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New York City Panel on Climate Change 2019 Report Chapter 5: Mapping Climate Risk

Lesley Patrick,[1] William Solecki,[1] Vivien Gornitz,[2] Philip Orton,[3] and Alan Blumberg[4]

[1]City University of New York, Hunter College, New York City, New York. [2]Columbia University, New York City, New York. [3]Stevens Institute of Technology, Hoboken, New Jersey. [4]Jupiter Intelligence, San Mateo, California

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5.1 Introduction

The mapping work of the NPCC is focused on illustrating spatial climate risk information to inform policy makers, stakeholders, and the public of the distribution of climate risk across the landscape of New York City. Flood risk, overall, has been the primary focus of climate risk, based on a variety of approaches including global climate models, semiempirical studies, literature surveys, expert-opinion, and historic tide gauge and more recently, satellite observations of sea level rise. Maps of potential future flood extents are used to visualize coastal flooding extents at the neighborhood scale and to assess the progression of citywide flood risk throughout the 21st century. The NPCC maps were developed as a tool to illustrate our present understanding of the potential futures for which we need to prepare.

This chapter reviews the background, methodology, and limitations of the NPCC3 (and NPCC2) mapping approach and features new citywide maps of mean sea level rise, monthly tidal flooding, and 100-year return period flooding under a high-end scenario of sea level rise. It concludes with a discussion of future mapping efforts and next steps that the NPCC could consider.

NPCC mapping history

The 2010 and 2015 NPCC reports featured citywide maps of current and projected future risk to extreme coastal flood events, specifically the 100-year flood.[a] These maps were displayed as standalone products and presented in the context of New York City jurisdictional boundaries, management areas, and critical infrastructure in order to highlight the need for interagency and interjurisdictional coordination in the development of adaptation strategies.

The NPCC chose to focus on the 100-year flood instead of sea level rise inundation or hurricane storm surge scenarios for two primary reasons: (1) the 100-year flood is used as the current critical benchmark for major land use, flood insurance, and policy decisions and therefore meaningful for decision makers and (2) as a theoretical value, the 100-year flood can be used to approximate potential flooding events, irrespective of the storm event with which they are associated.

The 2010 report featured 100-year flood maps based on two sets of sea level rise projections: 90th percentile model-based projections of sea level rise and semiempirical high-end "Rapid Ice Melt" projections of sea level rise, based on the average rate of sea level rise over the approximately 10,000-year period following the end of the last Ice Age. This scenario was intended to provide a rough simulation of what might occur with future accelerated rates of ice melt from the Greenland and West Antarctic ice sheets.

However, the record surge brought by Hurricane Sandy emphasized the need in follow-up research

[a]A map of the 100-year flood, also referred to as the 1-in-100 year flood or the 1% annual chance flood, identifies all locations that have a 1% chance of flooding in any given year. It is a statistical construct representing many possible flood events, not one particular event (Galloway *et al.*, 2006).

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to look beyond the 100-year flood to assess more upper end future flood possibilities. Though flood insurance is not required for structures located in the 500-year floodplain, knowledge of the potential extent of this floodplain in the future can serve to guide long-term efforts for planning and resiliency and allow for protection of critical infrastructure and essential facilities. For this reason, in the subsequent 2015 report, the NPCC2 chose to feature maps of both the current and potential future 100- and 500-year floodplains based on the 90th percentile model-based sea level rise projections.

NPCC3 mapping

In line with previous reports, the NPCC3 has created a map of the current and future 100-year flood based on 90th percentile model-based projections of sea level rise. However, this work also includes two new floodplains developed from high-impact, low-probability Antarctic Rapid Ice Melt (ARIM) sea level rise projections (see Chapter 3, for a discussion of the new ARIM scenario).

In addition, the NPCC3 has expanded its scope of mapping work beyond the 100-year and 500-year flood events to consider other types of coastal flood risk. Maps showing the expansion of land exposed to monthly tidal flooding and mean sea level rise over time were developed to illustrate areas increasingly impacted by frequent flooding, as well as areas that could become permanently submerged due to future sea level rise. Monthly tidal flood mapping is useful for planning, in that it is a useful threshold indicator of repeated flooding that is sufficient to trigger large-scale adaptation investments.

Mean sea level rise mapping also depicts land that could potentially be submerged in the future under a given sea level rise scenario. Submerged refers to areas of the coastline that are underwater at all times, and not just subject to flooding during high tides and coastal storm events.

Two new data products have yielded significant advancements in the NPCC3 mapping methodology and results: a new LiDAR data set for New York City and a hydro-enforced digital elevation model (DEM) used to depict baseline topography. The new LiDAR data set, collected in 2017, is an update from the 2010 data set and captures recent areas of enhanced coastal protection. The hydro-enforced DEM is an improvement upon the bare-earth DEM used in previous reports in that it removes artificial obstructions to water flow by accounting for culverts and other devices that allow water to flow beneath structures. A bare-earth DEM is unable to capture these structures resulting in artificial floodplain boundaries. These two data products have improved the accuracy of the mapping methodology, resulting in more conservative floodplain extents.

Each of the NPCC flood maps are meant to illustrate three distinct areas of interest worthy of further study: (1) areas currently subject to flooding that will continue to be subject to flooding in the future; (2) areas that are not currently subject to flooding but are expected to potentially experience flooding in the future; and (3) areas that do not currently flood and are unlikely to do so within the timeframe of the climate projection scenarios (end of the current century). In this way, the NPCC has established a framework by which to evaluate future flood scenarios.

All spatial data involve uncertainty and error. As a result, NPCC flood maps should be considered only as a representation of current and potential future conditions and never understood to be actual reality or predicted reality.[b]

Background

Many studies have produced maps of coastlines at risk of future sea level rise scenarios. Their purpose was to illustrate the impacts of accelerated sea level rise on coastal lands and to estimate the spatial extent of areas at risk of inundation. In many of these efforts, projections of sea level rise were added to topographic contours, orthometric datums, or tidal datums to map land that could be inundated or eroded by rising seas, and to delineate potential future coastlines within the continental United States.

However, many of these studies were limited in that they only evaluated sea level rise inundation and did not account for specific flood events; they did not connect their analyses with designated flood hazard metrics, nor did they evaluate populations or infrastructure at risk (Titus and Richman, 2001; Mazria and Kershner, 2007; Poulter and

[b]NPCC maps, unless otherwise noted, do not take into account future coastal protection measures or other changes in shoreline elevations that may reduce the extent of future flooding.

Halpin, 2007; Gesch, 2009; Li *et al.*, 2009; Cooper *et al.*, 2005; Gornitz *et al.*, 2002). Although high-resolution LiDAR (light detection and ranging) elevation data were used in a few studies (Larsen *et al.*, 2004; Poulter and Halpin, 2007; Titus and Wang, 2008; Gesch, 2009), the majority of elevation data sets used in these studies were of coarse resolution providing limited accuracy.

Projections of sea level rise have been added to specific flood events using the SLOSH (Sea, Lake and Overland Surges from Hurricanes) model, which estimates storm surge heights from hurricanes, to assess vulnerability within future sea level rise enhanced storm surge zones. See Wu *et al.* (2002); Kleinosky *et al.* (2006); Rygel *et al.* (2006) for examples of SLOSH application in other locations contexts.

These studies could be particularly useful in areas of the New York City coastline where higher topography or protective infrastructure limits sea level effects to increased height and extent of storm surge events. This is especially relevant in those waterfront areas of the city where high bulkheads have been built and as a result local flooding will initially be associated with storm surge as opposed to gradual sea level rise and increase of tidal water reach.

In addition to mapping future sea level rise scenarios, a few studies have evaluated sea level rise enhanced storm surge zones under future scenarios of population growth to assess potential emerging areas of community vulnerability (Wu *et al.*, 2002; Kleinosky *et al.*, 2006).

Data and imagery about sea level rise and coastal flood events have become increasingly accessible via online web mapping tools. Sea level rise mappers and viewers such as NOAA Digital Coast's Sea Level Rise Viewer and Coastal Flood Exposure Mapper (https://coast.noaa.gov/digitalcoast/tools/slr; and https://coast.noaa.gov/digitalcoast/tools/flood-exposure.html), Climate Central's Surging Seas Risk Zone Map (https://ss2.climatecentral.org), and NYC's Flood Hazard Mapper (https://www.nyc.gov/floodhazardmapper) visualize community-level impacts from coastal flooding or sea level rise and allow for the assessment of flood risk.

These tools enable the user to select various scenarios of sea level rise or coastal flood elevation at multiple scales, even down to the street level. Though the NPCC does not plan to develop a web mapping tool itself, the shapefiles developed for each of the floodplains have been and will continue to be made available to the public through NYC's Open Data portal.

Methodology and limitations

This section reviews the flood mapping methodology and limitations and describes the intended use of the maps.

Data sets used for mapping. The following data sets were used to develop the NPCC3 flood maps:

1. High-estimate (90th percentile) value projections of sea level rise elevations for the 2020s, 2050s, 2080s, and 2100 developed by NPCC2.
   - 2020s, 10 inches; 2050s, 30 inches; 2080s, 58 inches; 2100, 75 inches
   - Completed: December 2013
2. High-impact, low-probability ARIM projections of sea level rise elevations for the 2080s and 2100 developed by NPCC3.
   - 2080s, 81 inches; 2100, 114 inches
   - Completed: February 2018
3. Mean monthly high water (MMHW) tidal elevations based on the six projections of 90th-percentile and low-probability ARIM sea level rise.
   - Modeled using the New York Harbor Observation and Prediction System (NYHOPS)
   - Vertical datum: NAVD88
   - Completed: October 2018
4. Preliminary 2015 FIRMs derived from the FEMA 2013 Preliminary Flood Insurance Study for the City of New York, NY.
   - FEMA's best available flood maps for New York City
   - Flood extent and base flood elevation (BFE) information (relative to the North American Vertical Datum of 1988 (NAVD88)) for the 100-year floodplain
   - Release date: December 5, 2013
5. Hydro-enforced DEM for New York City
   - Surface developed from LiDAR data collected in May 2017 over New York City
   - Nominal pulse spacing of LiDAR: 0.35 m
   - Density: average 8 pulses/m^2
   - Non-vegetated vertical accuracy: 2.9 inches (7.4 cm)
   - Horizontal datum: North American 1983 (NAD83, 2011)

- Vertical datum: NAVD88 (GEOID012B)
- Release date: October 2018

The hydro-enforced DEM used in the NPCC3 flood map process was developed from LiDAR data collected in the spring of 2017 by Quantum Spatial, Inc. The non-vegetated vertical accuracy of the DEM was reported as 2.9 inches (7.4 cm) with 95% confidence (Quantum Spatial, 2017), a significant improvement over the 2010 DEM vertical accuracy of 3.7 inches (9.5 cm). The 90th percentile sea level rise projections of 10 inches (25.4 cm) for the 2020s, 30 inches (76.2 cm) for the 2050s, 58 inches (145.3 cm) for the 2080s, and 75 inches (190.5 cm) for 2100, and the ARIM projections of 81 inches (205.7 cm) for the 2080s and 114 inches (289.6 cm) for 2100 all exceed the 95% error bounds of the elevation data. Thus, the vertical accuracy of the underlying elevation data is sufficient to support the mapped sea level rise increments.

Methods. All NPCC3 map products were developed using spatial processing techniques in ESRI's ArcGIS software. The hydro-enforced DEM data set for New York City provided foundational topographic data upon which to model future floodplain extent. All floodplains were created using a static "bathtub" coastal flood-modeling technique that assumes floodwaters will continue to move landward until they reach an equivalent topographic elevation (see NPCC2; Rosenzweig and Solecki, 2015). Baseline flood elevation data sets were specific to the map being created.

The map of the potential progression of mean sea level over time did not reference a baseline flood elevation data set but instead directly referenced the hydro-enforced DEM to delineate flood extent. In the DEM, all cells at or below a given mean sea level elevation were flagged as flooded, capturing low elevation areas both along the coast and in the interior of the city. The interior areas of low elevation not connected to the ocean were removed and the low elevation coastal areas were retained to represent the mean sea level floodplain.

The future monthly tidal flood map was developed using a baseline data set of modeled tidal water elevations combined with projections of future mean sea level. Tides were modeled along the New York City coastline using the Stevens Institute of Technology Estuarine and Coastal Ocean Model on the NYHOPS model domain (Georgas and Blumberg, 2010; Orton *et al.*, 2016). Static flood mapping was used to extrapolate the tidal flood elevations from the coastline to the interior to approximate flood extent (Patrick *et al.*, 2015).

Future 100-year floodplains were developed using a baseline data set of FEMA's 2015 Preliminary FIRM BFE values combined with projections of sea level rise. The combined values were extrapolated from the coastline landward until reaching a topographic contour of equivalent elevation.

One distinguishing aspect of the NPCC 100-year flood maps as compared to some storm surge and sea level rise maps is the integration of base flood elevation data into their future flood projections. Many sea level rise and storm surge mapping methodologies use one spatially constant flood elevation as their baseline and simply add elevation to represent inundation.

For example, Cooper *et al.* (2005) considered the 100-year flood in their analysis of the impacts of sea level rise on New Jersey. They used FEMA's 100-year base flood elevation for Atlantic City (9.5 ft), added projections of sea level rise elevation, and applied that new value to the entire New Jersey coastline by mapping the corresponding topographic contour. However, the complex coastal configuration around New York City causes large spatial variations in tides and storm surge (Orton *et al.*, 2012), resulting in large changes in BFE values over small horizontal alongshore distances.

Change in flood elevation values should also be incorporated, such that the inland shape and extent of the flood zone reflects the changing base flood elevation values nearer to shore. The NPCC approach incorporates these lateral variations in flood elevation values by assuming that landward values of floodwater elevation are likely to be more similar to neighboring flood-elevation values and less similar to more distant values. This unique approach to flood modeling is creative but also simplistic in that it makes broad assumptions about the movement of floodwaters.

The across-shore variation in flood elevation is a complex process best quantified via a combination of high-resolution but computationally intensive hydrodynamic and wave modeling. This modeling accounts for the effects of soils, vegetation, surface permeability, topography, existing structural and nonstructural flood protections, friction, and other factors that affect the movement of floodwaters and result in local variations in flooding extent.

When the use of hydrodynamic and wave transformation modeling is not available to develop future flood projections, many assumptions, sometimes *ad hoc*, have to be made in the GIS-based NPCC methodology concerning storm surge movement and wave action, and connectivity to the open ocean. In addition, numerous sources of error and uncertainties exist in data sets that are foundational to the future flood maps. For example, the NPCC sea level rise projections, the modeled BFE values developed by FEMA, and the underlying topographic data set each have their own margin of error that is difficult to quantify and present visually on the NPCC flood maps.

The flood maps of future conditions developed by the NPCC are useful for presenting such data. A great advantage of these maps is that they are not specific to a given storm and instead present surge scenarios that could occur in tropical storm, hurricane, or nor'easter conditions, thereby broadening their applicability (see Chapter 4, Coastal Flooding). Maps that approximate future flood zone extents are critical to decision and policy makers as well as the public to prepare for floods of increased elevation, extent, and duration. Also, local and regional stakeholders and policy makers consider these NPCC maps in the development of their climate change adaptation plans and strategies. Thus, NPCC maps can complement and add value to ongoing citywide resiliency efforts.

5.2 Mean sea level

Mean sea level (specifically local MSL) is a term that describes the average elevation of the surface of the ocean, relatively to land elevations. We know that mean sea level is rising globally but at rates that vary regionally. In New York City, the historic rate of sea level rise has averaged 0.12 inches per year, a rise imperceptible to the naked eye but documented through measurements at local tide gauges (see Chapter 3, Sea Level Rise).

Unlike abrupt flooding events brought about by tides or storm surge, the rise of mean sea level is a gradual encroachment of the ocean upon shorelines. With the exception of areas of storm-induced coastal erosion, many neighborhoods in New York City that experience coastal flood events become high and dry again once waters recede. For this reason, the idea of permanent submersion remains an abstraction. Therefore, it is important to map the potential progression of mean sea level throughout the 21st century in order to emphasize the potential for current coastlines to become submerged in the future.

The significance of mean sea level in the context of sea level rise is that it marks the final stage of a sequence of progressively frequent and intense flooding as lands transition from lying above to lying below mean sea level. In this sequence, as sea levels rise, lands that were once beyond the reach of coastal flooding become vulnerable to extreme and infrequent coastal flood events such as the 1000-year and 500-year storm. As sea levels continue to rise, these same lands grow increasingly vulnerable to flooding during less extreme events, such as the 100-year storm flood, then monthly high tide[c] flooding, and eventually daily high tides. If sea level continues to rise, these lands fall below mean sea level, at which point they are wetted by tides more often than they are dry.

The map presented in Fig. 5.1 depicts the coastal areas potentially subject to submersion under 90th percentile model-based scenarios of sea level rise over time and upper-end, low-probability ARIM scenario sea level rise toward the end of the 21st century.

According to the 90th percentile model-based projections of sea level rise shown in Figure 5.1, areas more likely to experience submersion later in this century include low-lying wetlands, such as the marshes and Broad Channel neighborhood of Jamaica Bay; Saw Mill Creek, and Old Place Creek parks in western Staten Island; and Flushing Meadows Park in Queens. Areas bordering waterways such as the Gowanus Canal in Brooklyn, Newton Creek in Brooklyn and Queens, and Pelham Bay in the Bronx may also become submerged.

Also of note are areas of the Coney Island Peninsula protected from the Atlantic yet flooded from the north through Sheepshead Bay and the Coney Island Creek. Bayside neighborhoods of the Rockaway Peninsula such as Somerville and Edgemere

[c] King tides, or the Proxigean Spring Tide, refer to the very highest naturally occurring tides.

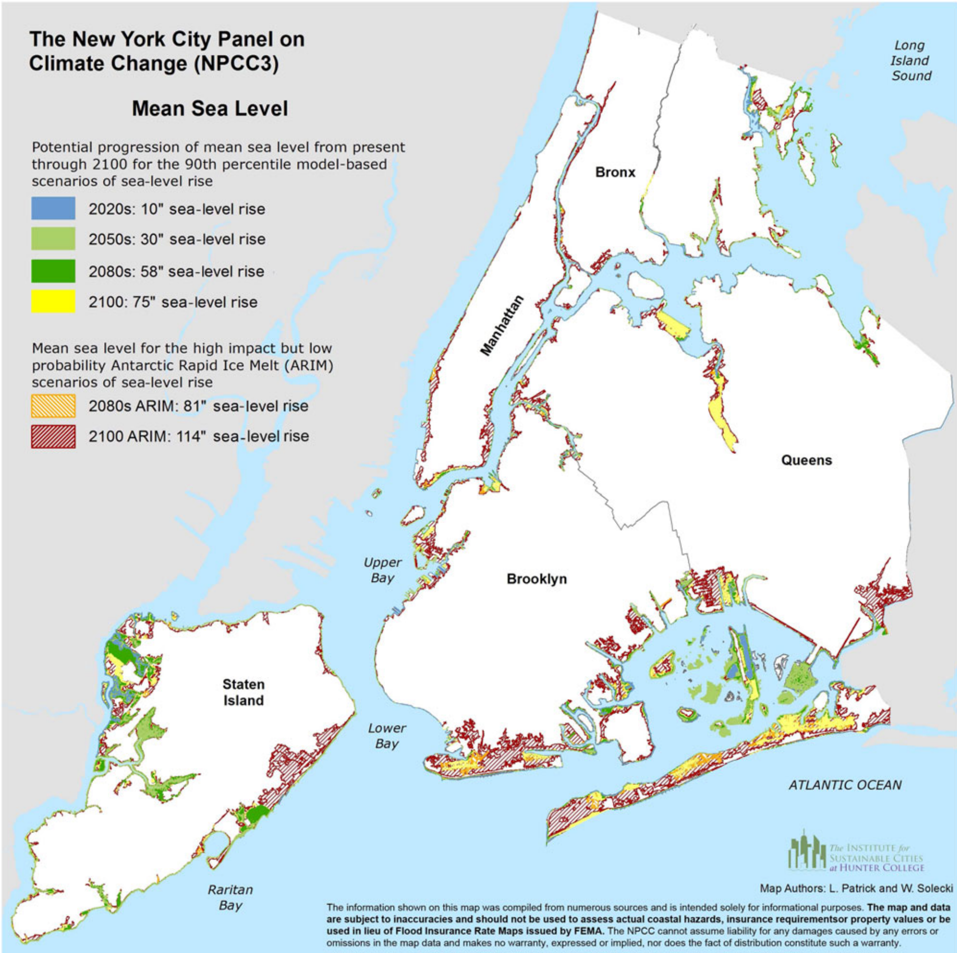

Figure 5.1. Potential progression of mean sea level from present through 2100 for 90th percentile model-based scenario and the ARIM scenario of sea level rise. NOTE: The 90th percentile sea level rise projections from NPCC (2015) remain the scientific basis for New York City resiliency planning programs. Furthermore, the areas delineated on this map do not represent precise flood boundaries, but rather illustrate distinct areas of interest: (1) Areas that are not currently below mean sea level but may become submerged in the future; and (2) Areas that are not currently below mean sea level and are unlikely to become submerged in the timeline of the climate projection scenarios (end of the current century).

may also become submerged along with parts of the Navy Yard and Red Hook in Brooklyn and LaGuardia Airport in Queens.

The low-probability, high-impact ARIM scenario shows further encroachment of sea level late in the 21st century into most of the Rockaway Peninsula and Coney Island up through Gravesend, the eastern coast of Staten Island, and the Howard Beach and Rosedale neighborhoods in Queens, among other areas. Although the ARIM scenario is an upper-end estimate of sea level rise, it is important to acknowledge the potential for an expanded mean sea level floodplain within the next 100 years.

5.3 Monthly tidal flooding

In contrast to the often-indiscernible long-term change of mean sea level, tides can be perceived and experienced daily along most coastlines. The term "tides" refers to the rise and fall of sea levels due to the combined effects of the gravitational forces exerted by the moon, sun, and Earth. In New York City, semi-diurnal tides produce two high waters and two low waters each day, with an average tidal range[d] of 5.06 ft (1.54 m). Spring tides exceed the

[d]The average tidal range refers to the difference in height between high and low waters.

average tidal range producing very high and very low tides during the full and new moons. Often the highest tide on one of the two spring tides is substantially higher than the other, controlled by the distance between Earth and the Moon that varies through the Moon's orbit. The significance of tidal flooding in the context of sea level rise is that the frequency of tidal flooding on streets is a metric of interruption of commerce and the necessity of adaptation.

NPCC3 uses dynamic model simulations with sea level projections to quantify the future evolution of tides (see Chapter 4, Coastal Flooding), though we use static mapping to map these water levels onto topography. Tides are far more predictable than storm surges because they are caused by the gravitational pull of the moon and the sun, and thus modeling their potential flooding requires a much smaller number of simulations and computational resources. Presently, monthly tidal flooding threatens the lowest properties in a few city neighborhoods (e.g., Howard Beach in Jamaica Bay). The NPCC has not previously evaluated how sea level rise will affect this tidally driven "sunny-day" nuisance flooding.

Mean monthly high water (MMHW) is a new metric defined as the average of all monthly maxima in predicted astronomical tide levels. Here, three-dimensional dynamic simulations of tides are performed using the Stevens Institute of Technology Estuarine and Coastal Ocean Model using the New York Harbor Observing and Prediction System (NYHOPS) operational model setup and grid (Georgas and Blumberg, 2010; Orton *et al.*, 2016).

Simulations cover a 35-day period beginning August 1, 2015, under tide and streamflow forcing (no wind). Modeled water-level time series at all model grid cells are subjected to tidal harmonic analysis (Pawlowicz *et al.*, 2002) to create 19-year tide time series that capture all the periodicities therein, and monthly maxima are computed and averaged (see Section 4.3.2 for a full discussion of tidal modeling).

The modeled MMHW data are mapped to illustrate potential future monthly sunny-day tidal flooding. MMHW is typically exceeded by observed water levels about 25–35 times per year in New York City, based on examination of observed water levels at The Battery, Kings Point, and Jamaica Bay (Inwood).[e]

Alternatively, the mean higher high water tidal (MHHW) datum is commonly used with static flood mapping to evaluate future flooding due to sea level rise (e.g., Climate Central, 2018; NYC-DCP, 2018). However, MHHW represents flooding that occurs far more frequently—hundreds of times per year—and is therefore less meaningful as a threshold indicator of livability (for more discussion, see Chapter 4, Coastal Flooding).

Figure 5.2 presents the map of monthly tidal flooding for New York City, based on projections of 90th-percentile and ARIM sea level rise. Under the 90th percentile sea level rise scenario, monthly tidal flooding by the 2050s will become moderately widespread, and by 2100 very widespread across many waterfront and coastal neighborhoods. In the more extreme ARIM scenario, at 2100 the flooding is extremely widespread.

One important consequence of an upper-end sea level rise scenario such as ARIM is a rapid advancement from sunny-day tidal flooding to complete loss of land to the ocean. Although New York City is not at immediate risk of extensive land inundation, some neighborhoods may face permanent land loss in 2100 under the ARIM scenario.

For example, a comparison of Figure 5.1 with Figure 5.2 suggests that some of the areas that could undergo monthly tidal flooding by the 2050s under the 90th percentile sea level rise projection (NPCC, 2015), shown in light green, respectively, might face permanent inundation by the 2080s if the latter half of the century begins to follow the ARIM sea level rise scenario, in the absence of additional coastal protection measures. Areas colored yellow (2100 90th percentile) often obscure those with orange hatching (2080s ARIM), as these two sea level scenarios are nearly equal (75 versus 81 inches).

Areas that would be permanently inundated in the 2080s of the ARIM scenario include portions of Rockaway Peninsula, Howard Beach, Coney Island, Red Hook, and Staten Island, as well as edges of lower Manhattan waterfront, the Gowanus Canal

[e]Sweet and Park (2014) associated approximately 30 floods per year as a tipping point for property abandonment.

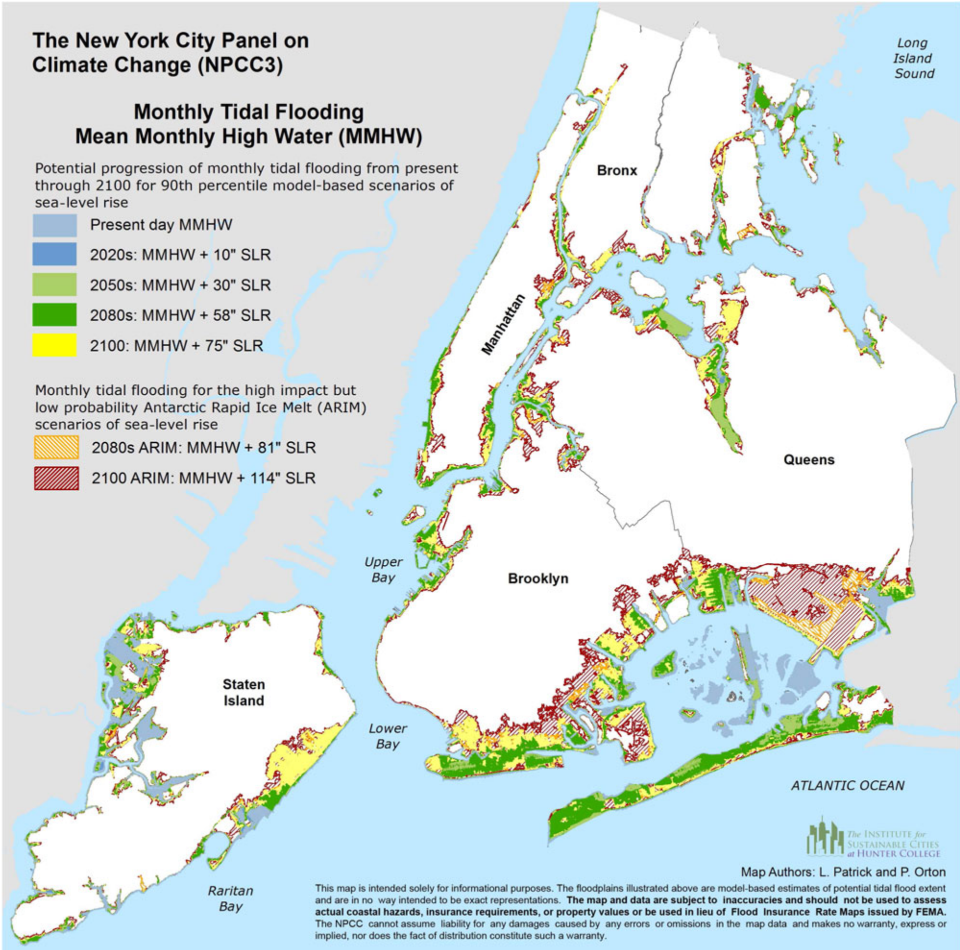

Figure 5.2. **Potential progression of MMHW flooding from present through 2100 for 90th percentile model-based scenarios and the ARIM scenarios of sea level rise. NOTE: The areas delineated on this map do not represent precise flood boundaries but rather illustrate distinct areas of interest: (1) Areas currently subject to flooding that will continue to be subject to flooding in the future; (2) Areas that do not currently flood but are expected to potentially experience flooding in the future; and (3) Areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios (end of the current century).**

in Brooklyn and Newtown Creek in Brooklyn and Queens, and Pelham Bay in the Bronx. Because Figure 5.1 is based on data with high associated uncertainties, it should be regarded as suggestive of areas that might become inundated and should therefore not be used for planning purposes. See the further discussion in Chapter 3, Sea Level Rise.

5.4 One hundred-year flood

While tidal flooding is frequently experienced in coastal communities, the 100-year flood is a higher-impact but lower-frequency event. The 100-year flood is based on statistical analysis of historical data and encompasses all locations that have a 1% or higher chance of being flooded in any given year. It can be a misleading term, in that neighborhoods situated within the current 100-year floodplain could be flooded 2 years in a row, or not flooded at all in 150 years. Regardless, the 100-year flood zone is an important benchmark in that it is considered a high-risk flooding area and subject to special building codes, insurance requirements, and environmental regulations.

The significance of the 100-year flood in the context of sea level rise is threefold: (1) neighborhoods not previously vulnerable to the 100-year flood will grow increasingly vulnerable as sea level rises, (2) neighborhoods currently within today's 100-year floodplain will experience higher 100-year flood elevations during future floods, and (3) neighborhoods currently within today's 100-year floodplain will experience such flooding much more frequently (in other words, the return period of the 100-year flood will become shorter).

Significant attention in NPCC3 mapping has been given to improved presentation and understanding of future flood events and how sea level rise projections may alter the spatial extent of the FEMA 100-year floodplain. A key question not considered in previous NPCC reports is what are the flood extents for the 2080s and 2100 under the ARIM scenario of sea level rise (see Chapter 3, Sea Level Rise, for discussion of the ARIM projections). The map presented in Figure 5.3 illustrates the potential landward progression of the 100-year floodplain from its current extent though the year 2100 for both 90th percentile and upper-end ARIM scenarios of sea level rise. The maps show a growing area of the city susceptible to future possible extreme events.

It is important to understand that these maps reflect the current coastline of New York City and do not account for planned or potential future coastal protection features. Site-specific projects to restore wetlands and fortify shorelines are in progress and under development, and these natured-based and hard-engineering approaches may serve to reduce the extent and elevation of the 100-year flood (see Chapter 9, Perspectives).

5.5 Moving forward

The NPCC has been mapping climate risk information for 10 years. Future NPCC mapping includes several next steps.

Incorporating confidence intervals into modeled results

Several data and process limitations are embedded in sea level rise maps. Inherent uncertainty is present in the flood extent shapefiles used to delineate future flood events. NPCC flood shapefiles contain numerous sources of potential error as a result of the data sets and methodologies used in their development: errors in the topographic elevation data, sea level rise projections, and FEMA model outputs all contribute to this uncertainty and limit the accuracy of the shapefiles. The population, facilities, and infrastructure within the future flood zones are defined as "flooded" by the shapefile extents.

Though not quantified, the uncertainty of future flood areas is lower near the coastline and greater near the inland boundaries of the flood extents. It is possible that small changes to the flood-extent boundary could result in large changes to the populations defined as "flooded." For this reason, future work should consider using flood data that incorporate confidence intervals in the analysis. Visualizing this uncertainty is a challenge to be addressed.

Mapping synergistic flood properties

Although current mapping only considers the impacts of storm surge flooding events, future work might consider how the cumulative effect of storm surges combined with intense rainfall flooding might impact the movement, timing, and drainage of floodwaters. Though coastal flooding dominates in NYC, fluvial and urban street flooding occurs during intense rainfall events resulting in overflows in residential and municipal drainage systems. Coastal flooding may reach greater extents and take longer to recede with storm drains already overfull. For these reasons, a storm event that brings both heavy precipitation and high surge is potentially worthy of inclusion in risk mapping.

Climate risk indicator mapping

The NPCC has proposed a robust climate risk indicator and monitoring system (see Chapter 8). Mapping of these indicators will be an essential component of an effective monitoring system. Indicator mapping should address climate risks, impacts, vulnerabilities, and adaptation effectiveness. Several issues need to be considered when developing climate risk indicator maps. These include the spatial extent of the data (e.g., does the data set cover NYC, and could it be expanded beyond the borders of the five boroughs) and the longitudinal extent of the data set (e.g., has it been collected in the past, and can it be easily and consistently collected in the future). Other considerations include whether the data are cost effective to collect; whether collection can be sustained (e.g., collection is not likely to suffer budget cuts); whether the data illustrate the concept/concern in question (e.g., the data define a specific climate metric today, and this climate metric will continue to be relevant in the future); and whether the data can be mapped

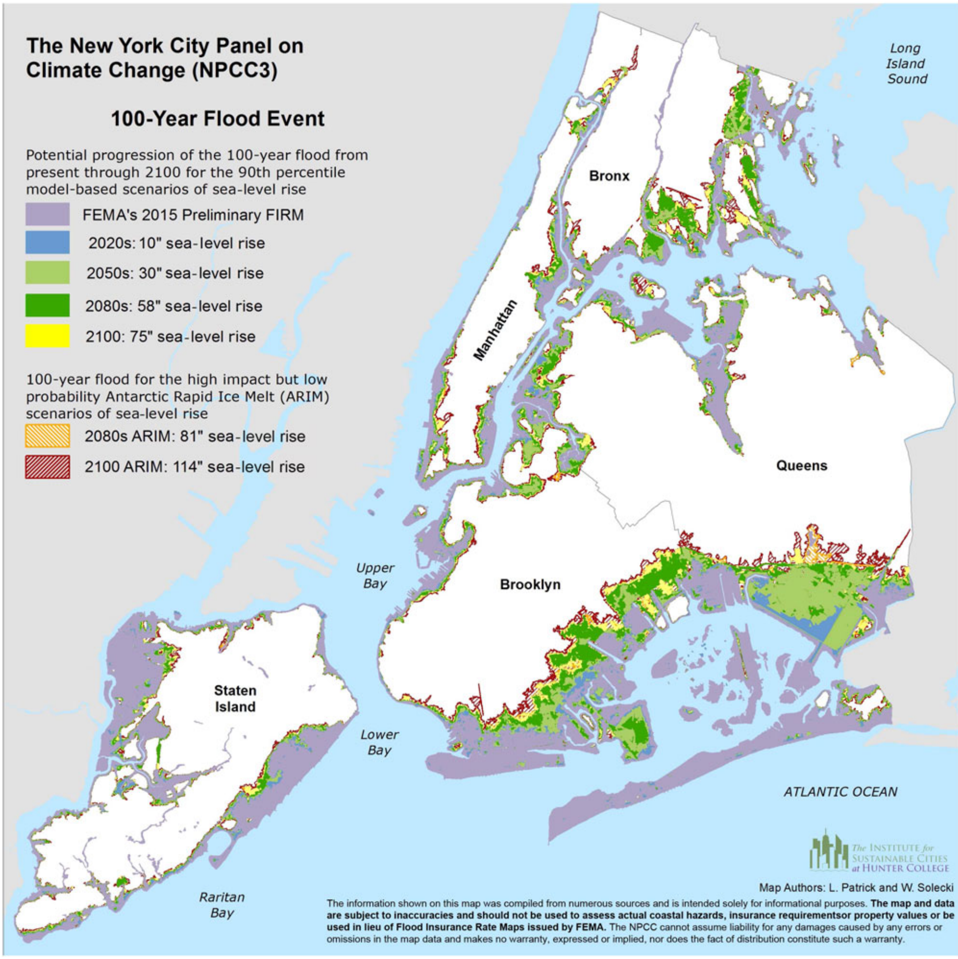

Figure 5.3. Potential progression of the 100-year floodplain from present through 2100 for the 90th percentile model-based scenarios and the ARIM scenarios of sea level rise. NOTE: The areas delineated on this map do not represent precise flood boundaries but rather illustrate distinct areas of interest: (1) Areas currently subject to flooding that will continue to be subject to flooding in the future; (2) Areas that do not currently flood but are expected to potentially experience flooding in the future; and (3) Areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios (end of the current century).

without methodological issues (e.g., data will not be distorted due to map projection; levels of uncertainty and error can be communicated).

Acknowledgments

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