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Analysis of Future Floodplains in New York State

Final Report

May 2016

Report Number 16-18

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Analysis of Future Floodplains in New York State

Final Report

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NYSERDA Report 16-18 NYSERDA Contract 28259 May 2016

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Abstract

This effort produced mapping information to depict the changes to the extent of coastal flood hazards in response to projected sea level rise (SLR) scenarios of 12, 18, 24, 36, 48, 60, and 72 inches. The study included the tidally influenced shorelines of New York State, including Nassau, Suffolk, and Westchester Counties, as well as the Hudson Valley to the Troy Dam. New York City shorelines were not included in this effort.

Coastal flood hazard mapping for future conditions was produced for the 10%, 2%, 1%, and 0.2% annual chance flood elevations under each SLR scenario. These are also commonly referred to as the 10-year, 50-year, 100-year, and 500-year return period elevations for coastal flooding. Maps were also produced for each scenario to represent the approximate landward extent of moderate wave hazards. These layers depict areas where waves over 1.5 ft may propagate during an event similar to the 1% annual chance event. Additional products include coverages depicting the relative flood probability for each SLR scenario and counts of exposed buildings where supporting data was available.

Keywords

New York State, sea level rise, floodplain, mapping

Acknowledgments

The authors would like to recognize the individual contributions of staff members who assisted in the completion of this effort, including James Bryant, Jr., Krista Rand, Zack Roehr, Stephen Sanchagrin, and Ryan Towell. Special thanks to Joel Plummer for his role in quality control and assembling the final products for delivery. We extend our appreciation to Nadia Dawson for the editing of this document.

We would also like to acknowledge the Project Advisory Committee for its participation and guidance throughout the execution of the study effort:

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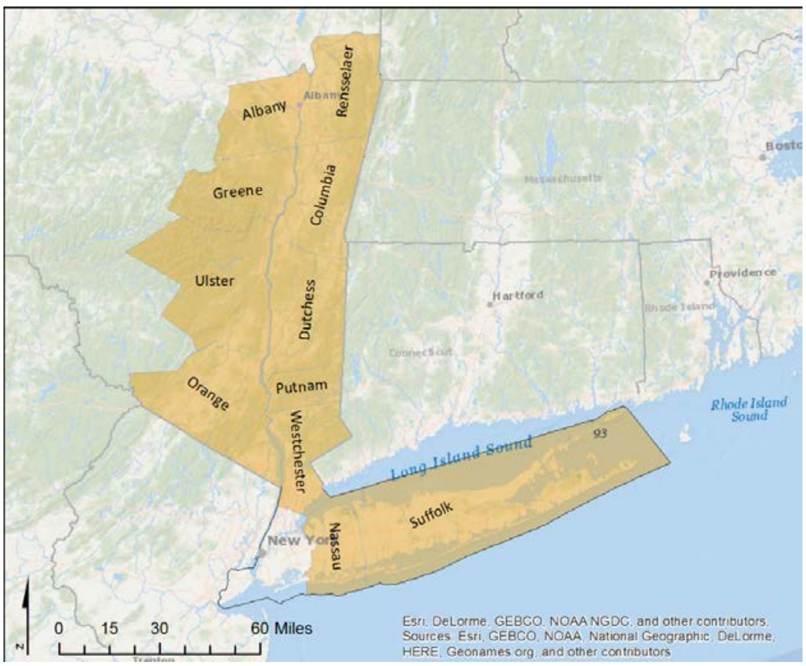
Acronyms and Abbreviations

2D	Two-dimensional
ADCIRC	ADvanced CIRCulation model for Oceanic, Coastal and Estuarine Waters
ASCE	American Society of Civil Engineers
BFE	Base Flood Elevation
CHAMP	Coastal Hazard Analysis Modeling Program
cm	Centimeters
DEM	Digital Elevation Model
FIRM	Flood Insurance Rate Map
DL	Depth-limited calculation of breaking wave heights
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
ft	Feet
ft^2	Square feet
GIS	Geographic Information System
in	Inches
LiDAR	Light Detection and Ranging
LiMWA	Limit of Moderate Wave Action
m	Meters
MOWA	Area of Moderate Wave Action
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSERDA	New York State Energy Research and Development Authority
PAC	Project Advisory Committee
PFD	Primary Frontal Dune
RAMPP	Risk Assessment, Mapping, and Planning Partners
SFHA	Special Flood Hazard Area
SLR	Sea level rise
SWAN	Simulating Waves Nearshore two-dimensional wave model
TSDN	Technical Study Data Notebook
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator coordinate system
WHAFIS	Wave Height Analysis for Flood Insurance Studies model
WSEL	Water Surface Elevation Model

1 Project Overview

This effort produced mapping information to depict the changes to the extent of coastal flood hazards in response to projected sea level rise (SLR) scenarios of 12, 18, 24, 36, 48, 60, and 72 inches (in). The study included the tidally influenced shorelines of New York State (NYS), including Nassau, Suffolk, and Westchester Counties, as well as the Hudson Valley to the Troy Dam (Figure 1). New York City shorelines were not included in this effort.

Figure 1. New York State Counties Included in the Study Area



Coastal flood hazard mapping for future conditions was produced for the 10%, 2%, 1%, and 0.2% annual chance flood elevations. These are also commonly referred to as the 10-year, 50-year, 100-year, and 500-year return period elevations for coastal flooding. The 1% annual chance floodplain defines the regulatory boundary of the Federal Emergency Management Agency's (FEMA) Special Flood Hazard Area (SFHA). Mapping was also produced for each scenario to represent the approximate landward extent of moderate wave hazards. These layers depict areas where waves over 1.5 ft may propagate during an event similar in nature to the 1% annual chance event. Such wave conditions have been shown to result in structural damage to residential homes and may be proactively managed with higher building standards to reduce storm damage. Additional products include coverages depicting the relative flood probability for each scenario and counts of exposed buildings where supporting data was available. A summary of study products, their intended use, and limitations is provided in the following section.

1.1 Study Products

1.1.1 Topographic Elevation Models

Description: Digital elevation model (DEM) of topographic elevations. Derived from best-available data in each geography of the study area. The majority of the study area was represented by a high-resolution, high-accuracy topographic DEM derived from a 2012 Light Detection and Ranging (LiDAR) survey of coastal zone elevations by the New York State Department of Environmental Conservation (NYSDEC). This coverage provided 1 meter (m), or 3.28 feet (ft), horizontal resolution with a vertical accuracy of 5.1 centimeters (cm).

Use: To derive floodplain extents and/or flood depths when assessed against a water surface elevation model (WSEL).

Limitations: NYSDEC coverage did not cover the full extent of the future floodplain in some areas in Nassau and Suffolk Counties. In these cases, study topography was supplemented by data available from recent FEMA Flood Insurance Studies (FISs). All topographic data used in study analyses were collected prior to Hurricane Sandy. Some sections of the coast composed of unconsolidated bluffs may have experienced erosion that is not represented by this topography, and as such, floodplain extents may underestimate future change. The topographic digital elevation model (DEM) is static and does not represent potential changes to the landscape for future conditions corresponding with the timing of the SLR scenarios.

1.1.2 Water Surface Elevation Models

Description: Digital elevation model of the coastal storm surge water surface elevation for the 10%, 2%, 1%, and 0.2% annual chance flood frequencies sourced from FEMA FISs across the project area. A separate file was developed for each SLR scenario and flood frequency. SLR scenarios were added to the existing flood elevations, then the surfaces were extended landward if the existing data extent did not reach the new floodplain boundary. Wave setup is only included for the 1% annual chance surfaces, as FEMA guidelines and methodologies did not specify calculation of wave setup for non-regulatory flood frequencies at the time the supporting FISs were completed.

Use: To derive floodplain extents when assessed against a topographic DEM. May also be used as a source of water surface elevations for depth-damage analysis or to derive depth grids.

Limitations: The baseline flood elevation surfaces were created from FEMA FISs. These surfaces were derived from statistical analysis of observations or modeling of extreme water levels based on historical events. These surfaces were simply raised to implement future conditions representing increased sea level. Dynamic changes to flow hydraulics due to the increased water levels, potential changes in tropical and extratropical storm climatology, and/or changes in the coastal landscape are not represented by this product.

1.1.3 Floodplain Coverages

Description: Vector polygons of the 10%, 2%, 1%, and 0.2% annual chance flood frequencies. Sourced from geospatial modeling of WSELs against the study Topographic Elevation Models. Coverages were post-processed to remove processing artifacts and to smooth boundary edges. Disconnected areas shown as flooded in the raw output were retained or removed as deemed reasonable by a visual hydraulic connectivity analysis using topography and aerial photography. A separate coverage was created for each SLR scenario and flood frequency.

Use: To identify the spatial extent of flood waters for each flood frequency and SLR scenario. Can be used to identify vulnerable assets that were processed against such data.

Limitations: Boundaries assume a static landscape for future conditions. Natural and anthropogenic responses to SLR that may alter the future landscape are not represented by this product.

1.1.4 Percent Chance of Flooding

Description: Gridded spatial coverages that provide values for the annual and 30-year percent chance of flooding. Coverages are based on the extent of the 10%, 2%, 1%, and 0.2% annual chance flood frequencies.

Use: Communication of the relative change in the percent chance of flooding for locations within the floodplain. Supports risk analysis and prioritization of areas and of structures for hazard mitigation.

Limitations: Values are independent of the likelihood of SLR and only represent the increased chance of flooding at a location due to the increased water level and associated probability of that flood event based on historical climatology (i.e., not accounting for any potential changes in storm frequency and/or intensity under future climate change).

1.1.5 Extent of Structurally Damaging Wave Action

Description: Vector polygons that represent the landward extent of flood depths associated with the 1% annual chance flood elevation that support a wave height that would result in structural damage to residential development. This polygon includes both Zone VE (wave heights greater than 3 ft) and the Coastal A Zone (wave heights from 1.5 to 3 ft). The landward edge of this area is known in FEMA parlance as the Limit of Moderate Wave Action (LiMWA). Derived from spatially variable flood depth values determined from post-analysis of FIS wave hazard modeling.

Use: Identification of areas and/or structures that may be subject to structural damage in response to future increases in wave action. Proactive management of construction requirements to FEMA high hazard zone (Zone VE) standards may help reduce long-term losses in these areas. This polygon corresponds with the "coastal risk management zone" as identified in the 2010 New York State Sea Level Rise Task Force (NYS SLRTF) Report.

Limitations: Detailed modeling and mapping of the LiMWA were not feasible under the project scope. Coverages were derived from representative depths across relatively large geographies. This methodology was shown to provide a reasonably accurate representation of the existing LiMWA location with the exception of heavily developed residential areas. In such areas, the product tends to under-represent wave attenuation and, therefore, over-represent the hazard area.

1.1.6 Vulnerable Buildings

Description: Vector polygons representing locations of building footprints attributed with vulnerability to each flood frequency, LiMWA, and SLR scenario combination considered by the study. Building footprints were available for Dutchess, Nassau, Orange, Rockland, Suffolk, and Westchester counties.

Use: Provides data on the relative exposure of building assets in terms of count and geo-location for each county in the study area.

Limitations: Represents only whether the building is in or out of the extent of the particular hazard and flood scenario. Some structures may be elevated over the flood condition; however, available data attributes such as first floor elevation were not available. In such cases, outlying structures and property remain subject to flooding and justify "vulnerable" classification.

2 Topographic Data Processing

2.1 Description and Acquisition

The base topography for the study effort was LiDAR-derived DEMs supplied by NYSDEC. NYSDEC and the National Oceanic and Atmospheric Administration (NOAA) collected these data in 2012 as a project to deliver topographic point elevation data derived from multiple return LiDAR measurements for the areas of coastal New York, including Long Island, eastern Westchester, and the tidal extents of the Hudson.

The project area for this NYSERDA study consists of areas along the Hudson River, Westchester, and Long Island (see Figure 2). Data for this project area were downloaded as individual DEM tiles from the NYS Orthos Online webpage (http://www.orthos.dhses.ny.gov). Each of these DEM tiles were in NAD83(NSRS2007) Universal Transverse Mercator coordinate system (UTM) Zone 18N coordinates, with the vertical datum referenced to North American Vertical Datum of 1988 (NAVD88). All associated units were in meters. The data set meets a horizontal accuracy of 50 cm and a vertical accuracy root mean square error of 5.1 cm with a 1.0 m ground sampling distance.

Figure 2. Footprint of LiDAR Topographic Base Data Supporting Study Analysis

2.2 Processing

Subsequent to retrieval, all individual DEM tiles were loaded into ArcGIS to ensure proper file integrity and completeness. After these initial checks were completed, two processing steps were performed on the topography in support of project needs:

1. Mosaicking the tiles into two continuous DEMs—one for the Hudson River and the other covering Westchester, Nassau, and Suffolk counties.
2. Converting the vertical units from meters to feet using a factor of 3.2808.

The vertical unit conversion from metric to standard units was undertaken to make the data compatible with FEMA flood hazard data. All operations enforced an environmental geoprocessing setting to snap raster to the original cell orientation of the delivered DEM tiles. This setting ensured that DEM cell locations remained constant as well as prevented re-interpolation of cell elevation values with neighbors during the geoprocessing operations.

2.3 Quality Control

A quality control review was performed on the final mosaicked topographic data sets to ensure that the data were free of significant artifacts and/or errors that would be detrimental to the quality of the study end products.

The quality control review consisted of the following checks:

1. Data Gaps and Voids: Visual review of dataset and use of hill shade to help identify apparent gaps in data. Limited to those larger than expected from bare earth processing.
2. Large Areas of Interpolation: Visual review to identify any locations where data have been triangulated and interpolated where actual ground elevations should be present. Interpolation over water areas acceptable.
3. Elevation Anomalies: Visual review to identify any anomalous elevations within dataset. Would include elevation spikes and wells, discontinuities, etc.
4. Edge Artifacts: Visual review to ensure that the elevation surface is not stair-stepped at tile joins or between LiDAR flight lines. This ensures that all data were captured and processed in a consistent manner.

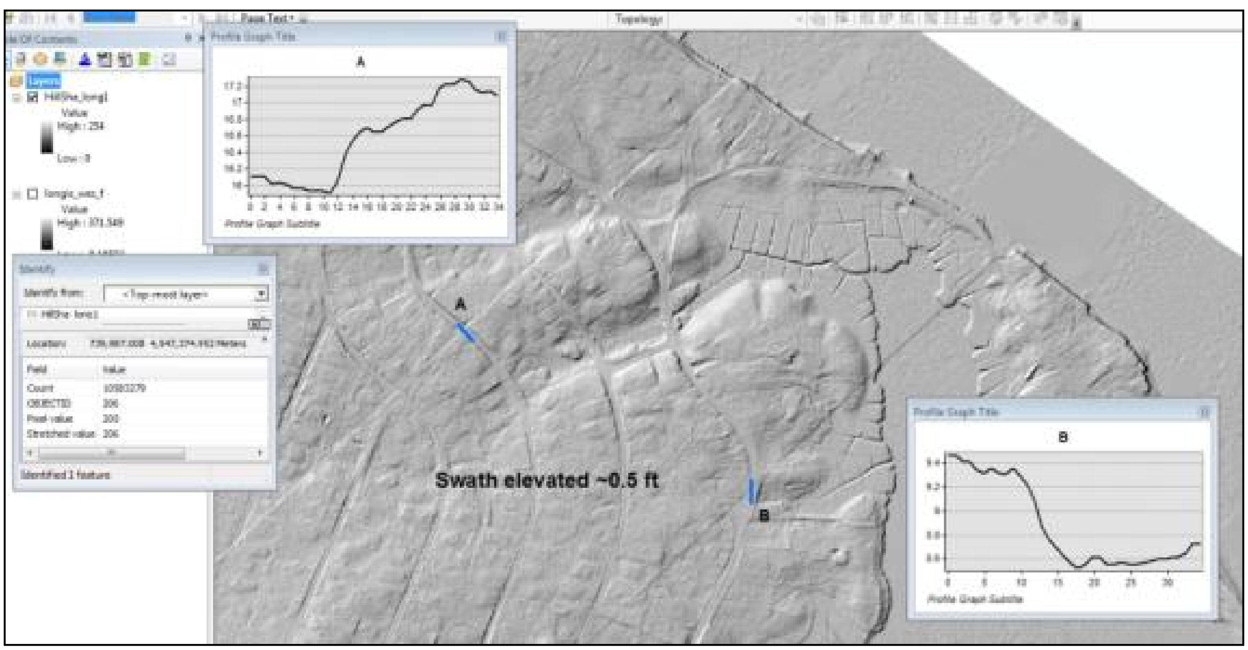
2.4 DEM Quality Issues

Although the Hudson Valley elevation data were found to be suitable for analysis, issues were identified in two areas of Suffolk County. In both cases, linear discontinuities were visible within the data set. Such issues can occur at the edge of LiDAR flight lines and are apparent as a “stair-step” or linear elevation drop across the surface of the DEM (Figure 3). These quality issues were raised to the attention of the data originator in July 2013, and revised data were received in October 2013.

The revised LiDAR tiles were incorporated into the previously established continuous DEM of Westchester, Nassau, and Suffolk Counties. The revised tiles were reviewed to ensure the noted issues were addressed. Vertical units were converted to feet in a consistent manner as the previous processing. The tiles were then mosaicked into the pre-existing surface, and a final quality review was performed to check for any edge discontinuities between original and revised data sets.

Figure 3. Example of Linear Discontinuity in LiDAR Topography

In this case located in Suffolk County, a swath of LiDAR was elevated 0.5 ft above the adjacent ground surface.



3 Sea Level Rise Scenarios

Initially, five SLR scenarios were identified to provide representation of the range of future conditions identified for the State in the ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State Final Report (NYSERDA 2011). Readers are encouraged to access the ClimAID documents for background information regarding the process and underlying assumptions in establishing the future SLR conditions used for this project.

The ClimAID Report presents ranges in the 2020s, 2050s, and 2080s for two regions across the tidally influenced geography of the state for conditions with and without rapid ice-melt (Figure 4). These projections were the source scenario values available to the study team at the initiation of the SLR mapping effort.

SLR projections are subject to change due to evolving scientific understanding of the forcing factors driving sea level change and the modeling process to assimilate the forcing factors into potential future conditions. Given this, as well as the general uncertainty in the range of projections, it is not advisable to use specific values for mapping purposes. The use of simpler, representative values for mapping scenarios helps address the uncertainty and provides a longer useful life of the mapping products in the face of changing SLR projections.

A representative value was needed for each range of SLR projections shown in Figure 4. The values were simplified by averaging and rounding the values presented for each time range of the two ice melt scenarios (Table 1). Next, the values were further simplified to the nearest half-foot value (Table 2).

Figure 4. ClimAID SLR Scenarios

Source: ClimAID – see source document (NYSERDA 2011) for further information.

Region 4: New York City and Long Island	2020s (inches)	2050s (inches)	2080s (inches)
GCM-based[1]	+2 to +5	+7 to +12	+12 to +23
Rapid ice-melt scenario[2]	~5 to +10	~19 to +29	~41 to +55
Region 5: East Hudson and Mohawk River Valleys	**2020s (inches)**	**2050s (inches)**	**2080s (inches)**
GCM-based[1]	+1 to +4	+5 to +9	+8 to +18
Rapid ice-melt scenario[2]	~4 to +9	~17 to +26	~37 to +50

1 Shown is the central range (middle 67%) of values from global climate model-based probabilities rounded to the nearest inch.

2 The rapid-ice melt scenario is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic Ice sheets and paleoclimate studies.

Table 1. Simplified ClimAID SLR Projection Values

Units are inches.

Lower Hudson and Long Island	2020s	2050s	2080s
SLR	4	10	18
SLR and rapid ice melt	8	24	48
Mid-Hudson Valley and Capital Region	**2020s**	**2050s**	**2080s**
SLR	3	7	13
SLR and rapid ice melt	7	22	44

Table 2. Further Simplified ClimAID SLR Projections

Further simplified into half-foot values, units of inches.

Lower Hudson and Long Island	2020s	2050s	2080s
SLR	6	12	18
SLR and rapid ice melt	6	24	48
Mid-Hudson Valley and Capital Region	**2020s**	**2050s**	**2080s**
SLR	6	6	12
SLR and rapid ice melt	6	24	48

The half-foot values were then broken out as the SLR scenarios for the mapping effort. Discussion with the Project Advisory Committee (PAC) called for two adjustments: 1) the 6 in scenario was dropped due to concerns about the negligible increment over existing conditions; and 2) a 36 in scenario was added to provide an incremental value between the 24 in and 48 in scenarios.

Updated SLR projections were published after the initial scenario selection production effort of this project. The 2014 update (NYSERDA 2014) provided projections for three locations, including Montauk Point (Long Island), New York City, and the Troy Dam (Hudson Valley). Values were presented as percentiles and include a low estimate (10th percentile), middle estimate (25th to 75th percentile), and high estimate (90th percentile). Review of those values against the 2011 SLR projections found that the ranges are essentially the same, with a slight upward adjustment of 1–4 inches in some cases. The mapping data produced by this project fully cover the middle estimate projections for Long Island and the Hudson Valley (3–50 in).

The 2014 update also includes additional projections for the 2100 time horizon as upper bound scenarios for the 2080 and 2100 time horizons (54 in and 71 in, respectively). Representative SLR scenarios of 60 and 72 in were added to the scope so that mapping products would represent a full range of data for the ClimAID projections. The final SLR mapping scenarios used in this project are presented in Table 3.

Table 3. Final SLR Scenarios for the Future Floodplain Mapping Effort

Representative Scenario	in	ft
1	12	1
2	18	1.5
3	24	2
4	36	3
5	48	4
6	60	5
7	72	6

4 Existing Flood Hazard Data

4.1 Flood Hazard Definition

The base flood hazard extent for this study was defined in accord with the FEMA floodplain designations. The primary flood hazard areas assessed for potential future SLR conditions were the 1% and 0.2% annual chance floods. The 1% annual chance floodplain is the area that will be inundated by the flood event having a 1% chance of being equaled or exceeded in any given year, which is commonly referred to as the base flood or 100-year flood. Likewise, the 0.2% condition defines an area with a 0.2% chance of being flooded in a given year, which is also referred to as the 500-year flood. The 1% condition defines the SFHA that is delineated on FEMA Flood Insurance Rate Maps (FIRMs).

The study effort also considered the 10% and 2% annual chance flood conditions, which are equivalent to the 10-year and 50-year floodplains, respectively. These elevations and flood hazard areas are not regulatory, but are produced through the FIS process and are necessary to calculate flood probability, a product of this effort. The 10-year floodplain is a significant metric, as properties within the 10% annual chance floodplain have a much higher flood risk than those in the 1% floodplain. Such properties are often subject to repetitive losses and targeted for flood mitigation efforts. Other studies on floodplain evolution with SLR have shown that growth of the 10% annual chance floodplain can be much greater than the 1% floodplain, due to elevation gradients at the edge of the existing flood hazard area.

4.2 Data Sources

The study area encompassed a large geography, which necessitated acquisition of existing flood hazard data from several sources. Ongoing FIS updates in the area required coordination with FEMA study contractor Risk Assessment, Mapping, and Planning Partners (RAMPP) to ensure the best and most up-to-date data resources were used in the study effort. Data sources and descriptions of the underlying analyses are provided for each sub-geography discussed in the following sections.

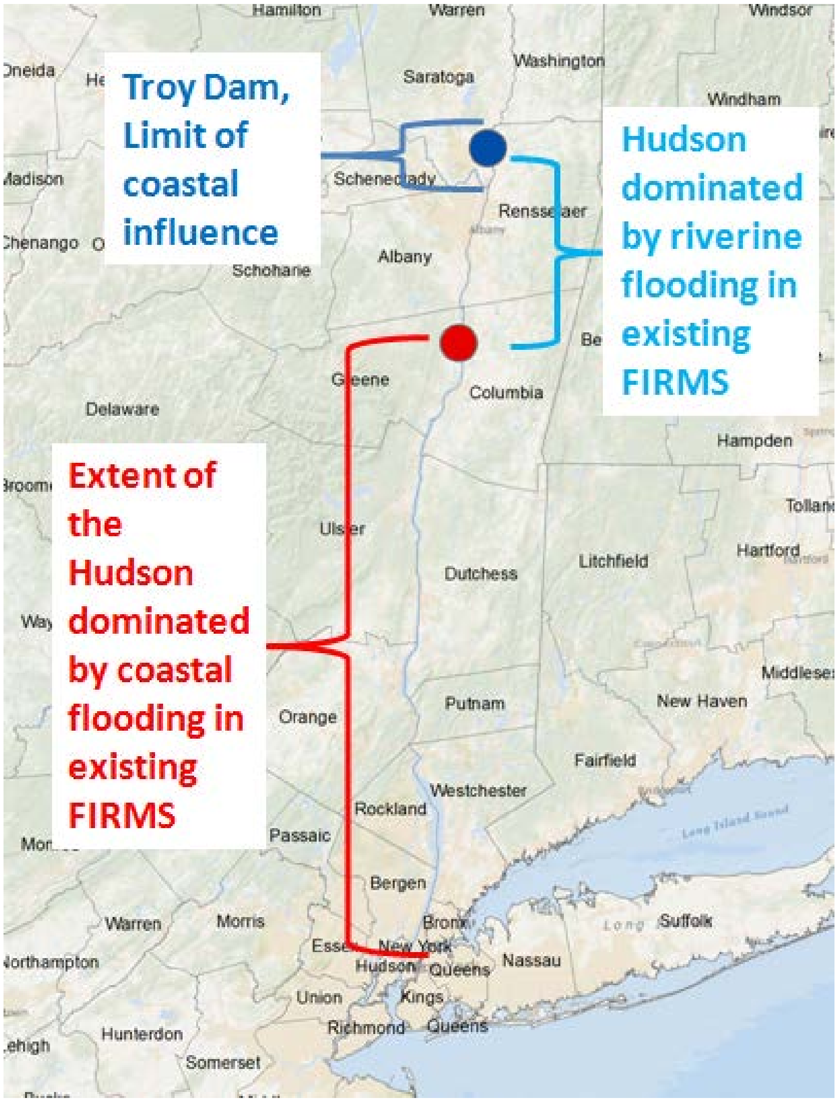
4.2.1 Hudson Valley

The Hudson Valley was defined as all counties above the New York City area to the Troy dam. These counties include Westchester, Putnam, Dutchess, Columbia, Rensselaer, Albany, Greene, Ulster, Orange, and Rockland. Flood hazard information for this area was available from two sources: 1) existing FEMA FISs and 2) a FEMA update of base flood elevations (BFEs) throughout the New York Bight, Hudson River Valley, and New Jersey area completed in 2012. The 2012 update of the base flood was chosen for use in the Hudson Valley over existing FIS information, as it represented the most up-to-date analysis. The 2012 data will supersede the existing coastal flood hazard information in the FIRMs along the Hudson Valley as they are updated by FEMA in the future. Such an update is already underway in Westchester County.

The 2012 FEMA coastal storm surge modeling study (FEMA 2013a) was composed of a numerical modeling effort using the two-dimensional (2D) ADvanced CIRCulation (ADCIRC) model for oceanic, coastal, and estuarine waters and the Simulating Waves Nearshore (SWAN) 2D wave model. A series of 159 hurricanes and 60 extratropical synthetic storm events were simulated in the framework, and resulting surge elevation input into the Joint Probability Method for statistical analysis and calculation of the annual chance flood elevations. These data have not yet been incorporated into the FEMA flood hazard analysis for the counties, but represent the best available information for the coastal flood hazard along the Hudson Valley shoreline.

Assessment of changes to the riverine floodplain were outside the scope of this effort; products from this effort represent the floodplain as controlled by coastal flood sources only. Coastal storm surge driven flooding dominates the majority of the Hudson River south of the Troy Dam. Review of existing FIRMs in the study area indicated that the dominant flood hazard shifts from coastal to riverine sources toward the northern boundary of Greene County (Figure 5). The contribution of the riverine flooding must be separated from the coastal influence north of this location to properly reflect how SLR may affect flood elevations and floodplain extents. The riverine-based flooding and associated BFEs are controlled by extreme precipitation and runoff. Although climate change and future land development is projected to alter these parameters, such aspects are independent of relative changes in sea level. The riverine flood hazard process and resultant flood elevations would not be changed by relative SLR alone; however, coastal flooding would potentially dominate farther upstream than at the present time. Users should also review the riverine data when evaluating the full extent of the floodplain upstream of Green County.

Figure 5. Dominant Flood Sources Along the Hudson River



4.2.2 Westchester County – Long Island Sound Shoreline

The effective FIRMs for the Long Island Sound shoreline of Westchester County are based off of coastal flood elevations derived from a 1982 study of tidal flood profiles in Long Island Sound (FEMA 2007a). An update of the coastal flood hazard mapping was initiated by FEMA in 2013. Coastal flood hazard information for this effort will be sourced from the 2012 FEMA coastal storm surge modeling study previously discussed in the Hudson Valley section. Flood elevation surfaces were directly sourced from the study contractor for the Westchester FIS update for use in the future floodplain mapping effort.

Wave setup is included in surge elevation surface for Westchester County. Starting conditions for the overland wave hazard modeling were statistically derived from the 2D wave model outputs.

4.2.3 Nassau and Suffolk Counties

The existing FIS coastal flood hazard data for Nassau and Suffolk Counties were derived from two sources. Storm surge elevations for the south shore of the counties were calculated based on numerical modeling as part of a baseline stage frequency analysis completed by the U.S. Army Corps of Engineers (USACE) Fire Island to Montauk Point Reformulation Study (USACE 2006). The USACE analysis involved 2D numerical modeling using the ADCIRC and Delft3D hydrodynamic models. A selection of historical storms were simulated through the framework, including 14 tropical and 22 extratropical events. Return period elevations were calculated from the model output using the Empirical Simulation Technique. A limited portion of Nassau County received an update to surge stillwater elevations in 2012. Coastal flood elevations and floodplain extents along the western county boundary, with coastal flooding sourced from Jamaica Bay, were updated with the 2012 FEMA surge modeling study through a Letter of Map Revision.

Surge elevations along the north shore of both counties, including the eastern fork embayments from Orient Point to Montauk Point, were based on an update of pre-existing tidal gage analysis. A new gage analysis at the New London, CT, NOAA water level station was conducted to update the existing analysis. Differences between the old and updated values were applied across the study area to adjust the existing surge elevations to the extended period of record.

Starting conditions for overland wave modeling in Nassau and Suffolk Counties were calculated through different methods depending on whether the coastline had an open or restricted fetch (amount of open water over which wind can build waves). Open fetch wave conditions were calculated through analysis of significant wave heights at offshore Wave Information Study hindcast stations and a NOAA wave gage. Restricted fetch wave conditions were calculated through site-specific fetch analysis. Wave setup was calculated using empirical techniques following methods in the FEMA Guidelines and Specifications for Flood Hazard Mapping Partners (FEMA 2007b).

4.3 Data Preparation

Flood hazard data from each of the respective FISs were acquired and prepared for use in the future floodplain mapping effort. This process entailed accessing each FIS Technical Study Data Notebook (TSDN) and extracting the relevant data. The available data and amount of preparation varied by geography and flood information source. Specific details are provided in the following text.

In the Hudson Valley, the available storm surge elevation data from the FEMA Region II modeling effort were acquired from RAMPP. The data was relatively unprocessed and consisted of an Esri point shapefile attributed with the 10%, 2%, 1%, and 0.2% storm surge elevations, including wave setup. Data preparation for application to the NYS future floodplain analysis included the following:

- Quality control of flood elevations to identify and remove spurious values at each flood frequency.
- Reprojection of the data to the project coordinate system.
- Extrapolation of flood surface values beyond the floodplain boundary and creation of an ESRI raster surface elevation model of each “baseline” flood frequency.

For Westchester County, raster surface flood elevation models were sourced from the RAMPP FIS effort. These data were reprojected to the project datum; otherwise, no additional effort was required.

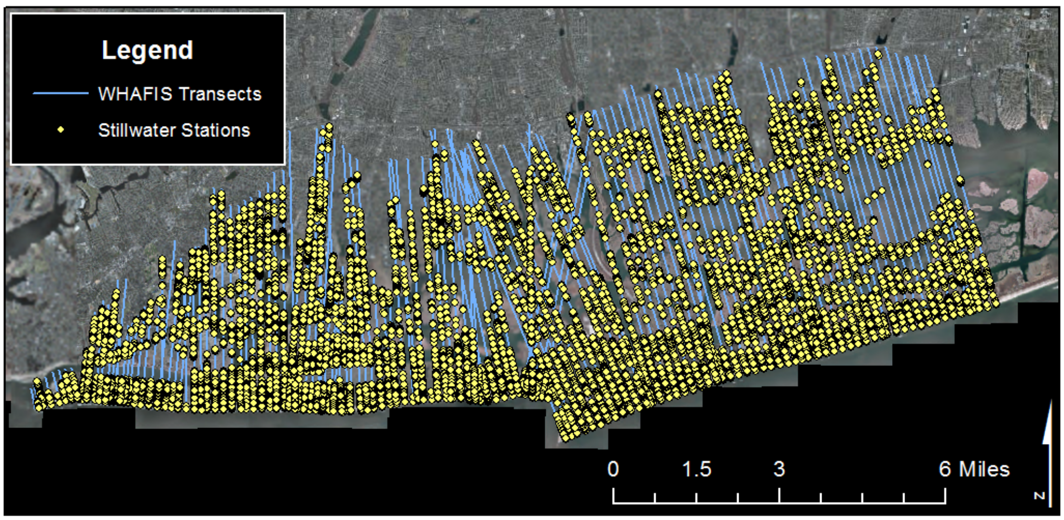
Flood elevation data in Nassau and Suffolk Counties were acquired from the FIS TSDNs. Flood surface elevation models were available; however, they did not include wave setup. At the time of the Nassau and Suffolk FISs, wave setup was calculated separately and implemented into the flood hazard mapping process through the overland wave modeling process using the Wave Height Analysis for Flood Insurance Studies (WHAFIS) model. Wave setup is an important component in determining floodplain boundaries, as it raises total water level and results in further land inundation. The WHAFIS model stores the wave setup and stillwater elevation data for the 1% annual chance condition at the transect level. It was necessary for the study application to extract the data for each transect (see Figure 6) from the database so that it could be included in the coastal flood WSELs. Given this detail, the data preparation workflow for Nassau and Suffolk Counties was as follows:

1. Compile WHAFIS transect and Coastal Hazard Analysis Modeling Program (CHAMP) database data from the TSDNs.
2. Extract the stillwater elevation table from each CHAMP database.
3. Extract WHAFIS stillwater and wave setup values to ESRI shapefile via a custom geographic information system (GIS) script.
4. Review extracted data and edit where needed to remove issues that would have been addressed during interpretation of results and final hazard mapping by the FIS coastal hazard analysts.
5. Surface the wave setup values.
6. Add the wave setup surface to the 1% annual chance surge stillwater surface to achieve full representation of total storm surge flood elevation.

The product of the above effort was the creation of storm surge surface elevation models for the 10%, 2%, 1%, and 0.2% annual chance elevations throughout the study area. These WSELs serve as the foundation for evaluating the changes to the floodplain and associated wave hazards. Surfaces for the Hudson Valley and Westchester County include representation of wave setup at all flood intervals; surfaces for Nassau and Suffolk Counties provide representation of wave setup only at the 1% annual chance condition. This limitation is a reflection of the older FIS methodology applied to determine coastal flood hazard conditions in Nassau and Suffolk Counties.

Figure 6. Example of WHAFIS Station Extraction

Wave setup values were extracted from the database and integrated into the stillwater surface elevation models to properly represent the total surge elevation. The example area along the south shore of Nassau County, NY, includes 145 transects and more than 20,000 stations.



5 Future Floodplain Analysis

5.1 Implementation of Sea Level Rise Conditions

The existing storm surge elevations were increased to include the study SLR scenarios through linear superposition, or simply adding the value of the SLR scenario to existing hazard information, i.e., *Existing Flood Elevation + SLR Scenario = SLR scenario flood elevation.* The SLR scenarios were incorporated into the WSELs compiled from the FEMA flood study data by a raster calculation in the GIS environment.

5.2 Floodplain Processing

Inundation and coastal flooding extents were established for each scenario and flood frequency by intersecting the WSEL raster surfaces with the topographic DEMs for each study geography. The process resulted in what is referred to as a "raw" polygon coverage representing the flood extent for each frequency. To provide the best representation of flood exposure, the raw flood extents were post-processed to remove small topographic artifacts and evaluate disconnected areas for hydraulic connectivity.

Raw floodplains were evaluated for full representation of the future flood extent. The existing condition WSELs were established to delineate current floodplains. In some cases, the data did not provide sufficient coverage to fully cover the floodplain increases resulting from the increased water level. When such issues were noted, the existing surfaces were extrapolated to ensure adequate coverage of the floodplain and conveyance of the appropriate flood elevation to the newly flooded areas.

5.3 Post-Processing

The raw flood extents were post-processed to improve their cartographic representation of the future floodplain. Automated post-processing for artifacts involved the removal of voids (relatively small unflooded areas surrounded by flooding) and islands (relatively small disconnected areas of flooding). Tolerances for voids and islands were evaluated and set at 22,500 and 40,000 square feet. The void tolerance was based on the desire to exclude un-inundated areas (such as the footprint of a large building and individual building footprint) less than 150 ft × 150 ft. Likewise, the island tolerance was based on the desire to remove insignificant disconnected areas less than 200 ft × 200 ft. After removal of the voids and islands, flood extent boundaries were smoothed with a tolerance of 20 ft.

To partially reflect the uncertainty in the topography and SLR flood conditions, tolerances for islands and voids were set at values higher than floodplain processing for FEMA FISs. Lower values would have resulted in over-specificity in terms of showing or not showing individual buildings or small areas in or out of the flood hazard area, which would not be suitable for SLR applications.

5.4 Hydraulic Connectivity

The next processing task involved removing disconnected areas of flooding. Such areas occur due to lack of hydraulic enforcement in the DEM, or the presence of culverts and/or underground drainage pathways. These types of features cause the flood polygon to be broken into pieces—areas disconnected from the main floodplain must be evaluated for hydraulic connection to provide the best approximation of the flood hazard area. This assessment was performed for all flood frequencies; however, the greatest scrutiny was placed on the 1% annual chance condition (the regulatory flood elevation).

Hydraulic connectivity was evaluated through a two-step process. First, an automated spatial query was executed to identify disconnected areas outside a given distance tolerance from the main flood area. The input tolerance represents the typical distance of disconnection caused by culverts under a four-lane road. Next, a visual review of each flood extent was completed by a flood hazard analyst to confirm or change the exclusion/inclusion of disconnected polygons flagged by the automated process. The visual assessment entailed reviewing disconnected areas against aerial photography and the topographic DEM to identify potential flood pathways, such as culverts or drainage pipes. Where such pathways were identified, the disconnected polygon was retained, otherwise the disconnected area was eliminated from the flood extent.

5.5 Topologic Enforcement

The geoprocessing operations and environmental parameters involved in the delineation of each floodplain may result in small variations in the floodplain boundary for similar flood elevations. These variations depend on the raster cell size of the DEM. For this study, the values would be expected to be on the order of 1–5 ft. Such variations can result in a lower flood condition flood extent being slightly larger than the higher condition, especially in areas with steep topographic gradients at the floodplain boundary.

Although such differences in boundary placement are negligible for cartographic purposes, they can accumulate over large geographic areas (as what are known as “slivers”) and influence assessments of changes in floodplain area. To eliminate such issues, a topological rule was enforced over the output floodplains. The rule, defined as “a higher frequency floodplain must have a smaller flood extent than a lower frequency floodplain,” was implemented by clipping flood extents down the frequency range. For example, prior to data finalization, the 1% annual chance condition flood extent would be clipped to the 0.2% condition extent to ensure that any dry areas during the 0.2% flood condition were also dry during the 1% condition. This approach also ensures consistency with removal of disconnected areas.

5.6 Percent Chance of Flooding

Probability or percent chance of flooding in a given period was calculated to show the potential for flood impacts at a given building within a single year, or 30-year period of time (equivalent to the standard home mortgage). For each scenario, these two values were calculated for all buildings within the 0.2% annual chance flood extent. The value was calculated by first determining the percent annual chance of flooding for each building by using the 0.2%, 1%, 2%, and 10% water surface elevations provided by FEMA, then interpolating the log-linear relationship between the associated flood elevations and the ground elevation within the 0.2% chance floodplain. Percent chance of flooding for each time interval was then calculated using the following relationship shown in Equation 1 (FEMA 2011b):

Equation 1 $$P_n = 1 - (1-p)^n$$

where:

- P_n is the percent chance of flooding for each time interval.
- p is the percent annual chance of flooding.
- n is the time period in years.

6 Extent of Structurally Damaging Wave Action

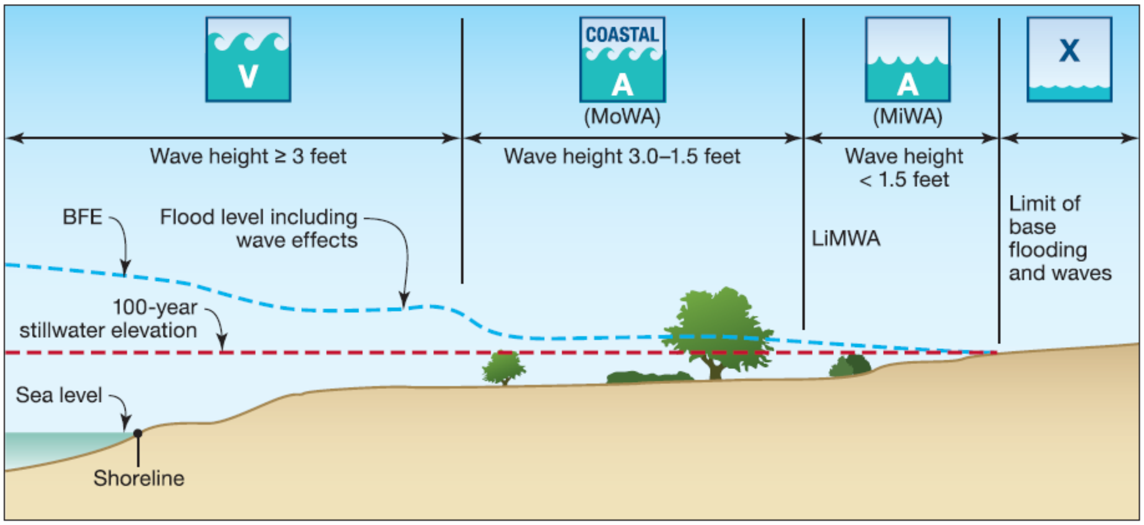
This effort established a polygon coverage depicting the extent of potential structurally damaging wave action for each SLR scenario. Flood risk is not equal across the coastal floodplain. Areas exposed to coastal flooding are subject to a combination of water inundation and wave impacts, depending on location. Research and post-disaster damage assessments have demonstrated that waves 1.5 ft or greater can cause significant damage to structures. In recognition of the risk of structural damage in areas subject to wave effects, the 2010 NYS SLRTF Report suggested the state define a new “coastal risk management zone,” which would include FEMA’s coastal high hazard zone and Areas of Moderate Wave Action.

Post-disaster assessments following Hurricanes Andrew, Opal, Ivan, Katrina, and Rita noted significant damage to properties and structures outside the designated FEMA coastal high hazard area (VE Zone, where predicted waves for the 1% annual chance event are 3 ft in height or greater). These assessments demonstrated that typical AE Zone construction techniques (e.g., wood-frame, light gauge steel, or masonry walls on shallow footings or slabs) are subject to damage when exposed to waves less than 3 ft in height (FEMA 2008). Additionally, full scale experiments in wave tanks have shown that walls designed for hurricane-strength winds consistently failed when subjected to 1.5 ft waves (Tung et al. 1999, Rogers 2001). In response, FEMA revised the Coastal Construction Manual in 2000 (FEMA 55) to recommend the use of VE Zone construction practices in areas subject to wave heights of 1.5 ft or greater. The 2006 and subsequent versions of the International Building Code reference the American Society of Civil Engineers (ASCE) Flood Resistant Design and Construction (ASCE 2005), which provides specific design requirements applicable to areas subject to waves greater than 1.5 ft.

The Area of Moderate Wave Action (MOWA), sometimes referred to as the “Coastal A Zone,” is defined by the FEMA Coastal Construction Manual (FEMA 2011a) as “the portion of the coastal SFHA referenced by building codes and standards, where base flood wave heights are between 1.5 and 3 ft, and where wave characteristics are deemed sufficient to damage many [National Flood Insurance Program]-compliant structures on shallow or solid wall foundations.” The Coastal A Zone includes areas landward of a V Zone or landward of an open coast without mapped V Zones (Figure 7). In a Coastal A Zone, the principal source of flooding is due to storm surge, astronomical tide, seiche, or tsunami, not riverine flooding.

Figure 7. Diagram Showing Coastal Hazard Zones

Source: From FEMA 2011a.



FEMA initiated mapping areas subject to moderate wave hazards within the coastal AE Zone during 2005 to assist with Hurricane Katrina recovery efforts. Subsequently, FEMA issued Procedure Memorandum 50 in December 2008, which required that all new coastal studies include the LiMWA on preliminary FIRMs and as an informational layer in the Flood Insurance Rate Map (FIRM) database. Inclusion of the LiMWA on the effective FIRM is recommended, but at the discretion of the community. Although communities are encouraged to adopt higher standards, FEMA does not impose floodplain management requirements or special insurance ratings based on properties or structures located within the MOWA.

6.1 Methodology

The study approach employed an approximate method to delineate the extent of the LiMWA for the future flooding conditions associated with each scenario. For a coastal FIS, the standard approach for determining the LiMWA is through the FEMA WHAFIS model. The locations of the beginning and end points for zones that designate the LiMWA location are extracted from the wave height information in the WHAFIS output file.

WHAFIS modeling is time-consuming. The effort here was focused on using geospatial modeling techniques to provide reasonably accurate estimates of the LiMWA location. Wave theory allows breaking wave heights to be defined in relation to water depth. Although criteria may vary depending on local topographic slope, the most accepted relationship for determining the depth-to-wave height ratio is shown in Equation 2:

Equation 2 $h_{b=0.78}/_{H_b}$

where:

- H_b is the height of the breaking wave.
- h_b is the limiting depth.
- 0.78 is coefficient of breaking.

The application of this relationship to the 1.5 ft wave results in a limiting depth of 1.9 ft. This approach, known as the depth-limited (DL) approximation, produces more conservative results than wave models such as WHAFIS. The methodology was used in the Hurricane Katrina recovery maps for Mississippi as well as Hurricane Sandy maps in New York and New Jersey, and has been successfully applied in many other areas of coastal engineering practice.

The DL approach tends to over-predict potential wave heights. In contrast to the WHAFIS model, the DL approach relies solely on depth-limiting relationships for breaking wave heights and does not consider wave attenuation by obstructions. The WHAFIS model considers obstructions, wave length, and wave regeneration in addition to the DL wave relationships. The inclusion of obstructions ensures that the wave conditions will realistically respond to obstacles as a wave propagates inland. The DL method calculates wave height based solely on depth; therefore, it will consistently over-predict wave conditions in areas with obstructions and become increasingly less accurate as obstruction density increases. At shallower depths, the depth to wave height ratio becomes a stronger controlling factor than obstructions. As such, waves calculated by the two methods in shallower depths will be more comparable, regardless of obstruction density.

This effort sought to improve the accuracy of approaches for delineated approximate LiMWA position. The LiMWA location can be geospatially modeled by creating a depth grid from the topographic and water surface elevations models, and then extracting the 1.9 ft depth contour. A sensitivity test was conducted to better inform the study on the relative accuracy of the DL-extracted LiMWA. The test assessed the WHAFIS-derived (modeled through FIS procedures) versus the DL-extracted LiMWA location for existing conditions, and SLR scenarios of 1, 2, and 4 ft. Results showed that, with the exception of steep areas, the DL-extracted LiMWA location over-predicted in the baseline and each of the SLR scenario conditions (Figure 8).

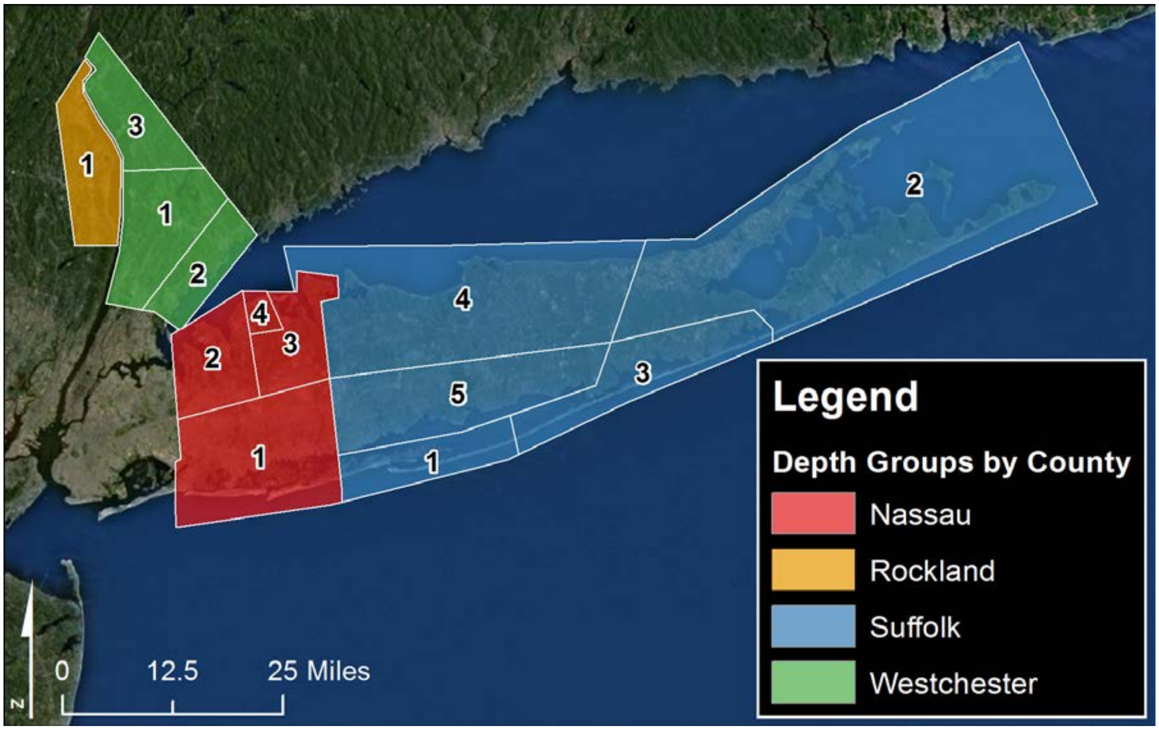
The WHAFIS-derived LiMWA includes additional considerations, primarily obstructions, in locating the limit of the 1.5 ft wave, which causes the depth to be greater than the theoretical limit. As the DL-extracted LiMWA lacks this information, it tends to over-predict the LiMWA location. Sampling of the actual depth can help "tune" the approximation by providing proxy inclusion of wave attenuation from obstructions. The difference between the WHAFIS and DL-extracted LiMWA location was assessed by sampling the depth of the WHAFIS-derived LiMWA at each WHAFIS modeling transect location. The averaged sampled depth in the test area was 2.5 ft, 0.6 ft deeper than the conservative estimate provided by the DL solution. Re-extraction of the contour at the 2.5 ft depth provided an improved fit to the modeled LiMWA line (Figure 9). Testing of the adjusted depth against the WHAFIS-modeled LiMWA for additional SLR conditions of +1, 2, and 4 ft continued to show improved agreement over the DL-extracted LiMWA.

Figure 8. Comparison of FIS LiMWA and DL-derived LiMWA at Test Location

Figure 9. FIS LiMWA and Adjusted Depth LiMWA at Test Location

Based on the initial success, the study team pursued further investigation into the spatial variability of the modeled LiMWA depth. The original LiMWA point data were retrieved from the FIS archives for Nassau and Suffolk Counties, and depths at each point were sampled from the FIS water surface and topographic data files. To assess spatial trends associated with obstruction or fetch types, the points were subjected to a k-means spatial clustering analysis within ArcInfo, with obstruction type (building, vegetation, marsh, or open space), depth, and fetch environment (open ocean, back-bay, and sheltered waters) as inputs. Results from this assessment showed clear correlation between the parameters, but did not provide spatially continuous blocks of values that were suitable for production. Further experimentation found that clustering with the depth using a nearest neighbor constraint provided the best representation of depth values in continuous blocks along the coast. This process was repeated for each county, for which the optimal number of groups was assessed through iterative runs and set at a number that provided clear differentiation of large groups of points with similar depth values. The final groups for the study area are shown in Figure 10 and depth values are reported in Table 4.

Figure 10. Final LiMWA Depth Value Groups

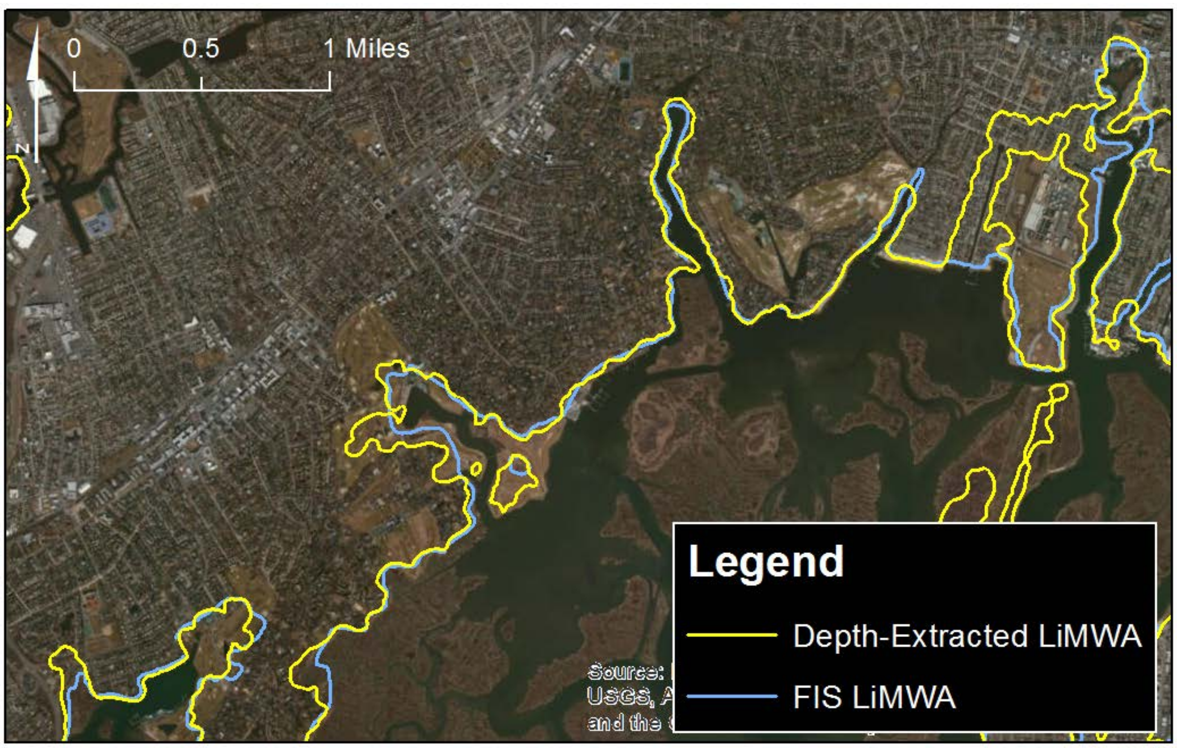


The mean depths were used to approximate the LiMWA line for each group, with a contour generated along those depths. This methodology was used for the baseline scenario and the resultant LiMWA was compared to the FIS LiMWA to determine the accuracy and identify any potential problems. There was good agreement across the majority of the study area; however, one limitation of the methodology is over-prediction of the LiMWA location in high-density urban environments. This is shown in the upper right of Figure 11. In the cases of urban areas, WHAFIS reduces wave heights quickly as the wave encounters the obstruction. Use of the representative mean depth value over each geographic area did not allow capture of this effect and any further increase in resolution was beyond the scope of the effort. These urban areas are still subject to increased hazards in flood events due to their relative depth-of-flooding. The depth-extracted LiMWA should help raise risk awareness and promote mitigation actions.

Table 4. Mean LiMWA Depth Values by County Groups

County	Group	Representative LiMWA depth value (ft)
Nassau	1	2.8
	2	3.4
	3	4.1
Suffolk	1	2.8
	2	2.9
	3	3.0
	4	3.8
	5	2.7
Westchester	1	2.4
	2	3.0
	3	3.3
Rockland	1	3.3

Figure 11. Comparison of Depth-Extracted and FIS LiMW



6.2 LiMWA Post-Processing

The raw LiMWA layer was post-processed through a standard procedure to reflect FEMA mapping guidance discussed in Section 6.2.1. LiMWA coverage was truncated from the geospatial output into two areas to reflect available fetch for wave generation discussed in the LiMWA truncation section.

6.2.1 Standard Post-Processing

The product of the LiMWA analysis is derived from an approximate method, and, in turn, the cartographic representation of the product should have the appropriate form as to not over-represent the accuracy of the product. For example, detailed linework and delineation of small areas should be avoided. The post-processing procedures of the LiMWA linework were designed to generalize the data to an appropriate degree, remove geoprocessing artifacts, and integrate additional LiMWA guidelines as noted in FEMA Operating Guidance No. 13-13 (FEMA 2013b) and FEMA Procedure Memorandum No. 50 (FEMA 2008). The raw linework output from the depth extraction was post-processed through the following steps:

1. Minimum Length: linework less than 500 ft was automatically removed from the coverage. This eliminated small circles in the coverage, which could imply over-precision and/or accuracy of the product.
2. Polygon Voids: Voids, or holes, inside the MOWA were automatically filled if less than half an acre (approximately 22,000 ft^2). This simplified the cartographic representation and eliminated over-representation of production accuracy.
3. Disconnected Areas: FEMA Operating Guidance No. 13-13 recommends that the LiMWA should only be drawn adjacent to the primary flooding source, with exceptions occurring in large open space or over-water areas. In recognition of this guidance, LiMWA areas landward of the continuous main line were screened against the open space or over-water criterion and removed if they did not comply.
4. LiMWA seaward of the Primary Frontal Dune (PFD): FEMA Procedure Memorandum 50 specifies that the LiMWA should be placed immediately landward of areas where Zone VE was extended due to the PFD mapping rule. FEMA Operating Guidance No. 13-13 modified this rule to state that LiMWA should not be shown on the FIRM where Zone VE is controlled by the PFD. An issue with this second rule is that it does not allow for creation of a MOWA polygon. The process here sought to balance the present FEMA guidance with the product specification. Where PFDs were present, LiMWA linework seaward of the PFD was removed and the line was adjusted to the PFD location. This included removal of all linework on the open beach.

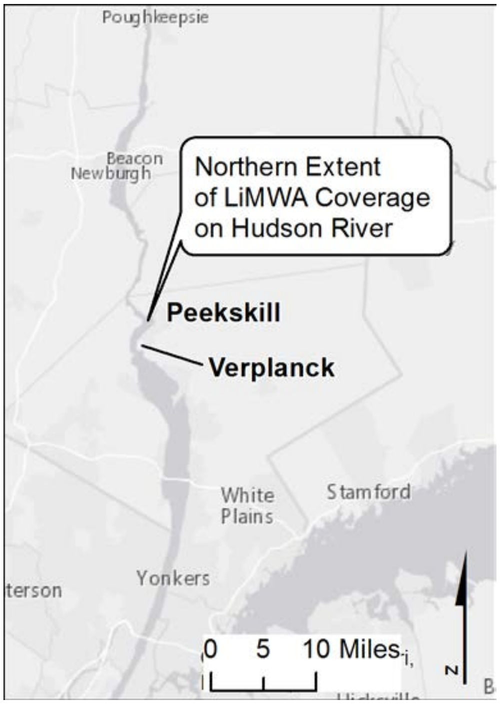
5. Narrow Areas: As the MOWA narrows in canals or valleys, wave diffraction and refraction will limit significant further landward wave propagation. A representative minimum width of 300 ft was identified from the LiMWA mapping on the effective FIS. Areas narrowing below this criterion were removed from the coverage.
6. LiMWA Boundary Consistency Across Scenarios: In some instances, small differences in LiMWA placement occurred due to geoprocessing operations, rather than changes in hazard. These inconsistencies were eliminated by merging the boundaries up-scenario. For example, the final boundaries for the 12-inch SLR scenarios were merged into the final boundaries of the 18-inch scenario. This process removed geoprocessing artifacts in boundary placement from scenario to scenario.
7. Floodplain Consistency: Similar to the previous item, small differences in placement occasionally occurred due to geoprocessing operations that placed the LiMWA boundary landward of the floodplain boundary in relatively steep areas. Consistency with the floodplain boundary was enforced by clipping all LiMWA coverages to the corresponding 1% annual chance flood extent for that scenario.

6.2.2 Limit of the LiMWA on the Hudson River

The LiMWA was mapped up the Hudson River to just north of Peekskill, NY (Figure 12). Mapping was not undertaken north of this location due to the decreasing effective fetch. Throughout Westchester and Rockland Counties, river widths are on average 2–3 miles, narrowing to less than 1 mile at Verplanck. The coverage was extended to Peekskill due to its location at the bend of the river and the fetch distance from the southwest. To the north, the river generally is narrower than 1 mile, which limits the available fetch to build significant wave action. One exception is the reach including Cornwall-on-Hudson, Newburgh, and Balmville, where the river width increases to more than 1 mile for an approximate 8-mile stretch. The effective FISs and floodplain coverages generated by this effort were reviewed to assess the feasibility of mapping the LiMWA in this reach. The FISs did not provide a precedent for wave hazard potential, confirmed by the relative steepness of the terrain adjacent to the river, which limits flood depths and potential for overland wave action. For these reasons, the LiMWA was not mapped in this reach.

Figure 12. LiMWA Coverage on the Hudson River

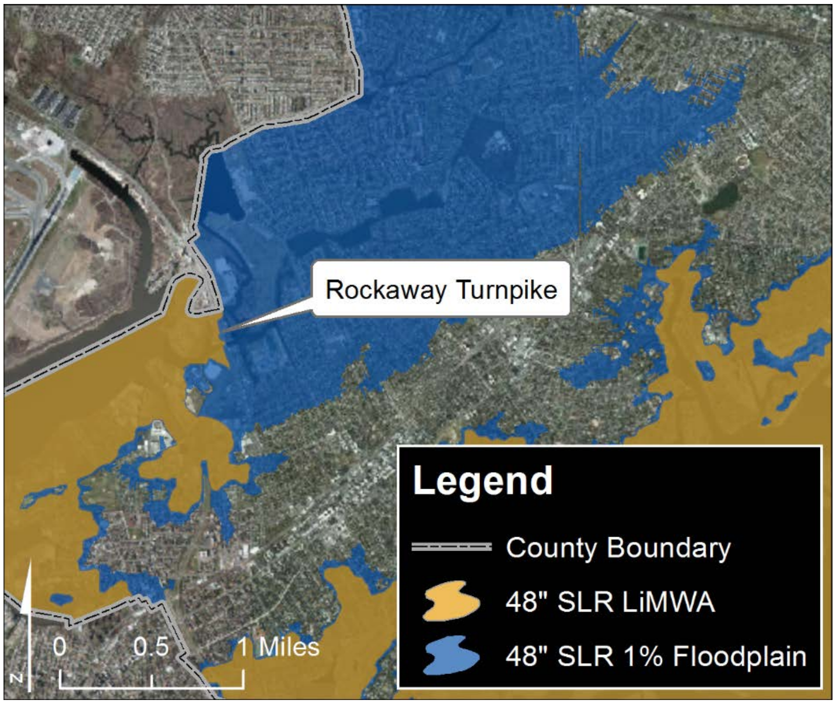
As the river narrows, wave height potential decreases and the mapped LiMWA is limited to areas south of Peekskill.



6.2.3 Truncation of LiMWA Near Woodmere, Nassau County

The LiMWA coverage was cropped in southwestern Nassau County to remove areas north of Rockaway Turnpike that are flooded by waters from Motts Creek (Figure 13). The effective FIS precluded this area from wave hazard modeling due to the limited fetch environment to allow wave generation and propagation to this locality. LiMWA coverages were cropped at Rockaway Turnpike, as it provides a raised obstruction that would dissipate waves propagating from the southwest.

Figure 13. Location of LiMWA Termination in Southwest Nassau County



7 Building Footprint Analysis

Exposure of individual buildings was assessed against the hazard layers across all study scenarios developed by the study effort. This activity consisted of a data mining effort across the study area. Next, an attribution schema was developed and then each county building footprint data set was attributed though cross-analysis against the hazard layers. Quality control followed, and finally, the data was exported to a spreadsheet for easy access and interpretation.

Available data assets were acquired through coordination with each county and/or by leveraging existing data assets where license agreements allowed. Footprints were assembled for the counties identified in Table 5.

Table 5. Summary of Available Building Footprint Data.

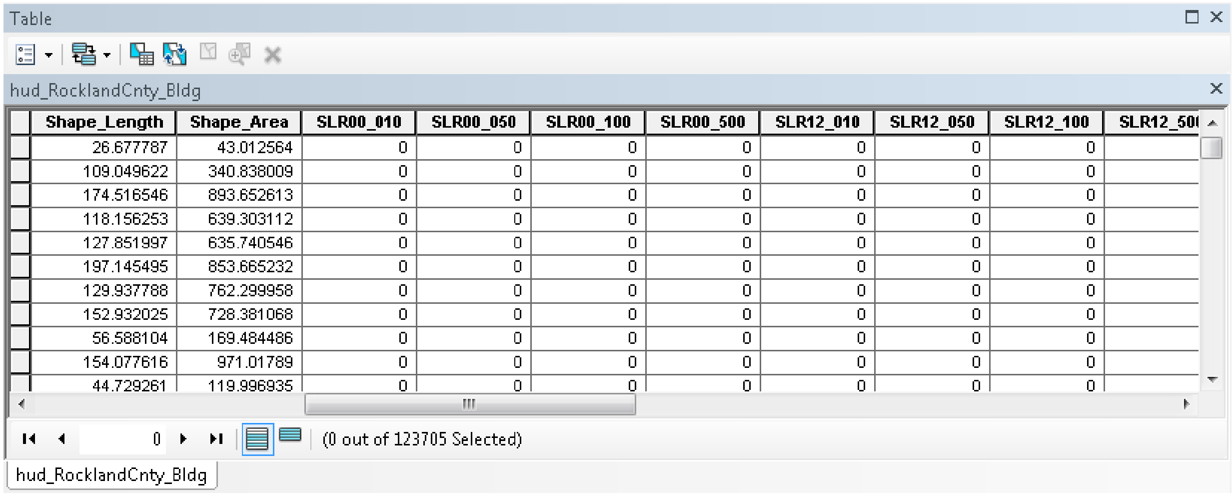
County Name	Status
Albany	Not Available
Columbia	Not Available
Dutchess	Available
Greene	Not Available
Nassau	Available
Orange	Available
Putnam	Not Available
Rensselaer	Not Available
Rockland	Available
Suffolk	Available
Ulster	Available
Westchester	Available

7.1 Data Preparation and Analysis

Limited data preparation was needed prior to analysis. Each dataset was loaded into a standardized working geodatabase. Then, 24 new fields were added to each dataset—one for each possible SLR/floodplain scenario with the following convention: SLR + Scenario + Floodplain (Figure 14).

Figure 14. Building Footprint Data Attribute Table

Example attribute table for building footprints showing naming convention (SLR00_010 = Baseline SLR Scenario, 10% annual chance condition).



Table

hud_RocklandCnty_Bldg

Shape_Length	Shape_Area	SLR00_010	SLR00_050	SLR00_100	SLR00_500	SLR12_010	SLR12_050	SLR12_100	SLR12_50(
26.677787	43.012564	0	0	0	0	0	0	0	
109.049622	340.838009	0	0	0	0	0	0	0	
174.516546	893.652613	0	0	0	0	0	0	0	
118.156253	639.303112	0	0	0	0	0	0	0	
127.851997	635.740546	0	0	0	0	0	0	0	
197.145495	853.665232	0	0	0	0	0	0	0	
129.937788	762.299958	0	0	0	0	0	0	0	
152.932025	728.381068	0	0	0	0	0	0	0	
56.588104	169.484486	0	0	0	0	0	0	0	
154.077616	971.01789	0	0	0	0	0	0	0	
44.729261	119.996935	0	0	0	0	0	0	0	

0 (0 out of 123705 Selected)

hud_RocklandCnty_Bldg

Next, a data schema was developed to populate each of the analysis fields based upon the spatial relation each individual building has to the floodplain and LiMWA. For the 10%, 2%, and 0.2% annual chance conditions, buildings were attributed with a “1” if within the flood extent or a “0” if outside the flood extent. For the 1% annual chance condition, buildings were attributed with a “1” if within the flood extent, a “2” if within the flood extent and LiMWA boundary, and “0” if outside the flood extent. It should be noted that the LiMWA is only available for the 1% annual chance condition for each SLR scenario. This data schema is summarized in Table 6.

Table 6. Building Footprint Analysis Table Schema

Values were assigned based on exposure. A value of “2” was only possible within the 1% annual chance condition.

Table Value	Description
0	Building not in floodplain
1	Building in floodplain
2	Building in LiMWA and floodplain

A custom Python script was developed to conduct the building footprint analysis. Each data set was processed systematically to attribute the spatial relationship to the individual buildings for each SLR/floodplain combination, in addition to each of the generated LiMWA boundaries.

Following the intersection, a subset of the data was visually checked for accuracy. This check was conducted by randomly selecting five scenarios from each building footprint data set. Data were then symbolized based upon the table schema, and a visual check was conducted to verify inclusion/exclusion attribution to the appropriate floodplain coverages. Once the analysis was validated, a final union with the previously used master political boundary schema was conducted and the data sets were placed in a deliverable geodatabase.

8 Data Finalization

Following the flood hazard mapping and exposure analysis, data were finalized for delivery. This included conflation with political areas, implementation of a consistent naming system, and organization into discreet deliverable geodatabases.

8.1 Conflation with Political Areas

One objective for the floodplain mapping products was to provide the ability for downstream tools and/or end users to easily query change in specific geographies, including the county, town, and village level. To facilitate this work, a master political boundary layer was created with unique identifiers keyed to the originating input political feature class object identifiers. The general format for the unique identifiers can be found in Table 7.

Although the example master political boundary in Table 7 contains a unique ID for each of the input boundaries, it was possible for a particular feature to be outside of, or not included in, either a city/town or village. In that situation, the Dewberry-generated ID was replaced with a "0" (e.g., 36019_CTN0990_0).

Table 7. Unique Identifier Elements

Political Boundary Type	Political Boundary ID Type	Example
County	FIPS Code	36019
City/Town	Dewberry Generated (CTN + 4 digit code)	CTN0990
Village	Dewberry Generated (VLG + 4 digit code)	VLG0114
Master Political Boundary	Dewberry Generated (FIPS + CTN + VLG)	36019_CTN0990_VLG0114

Once the master political boundary feature class was created, the inundation layers were then aggregated, and the output stored in a file geodatabase. All extraneous fields were then dropped from the feature classes and the area was calculated for each of the inundation polygons in both square feet and square miles.

8.2 Data Organization

Data outputs from the study effort were organized into five geodatabases, each containing a discreet data type. The deliverable geodatabase contents are listed in Table 8.

8.3 File Naming Conventions

Standardized file naming conventions were applied to the floodplain, LiMWA, probability, and water surface elevation raster deliverables. A separate coverage was created for each SLR scenario and flood frequency, which can be identified from the coverage name, formatted in a three-part schema to allow easy identification of each layer. The schema elements are separated by an underscore and varied by deliverable type, shown in Table 9. Building footprint layers needed a two-part schema due to the inclusive nature of the data.

Table 8. Description of Deliverable Geodatabases, Contents, and Data Organization

Database	Contents	Organization
NYSERDA_SLR_Bldg_Footprints.gdb	Building footprint data with attribution for exposure to each flood condition assessed in the study	Feature class by county
NYSERDA_SLR_Floodplains.gdb	Floodplain polygons for each scenario and flood frequency	Feature dataset by county for Nassau, Suffolk; Westchester, and counties in Hudson Valley combined in a single dataset; individual floodplain as feature classes under each geography
NYSERDA_SLR_LiMWA.gdb	Polygons representing extent of Moderate Wave Action	Feature class by county and scenario; Westchester and counties in Hudson Valley combined in a single dataset
NYSERDA_SLR_ProbabilityGrids.gdb	Raster data for annual and 30-year chance of flooding relative to each scenario	Raster dataset by county for Nassau, Suffolk, and Westchester; counties in Hudson Valley included in single dataset; individual raster for each geography, scenario, and probability type
NYSERDA_SLR_WSEL_Data.gdb	Raster data providing water surface elevations for each coastal flood return period condition by scenario	Raster dataset by county for Nassau, Suffolk and Westchester; counties in Hudson Valley included in single dataset; individual raster for each geography, scenario and return period

Table 9. Naming Convention Schema by Data Type

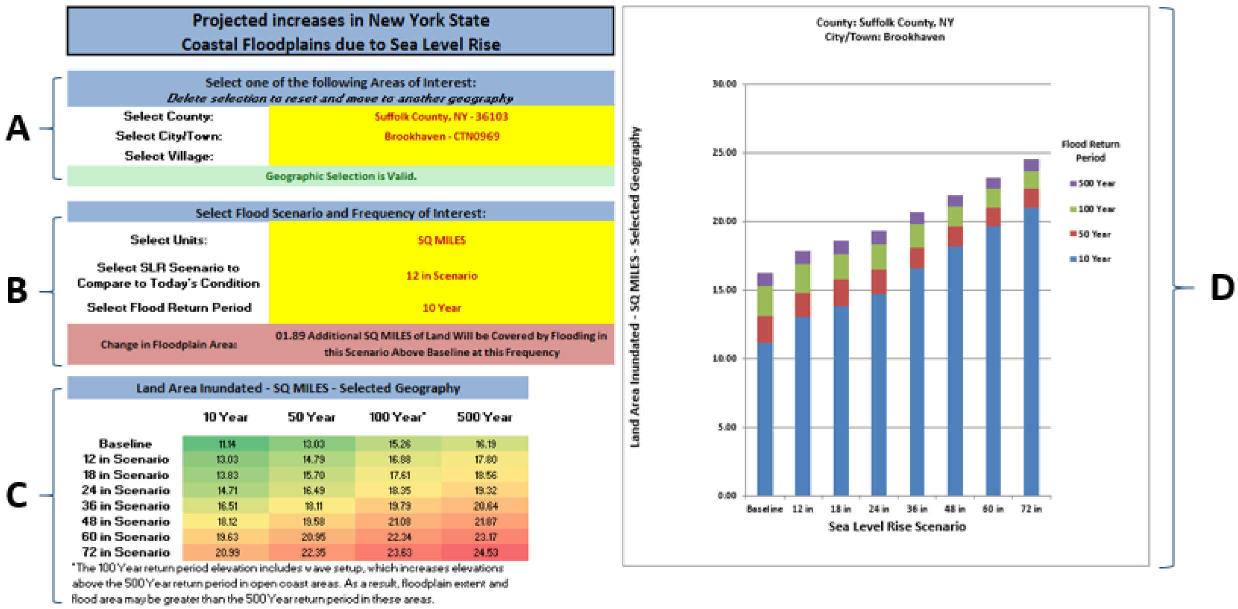
Data type	Part 1	Part 2	Part 3	Example
Building Footprints	Geography Full County Name	Data Type Bldgs (Buildings)	None	“DutchessCnty_Bldgs” Building footprints with exposure attributes for Dutchess County, all scenarios
Future Floodplains	Geography Abbreviations wh = Hudson Valley (all coastal floodplains along Hudson River) and Westchester County including the Long Island Sound floodplain nas = Nassau County suf = Suffolk County	Sea Level Rise Scenario in inches “00” is today’s condition	Flood Return Period “010” = 10-yr return period; “050” = 50-yr return period; “100” = 100-yr return period; “500” = 500-yr return period	“wh_18_500” Floodplain for the Hudson Valley and Westchester County for an SLR scenario of 18 in and coastal flood return period of 500 years.
Limit of Area of Moderate Wave Action (LiMWA)	Same as Floodplains	Same as Floodplains	Data type limwa	“nas_12_limwa” Limit of area of moderate wave action in Nassau County for a SLR scenario of 12 inches, 100-yr return period
Probability Grids	Same as Floodplains	Same as Floodplains	Time interval for percent chance of flooding Annual Percent Chance = “apcg” Percent Chance in 30-yr Period = “30ypg”	“suf_36_apcg” Annual Percent Chance of flooding in Suffolk County for an SLR scenario of 36 in
Water Surface Elevation Rasters	Same as Floodplains	Same as Floodplains	Same as Floodplains	Same as Floodplains

8.4 Data Summarization Spreadsheets

Key metrics of floodplain area change and building exposure were exported from the data layers and summarized into spreadsheets to facilitate end-use and access outside of GIS.

An interactive spreadsheet tool (FloodplainAreaChange_CommunityArea_Tool_04282015.xlsx) was created as a value-added product to query and display floodplain change at the county, town, and village level geography in the study area (Figure 15). Element A allows users to select the political area of interest at these three levels from drop-down lists. Data presented in elements B, C, and D are controlled by the selected geography in Element A. Element B allows the user to select reporting units in square feet or miles (controls values presented in Elements B, C, and D). A summary of the floodplain change from a zero-level rise to the specified SLR scenario and return period of interest is reported at the bottom of Element B. Element C provides a summary of the total area of the floodplain for the selected geography for all scenarios and return periods. Element D provides a stacked bar chart showing total flood area for each return period by scenario.

Figure 15. Interface of Future Floodplain Area Change Summary Tool



Tabular summaries of building footprint counts for structures exposed to flooding and moderate wave action were also compiled. A separate spreadsheet was created for exposure to flooding (Building_Footprints_CommunityCounts_FloodExposure_1117015.xlsx) and exposure to wave action (Building_Footprints_CommunityCounts_WaveExposure_11242015.xlsx). Each spreadsheet contains an array of subsheets, one for each county in the study area, that provide totals of exposed buildings for each SLR scenario and return period combination and community (Figure 16). Data are only available for communities with available building footprint data.

Figure 16. Example of Exposed Building Footprint Tabular Summary

POL_ID	Community	SLR00_010	SLR00_050	SLR00_100	SLR00_500	SLR12_010	SLR12_050	SLR12_100	SLR12_500
36103	**SUFFOLK COUNTY**	**18,430**	**26,548**	**32,387**	**41,313**	**26,718**	**34,699**	**39,892**	**48,490**
36103_CTN0945	**CTN OF EAST HAMPTON**	**291**	**1,054**	**2,037**	**2,716**	**530**	**1,576**	**2,429**	**3,118**
36103_CTN0945_0	ctn of East Hampton	284	987	1,826	2,340	501	1,474	2,152	2,672
36103_CTN0945_VLG0427	Sag Harbor	4	15	19	65	15	27	30	85
36103_CTN0945_VLG0431	East Hampton	3	52	192	311	14	75	247	361
36103_CTN0952	**CTN OF RIVERHEAD**	**86**	**314**	**522**	**1,367**	**270**	**571**	**714**	**1,614**
36103_CTN0952_0	ctn of Riverhead	86	314	522	1,367	270	571	714	1,614
36103_CTN0953	**CTN OF SOUTHOLD**	**488**	**1,231**	**1,612**	**3,644**	**1,089**	**1,858**	**2,262**	**4,374**
36103_CTN0953_0	ctn of Southold	430	1,134	1,499	3,458	1,002	1,723	2,097	4,054
36103_CTN0953_VLG0416	Greenport	58	97	113	186	87	135	165	320
36103_CTN0954	**CTN OF SHELTER ISLAND**	**55**	**99**	**123**	**358**	**101**	**160**	**188**	**451**
36103_CTN0954_0	ctn of Shelter Island	54	98	122	353	100	159	187	445
36103_CTN0954_VLG0420	Dering Harbor	1	1	1	5	1	1	1	6
36103_CTN0959	**CTN OF ISLIP**	**4,349**	**5,408**	**6,050**	**6,570**	**6,350**	**7,296**	**7,850**	**8,279**
36103_CTN0959_0	ctn of Islip	3,447	4,419	4,963	5,454	5,279	6,178	6,657	7,081
36103_CTN0959_VLG0450	Islandia	0	0	0	0	0	0	0	0
36103_CTN0959_VLG0517	Brightwaters	34	85	110	139	147	176	187	192
36103_CTN0959_VLG0533	Ocean Beach	489	511	545	545	524	538	565	565
36103_CTN0959_VLG0535	Saltaire	379	393	432	432	400	404	441	441
36103_CTN0961	**CTN OF HUNTINGTON**	**215**	**449**	**738**	**845**	**402**	**643**	**847**	**958**
36103_CTN0961_0	ctn of Huntington	116	201	276	352	176	272	337	417
36103_CTN0961_VLG0424	Huntington Bay	24	45	81	88	41	69	95	103
36103_CTN0961_VLG0437	Asharoken	35	139	294	300	124	219	313	314
36103_CTN0961_VLG0438	Lloyd Harbor	21	32	42	48	30	37	48	54
36103_CTN0961_VLG0442	Northport	19	32	45	57	31	46	54	70

9 Results Overview

Mapping of the changes to the coastal floodplains throughout the tidally influenced area of the State has shown that considerable increases can be expected in response to current projections of future SLR. The most substantial increases are expected along the Long Island coast, especially in Suffolk County, where the relatively low-lying topography provides a pathway for the expansion of existing floodplains. Although floodplains are relatively constrained in the Hudson Valley, Rensselaer, Albany, and Green Counties can expect greater increases in floodplain area than areas to the south.

Areas of higher-frequency flooding, as represented by the 10% annual chance floodplain, are expected to increase on average 1.5 times more than the regulatory floodplain. The 10% annual chance floodplain has a 96% chance of being flooded during a 30-year mortgage timeframe. The increasing footprint of this area highlights the need for pro-active management to mitigate the potential for increasing flood impacts.

A summary of county-by-county change in the area of the 1% annual chance floodplain for the 12-inch SLR scenario is provided in Figure 17. Full tabular summaries of changes to the 10% and 1% annual chance floodplains are provided in Tables 10 through 13. Figure 18 and Figure 19 show change in the floodplain relative to the baseline condition for each county. Plots of change within each community by scenario and flood return period are provided in Appendix A.

Figure 17. Change in the 1% Annual Chance Floodplain Area for a 12-in SLR

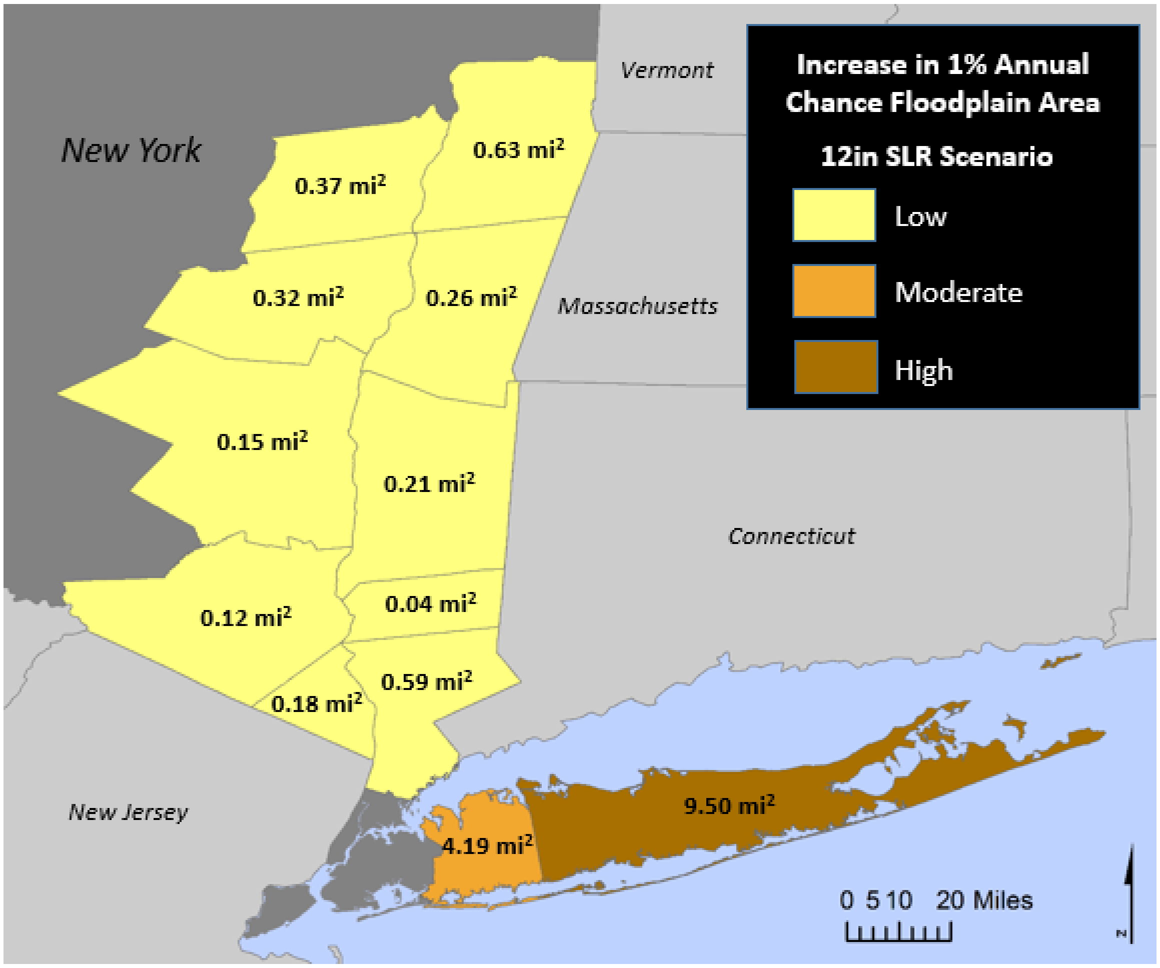


Table 10. Increase (square miles) in the 10% Annual Chance Floodplain from Today's Conditions

County	12-in Scenario	18-in Scenario	24-in Scenario	36-in Scenario	48-in Scenario	60-in Scenario	72-in Scenario
Albany	0.09	0.18	0.31	0.74	1.24	1.51	1.69
Columbia	0.56	0.83	1.04	1.51	1.80	2.05	2.31
Dutchess	0.20	0.74	0.81	1.01	1.23	1.45	1.69
Greene	1.11	1.31	1.53	1.94	2.25	2.54	2.77
Nassau	6.62	9.71	12.70	17.50	20.72	23.45	25.73
Orange	0.06	0.09	0.14	0.22	0.36	0.46	0.55
Putnam	0.09	0.11	0.13	0.16	0.20	0.24	0.28
Rensselaer	0.19	0.43	0.80	1.72	2.41	2.87	3.23
Rockland	0.21	0.29	0.37	0.56	0.73	0.85	0.94
Suffolk	12.71	17.96	23.61	34.19	43.22	52.05	60.63
Ulster	0.14	0.22	0.31	0.48	0.64	0.77	0.87
Westchester	0.71	1.05	1.37	2.02	2.58	3.16	3.58

Table 11. Increase (square miles) in the 2% Annual Chance Floodplain from Today's Conditions

County	12-in Scenario	18-in Scenario	24-in Scenario	36-in Scenario	48-in Scenario	60-in Scenario	72-in Scenario
Albany	0.53	0.79	0.98	1.24	1.41	1.57	1.72
Columbia	0.42	0.54	0.67	0.91	1.17	1.44	1.68
Dutchess	0.22	0.79	0.90	1.12	1.36	1.58	1.73
Greene	0.39	0.53	0.67	0.95	1.18	1.38	1.57
Nassau	5.43	7.70	9.57	12.49	14.76	17.10	19.11
Orange	0.09	0.16	0.22	0.31	0.42	0.54	0.63
Putnam	0.04	0.06	0.08	0.12	0.16	0.19	0.22
Rensselaer	0.76	1.11	1.42	1.86	2.21	2.44	2.60
Rockland	0.23	0.31	0.38	0.49	0.59	0.67	0.73
Suffolk	11.54	16.56	21.66	30.27	38.47	47.03	55.42
Ulster	0.19	0.27	0.34	0.48	0.60	0.71	0.80
Westchester	0.68	0.96	1.21	1.68	2.07	2.49	2.93

Table 12. Increase (square miles) in the 1% Annual Chance Floodplain from Today's Conditions

County	12-in Scenario	18-in Scenario	24-in Scenario	36-in Scenario	48-in Scenario	60-in Scenario	72-in Scenario
Albany	0.37	0.49	0.58	0.74	0.90	1.07	1.26
Columbia	0.26	0.38	0.51	0.76	1.04	1.27	1.42
Dutchess	0.21	0.80	0.91	1.15	1.38	1.53	1.65
Greene	0.32	0.46	0.58	0.80	1.01	1.18	1.34
Nassau	4.19	5.77	7.18	9.43	11.48	13.51	15.38
Orange	0.12	0.17	0.22	0.33	0.45	0.54	0.61
Putnam	0.04	0.06	0.08	0.12	0.15	0.18	0.20
Rensselaer	0.63	0.85	1.04	1.32	1.55	1.71	1.87
Rockland	0.18	0.23	0.28	0.38	0.46	0.52	0.57
Suffolk	9.50	14.05	18.40	26.20	33.90	42.32	50.34
Ulster	0.15	0.23	0.30	0.41	0.53	0.61	0.68
Westchester	0.59	0.85	1.04	1.44	1.81	2.27	2.68

Table 13. Increase (square miles) in the 0.2% Annual Chance Floodplain from Today's Conditions

County	12-in Scenario	18-in Scenario	24-in Scenario	36-in Scenario	48-in Scenario	60-in Scenario	72-in Scenario
Albany	0.18	0.28	0.46	0.70	1.12	1.43	1.71
Columbia	0.22	0.31	0.39	0.51	0.62	0.72	0.81
Dutchess	0.23	0.84	0.93	1.05	1.16	1.26	1.36
Greene	0.18	0.27	0.35	0.51	0.66	0.79	0.91
Nassau	3.28	4.58	5.76	7.81	9.63	11.70	13.68
Orange	0.09	0.15	0.23	0.31	0.37	0.41	0.46
Putnam	0.04	0.05	0.06	0.09	0.11	0.14	0.16
Rensselaer	0.15	0.23	0.43	0.67	1.00	1.40	1.73
Rockland	0.07	0.10	0.12	0.17	0.21	0.25	0.29
Suffolk	8.99	13.32	17.43	25.41	33.41	42.04	50.03
Ulster	0.10	0.16	0.21	0.28	0.34	0.39	0.45
Westchester	0.47	0.66	0.85	1.24	1.62	2.05	2.47

Figure 18. Relative Change to the Future 10-year Floodplain

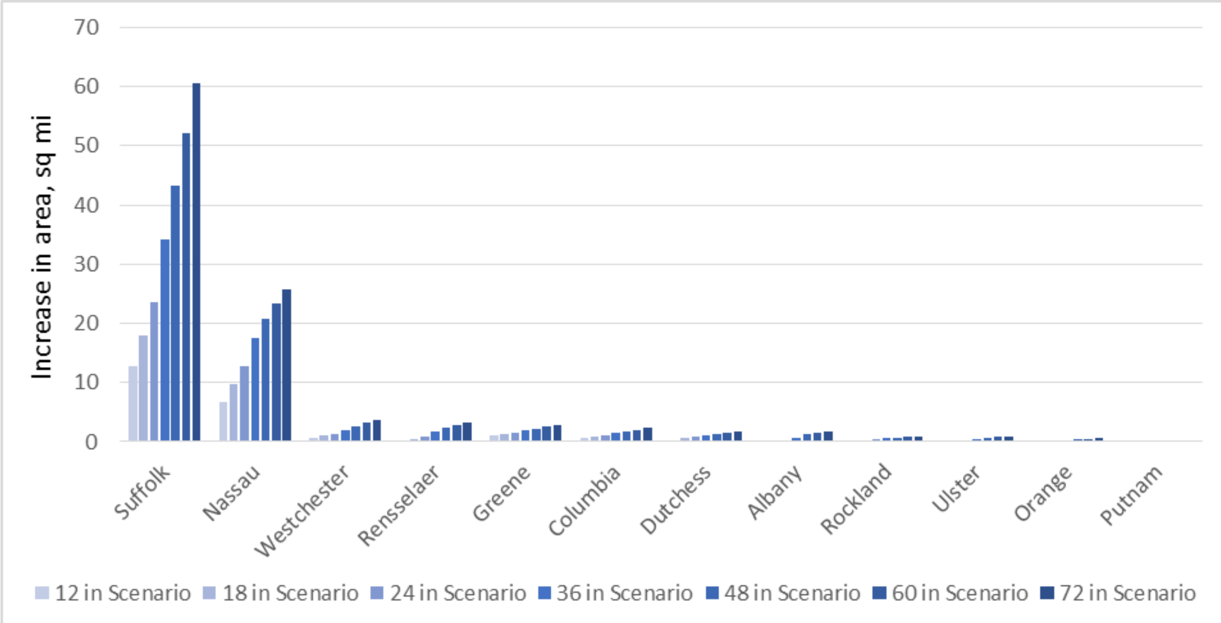
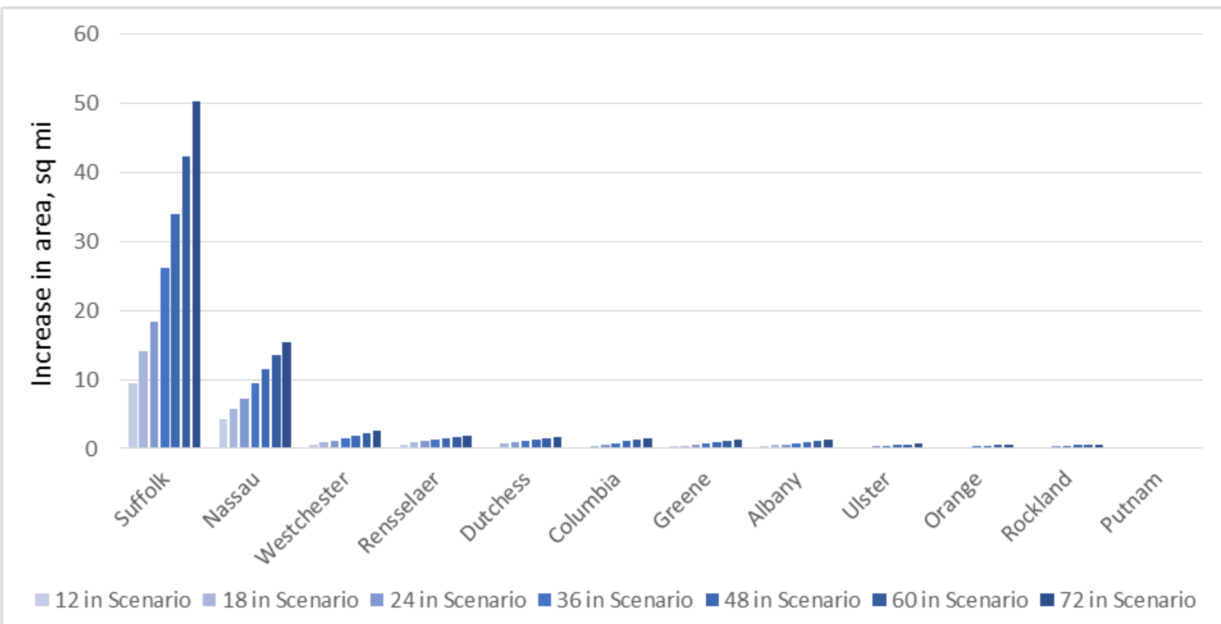


Figure 19. Relative Change to the Future 100-year Floodplain



Increases in floodplain area are accompanied by greater exposure of buildings. The lower-lying and highly developed areas in Nassau and Suffolk Counties carry an order of magnitude higher building exposure as compared to Westchester County and the remainder of the Hudson Valley for both the 10-year and 100-year floodplains, as shown in Figure 20 and Figure 21. A larger increase in exposed buildings is seen in the 10-year floodplain—a SLR scenario of 12 inches is projected to add more than 23,000 structures to this area of higher-frequency flooding in Nassau and Suffolk counties alone. Changes in the flood exposure of buildings with increasing SLR is summarized in Tables 14 through 17.

Figure 20. Change in Exposed Building Footprints to the Future 10-year Floodplain

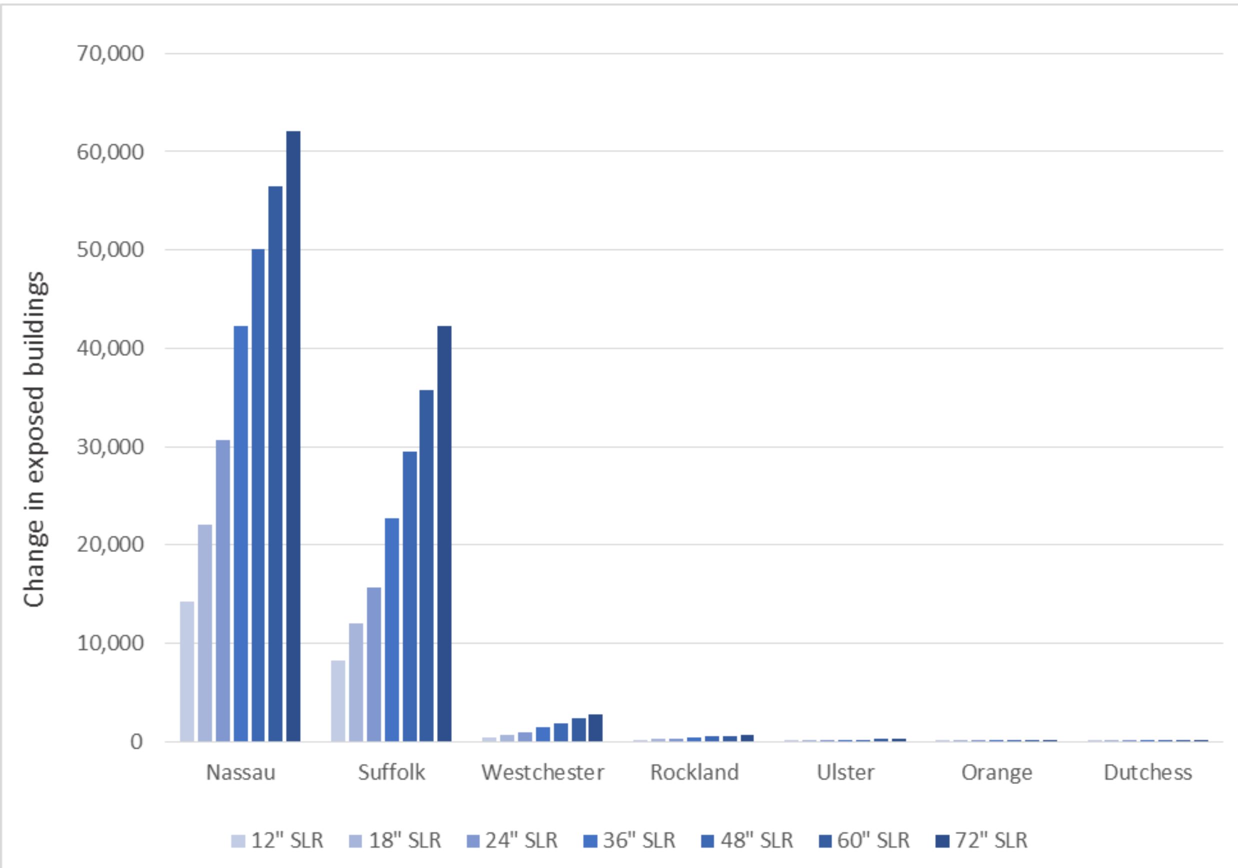


Figure 21. Change in Exposed Building Footprints to the Future 100-year Floodplain

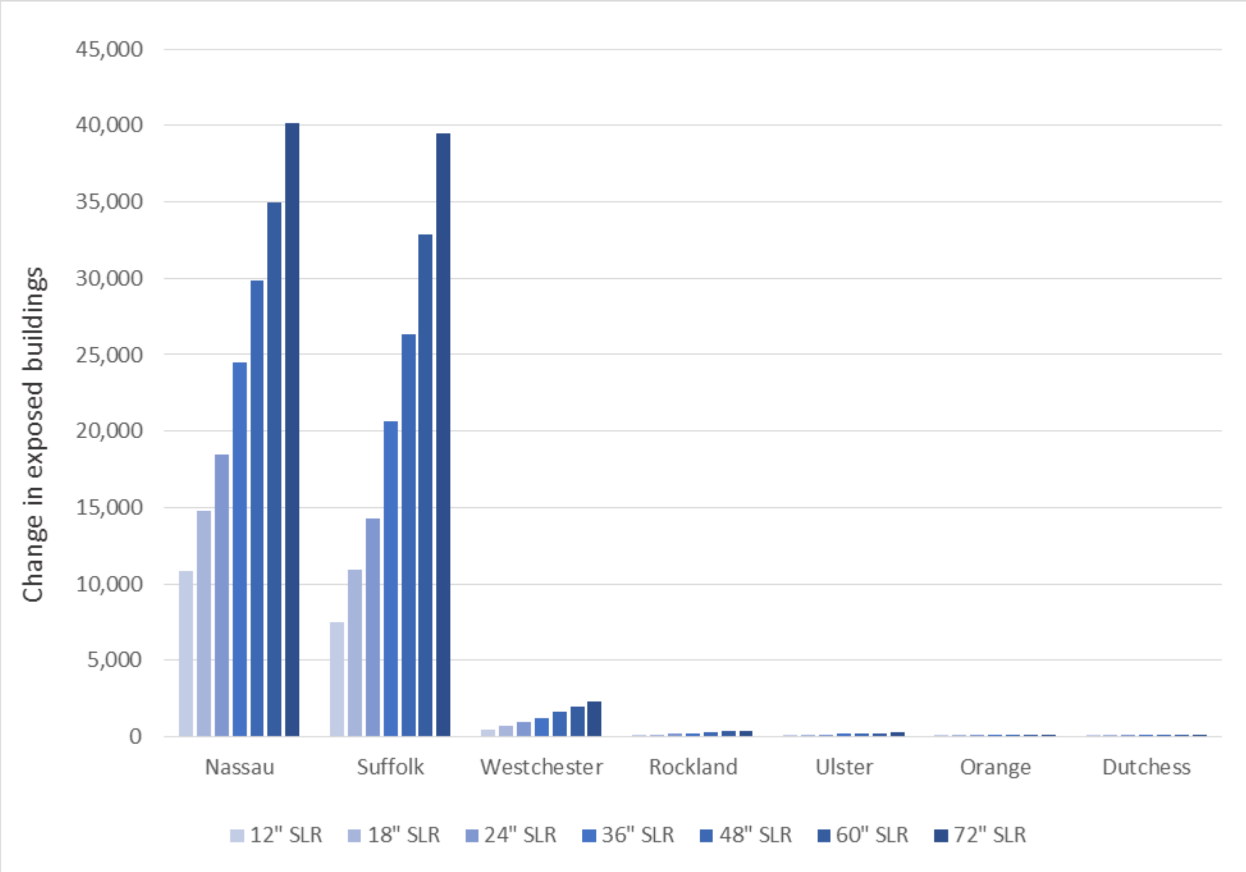


Table 14. Changes to Building Footprint Exposure with Projected SLR Scenarios for the 10-year Floodplain

County	12-in SLR	18-in SLR	24-in SLR	36-in SLR	48-in SLR	60-in SLR	72-in SLR
Westchester	489	720	952	1,425	1,945	2,423	2,758
Ulster	16	38	68	146	215	279	312
Suffolk	8,288	12,065	15,735	22,777	29,465	35,820	42,310
Rockland	171	267	330	453	563	630	689
Orange	8	12	20	44	93	112	131
Nassau	14,264	22,138	30,661	42,288	50,097	56,463	62,021
Dutchess	11	25	35	55	75	91	114

Table 15. Changes to Building Footprint Exposure with Projected SLR Scenarios for the 50-year Floodplain

County	12-in SLR	18-in SLR	24-in SLR	36-in SLR	48-in SLR	60-in SLR	72-in SLR
Westchester	512	754	1,001	1,407	1,733	2,082	2,465
Ulster	79	108	145	195	242	273	301
Suffolk	8,151	11,705	15,347	21,892	28,171	34,574	41,392
Rockland	142	186	238	300	375	443	496
Orange	28	55	69	87	115	136	152
Nassau	14,270	19,941	24,485	31,398	37,271	42,728	47,885
Dutchess	15	31	36	55	79	107	126

Table 16. Changes to Building Footprint Exposure with Projected SLR Scenarios for the 100-year Floodplain

County	12-in SLR	18-in SLR	24-in SLR	36-in SLR	48-in SLR	60-in SLR	72-in SLR
Westchester	492	731	918	1,235	1,590	1,974	2,334
Ulster	75	107	134	178	207	237	260
Suffolk	7,505	10,906	14,248	20,639	26,370	32,849	39,478
Rockland	104	138	164	235	309	357	394
Orange	38	56	64	91	110	129	136
Nassau	10,829	14,773	18,425	24,515	29,866	34,957	40,194
Dutchess	19	28	37	62	93	112	129

Table 17. Changes to Building Footprint Exposure with Projected Sea Level Rise Scenarios for the 500-year Floodplain

County	12-in SLR	18-in SLR	24-in SLR	36-in SLR	48-in SLR	60-in SLR	72-in SLR
Westchester	378	538	710	1,093	1,485	2,058	2,489
Ulster	26	40	55	82	101	119	134
Suffolk	7,177	10,548	13,791	19,914	25,923	32,700	39,328
Rockland	54	76	100	132	171	208	231
Orange	15	32	55	67	73	76	78
Nassau	8,601	12,144	15,130	20,445	25,024	30,479	35,876
Dutchess	19	46	57	78	91	101	110

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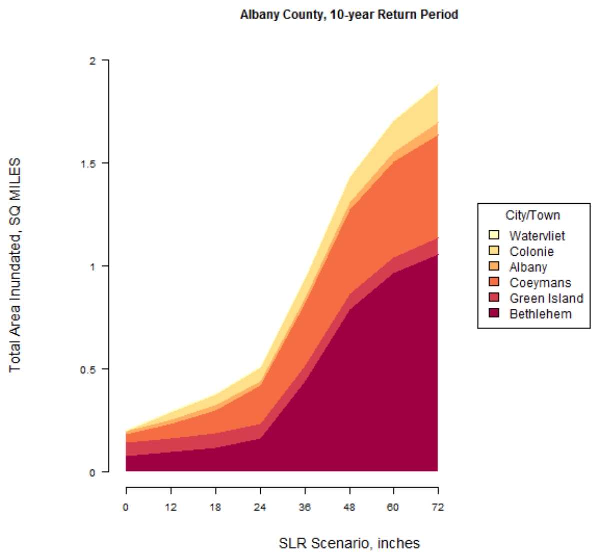
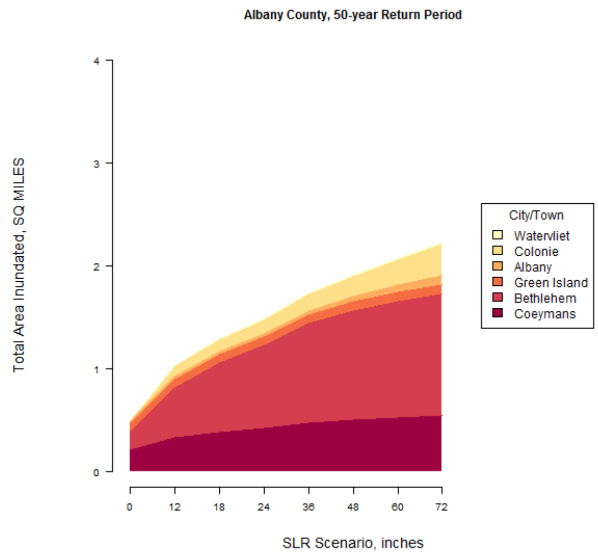
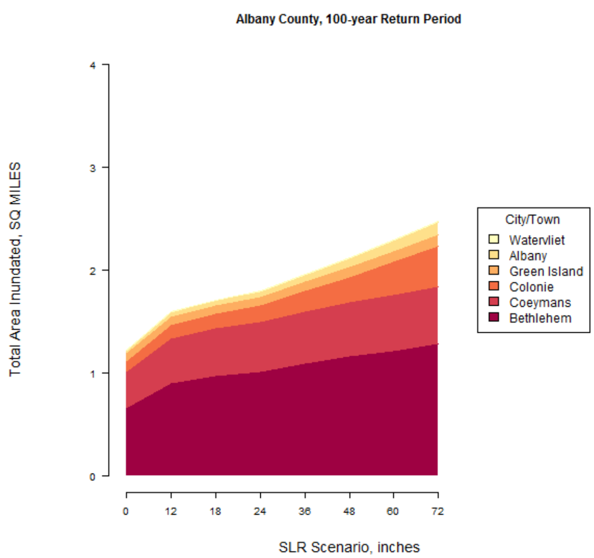
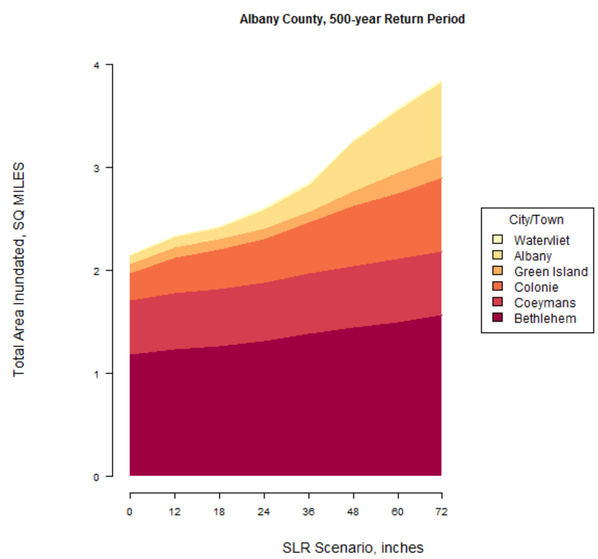
Appendix A: Floodplain Change by County

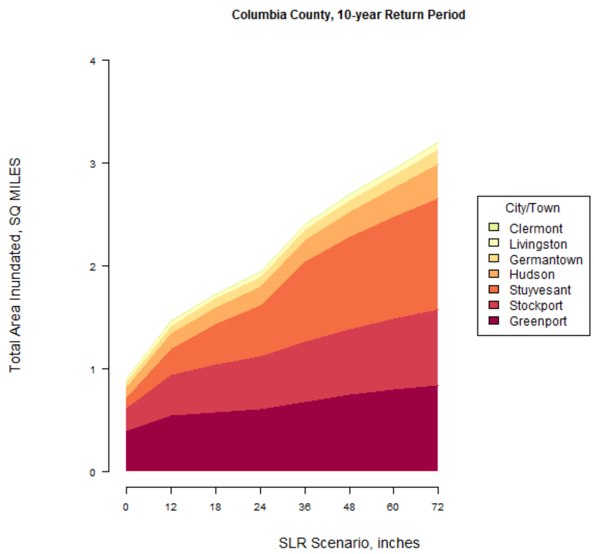
The following figures provide a county-by-county summary of the projected change in floodplain area for each community and flood return period. Floodplain area for each community is represented by the discreet shaded area as indicated in the plot legend. The total of all community areas is equivalent to the total floodplain area in each county. Differing topographic gradients at the elevations of each flood return period control how the floodplain will evolve with projected increases in water elevation due to SLR. Increasing flood elevation at a steep gradient such as a bluff will not result in much increase in the floodplain; however, if SLR increases a flood elevation over the crest of a rise to a plateau or other low-lying area, larger increases would be expected. The amount of change depends on the local topography at each of the four flood return period elevations considered by the study. Large increases in floodplain area for the 10-year and 50-year floodplains should raise concerns given the relatively higher frequency of flooding in these areas. Counties are presented in alphabetical order.

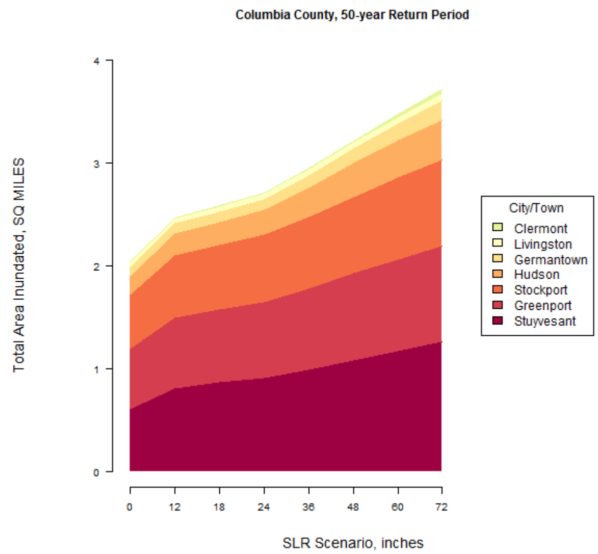

Albany County, 10-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Watervliet
Colonie
Albany
Coeymans
Green Island
Bethlehem

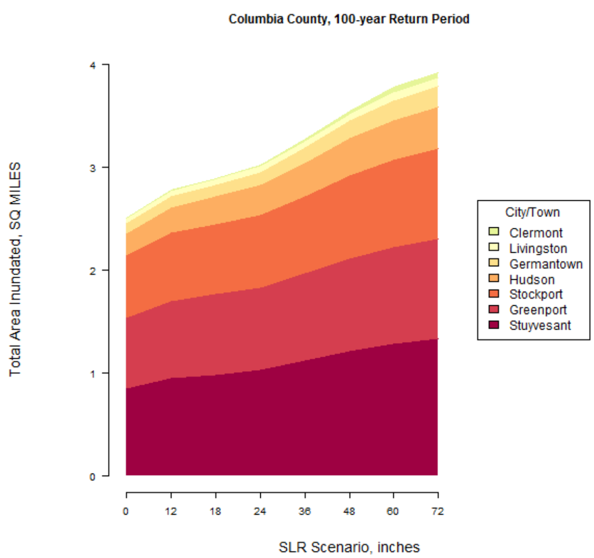

Albany County, 50-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Watervliet
Colonie
Albany
Green Island
Bethlehem
Coeymans

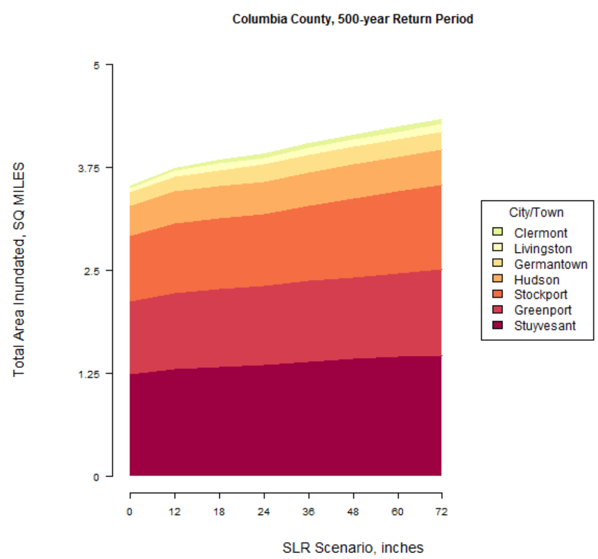

Albany County, 100-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Watervliet
Albany
Green Island
Colonie
Coeymans
Bethlehem

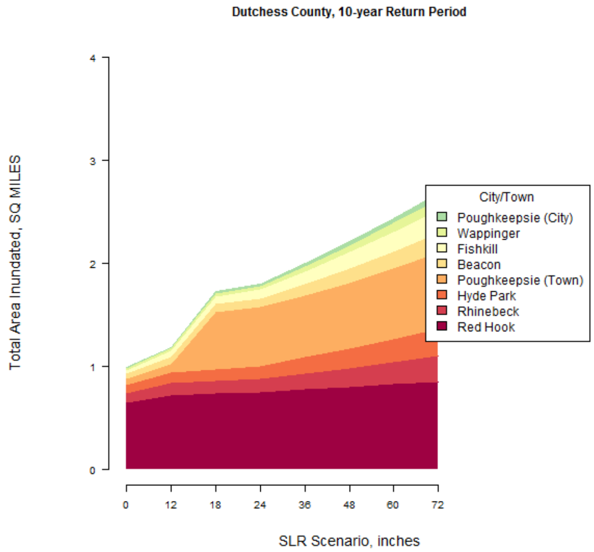

Albany County, 500-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Watervliet
Albany
Green Island
Colonie
Coeymans
Bethlehem

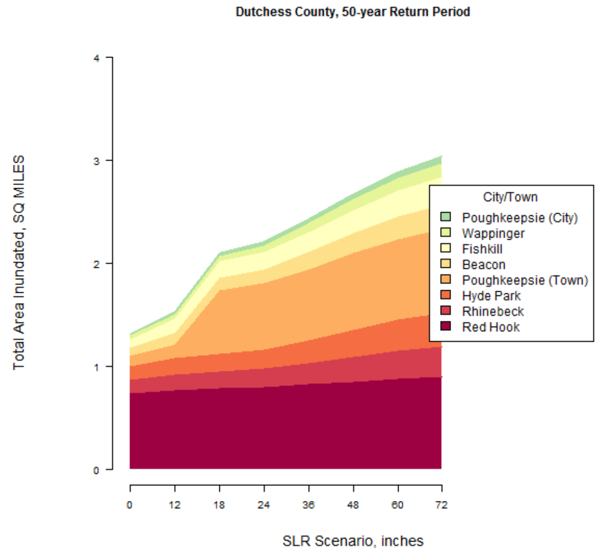

Columbia County, 10-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
1
2
3
4
0 12 18 24 36 48 60 72
City/Town
Clermont
Livingston
Germantown
Hudson
Stuyvesant
Stockport
Greenport

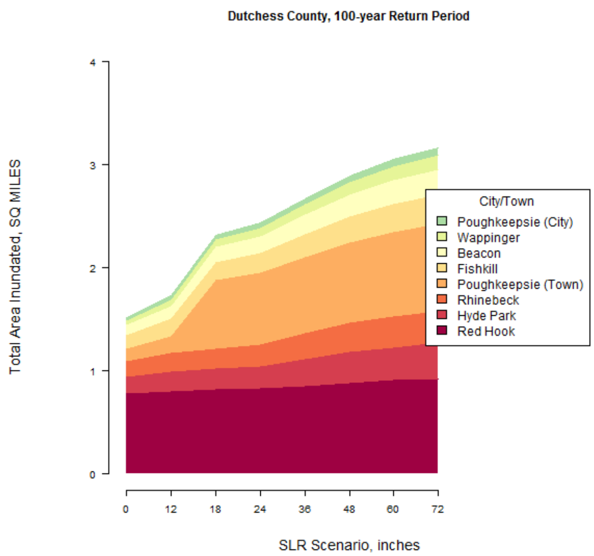

Columbia County, 50-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
1
2
3
4
0 12 18 24 36 48 60 72
City/Town
Clermont
Livingston
Germantown
Hudson
Stockport
Greenport
Stuyvesant

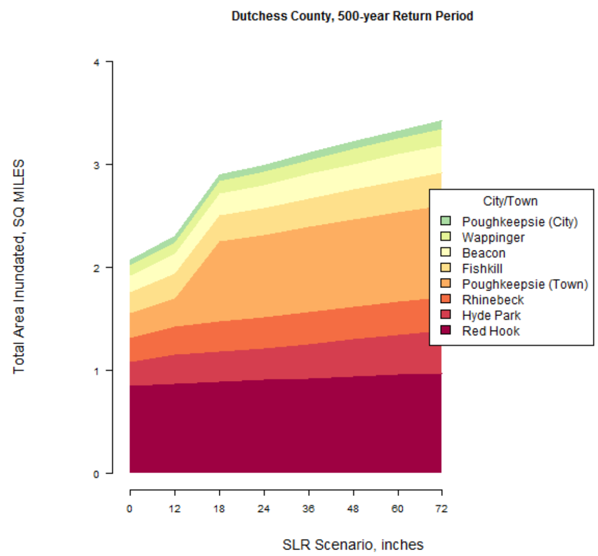

Columbia County, 100-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
1
2
3
4
0 12 18 24 36 48 60 72
City/Town
Clermont
Livingston
Germantown
Hudson
Stockport
Greenport
Stuyvesant


Columbia County, 500-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
1.25
2.5
3.75
5
0 12 18 24 36 48 60 72
City/Town
Clermont
Livingston
Germantown
Hudson
Stockport
Greenport
Stuyvesant

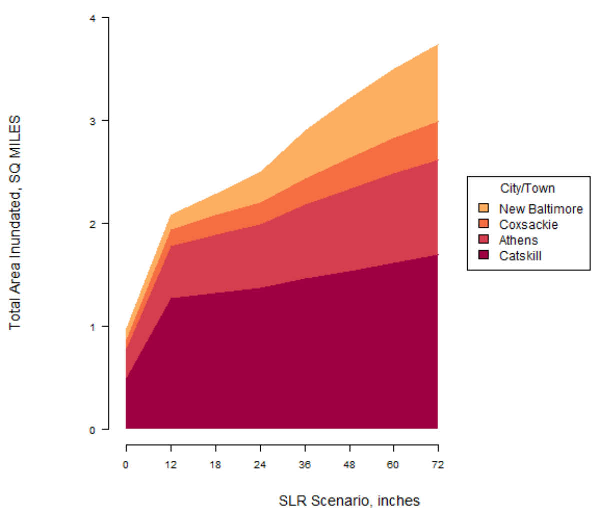

Dutchess County, 10-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Poughkeepsie (City)
Wappinger
Fishkill
Beacon
Poughkeepsie (Town)
Hyde Park
Rhinebeck
Red Hook


Dutchess County, 50-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Poughkeepsie (City)
Wappinger
Fishkill
Beacon
Poughkeepsie (Town)
Hyde Park
Rhinebeck
Red Hook

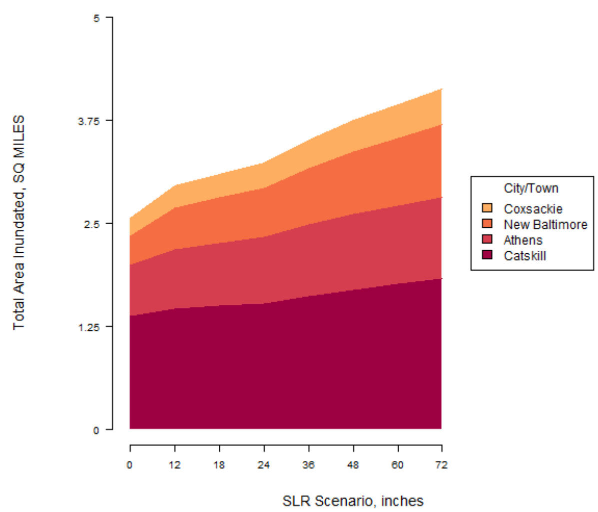

Dutchess County, 100-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Poughkeepsie (City)
Wappinger
Beacon
Fishkill
Poughkeepsie (Town)
Rhinebeck
Hyde Park
Red Hook


Dutchess County, 500-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Poughkeepsie (City)
Wappinger
Beacon
Fishkill
Poughkeepsie (Town)
Rhinebeck
Hyde Park
Red Hook

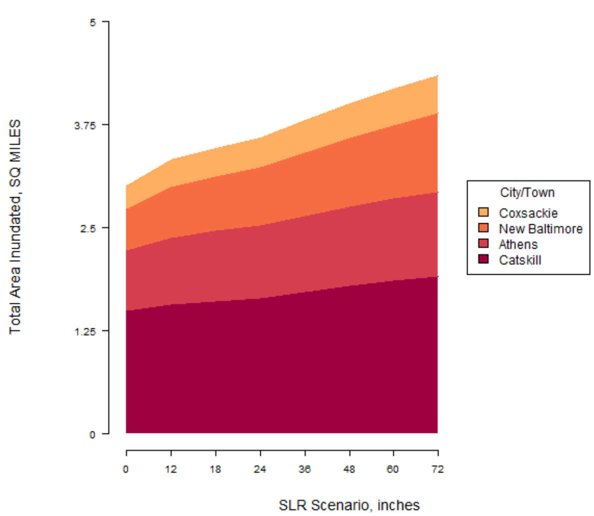
Greene County, 10-year Return Period



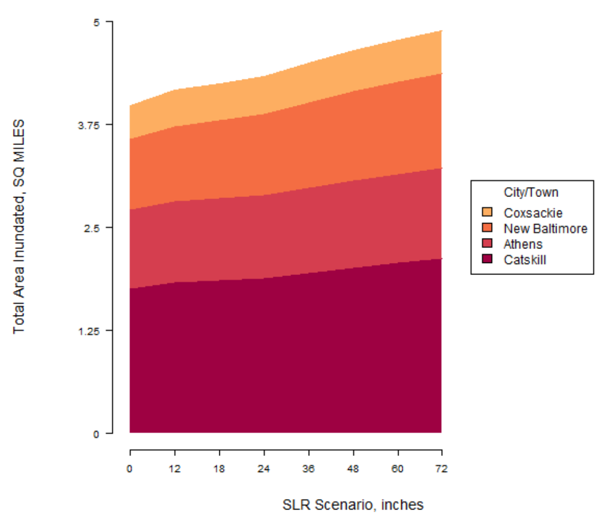
Greene County, 50-year Return Period

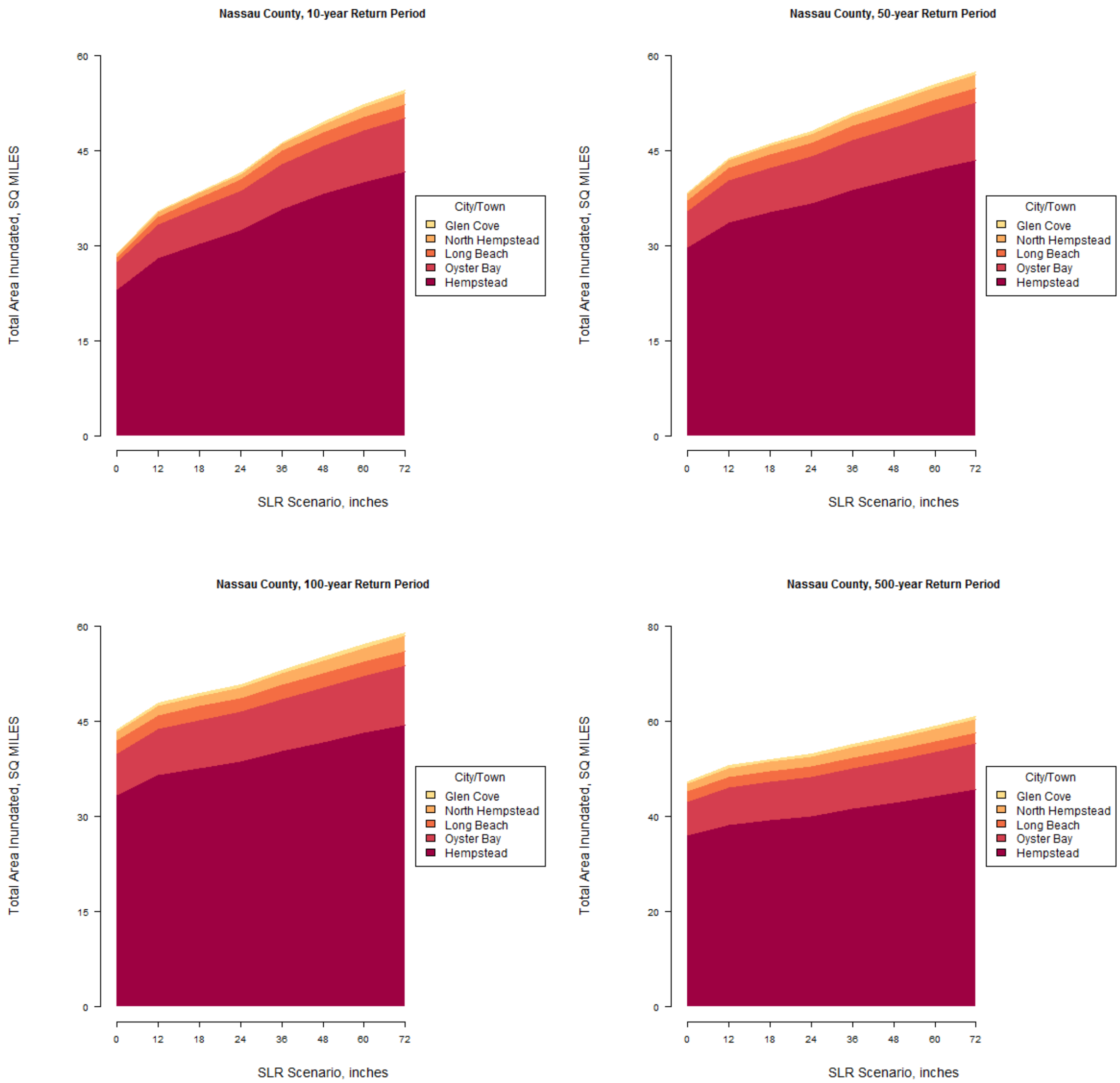


Greene County, 100-year Return Period

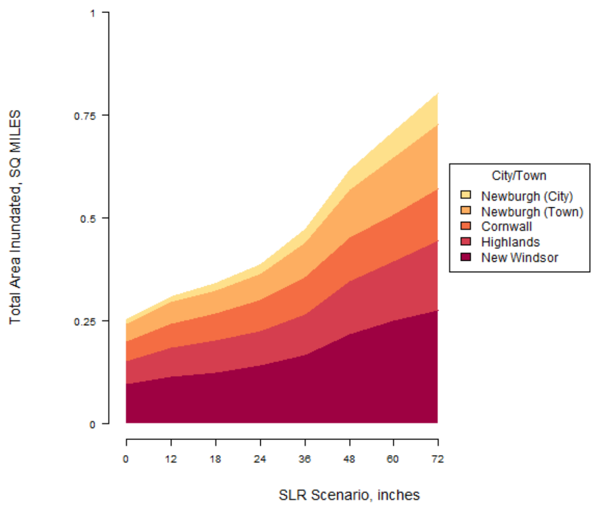


Greene County, 500-year Return Period

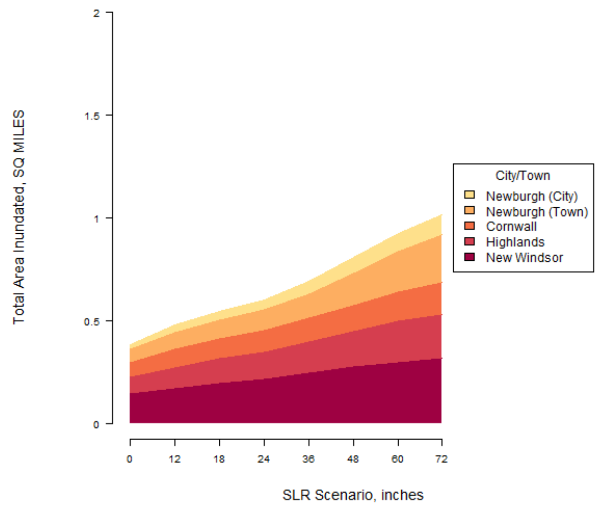



Nassau County, 10-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Glen Cove
North Hempstead
Long Beach
Oyster Bay
Hempstead
Nassau County, 50-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Glen Cove
North Hempstead
Long Beach
Oyster Bay
Hempstead
Nassau County, 100-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Glen Cove
North Hempstead
Long Beach
Oyster Bay
Hempstead
Nassau County, 500-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Glen Cove
North Hempstead
Long Beach
Oyster Bay
Hempstead

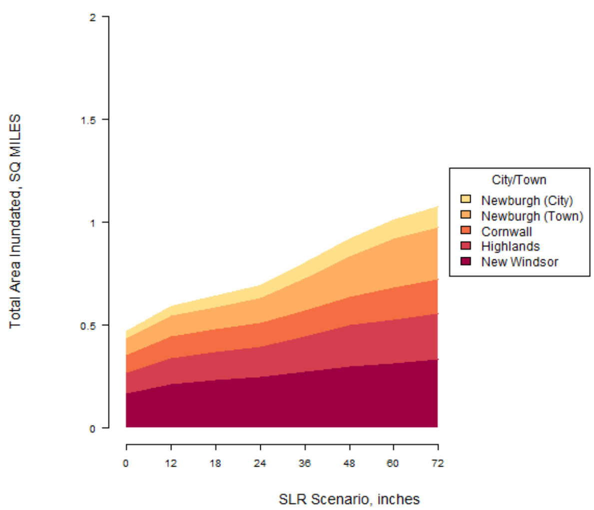
Orange County, 10-year Return Period



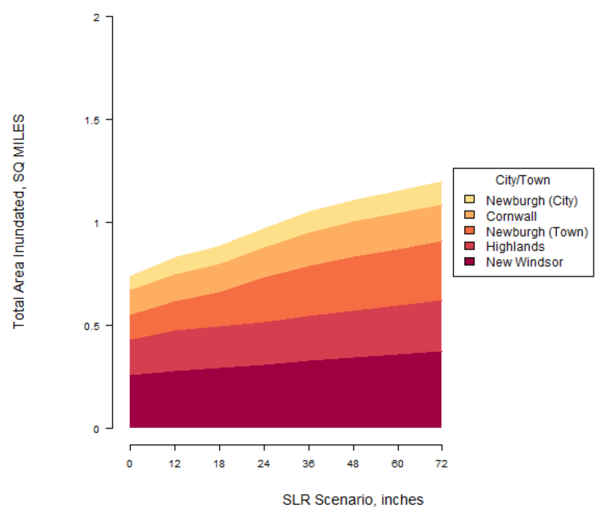
Orange County, 50-year Return Period

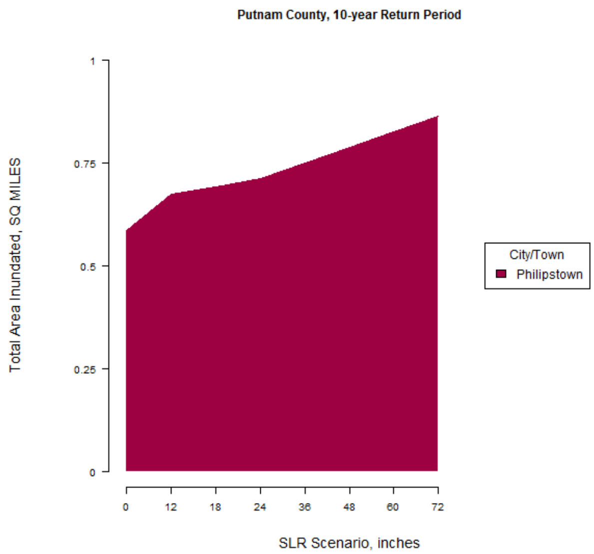


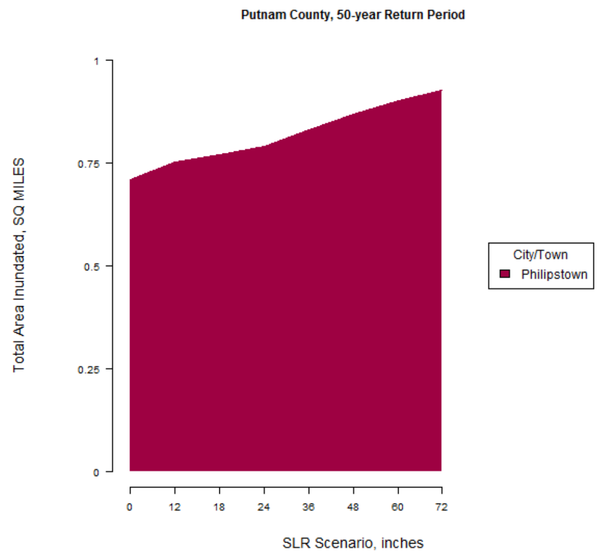
Orange County, 100-year Return Period

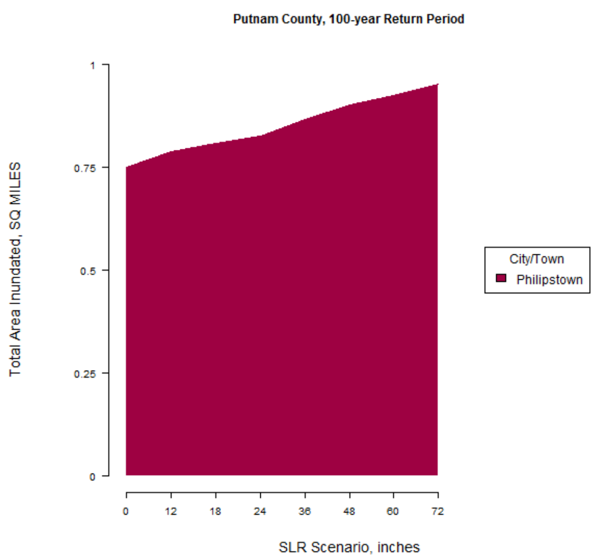


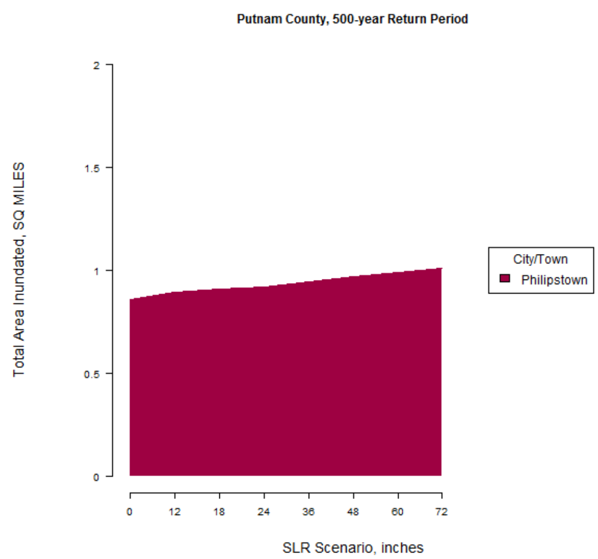
Orange County, 500-year Return Period

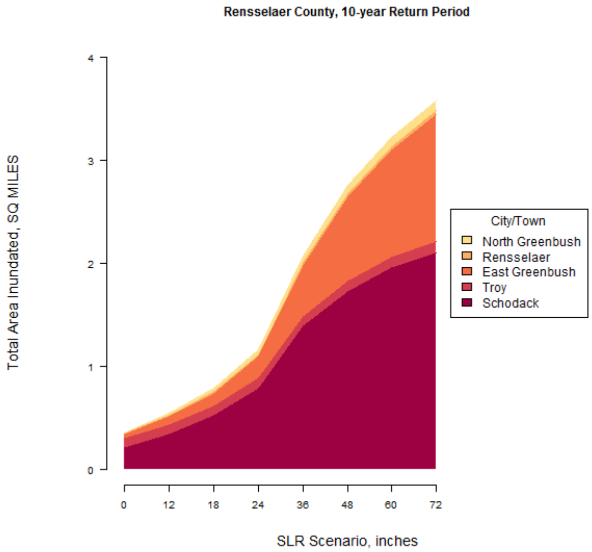


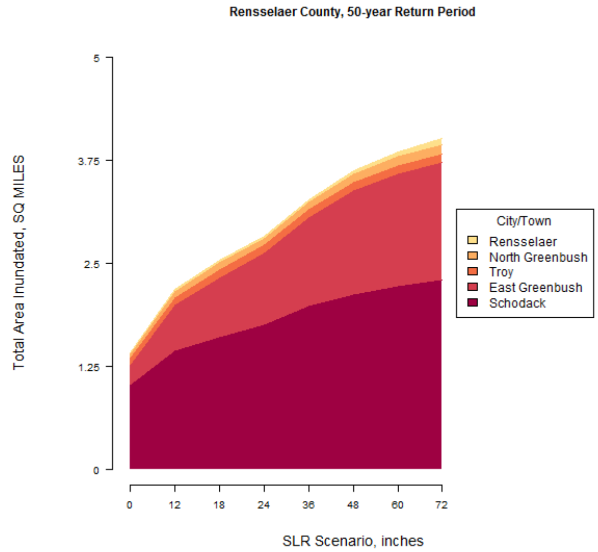

Putnam County, 10-year Return Period
Total Area Inundated, SQ MILES
1
0.75
0.5
0.25
0
0
12
18
24
36
48
60
72
SLR Scenario, inches
City/Town
Philipstown

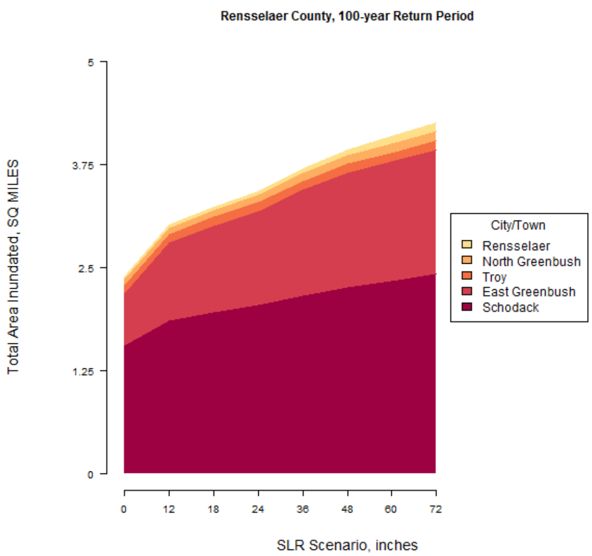

Putnam County, 50-year Return Period
Total Area Inundated, SQ MILES
1
0.75
0.5
0.25
0
0
12
18
24
36
48
60
72
SLR Scenario, inches
City/Town
Philipstown

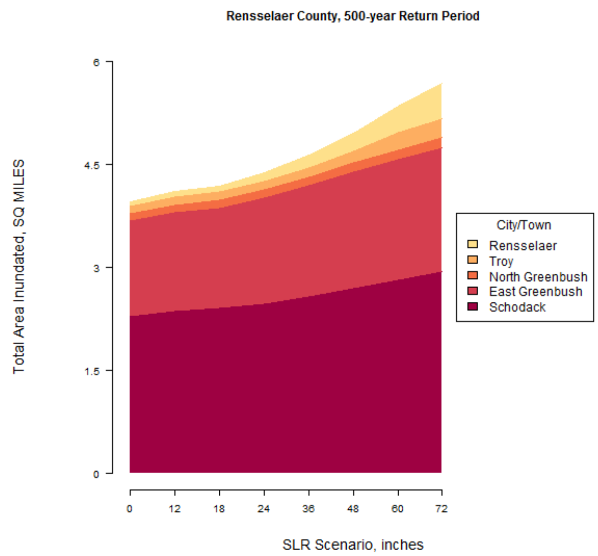

Putnam County, 100-year Return Period
Total Area Inundated, SQ MILES
1
0.75
0.5
0.25
0
0
12
18
24
36
48
60
72
SLR Scenario, inches
City/Town
Philipstown

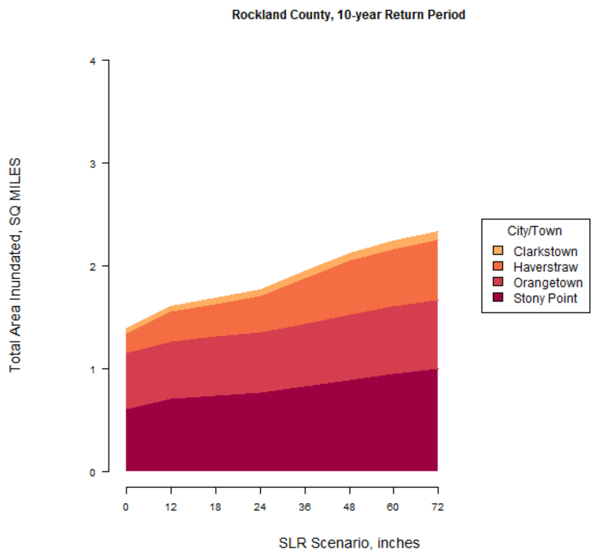

Putnam County, 500-year Return Period
Total Area Inundated, SQ MILES
2
1.5
1
0.5
0
0
12
18
24
36
48
60
72
SLR Scenario, inches
City/Town
Philipstown

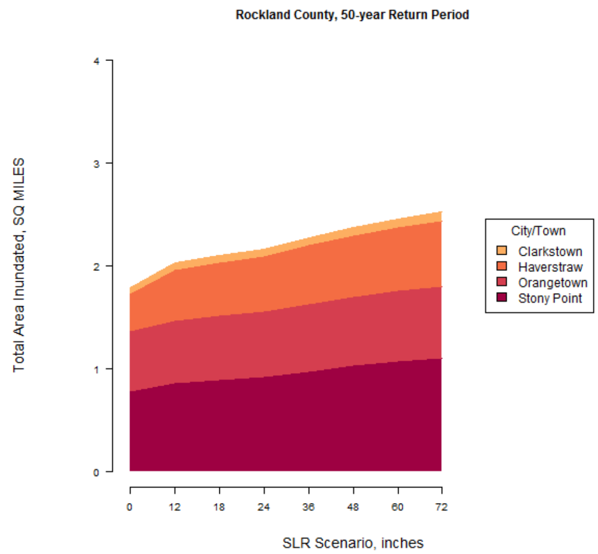

Rensselaer County, 10-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
1
2
3
4
0
12
18
24
36
48
60
72
City/Town
North Greenbush
Rensselaer
East Greenbush
Troy
Schodack

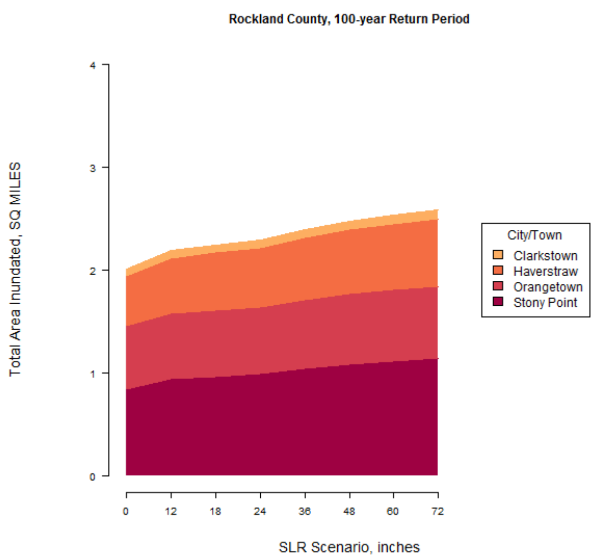

Rensselaer County, 50-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
1.25
2.5
3.75
5
0
12
18
24
36
48
60
72
City/Town
Rensselaer
North Greenbush
Troy
East Greenbush
Schodack

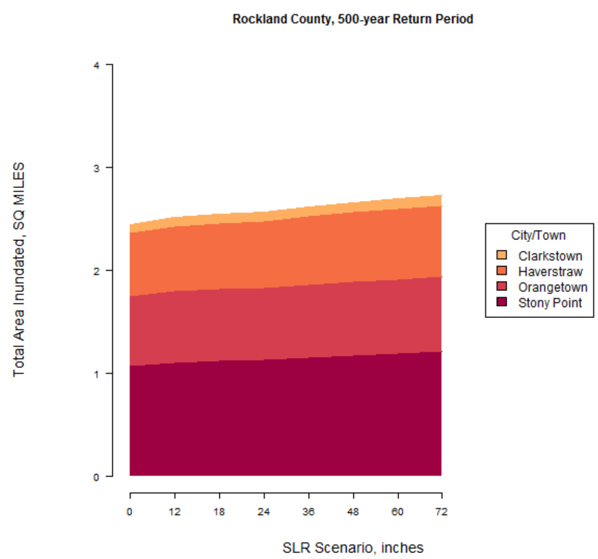

Rensselaer County, 100-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
1.25
2.5
3.75
5
0
12
18
24
36
48
60
72
City/Town
Rensselaer
North Greenbush
Troy
East Greenbush
Schodack

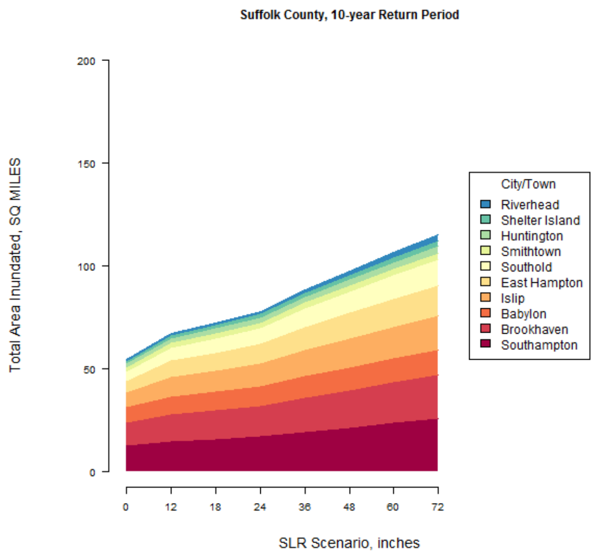

Rensselaer County, 500-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
1.5
3
4.5
6
0
12
18
24
36
48
60
72
City/Town
Rensselaer
Troy
North Greenbush
East Greenbush
Schodack

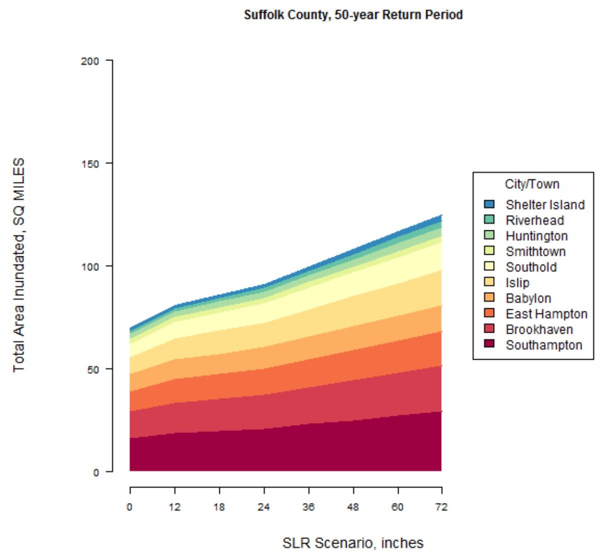

Rockland County, 10-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Clarkstown
Haverstraw
Orangetown
Stony Point

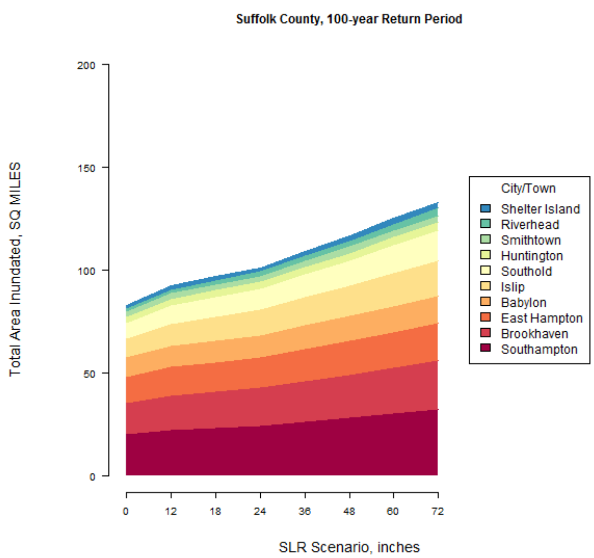

Rockland County, 50-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Clarkstown
Haverstraw
Orangetown
Stony Point

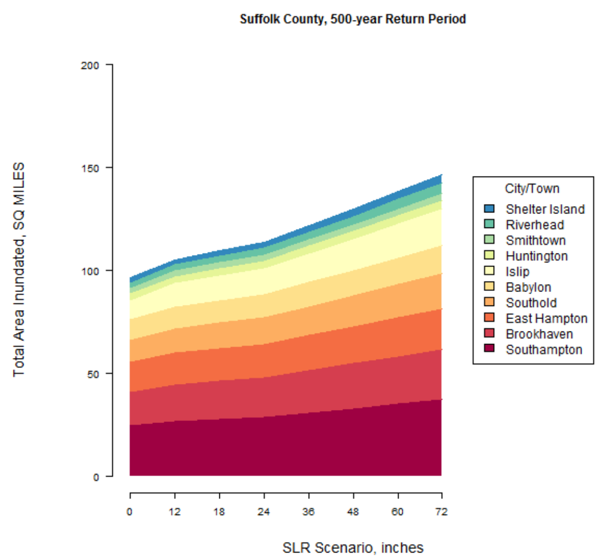

Rockland County, 100-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Clarkstown
Haverstraw
Orangetown
Stony Point


Rockland County, 500-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
City/Town
Clarkstown
Haverstraw
Orangetown
Stony Point

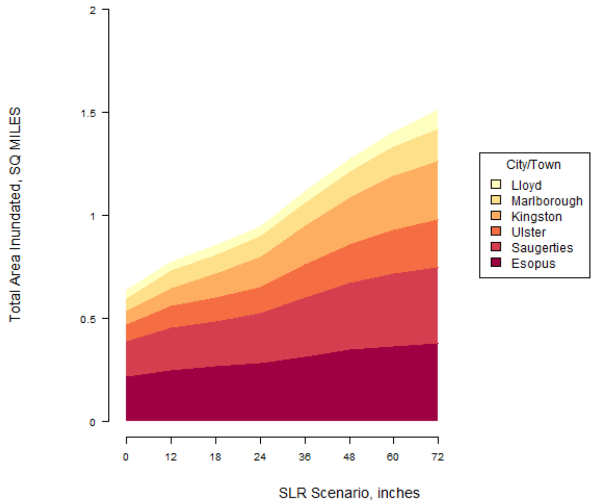

Suffolk County, 10-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
50
100
150
200
0
12
18
24
36
48
60
72
City/Town
Riverhead
Shelter Island
Huntington
Smithtown
Southold
East Hampton
Islip
Babylon
Brookhaven
Southampton


Suffolk County, 50-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
50
100
150
200
0
12
18
24
36
48
60
72
City/Town
Shelter Island
Riverhead
Huntington
Smithtown
Southold
Islip
Babylon
East Hampton
Brookhaven
Southampton

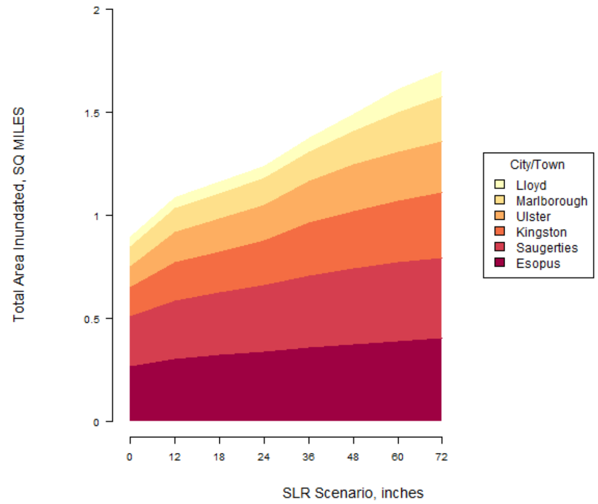

Suffolk County, 100-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
50
100
150
200
0
12
18
24
36
48
60
72
City/Town
Shelter Island
Riverhead
Smithtown
Huntington
Southold
Islip
Babylon
East Hampton
Brookhaven
Southampton


Suffolk County, 500-year Return Period
Total Area Inundated, SQ MILES
SLR Scenario, inches
0
50
100
150
200
0
12
18
24
36
48
60
72
City/Town
Shelter Island
Riverhead
Smithtown
Huntington
Islip
Babylon
Southold
East Hampton
Brookhaven
Southampton

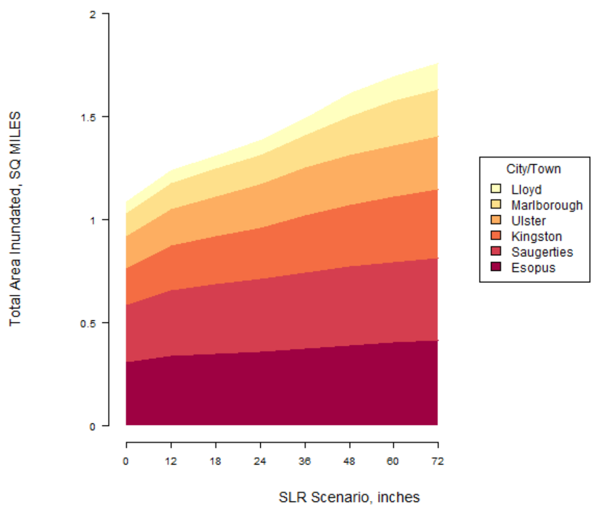
Ulster County, 10-year Return Period



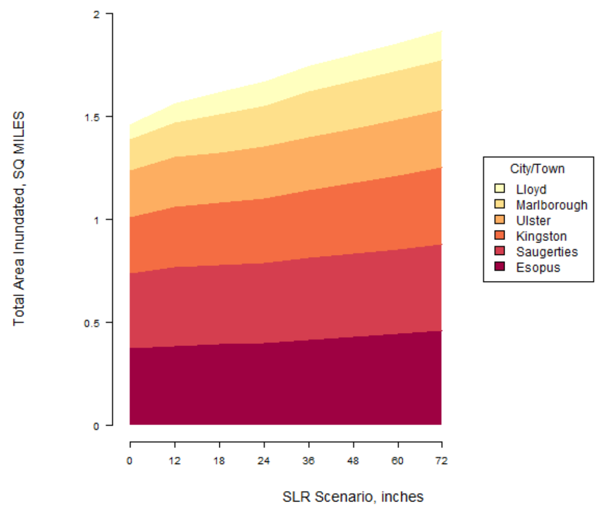
Ulster County, 50-year Return Period

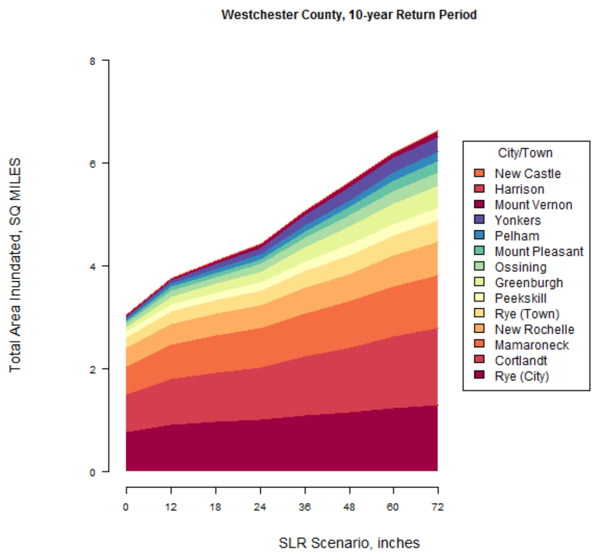


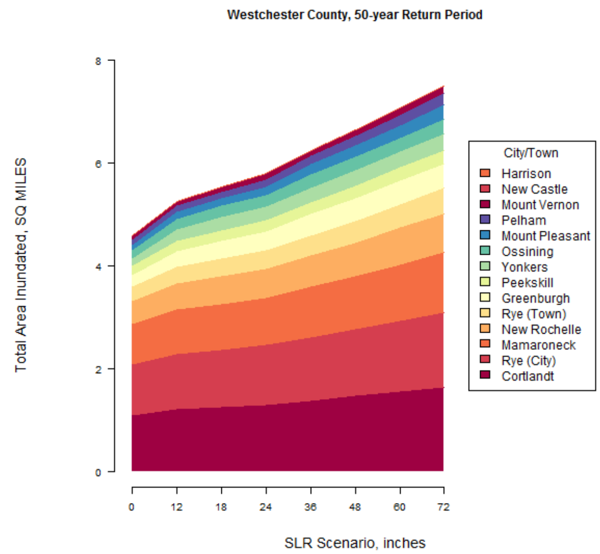
Ulster County, 100-year Return Period

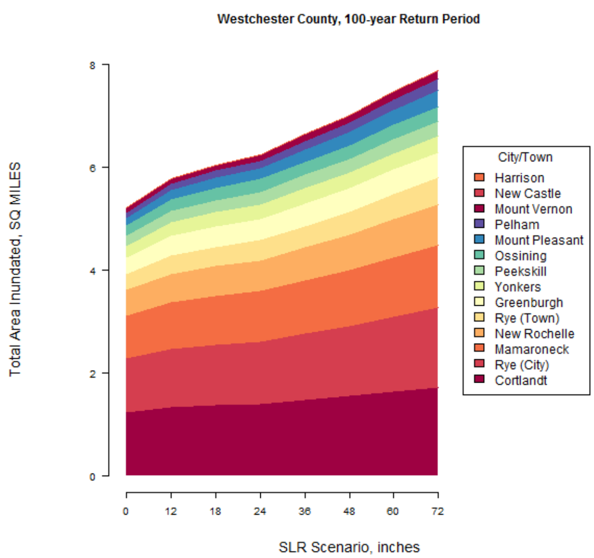


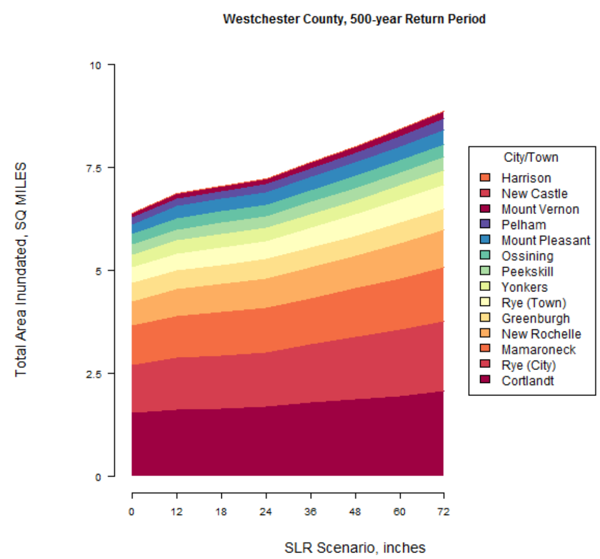
Ulster County, 500-year Return Period




Westchester County, 10-year Return Period
Total Area Inundated, SQ MILES
0
2
4
6
8
0 12 18 24 36 48 60 72
SLR Scenario, inches
City/Town
New Castle
Harrison
Mount Vernon
Yonkers
Pelham
Mount Pleasant
Ossining
Greenburgh
Peekskill
Rye (Town)
New Rochelle
Mamaroneck
Cortlandt
Rye (City)


Westchester County, 50-year Return Period
Total Area Inundated, SQ MILES
0
2
4
6
8
0 12 18 24 36 48 60 72
SLR Scenario, inches
City/Town
Harrison
New Castle
Mount Vernon
Pelham
Mount Pleasant
Ossining
Yonkers
Peekskill
Greenburgh
Rye (Town)
New Rochelle
Mamaroneck
Rye (City)
Cortlandt


Westchester County, 100-year Return Period
Total Area Inundated, SQ MILES
0
2
4
6
8
0 12 18 24 36 48 60 72
SLR Scenario, inches
City/Town
Harrison
New Castle
Mount Vernon
Pelham
Mount Pleasant
Ossining
Peekskill
Yonkers
Greenburgh
Rye (Town)
New Rochelle
Mamaroneck
Rye (City)
Cortlandt


Westchester County, 500-year Return Period
Total Area Inundated, SQ MILES
0
2.5
5
7.5
10
0 12 18 24 36 48 60 72
SLR Scenario, inches
City/Town
Harrison
New Castle
Mount Vernon
Pelham
Mount Pleasant
Ossining
Peekskill
Yonkers
Rye (Town)
Greenburgh
New Rochelle
Mamaroneck
Rye (City)
Cortlandt

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New York State Energy Research and Development Authority

17 Columbia Circle
Albany, NY 12203-6399

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fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov