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ORIGINAL ARTICLE

New York City Panel on Climate Change 2019 Report Executive Summary

Cities and the communities who live in them are significantly impacted by climate shifts in both means and extremes. These are already affecting the New York metropolitan region and will increasingly do so in the coming decades. Following the Metro East Coast Study (MEC), NPCC1, and NPCC2, the New York City Panel on Climate Change 2019 Report (NPCC3)[a] provides co-generated[b] tools and methods for implementing region-wide resilience strategies.

As the city follows flexible adaptation pathways[c] to respond to the increasing risks posed by climate change, these tools and methods can be used to observe, project, and map climate extremes; monitor risks and responses; and engage with communities to develop effective policies and programs (Fig. ES.1).

This information is especially important at "transformation points" in the adaptation process when large changes in the structure and function of physical, ecological, and social systems of the city are undertaken. The city's portfolio approach to resilience includes a range of policies, social programs, engineering projects, and ecosystem-based solutions.

Spatial and temporal scales

The tools and methods developed for the NPCC 2019 Report are for use by the entire metropolitan region over long-term, medium-term, and short-term time frames.

- The spatial domain of the NPCC 2019 Report is the New York metropolitan region, consisting of 31 counties across New York State, New Jersey, and Connecticut. This is important because many critical infrastructure systems extend far beyond the city's five boroughs. Regionally coordinated approaches can help to scale up climate change resilience and lessen widespread vulnerability.
- Climate change is an ongoing challenge that affects long-term (2080s, 2100, and beyond), medium-term (2050s), and short-term (2020s) decision-making. The three time horizons are useful in framing climate risk information and indicators used to guide adaptation planning and implementation.

Because climate change is projected to continue for the foreseeable future, the NPCC3 considers, for the first time, potential changes in climate in New York City (NYC) beyond 2100. For example, rising sea levels are expected to persist for centuries.

Climate observations and projections

NPCC3 analyzes how recent climate trends compare to the projections that the NPCC made in 2015. The goal is to understand how well what the New York metropolitan region is experiencing tracks the projections.

- Increasing observed annual temperature and precipitation trends between 2010 and 2017 fell largely within the NPCC 2015 projected range of temperature and precipitation changes for the 2020s time period

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[a] The MEC study was published in 2001; the first NPCC Report was published in 2010 (NPCC1); and the second NPCC Report was published in 2015 (NPCC2).

[b] Co-generation is defined by the NPCC as an interactive process by which stakeholders and scientists work together to produce climate change information that is targeted to decision-making needs.

[c] The term flexible adaptation pathways describes an overall approach to developing effective climate change adaptation strategies for a region under conditions of increasing risk. Flexible adaptation pathways are not fixed; they are ones in which adaptations are defined in terms of acceptable risk levels and re-evaluated over time, rather than using an approach that sets inflexible standards for adaptation early in the process (NPCC, 2010).

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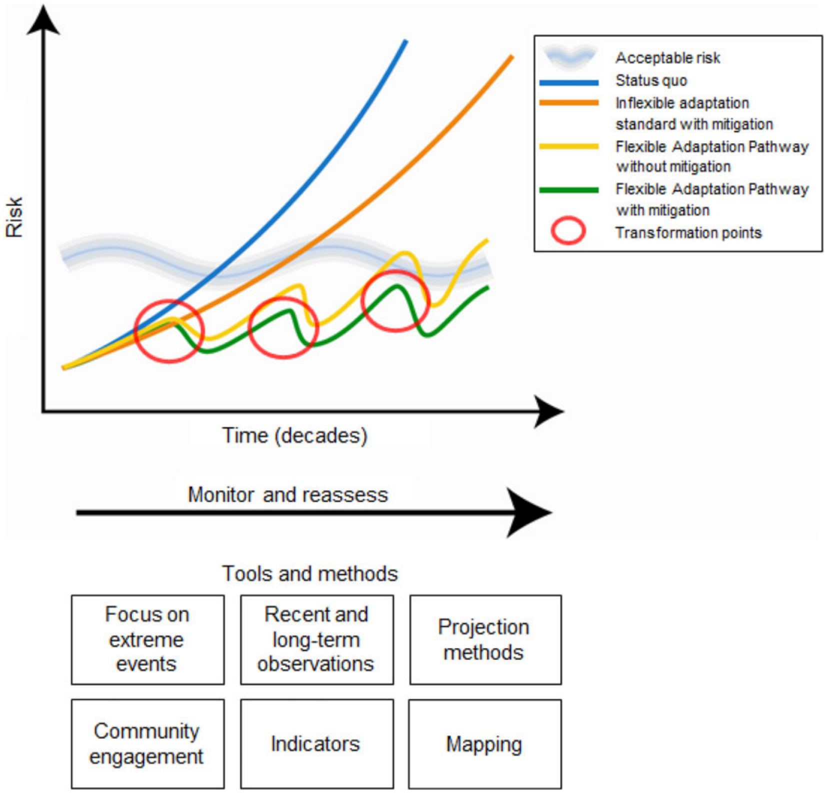


Figure ES.1. Tools and methods for implementing flexible adaptation pathways and transformation points presented in the NPCC 2019 Report.

encompassing the years 2010–2039 (Fig. ES.2a and ES.2b).

- However, these comparisons should be viewed with caution because of the role that natural variation plays on small spatial and short temporal scales.

[Correction added on June 12, 2019, after first online publication: In the bullet point above, “short timescales” was changed to “small spatial and short temporal scales.”]

Projections of Record

Based on climate analyses, regional and global trends, and a review of scientific literature, NPCC3 confirms the NPCC2 2015 projections of temperature, precipitation, sea level rise, and coastal flooding for use in resiliency planning for the city and region.

New methods for extreme temperatures, heavy downpours, and droughts

Projected increases in the frequencies and intensities of extreme events pose particular challenges to New York City. The climate extremes considered in NPCC3 are extreme heat and humidity, heavy downpours, droughts, extreme winds, and cold snaps, as well as sea level rise and coastal flooding.

NPCC3 develops and tests new methods for observations and projections of extreme events to be used in resilience planning for the region. They utilize expanded observations, bias correction, and regional climate models (RCMs).

Extreme heat

NPCC3 analysis of extreme heat builds on NPCC2 projections for temperature extremes by expanding the number of reference weather stations and concentrating on the summer months.

- Decadal trends in annual average daily maximum summer temperatures in June, July, and August vary spatially across the city (Fig. ES.3). Central Park has experienced an increasing trend of 0.2 °F per decade from 1900 to 2013. Since 1970, annual average daily maximum summer temperatures have been rising

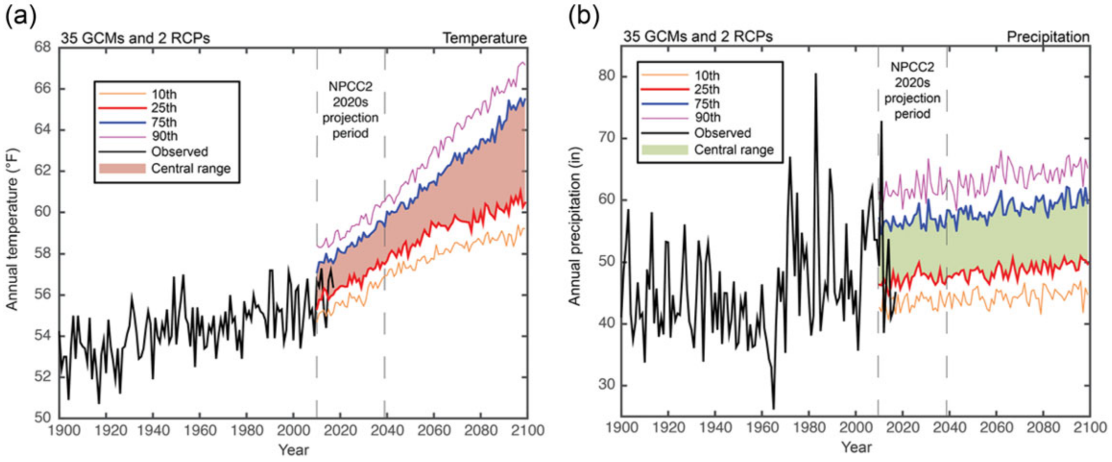


Figure ES.2. Observations at Central Park (1900–2017) compared to the 2020s (2010–2039) timeslice of NPCC2 projected changes for (a) average annual temperature and (b) average annual precipitation. Colored lines represent the 10th, 25th, 75th, and 90th percentiles of model projections across RCPs 4.5 and 8.5 for 35 GCMs. Shading shows the central range of projections between the 25th and 75th percentiles. Vertical dotted lines represent the range of the 2020s time slice from 2010 to 2039. Observed data are from the United States Historical Climatology Network (USHCN) and climate projections are from the Coupled Model Intercomparison Project Phase 5 (CMIP5). *Note:* These comparisons should be viewed with caution because of the role that natural variation plays on small spatial and short temporal scales.

[Correction added on June 12, 2019, after first online publication: In the last sentence of the legend for Figure ES.2, "in the short term" was changed to "on small spatial and short temporal scales."]

at rates of 0.5 °F per decade at JFK airport, and 0.7 °F per decade at LaGuardia airport.

- New projection methods for extreme heat events were developed and tested for the New York metropolitan region for use in future assessments of the NPCC. The new methods utilize bias correction, a method that adjusts the mean and variance of global climate model (GCM) results to match a representative set of observations from the region, and high-resolution RCMs to represent the spatial variation of future projections across the city.

Heavy downpours

NPCC3 analysis of heavy downpours and urban flooding builds on NPCC2 projections for daily extreme rainfall by more closely examining past and present rainfall across New York City and across

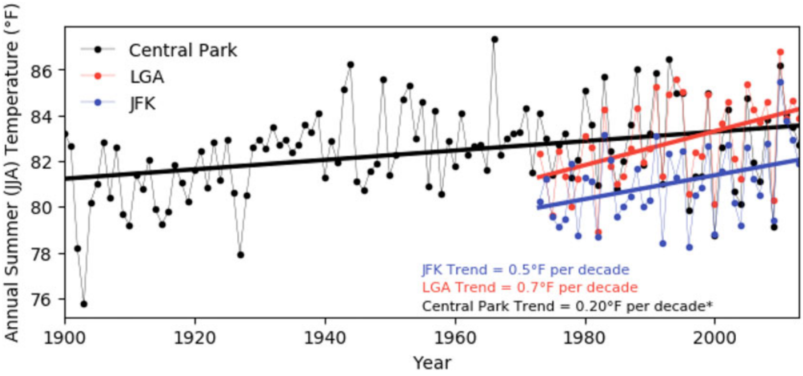


Figure ES.3. Annual average daily maximum summer temperatures (June, July, and August) at Central Park from 1900 to 2013, LGA Airport from 1970 to 2013, and JFK Airport from 1970 to 2013. Solid lines represent linear trend for each station. Station records were obtained from the U.S. Historical Climatology Network (USHCN) Version 2.5. *Central Park trend is significant at 0.01 level, while LGA and JFK trends are positive but not significant, possibly due to shorter record length.

Table ES.1. Comparison of NPCC2 daily extreme rainfall projections (1 inch, 2 inches, and 4 inches) for the 2020s time slice (2010–2039) to observed values at Central Park (2011–2017) and baseline values (1971–2000)

Heavy rainfall days	Baseline values (1971–2000)	NPCC2 2020s low estimate (10th percentile)	NPCC2 2020s middle range (25th–75th percentile)	NPCC2 2020s high estimate (90th percentile)	Observed values (2011–2017)
Number of days ≥1 inch	13	13	14–15	16	14.1
Number of days ≥2 inches	3	3	3–4	5	2.7
Number of days ≥4 inches	0.3	0.2	0.3–0.4	0.5	0.4

Note: These comparisons should be viewed with caution because of the role that natural variation plays on small spatial and short temporal scales.

[Correction added on June 12, 2019, after first online publication: In the note below Table ES.1, “in the short term” was changed to “on small spatial and short temporal scales.”]

timescales. Heavy downpours are defined as rarely occurring rainfall at less than daily timescales that can produce urban flooding.

- Heavy downpours on the daily timescale are for the most part tracking the NPCC2 projected values for daily extreme rainfall in the region (Table ES.1). These comparisons should be viewed with caution because of the role that natural variation plays on small spatial and short temporal scales.

  [Correction added on June 12, 2019, after first online publication: In the bullet point above, “in the short term” was changed to “on small spatial and short temporal scales.”]

- In the New York metropolitan region, extratropical cyclones (e.g., nor’easters) cause the greatest number of extreme daily precipitation events in each month of the year, compared to tropical cyclones (e.g., hurricanes) and noncyclone rain events.
- Baseline data of urban flooding based on complaint calls indicate substantial spatial variation across NYC from 2004 to 2015 (Fig. ES.4). Separate sewers occur generally in the locations of higher flood complaints, avoiding combined overflows.

Droughts

NPCC3 uses tree-ring analysis to understand the long-term occurrence of drought in the New York

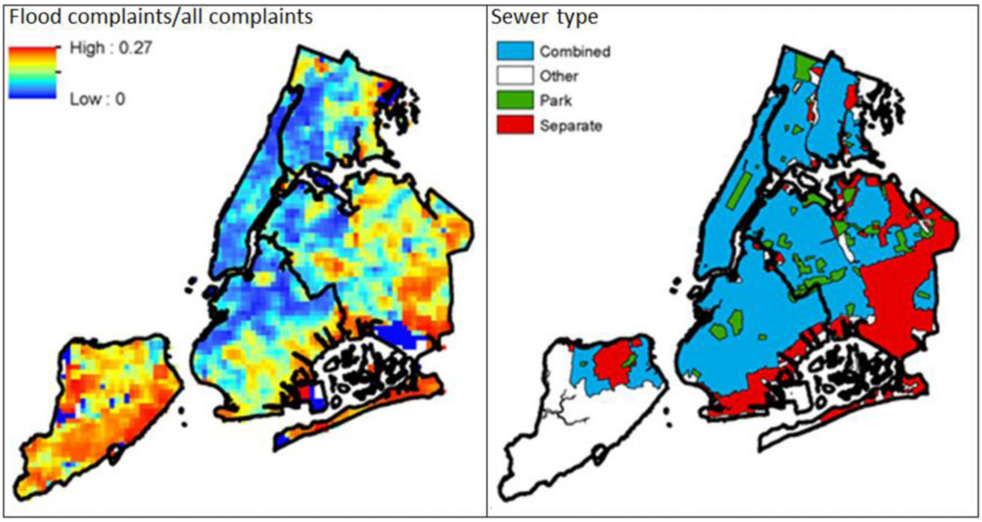


Figure ES.4. Flood reports to 311 for the period 2004–2015. Left panel: Flood reports to 311, normalized by all 311 reports. Units are in flood reports per any report in 0.5 mi^2. Right panel: NYC sewer type. Adapted from Smith and Rodriguez (2017).

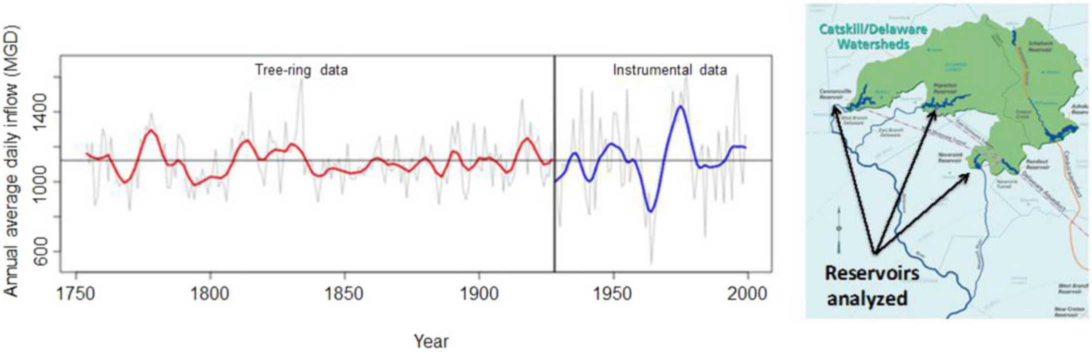


Figure ES.5. Reconstruction of combined annual average daily inflow from eight tree-ring chronologies in the Pepacton, Cannonsville, and Neversink Reservoirs from 1750 to 2000.

metropolitan region. Since tree growth is dependent on climate and since each tree-ring represents a season of growth, tree-ring measurements provide information on hydrological indicators over a tree's life span that can be used to understand long-term variations in climate.

- Analysis based on tree rings since 1750 shows that 8 five-year or longer droughts have occurred in the New York City watershed region over this 250-year period (Fig. ES.5).

Warming winters

NPCC3 analyzes trends in the number of days below freezing (a day where minimum temperatures reach less than or equal to 32 °F) in a year and in the number of cold days (a day with minimum temperatures less than or equal to the 10th percentile of daily minimum temperature of a given year) between 1900 and 2017 at the Central Park weather station.

- Days below freezing temperatures decreased at a rate of roughly 1.9 days per decade, with about 22 fewer days below freezing per year in 2017 than in 1900.
- The 10th percentile threshold for cold days was 24.1 °F from the entire 1900–2017 record. The number of cold days decreased about 1.5 days per decade, with about 17 fewer cold days per year in 2017 than in 1900.

New sea level rise scenario for long-term high-end risk awareness

Recent observations and modeling suggest the possibility of greater global mean sea level rise late in this century than previously anticipated, particularly under high greenhouse gas emission scenarios, due to rapid ice melt in the Antarctic.

To raise awareness of this emerging high-end risk, NPCC3 developed a new sea level rise Antarctic Rapid Ice Melt (ARIM) Scenario, which includes the possibility of Antarctic ice sheet destabilization later this century under continued warming at high greenhouse gas emissions rates. The ARIM Scenario represents a low-probability, upper-end case for the late 21st century.

This scenario is associated with high uncertainty due to incomplete knowledge about ice loss processes and atmosphere, ocean, and ice sheet interactions, and how fast these processes and interactions may proceed. Nevertheless, because of the potentially severe consequences of such a low-probability upper-end outcome, city planners should be aware of this growing risk.

- Sea level at The Battery has been rising at a rate of 0.11 inches per year since 1850.
- Sea level rise in New York City is higher than the global average because of the region's ongoing land subsidence in response to retreat of ice age glaciers and warmer ocean waters nearby.
- Recent evidence has shown that Antarctica is increasingly contributing to global sea level changes, indicating a need to better understand how this could amplify future sea level rise projections.
- The new upper-end, low-probability NPCC3 ARIM Scenario projects 6.75 ft in the 2080s and 9.5 ft of sea level rise by 2100. This projection takes into account the latest developments in ice sheet behavior and supplements the current

Table ES.2. **New York City sea level rise projections relative to 2000–2004, including the NPCC2 2015 projections of record for planning and the new Antarctic Rapid Ice Melt (ARIM) scenario for risk awareness**

	NPCC2 2015 sea level rise projections[a]			NPCC3 ARIM scenario[b]
	Current projections of record for planning			Growing awareness of long-term risk
Baseline (2000–2004) 0″	Low estimate (10th percentile)	Middle range (25th–75th percentile)	High estimate (90th percentile)	ARIM scenario
2020s	0.17 ft	0.33–0.67 ft	0.83 ft	–
2050s	0.67 ft	0.92–1.75 ft	2.5 ft	–
2080s	1.08 ft	1.50–3.25 ft	4.83 ft	6.75 ft
2100	1.25 ft	1.83–4.17 ft	6.25 ft	9.5 ft

[a] The 10th, 25th–75th, and 90th percentile projections are from NPCC2 (2015); they are based on six components that include global and local factors. This report confirms the use of the NPCC (2015) sea level rise projections for decision-making.

[b] ARIM represents a new, physically plausible upper-end, low-probability (significantly less than 10% likelihood of occurring) scenario for the late 21st century, derived from recent modeling of ice sheet–ocean behavior. However, uncertainties remain regarding ice sheet processes and atmosphere, ocean, and ice sheet interactions.

NPCC 2015 projections used by the city for planning (Table ES.2).

- Although many future global sea level rise projections end in 2100, the longevity of atmospheric CO_2 commits the planet to higher temperatures and sea levels long after reduction and stabilization of greenhouse gas emissions. Sea level in the New York metropolitan region is projected to continue to rise well beyond 2100.

Coastal flooding

Rising sea levels will result in coastal flooding, one of the most dangerous and damaging natural hazards that societies face. Extreme water levels are increasing globally, mainly driven by rise in mean sea levels. To inform decision-making in the region, NPCC3 analyzes sea level rise effects on monthly tidal flooding, uses of a broadened set of sea level rise scenarios including the Antarctic Rapid Ice Melt (ARIM) scenario, and examines the latest science on extreme winds.

- If the city experiences high-end (NPCC2 2015 90th percentile) sea level rise, monthly tidal flooding will begin to affect neighborhoods around Jamaica Bay by the 2050s and many other areas by the 2080s.
- A new approach for mapping monthly tidal flooding through mean monthly high water (MMHW) provides a broadened perspective on future flood risk, and serves as a useful indicator of when areas may begin to be affected by recurring "sunny-day" flood events due to sea level rise.

Mapping climate risk

This report continues the use of the NPCC2 2015 projections for the 100-year flood map, and presents two new coastal flood maps illustrating potential mean sea level and monthly tidal flooding. New coastal floodplains have been added to each map to illustrate the upper-end, low-probability ARIM scenario.

Two new data products have yielded significant advancements in the mapping methodology and results: a new LiDAR data set (2017) for NYC and a more accurate digital elevation model (DEM) used to depict baseline topography.

- NPCC3 mapped 100-year (1% annual) recurrence-interval flooding associated with sea level rise for the 90th percentile scenario (NPCC 2015) and the ARIM scenario (Fig. ES.6).

Community-based assessments of adaptation and equity

Vulnerability to climate change in New York City varies across social groups, economic levels, and neighborhoods. Spatial analysis of vulnerability can aid in the targeting of adaptation resources. There is broad recognition of the need to involve local communities earlier and more often into adaptation decision-making.

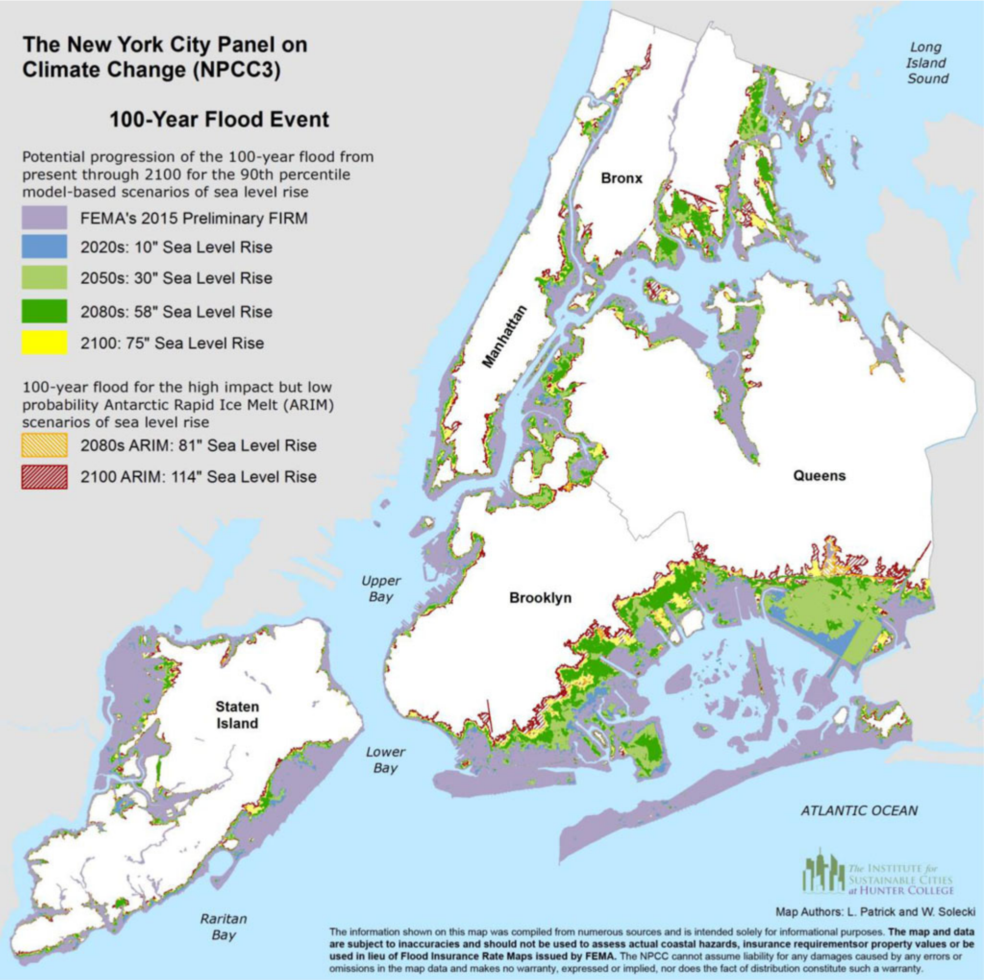
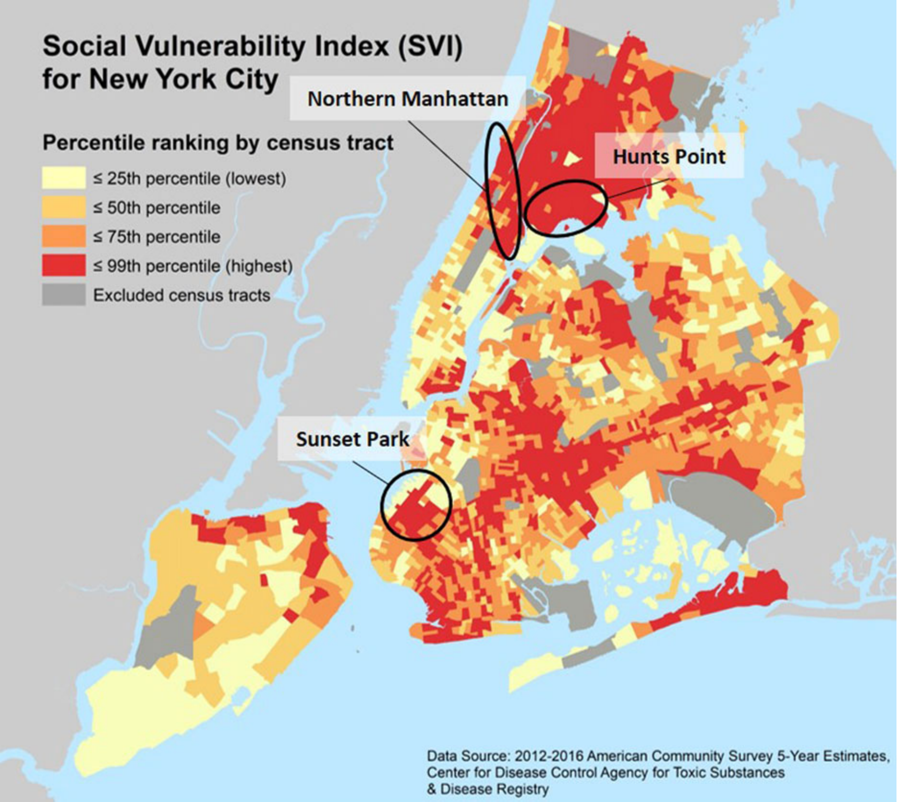


Figure ES.6. Potential progression of the 100-year floodplain from present through 2100 for the 90th percentile model-based projections and the ARIM scenario of sea level rise. *Note:* The areas delineated on this map do not represent precise flood boundaries but rather illustrate distinct areas of interest: (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). All spatial data contain uncertainty and error; as a result NPCC maps should be considered as representations of current and potential future conditions. The case of ARIM, a higher-impact but lower-probability sea level rise scenario, is included to raise awareness, but not for planning purposes.

- Social vulnerability to climate change hazards is unequally distributed across NYC; high levels of social vulnerability are consistently found in areas with lower incomes and higher shares of African American and Hispanic residents (Fig. ES.7).
- Collaboratively produced case studies (northern Manhattan; Hunts Point, South Bronx; and Sunset Park, Brooklyn) demonstrate that high levels of social vulnerability to climate change overlap with disproportionate exposure to environmental pollution, health stressors, and gentrification pressures.
- Communities are involved in many forms of adaptation planning (e.g., traditional government-led, inclusive, nongovernmental), but express a desire for deeper engagement with the city via use of fully collaborative, co-production planning approaches.
- Recognizing this importance, New York City has made community engagement a central component of the OneNYC planning process



Data Source: 2012-2016 American Community Survey 5-Year Estimates, Center for Disease Control Agency for Toxic Substances & Disease Registry

Figure ES.7. Social Vulnerability Index (SVI) for New York City. The SVI utilizes 15 indicators categorized into four themes: socioeconomic status, household composition and disability, minority status and language, and housing and transportation. NPCC3 community case study neighborhoods are circled. (Map constructed by NPCC3 Community-Based Adaptation Workgroup.)

and will continue to prioritize it using fully collaborative adaptation approaches.

- Cross-city analysis reveals that New York and other cities in the Northeast are incorporating equity in their adaptation planning, but largely emphasize distributional equity in these efforts.

Resilience strategies for critical infrastructure

NPCC3 analyzes dependencies and interdependencies among infrastructure systems to examine how climate change will exacerbate the risks associated with these connections. The infrastructure sectors covered are energy (electricity), transportation, telecommunications, and water/waste/sewer. It also examines risks to energy infrastructure in the context of two sectors on which communities strongly depend, hospitals and housing (Box ES.1).

Vulnerabilities, dependencies, and interdependencies

- Critical infrastructure in the New York metropolitan region has underlying vulnerabilities that are not directly related to climate change, which affect the region's resilience or ability to withstand climate change stresses. Examples include age, deterioration, construction or maintenance flaws, and usage exceeding capacity. All of these indicate potential vulnerabilities for New York City that can interact with climate risks.
- Critical infrastructure is directly vulnerable to climate change risk factors, such as extreme heat, heavy downpours, sea level rise, and coastal storms, depending on their location.
- Interdependent infrastructures create vulnerabilities that can develop into cascading impacts. These include water, energy,

Box ES.1. Community-based infrastructure dependencies and resilience strategies

Hospitals. NYC's 62 hospitals are dependent on transportation, power, and water, especially in emergencies. Many hospitals are in locations at risk of flooding. Hospital Row is an area along the East River in Manhattan, between East 23rd to 34th Streets and First Avenue, where three at-risk hospitals are situated. The vulnerability of these facilities to climate-related extreme events is shown by the impacts that Hurricane Sandy had on them in 2012. Five acute-care hospitals shut down in NYC due to Hurricane Sandy, and there were substantial delays in returning to normal functioning. Adaptation planning with consideration of hospital capacity and lifeline infrastructure in vulnerable areas will be essential for minimizing costs and damages to health institutions during and after future extreme weather events.

NYC Housing Authority (NYCHA). During Hurricane Sandy, infrastructure service outages affected hundreds of buildings and thousands of residents. The infrastructure systems of these residential buildings sustained significant damage—residents endured loss of electricity, elevators, heat, and hot water. NYCHA housing in Coney Island, Brooklyn, for example, sustained significant damage from sand and saltwater infiltration, while damage to other NYCHA housing was mostly the result of flooding. NYCHA's challenges during Hurricane Sandy have underscored the dependence of NYCHA infrastructure systems for heat, hot water, elevators, trash compacting, and other functions on grid-connected electrical power. Incorporating distributed energy resources into the power systems of apartment complexes in neighborhoods vulnerable to sea level rise, storm surge, and heat waves is one way to rethink and adjust the mix of energy sources, access to power during emergencies, and carbon emissions.

transportation, and information technology (IT) systems.

Insurance and finance

- Economic losses from hurricanes and floods have significantly increased in past decades and are likely to increase further in the future from more intense hurricanes and higher sea level rise.
- Insurance can be a catalyst for infrastructure resilience by encouraging investment in adaptation measures prior to a disaster through a reduction in premiums to reflect lower claim payments.
- Financing mechanisms for enhancing the resilience of NYC's infrastructure need to draw from diverse sources, in particular with respect to local, state, and federal agencies, and the private sector.

Links to mitigation

- Mitigation and adaptation strategies for critical infrastructure need to be coordinated to amplify synergies, avoid trade-offs, and to ensure equity.
- New construction and major renovation of infrastructure in the public and private sectors offer major opportunities to reduce CO_2 emissions and transition to lower-carbon, greener-energy feedstocks that can be coupled with initiatives to reduce water and waste footprints in the built environment.

Indicators and monitoring

Figure ES.8 depicts the operational components of the proposed New York City Climate Change Resilience Indicators and Monitoring (NYCLIM) system. These components include data collection agencies and processing centers, and online repositories of climate change adaptation databases that are equipped with references, resources, topical categories, and key words.

The proposed system includes community–stakeholder partnerships that inform decision makers and contribute to prudent, equitable, and scientifically sound climate change policy. The system would also be robust and flexible enough to incorporate ongoing research and new knowledge, the potential for indicators to change, and for new indicators to be developed.

An initial set of indicators for the energy and transportation sectors was co-generated in concert with practitioners from several city and regional agencies. NPCC3 further explores how indicators may track interdependencies among infrastructure systems.

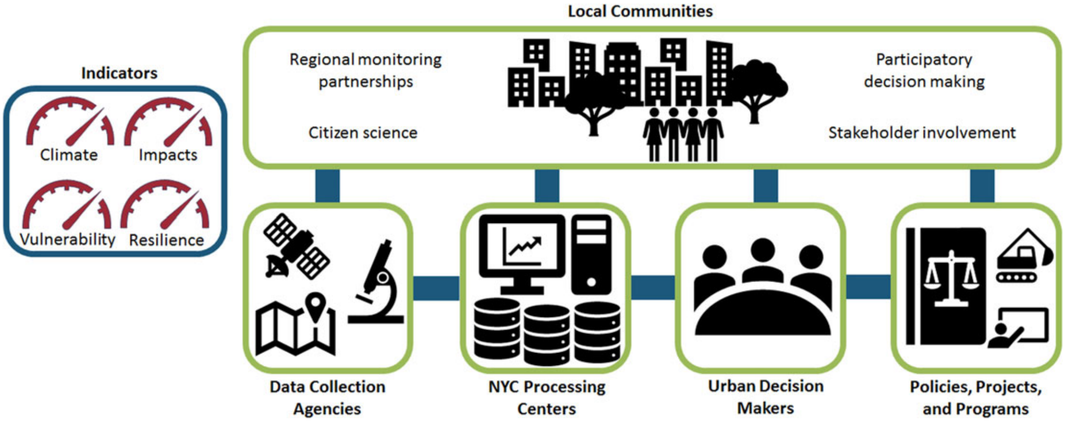


Figure ES.8. Prototype structure and functions of the proposed New York City Climate Change Resilience Indicators and Monitoring System (NYCLIM). The proposed system tracks four types of indicators from data collection agencies, processing centers, urban decision makers, and policies, projects, and programs. The proposed NYCLIM system is co-generated by scientists, practitioners, and local communities to determine which indicators should be tracked over time to provide the most useful information for planning and preparing for climate change in New York City.

Indicator and monitoring system

- A centralized, coordinated indicators and monitoring system is essential for a comprehensive, city-wide risk assessment of trends in climate and impacts and course correction toward climate change adaptation and resiliency goals and targets. Damage to energy assets from extreme storms like Hurricanes Irene and Sandy is an example of the types of indicators that can be tracked in the proposed NYCLIM system (Fig. ES.9).
- To detect trends and differences across sectors and to allow for effective comparisons, spatial and temporal scales of indicators need to be consistent and comparable.

Infrastructure system indicators

- Illustrative indicators for energy sector transmission and distribution under extreme heat and humidity include reduction in transmission due to sag in overhead power lines, complaint and fire department emergency calls, and power outages and brownouts.
- A set of preliminary, decision-support indicators for the transportation sector have been

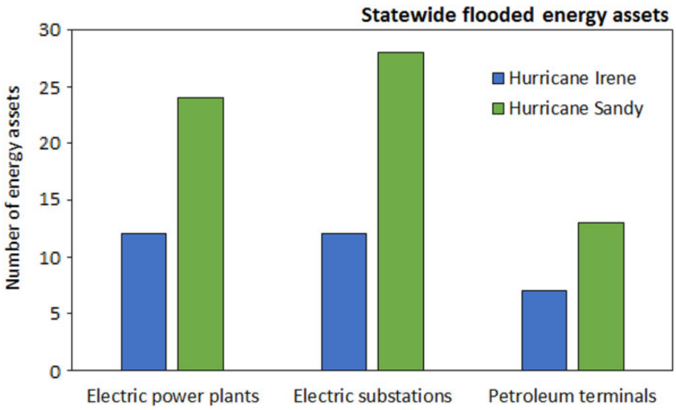


Figure ES.9. Comparative damages to energy assets in flooded areas in New York (statewide) during Hurricanes Irene (2011) and Sandy (2012). *Source:* Data from U.S. DOE (2013).

identified as being critical to the city's adaptive responses to promote resilience.

Financial indicators[d]

- The city's credit rating was stable through Hurricane Sandy (2012) despite major damages.
- As credit rating agencies incorporate climate change into their risk analyses, indicators such as coastal flood heights and number of vulnerable properties in the flood plain can be included in NYCLIM for tracking and evaluation.

Conclusions and recommendations

Understanding climate change in cities is important because of the dramatic growth in urban populations and thus vulnerability, as well as the emerging role of cities as first responders to climate change. Since 2008, the New York Panel on Climate Change (NPCC) has analyzed climate trends, developed projections, explored key impacts, and advised on response strategies. Charting a future course for the NPCC ensures that NYC continues to play its role as a climate change leader for other cities, not only in the United States but around the world.

Overall NPCC3 Report recommendations

- The City should establish a pilot climate indicators and monitoring system (NYCLIM).
- The City should task the NPCC to coordinate with other regional organizations, such as the Consortium for Climate Risk in the Urban Northeast (CCRUN), to conduct integrated climate assessments for the New York metropolitan region on a regular basis. These assessments should encourage the participation of a wide range of city and regional agencies and communities, and a full range of systems and sectors.
- As the City complies with Local Law 42 of 2012, the next generation of projections should incorporate updated methods and analyses, such as presented in the NPCC 2019 Report.
- The City and the NPCC should host a climate summit once every mayoral term in order to bring together the key groups working on climate change around the New York metropolitan region: scientists, practitioners, decision makers, and stakeholders. The climate summits will provide opportunities for inclusive discussion on flexible adaptation pathways to achieve climate resilience in the region.

Data Sources

Figure ES.2.

United States Historical Climatology Network (USHCN). https://www.ncdc.noaa.gov/ushcn/introduction

Coupled Model Intercomparison Project Phase 5 (CMIP5). https://esgf-node.llnl.gov/projects/cmip5/

Figure ES.3.

United States Historical Climatology Network (USHCN). https://www.ncdc.noaa.gov/ushcn/introduction

Figure ES.4.

Smith, B. & S. Rodriguez. 2017. Spatial analysis of high-resolution radar rainfall and citizen-reported flash flood data in ultraurban New York City. Water 9: 736.

Figure ES.9.

U.S.DOE. 2013. Comparing the impacts of northeast hurricanes on energy infrastructure. http://energy.gov/sites/prod/files/2013/04/f0/Northeast%20Storm%20Comparison_FINAL_041513c.pdf.

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[d] Financial indicators were developed in collaboration with the NYC Comptroller's Office. Adoption of financial indicators would require NYC Office of Management and Budget and Bond Council review.