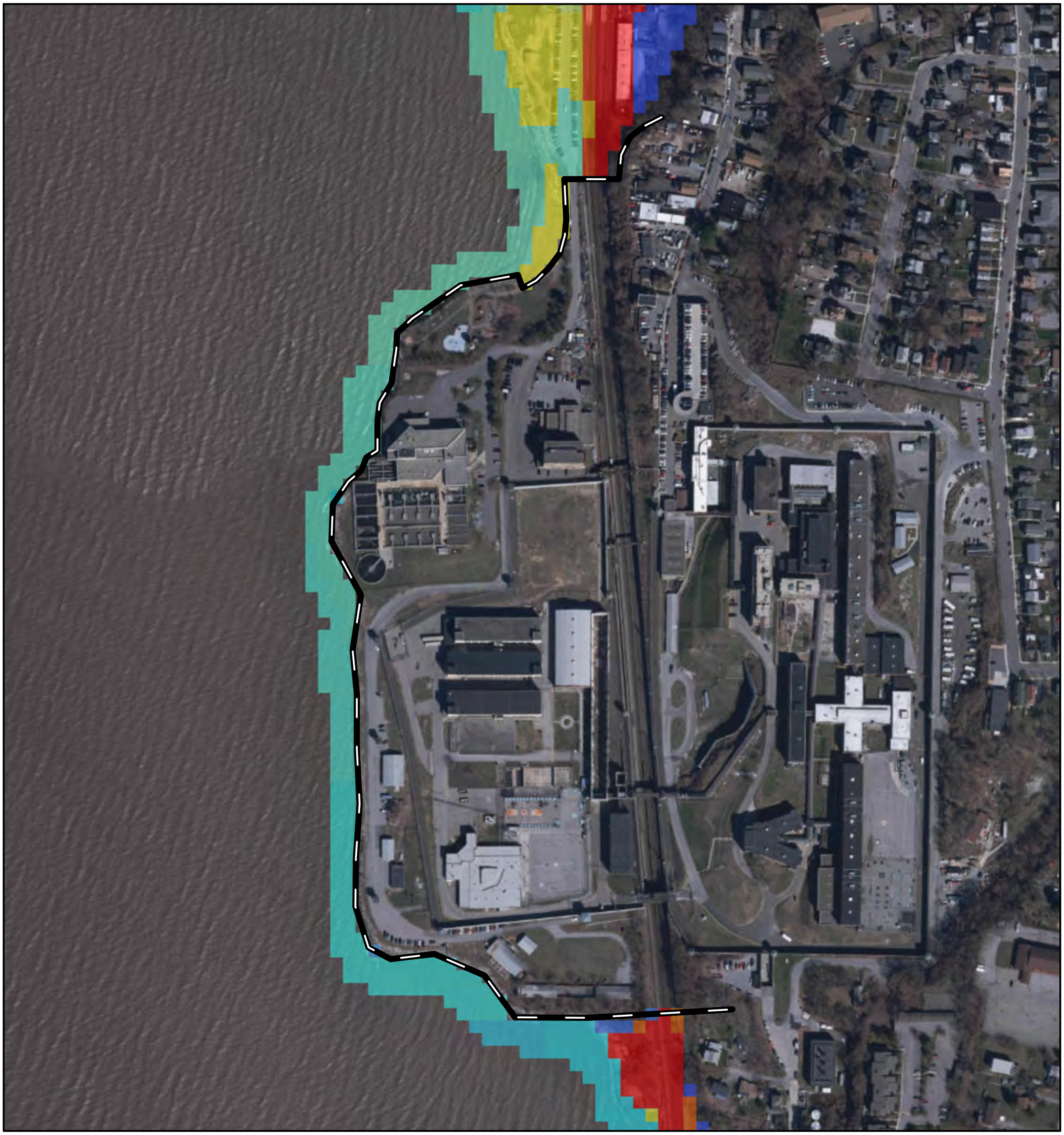
Risk
High : 100
Low : 0

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 140 280 420 560 700
Feet



Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

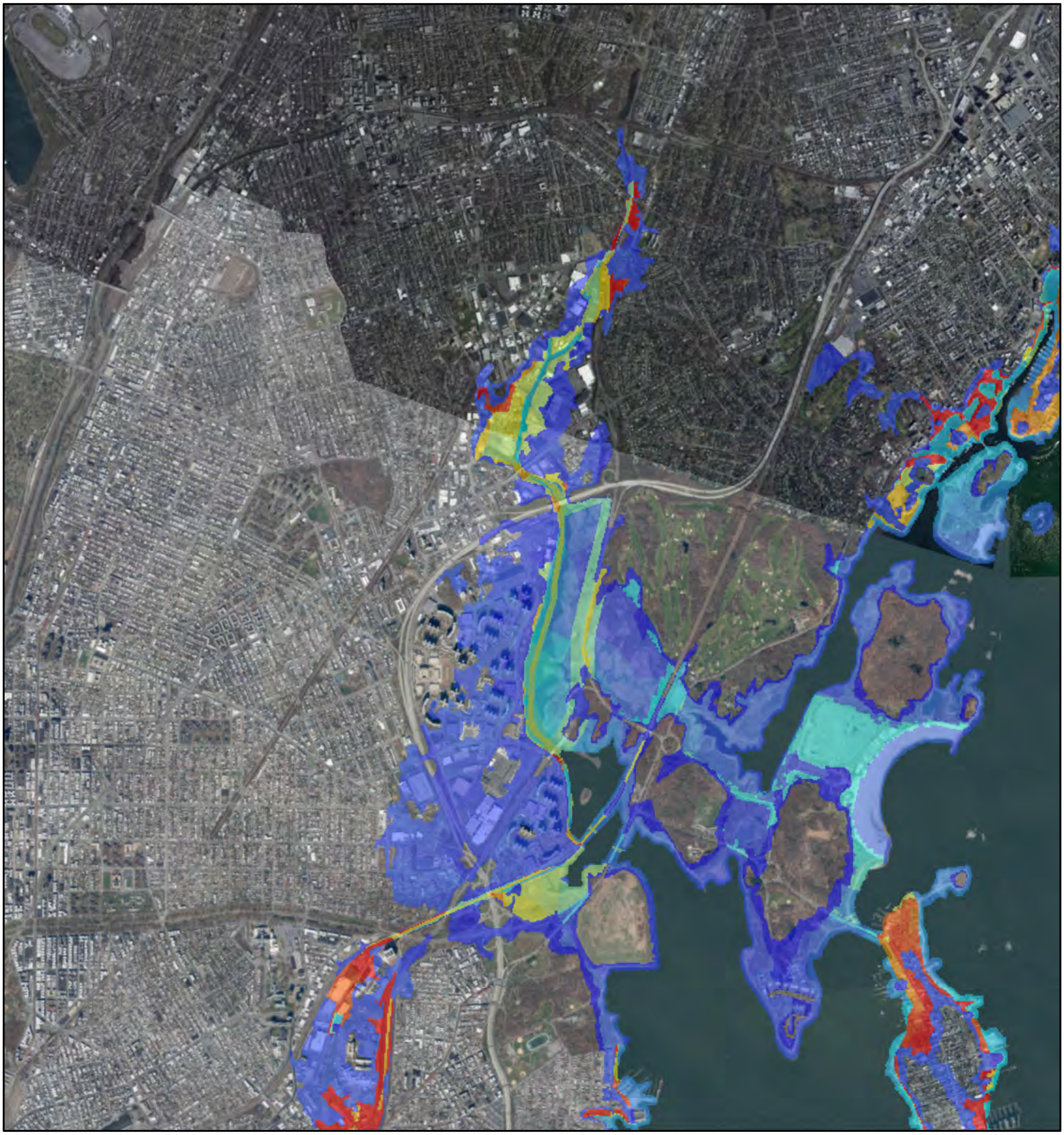
New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Ossining SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 140 280 420 560 700 Feet



Risk

High : 100

Low : 0

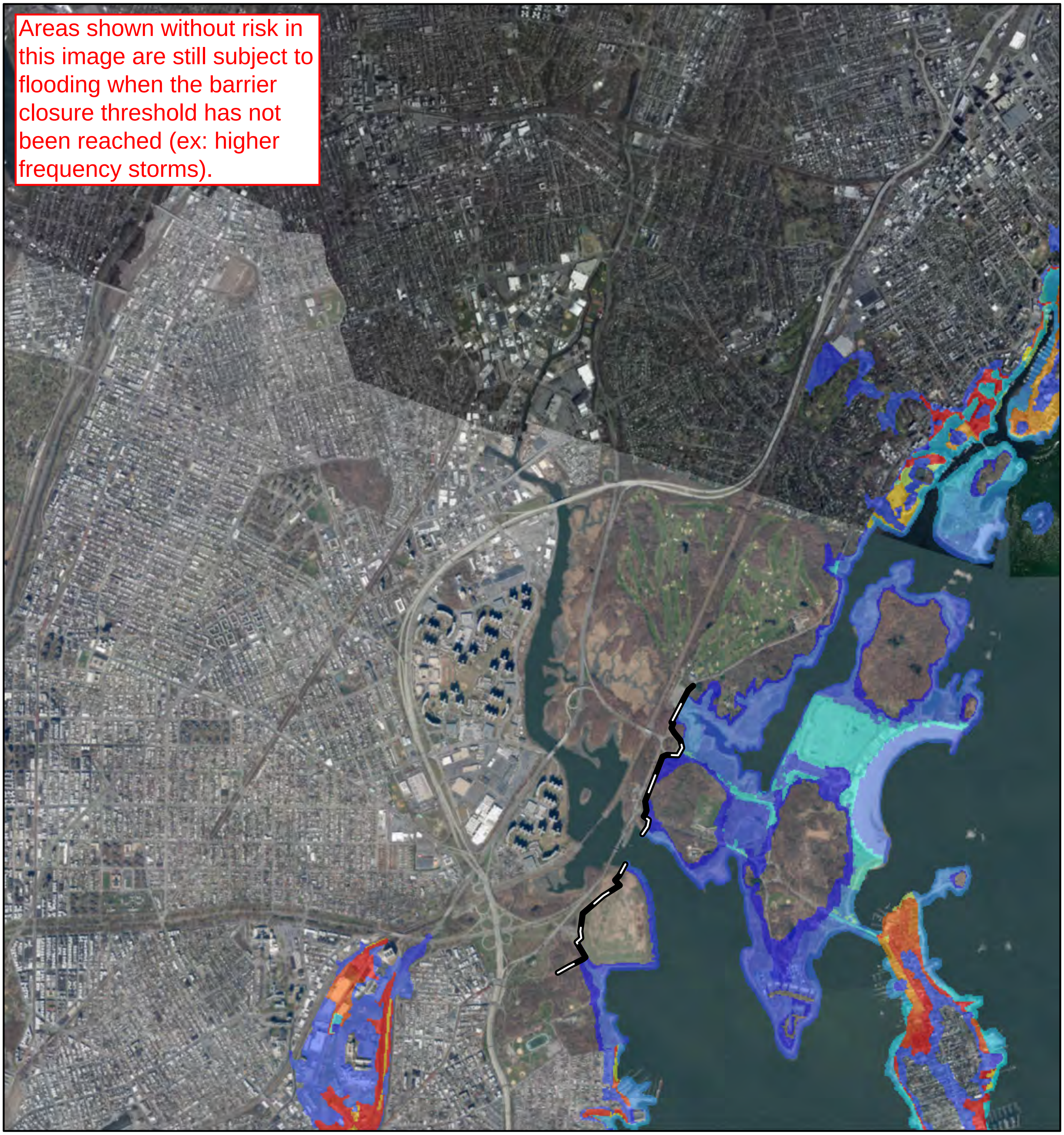
New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Pelham Barrier

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 | 1,400 | 2,800 | 4,200 | 5,600 | 7,000 Feet



Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

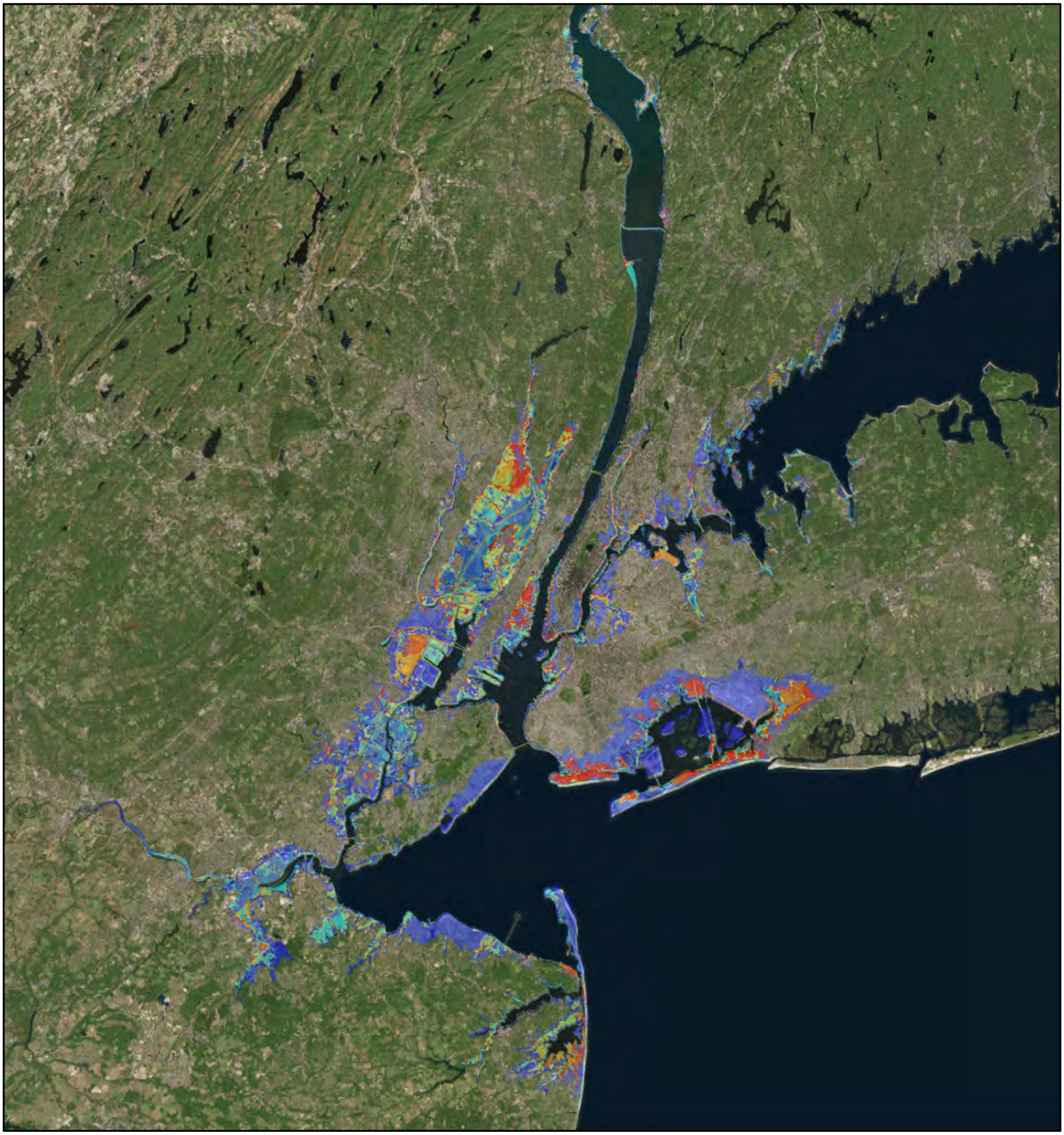
New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Pelham Barrier

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 1,400 2,800 4,200 5,600 7,000 Feet

Figure 34
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Risk
High : 100
Low : 0

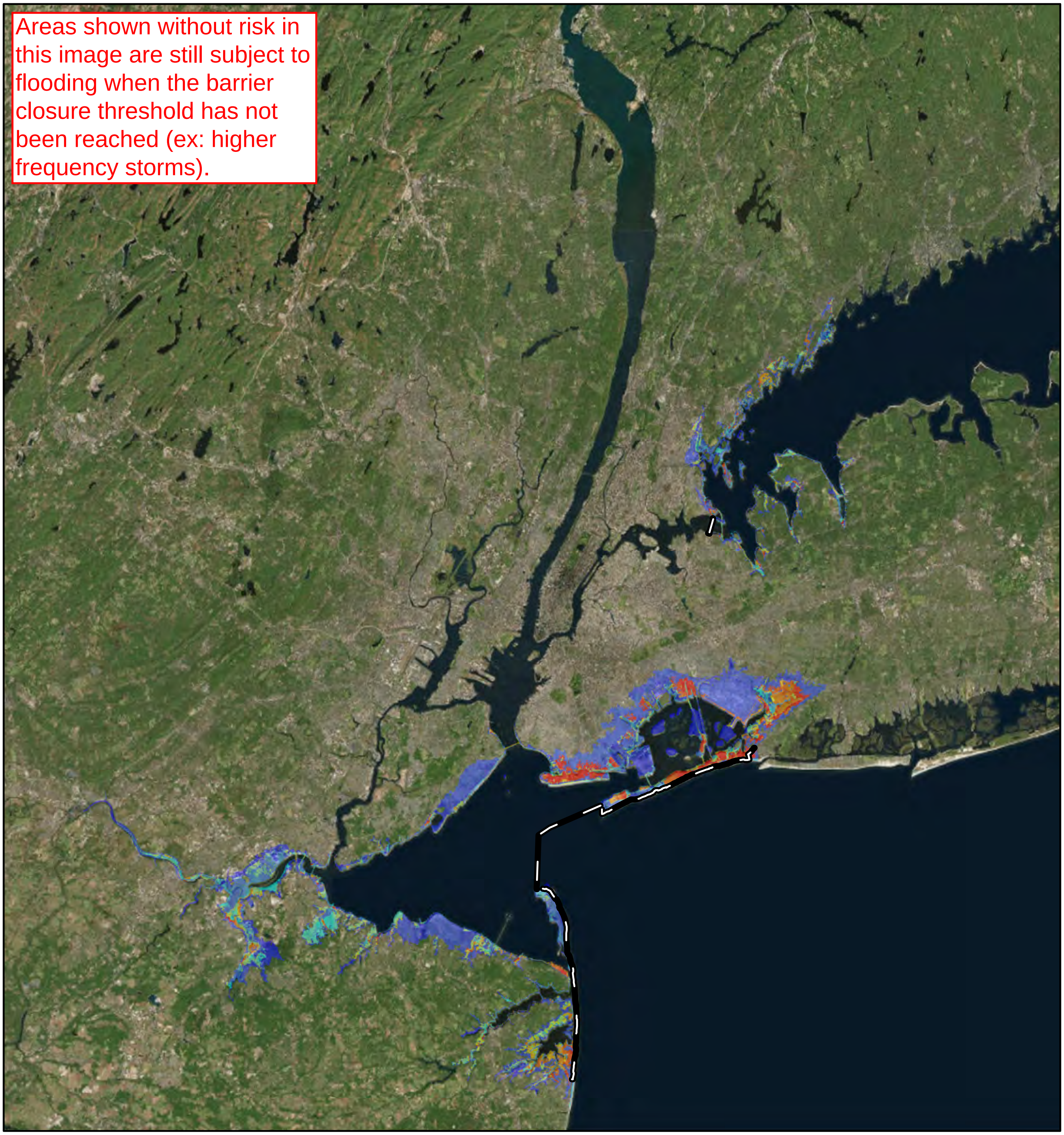
Future Without-Project Risk
Feature: Sandy Hook-Breezy Point & Throgs Neck Barriers

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 18,000 36,000 54,000 72,000 90,000 Feet

N S E W



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature: Sandy Hook-Breezy Point & Throgs Neck Barriers

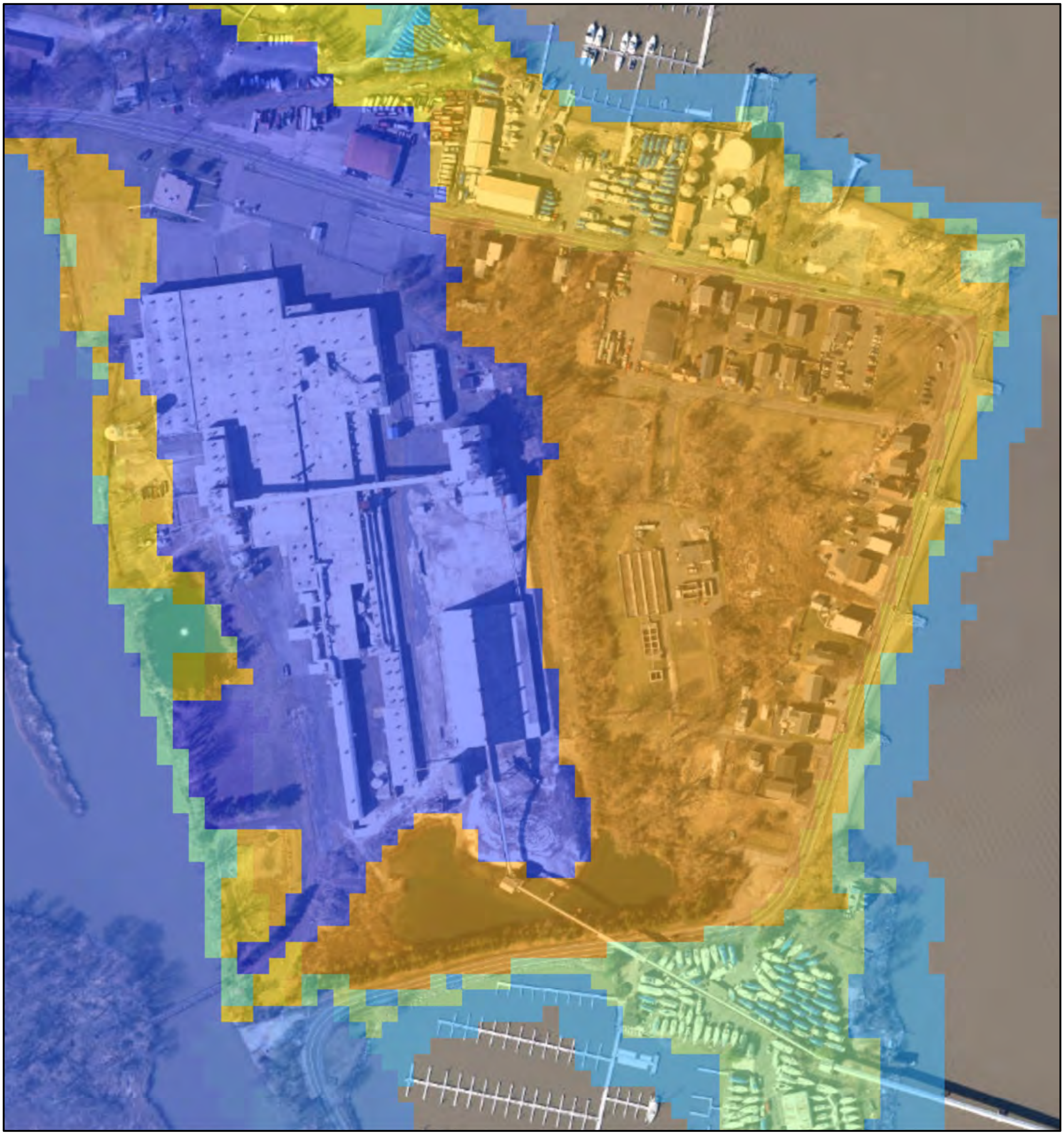
Risk
High : 98
Low : 0
Featuree Alignment

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 18,000 36,000 54,000 72,000 90,000
Feet

N
W E
S



Risk
High : 100
Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

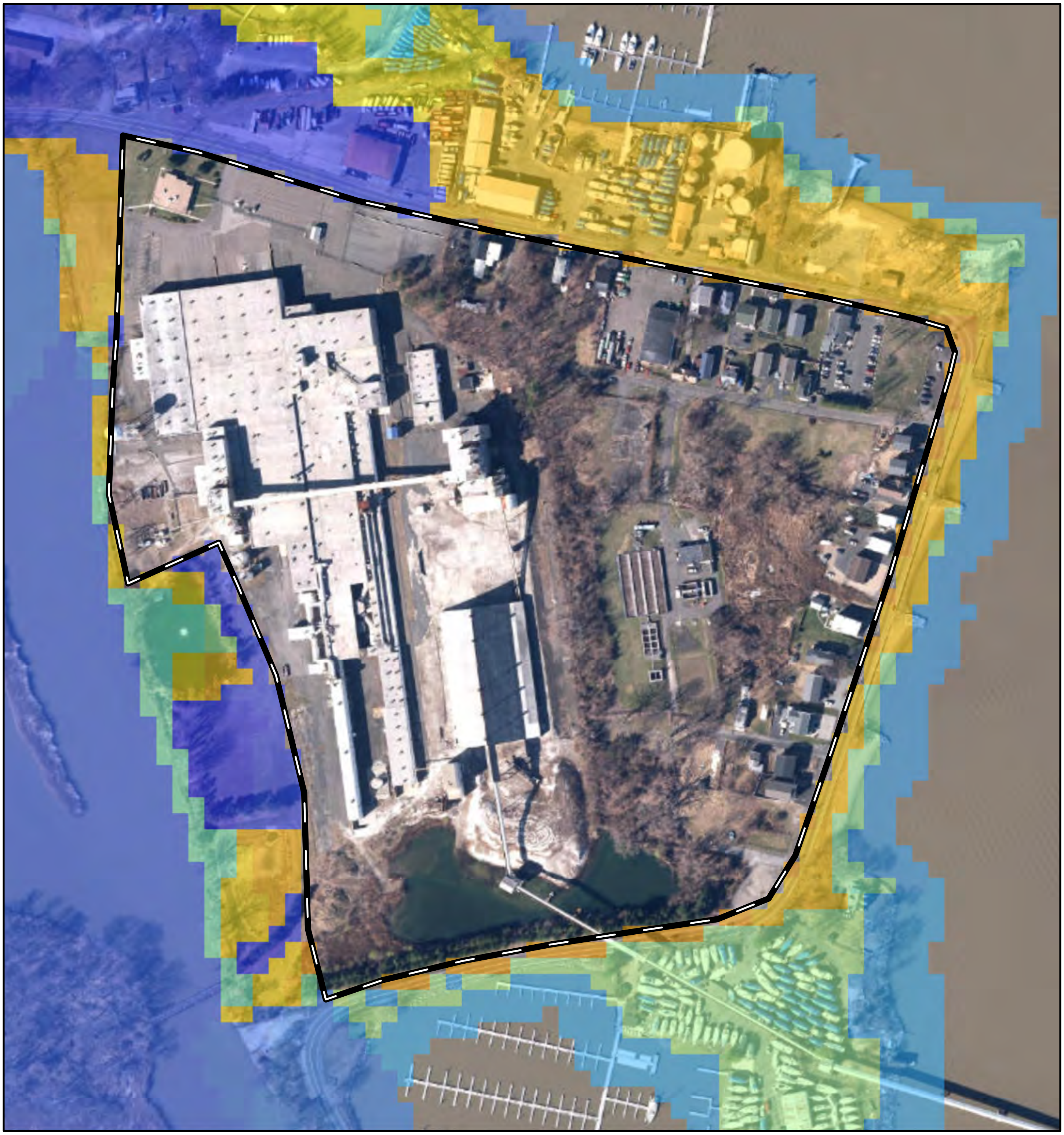
Future Without-Project Risk Feature: Stony Point Perimeter

0.01 Annual Exceedance Probability (100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 110 220 330 440 550 Feet

US Army Corps of Engineers
New York District

Figure 37
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk Feature: Stony Point Perimeter

Risk
High : 100
Low : 0
Feature Alignment

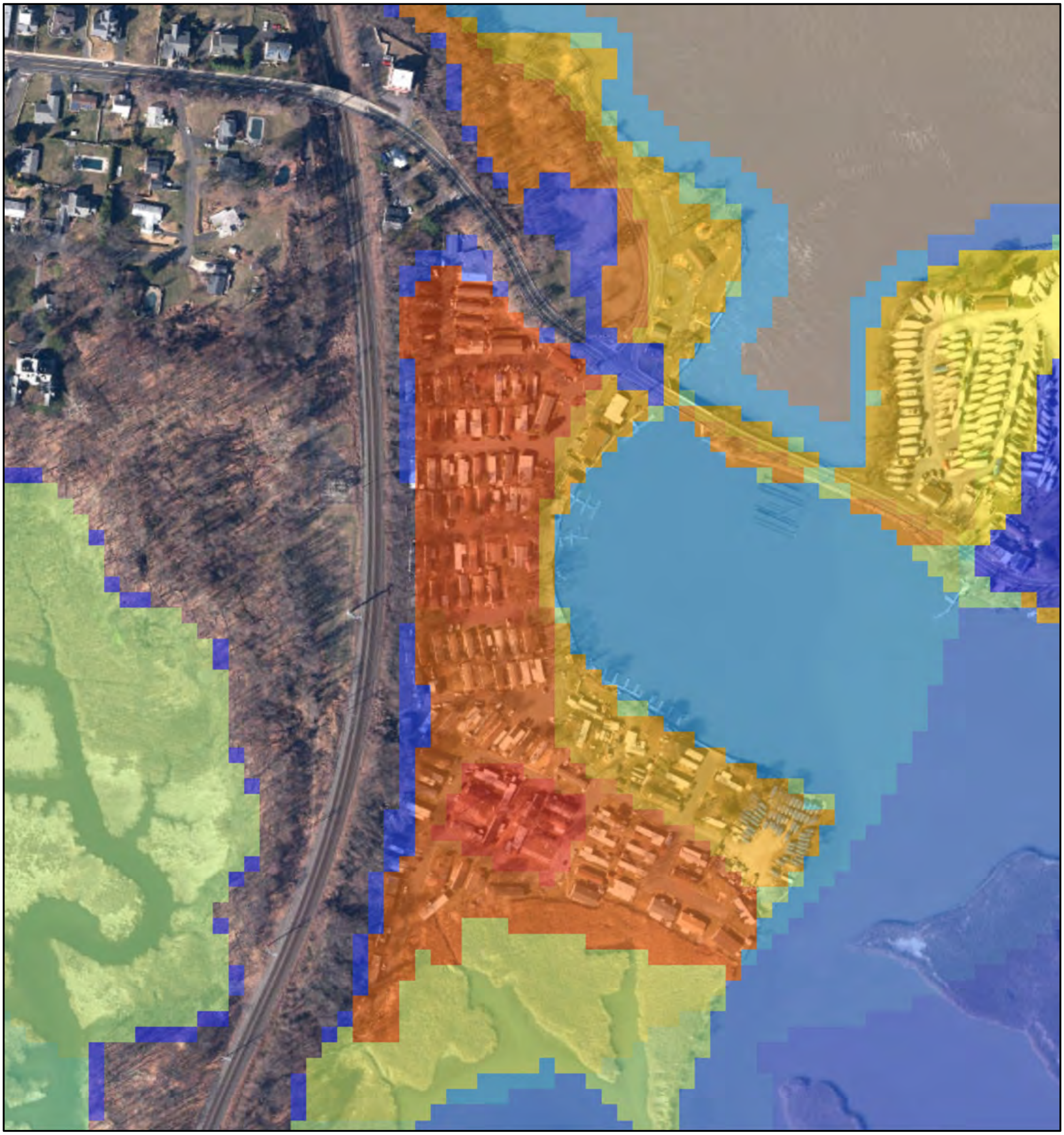
US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N
W E
S

0 110 220 330 440 550 Feet

Figure 38



Risk

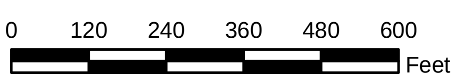
High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

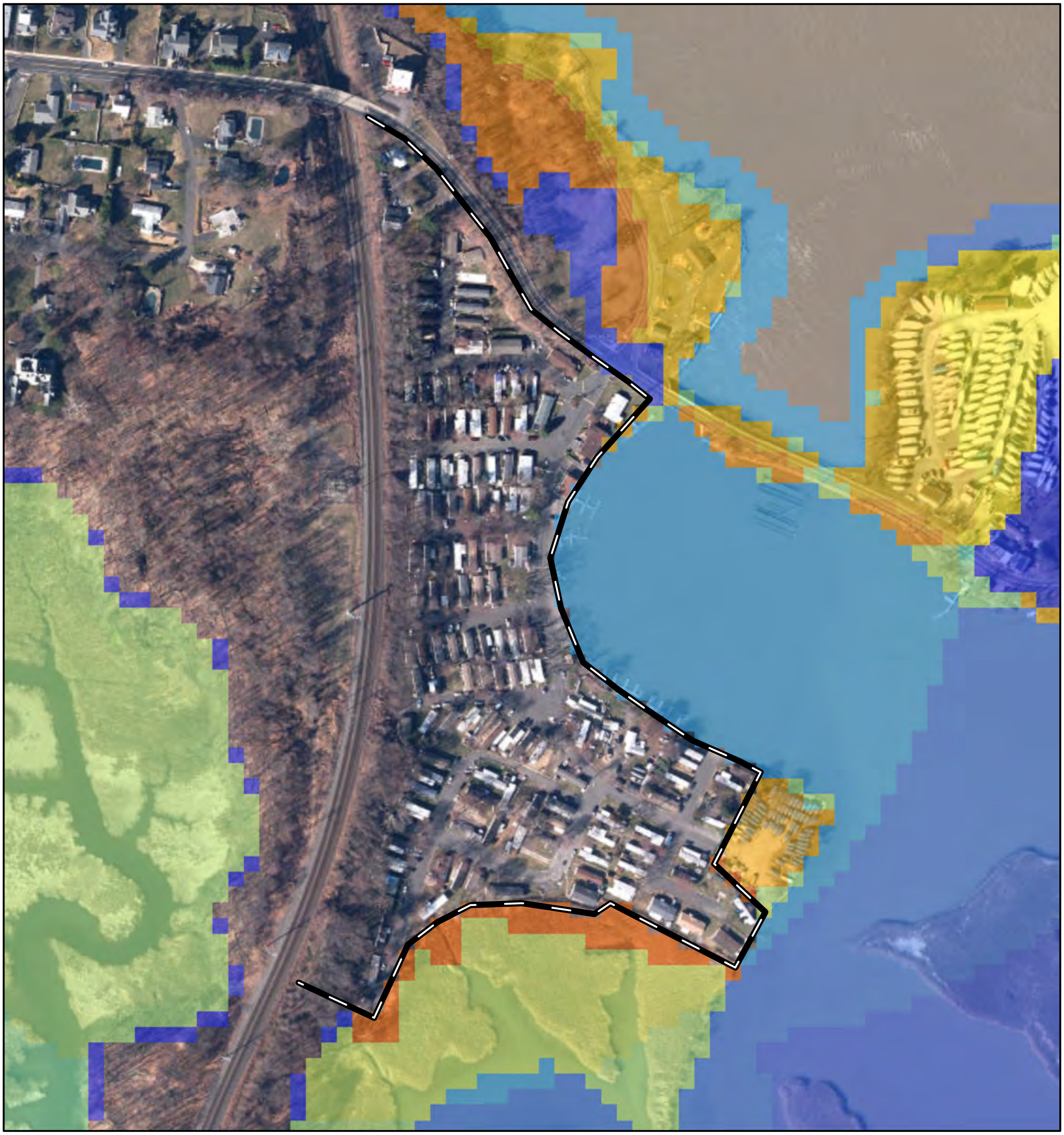
Future Without-Project Risk
Feature:
Stony Point SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL



US Army Corps of Engineers
New York District

Figure 39
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk Feature: Stony Point SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N
W
E
S

0 120 240 360 480 600 Feet

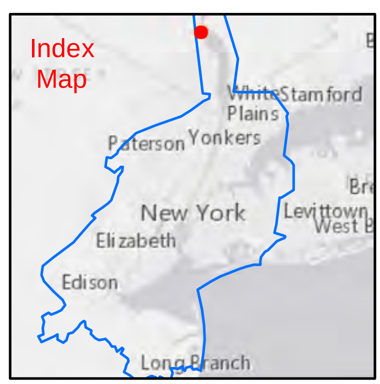
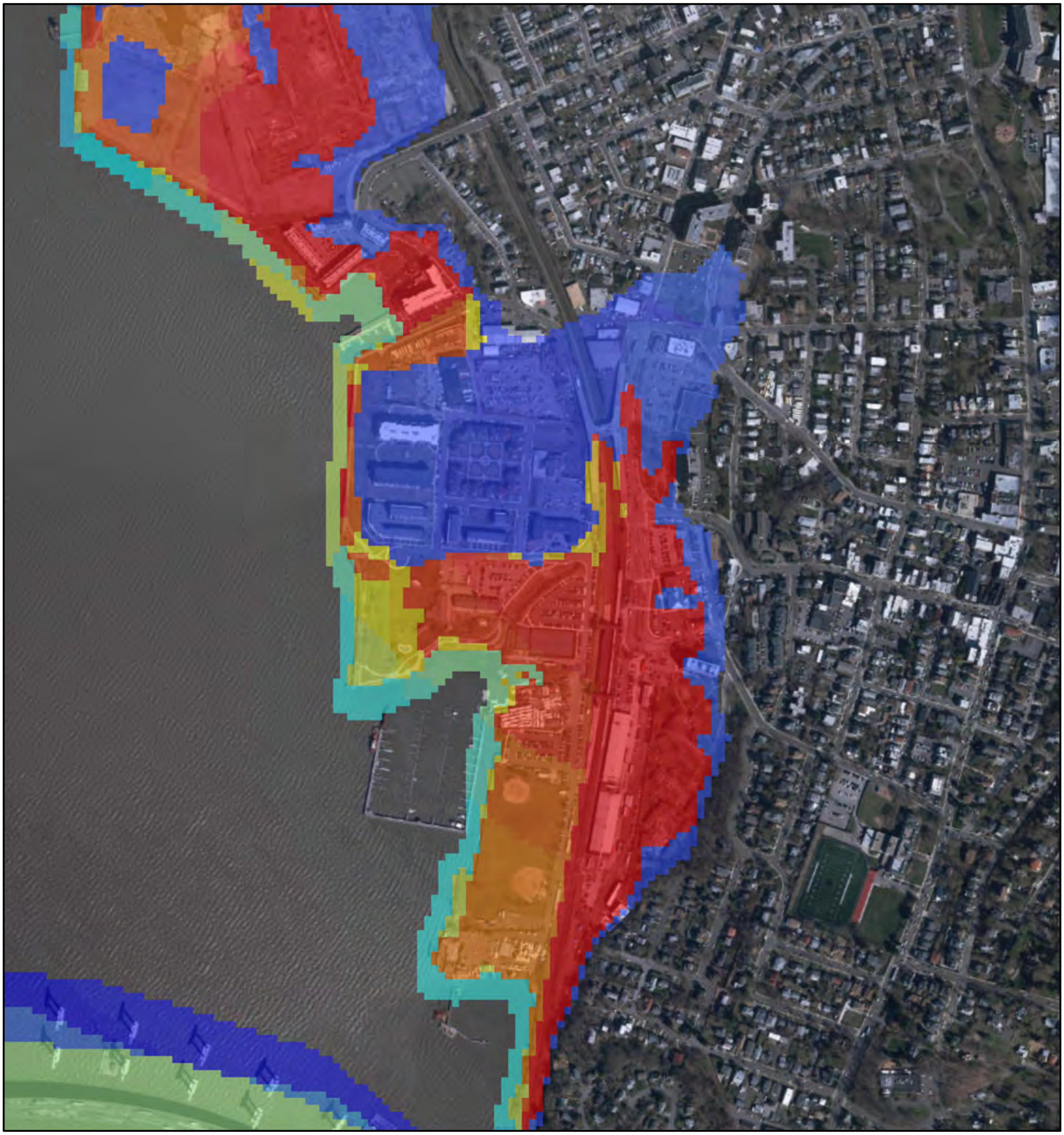


Figure 40
NYNJHATS Enhanced Tier 2 GIS Analysis - Report Addendum



Risk

High : 100

Low : 0

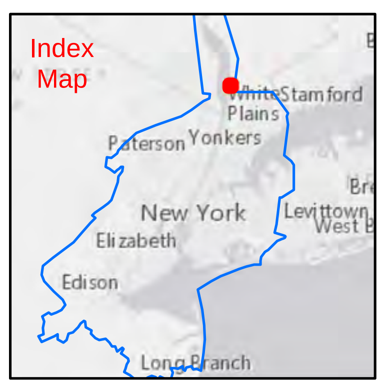
New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Tarrytown SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 260 520 780 1,040 1,300
Feet

N
W E
S



US Army Corps
of Engineers
New York District

Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Tarrytown SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

N W E S

0 260 520 780 1,040 1,300 Feet

Risk

High : 100

Low : 0

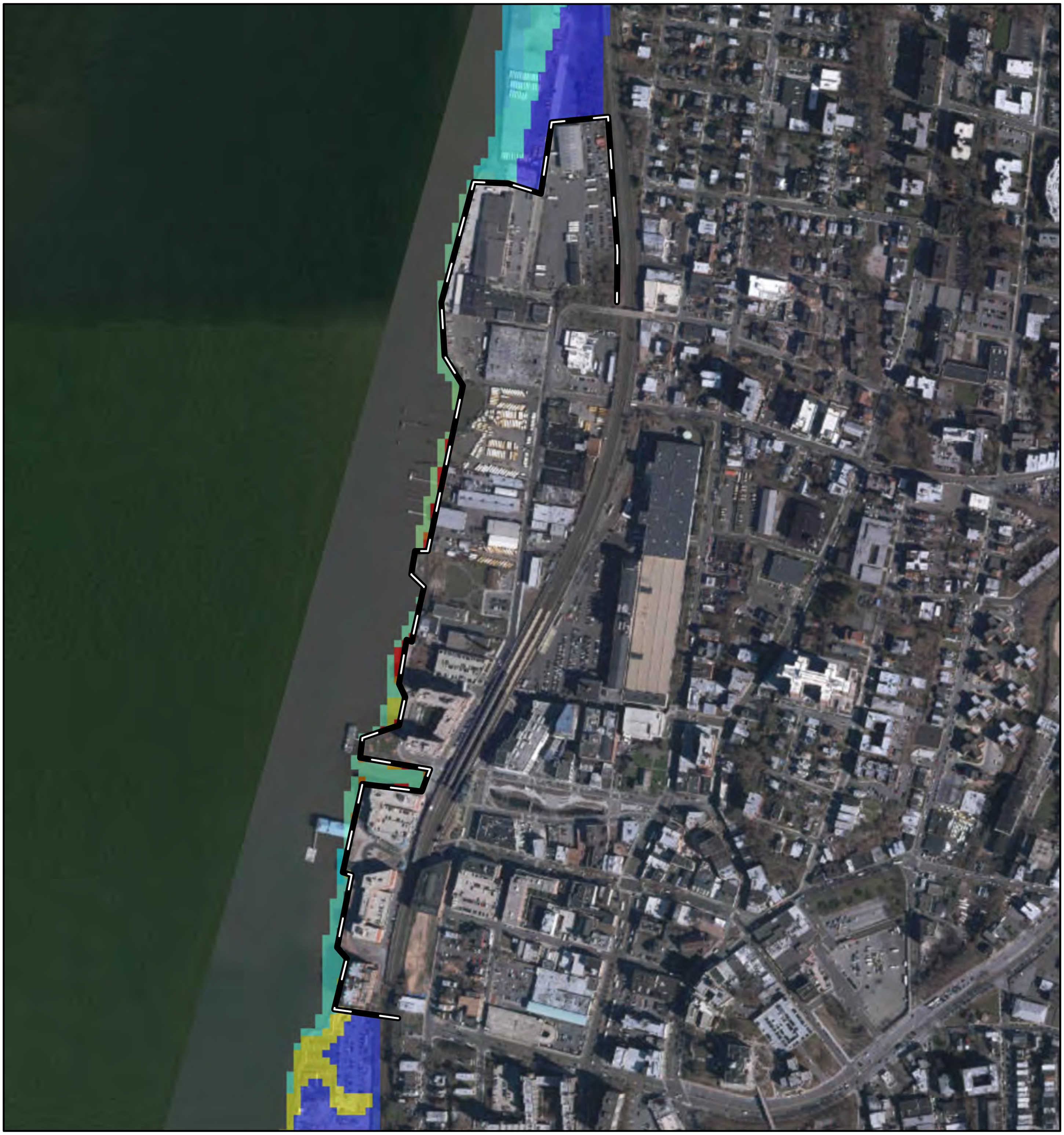
New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Yonkers North SBM

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 260 520 780 1,040 1,300 Feet



Risk

High : 100

Low : 0

Feature Alignment

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Yonkers North SBM

N
W E
S

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 260 520 780 1,040 1,300
Feet

Risk

High : 100

Low : 0

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future Without-Project Risk
Feature:
Yonkers South SBM

US Army Corps of Engineers
New York District

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 290 580 870 1,160 1,450 Feet

N S E W

Risk

High : 100

Low : 0

Feature Alignment

US Army Corps of Engineers
New York District

New York/New Jersey Harbor & Tributaries Study
Enhanced Tier 2 GIS Risk Analysis - Option 2

Future With-Project Risk
Feature:
Yonkers South SBM

0.01 Annual Exceedance Probability
(100-yr floodplain) +3 feet
ADCIRC - 95% CL

0 290 580 870 1,160 1,450 Feet