ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Issue: *Building the Knowledge Base for Climate Resiliency*

New York City Panel on Climate Change 2015 Report Executive Summary

The climate of the New York metropolitan region is changing—annual temperatures are hotter, heavy downpours are increasingly frequent, and the sea is rising. These trends, which are also occurring in many parts of the world, are projected to continue and even worsen in the coming decades due to higher concentrations of greenhouse gases (GHGs) in the atmosphere caused by burning of fossil fuels and clearing of forests for agriculture. These changing climate hazards increase the risks for the people, economy, and infrastructure of New York City. As was demonstrated by Hurricane Sandy, populations living in coastal and low-lying areas, the elderly and very young, and lower-income neighborhoods are highly vulnerable. In response to these climate challenges, New York City is developing a broad range of climate resiliency policies and programs as well as the knowledge base to support them.

Initially formed as a scientific panel in 2008, the first New York City Panel on Climate Change (NPCC) was comprised of academic and private sector experts in climate science, infrastructure, social science, and risk management. It established a risk-management framework for the city's critical infrastructure throughout the extended metropolitan region under climate change (NPCC, 2010). Following Hurricane Sandy, the City convened the Second New York City Panel on Climate Change (NPCC2) in January 2013 to provide up-to-date scientific information and analyses on climate risks for the creation of *A Stronger, More Resilient New York* (City of New York, 2013). This report (NPCC, 2015) presents the work of the New York City Panel on Climate Change from January 2013 to January 2015.

The report documents recently observed climate trends and climate projections for the New York metropolitan region up to 2100. It compares the NPCC2 methods and projections for the local scale to those done at the global scale by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013). The report presents new maps that show increasing flood risks due to climate change defined for the 100- and 500-year coastal flood event[a] in the 2020s, 2050s, 2080s and 2100. It compares future coastal flooding simulated by static and dynamic modeling that include the effects of sea level rise. The report reviews key issues related to climate change and health relevant to the citizens of New York City and sets forth a process for developing a system of indicators and monitoring to track data related to climate change hazards, risks, impacts, and adaptation strategies. Research needs and recommendations for climate resiliency are provided.

Climate observations and projections

Observations show that temperatures and precipitation in New York City are increasing. In the New York metropolitan region, projections from global climate models (GCMs) indicate significant future changes in temperature and precipitation, and thus the potential for large impacts. Reducing greenhouse gas emissions now will reduce the likelihood of more extreme climate risks in the future.

Observations

- **Mean annual temperature** has increased at a rate of 0.3°F per decade (total of 3.4°F) over the 1900 to 2013 period in Central Park, although the trend has varied substantially over shorter periods.
- **Mean annual precipitation** has increased at a rate of approximately 0.8 inches per decade (total of 8 inches) over 1900 to 2013 in Central Park. Year-to-year (and multi-year) variability of precipitation has also become more pronounced, especially since the 1970s.

[a]The 100-year coastal flood event refers to the flood with a 1% annual chance of occurrence. The 500-year coastal flood event refers to the flood with a 0.2% annual chance of occurence.

doi: 10.1111/nyas.12591

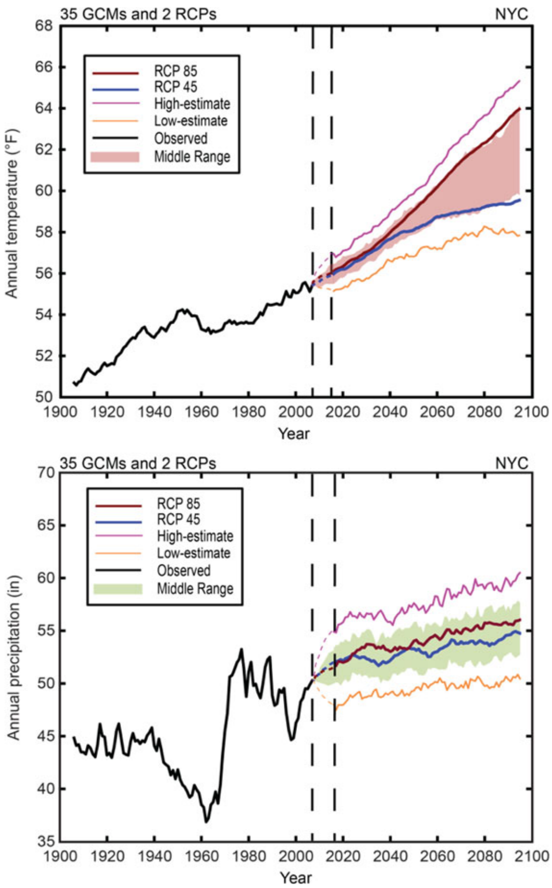

Figure ES.1. Observed and projected temperature and precipitation. Projected global climate model changes through time are applied to the observed historical data.[c]

Future projections

Climate change is extremely likely[b] to bring warmer temperatures to the New York metropolitan region.

- **Mean annual temperatures** are projected by GCMs to increase by 4.1 to 5.7°F[d] by the 2050s and by 5.3 to 8.8°F by the 2080s.[e]

Total annual precipitation will likely increase.

- **Mean annual precipitation** increases projected by the GCMs are 4 to 11 percent by the 2050s and 5 to 13 percent by the 2080s.

Heat waves and extreme precipitation days[f] are also very likely to increase.

- The frequency of **heat waves** is projected to triple by the 2080s, and extreme cold events are projected to decrease.
- The frequency of **extreme precipitation days** is projected to increase, with approximately one and a half times more events per year possible by the 2080s compared to the current climate.

Figure ES.1 shows observed annual trends and future projections for temperature and precipitation in New York City. The range of NPCC2 projections increases to the end of the century.

Sea level rise and coastal storms

Sea level rise in New York City is a significant hazard, increasing the risks posed to coastal communities, infrastructure, and ecosystems.

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[b]Probability of occurrence and likelihood defined as (IPCC, 2007): virtually certain, >99% probability of occurrence; extremely likely, >95% probability of occurrence; very likely, >90% probability of occurrence; likely, >66% probability of occurrence; more likely than not, >50% probability of occurrence; about as likely as not, 33% to 66% probability of occurrence.

Likelihoods are assigned for the direction and characterization of change of projected climate hazards based on observations, model projections, physical understanding, literature review, and expert judgment.

[c]The two thick lines show the average for each representative concentration pathway (RCP) across the 35 global climate models (GCMs). Shading shows the middle range (25th to 75th percentile). The bottom and top lines respectively show each year's low-estimate and high-estimate projections across the suite of simulations. A 10-year smoothing filter has been applied to the observed data and model output. The dotted area between 2007 and 2015 represents the time period that is not covered because of the smoothing procedure.

[d]Middle range (25th to 75th percentile) of model-based projections.

[e]Specific quantitative projections are not assigned a likelihood due to uncertainties in future greenhouse gas concentrations, sensitivity of the climate system to changes in greenhouse gases, climate variability, and changes in regional and local processes.

[f]The NPCC defines heat waves as three or more consecutive days with maximum temperatures at or above 90°F. Extreme precipitation days are defined as days with total precipitation of 1 inch or more.

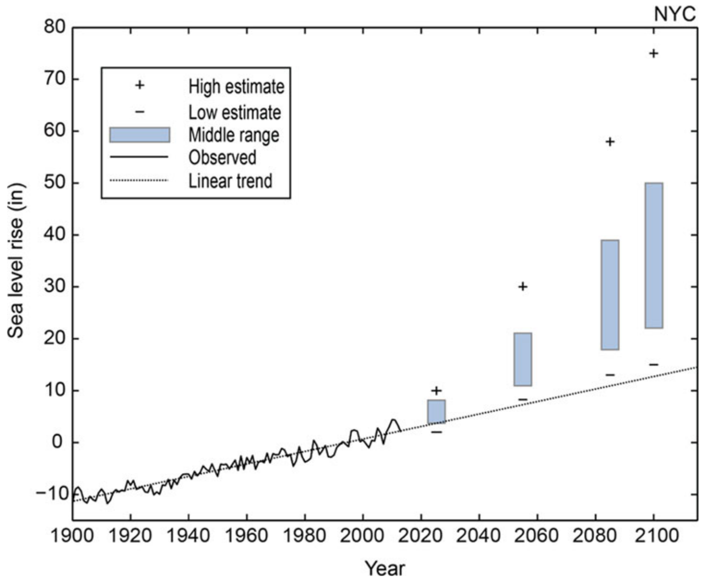

Figure ES.2. New York City sea level rise observations and projections. Projections shown are the low estimate (10th percentile), middle range (25th to 75th percentiles), and the high estimate (90th percentile). The historical trend is also included. Projections are relative to the 2000 to 2004 base period.

Observations

- **Sea level rise** in New York City has averaged 1.2 inches per decade (total of 1.1 feet) since 1900, nearly twice the observed global rate of 0.5 to 0.7 inches per decade over a similar time period.

Projections

Sea level rise in New York City is projected to continue to exceed the global average. Sea level rise is very likely to accelerate as the century progresses.

- Projections for **sea level rise** in New York City are 11 to 21 inches by the 2050s, 18 to 39 inches by the 2080s, and could reach as high as 6 feet by 2100.

It is virtually certain that sea level rise alone will lead to an increased frequency and intensity of coastal flooding as the century progresses.

- Projected sea level changes alone would increase the frequency and intensity of **coastal flooding**, leading to (absent any change in storms themselves) between a doubling and an approximately 10- to 15-fold increase in the frequency of the current 100-year coastal flood by the 2080s.

Figure ES.2 shows the observed trend and future projections for sea level rise in New York City. The NPCC2 projections take global and local components into account.

Projected changes in the frequency and intensity of coastal storms are uncertain at local scales. The two types of storms with the largest influence on the coastal areas of the New York metropolitan region are tropical cyclones (hurricanes and tropical storms) and nor'easters.

- It is more likely than not that the number of the **most intense hurricanes** will increase in the North Atlantic Basin, along with extreme winds associated with these storms.
- As the ocean and atmosphere continue to warm, **intense precipitation from hurricanes** in the North Atlantic Basin is more likely than not to increase.
- It is currently not known how **nor'easters** in the New York metropolitan region may change in the future.

Static coastal flood mapping

Mapping climate hazards is an essential part of an overall risk management strategy for densely populated urban areas such as the New York metropolitan region. The strength of a flood-mapping tool

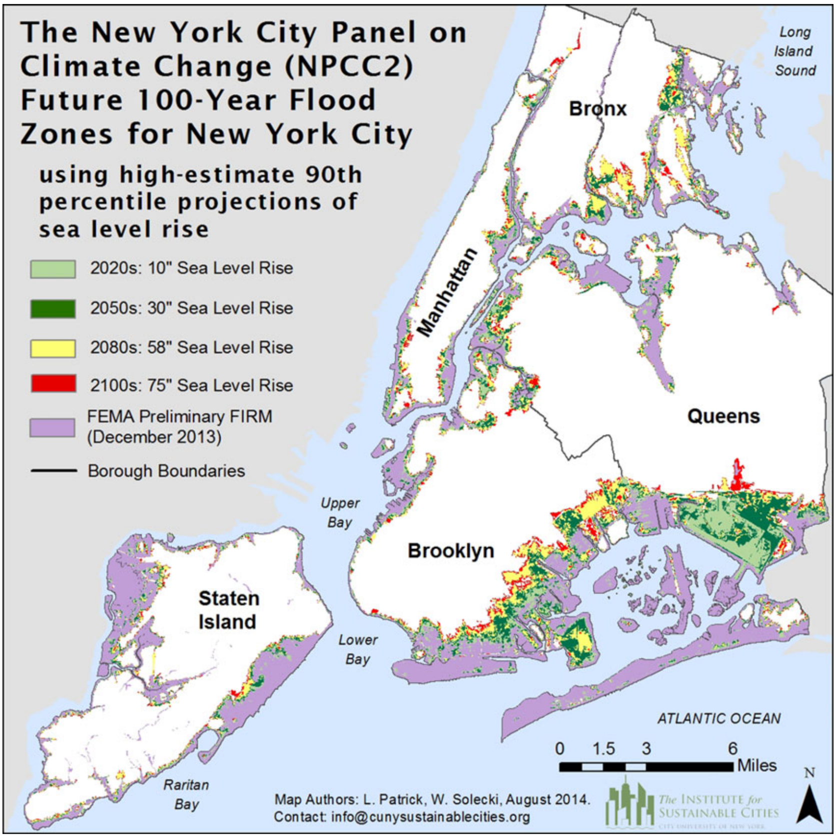

Figure ES.3. Potential areas that could be impacted by the 100-year flood in the 2020s, 2050s, 2080s, and 2100 based on projections of the high-estimate 90th percentile NPCC2 sea level rise scenario. Map developed using the static approach. NOTE: This map is subject to limitations in accuracy as a result of the quantitative models, data sets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements, or property values or be used in lieu of FIRMS issued by FEMA. The flood areas delineated in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: (1) areas currently subject to the 100-year flood that will continue to be subject to flooding in the future; (2) areas that do not currently flood but are expected to potentially experience the 100-year flood in the future; and (3) areas that do not currently flood and are unlikely to do so in the timeline of the climate scenarios used in this research (end of the current century).

depends on the quality of the underlying data and the techniques used for presentation. The updated future 100-year and 500-year flood maps by the NPCC2 show large-scale coastal vulnerability.

- Higher sea level elevations result in greater floodplain areas, with the extent of landward flooding dependent on elevation and slope of land, presence of man-made structures, permeability of soils, vegetation, and other impediments to movement of water.
- For the 100-year flood, sea level rise by 2100 roughly doubles the affected area compared to the December 2013 FEMA Preliminary Flood Insurance Rate Maps (FIRMs); for the 500-year flood, sea level rise by 2100 increases the affected area by 50% compared to the December 2013 FEMA FIRMs 500-year flood area.
- Queens is the borough with the most land area at risk of future coastal flooding due to sea level rise, followed by Brooklyn, Staten Island, the Bronx, and Manhattan.

Figure ES.3 presents the updated future 100-year flood map for New York City for the 90th percentile projections of sea level rise for the 2020s, 2050s, 2080s, and 2100 compared to FEMA's December 2013 FIRMs.

Dynamic modeling of future coastal flood hazards

Sea level rise interacts with coastal storms to cause increased flood heights and expanded floodplains. The static approach to projecting coastal flooding adds sea level rise onto current storm tide levels, and dynamic models capture the roles of friction and wind as well as sea level rise and tides.

- NPCC2 results generally support the finding that both static and dynamic modeling approaches are valid and reliable approximations of coastal flooding for most locations in the New York metropolitan region.
- For results with hurricanes only, the static approach projects lower coastal flood heights and reduced flood zone areas for several locations in the New York metropolitan region, compared to results of the dynamic modeling approach.
- Many sources, including sea level rise, type of storm, errors in elevation data, and statistical methods, contribute to uncertainties in coastal flooding projections.

Figure ES.4 illustrates the differences between the dynamic and static approaches for the 100-year flood elevations for the 2050s, using the NPCC2 90th percentile sea level rise projections.

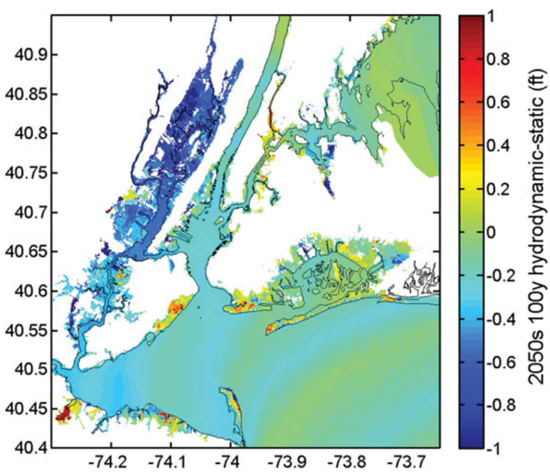

Figure ES.4. Difference between dynamic and static mapping results for 100-year flood elevations (2050s 90th percentile NPCC sea level rise scenario). Results show the combined assessment of extratropical cyclones and tropical cyclones (extratropical cyclones are coastal storms existing or occurring outside of the tropical latitudes).

Public health impacts and resiliency

New York City faces potential health risks related to two principal climate hazards: increasing temperatures and heat waves and coastal storms with flooding, as well as a range of secondary hazards related to air pollution, pollen, vector-borne diseases, and water/food-borne illnesses. Recent experience from Hurricane Sandy and other extreme events has clearly demonstrated that the health of New Yorkers can be compromised by these hazards.

- Health impacts from exposure to extreme weather events include direct loss of life, increases in respiratory and cardiovascular diseases, and compromised mental health. The risk of these impacts is projected to increase in the future.
- Rising temperatures over the coming century are projected to increase the number of heat-related deaths that occur in Manhattan. However, uncertain future trends in the use of home air conditioning, improved population health, and better air quality during heat waves make it difficult to predict the magnitude of these increases.
- The health impacts of Hurricane Sandy varied across the city considerably due to local effects of storm and tidal surges, differing housing types, the degree to which energy, water, and/or transportation infrastructure was disrupted, and the underlying health and resilience factors of the affected population.
- Vulnerable groups include the old and the very young; women; those with preexisting physical, mental, or substance-abuse disorders; residents of low-income households; members of disadvantaged racial/ethnic groups; workers engaged in recovery efforts; and those with weak social networks.

Figure ES.5 shows projected increases in heat mortality in New York City for two GHG emissions scenarios (A2 and B1).

Indicators and monitoring

Climate change indicators are defined as empirically based quantities that can be tracked over time

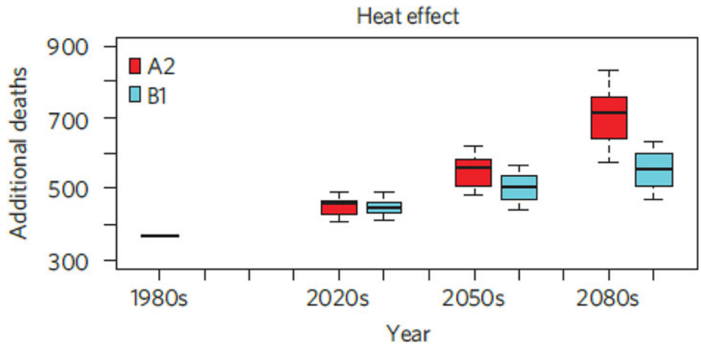

Figure ES.5. Heat-related deaths in the 1980s (observed), 2020s, 2050s, and 2080s for 16 global climate models and the A2 and B1 GHG scenarios. Source: Li *et al.*, 2013.

to provide relevant information for stakeholder decisions on climate resiliency and on the efficacy of resiliency measures to reduce vulnerability and risk. The three main categories of climate change indicators are (1) physical climate change variables; (2) exposure, vulnerability, and impact metrics; and (3) adaptation measures and their effectiveness.

- New York City maintains an extensive set of indicators and monitoring programs that can be harmonized and expanded to provide targeted information about current and emerging climate risks, impacts, and adaptation. This will provide key information for climate resiliency decision-making in regard to critical infrastructure, ecosystems, and health.
- Building on current tracking efforts, New York City is well placed to develop an expanded Climate Resiliency Indicators and Monitoring System for the New York metropolitan region.
- Developing an effective indicators and a monitoring system involves seven steps, which include interacting with stakeholders to ascertain information needs and key decisions; determining what data are available; developing a preliminary set of indicators; presenting indicators to stakeholders for feedback; revising preliminary indicators based on stakeholder input; setting up and maintaining the monitoring system; and conducting indicator evaluations through time to track general trends and to evaluate specific adaptation interventions.
- The NYC Cool Roofs Program provides a valuable testbed for the establishment of indicators and monitoring systems for tracking the effectiveness of adaptation measures.

An example of data tracked as part of the NYC Cool Roofs Program is shown in Figure ES.6, which illustrates that white roofs are more effective than black roofs in reducing peak temperatures.

Research needs

There is a need for ongoing research across a broad spectrum of areas in order to provide the people of New York City and the surrounding metropolitan region with the knowledge required to enhance climate resiliency through the coming decades. Economic studies of potential damages and costs of adaptation are critical to provide the knowledge base needed for wise climate change policy. It is important that budgetary resources are focused on building the scientific basis for resiliency planning.

Climate

Although there is a growing understanding of how the New York metropolitan region as a whole may be impacted by climate change, more research is needed on neighborhood-specific hazards and impacts. High-resolution regional climate modeling is needed to illuminate how projected changes vary throughout the city due to factors including coastal breezes, topography, and different urban land surfaces.

Sea level rise and coastal storms

More research is needed on how the Greenland and West Antarctic ice sheets will respond to climate change because these ice sheets are the largest long-term source of "high-end" sea level rise uncertainty. Future research efforts should also explore the

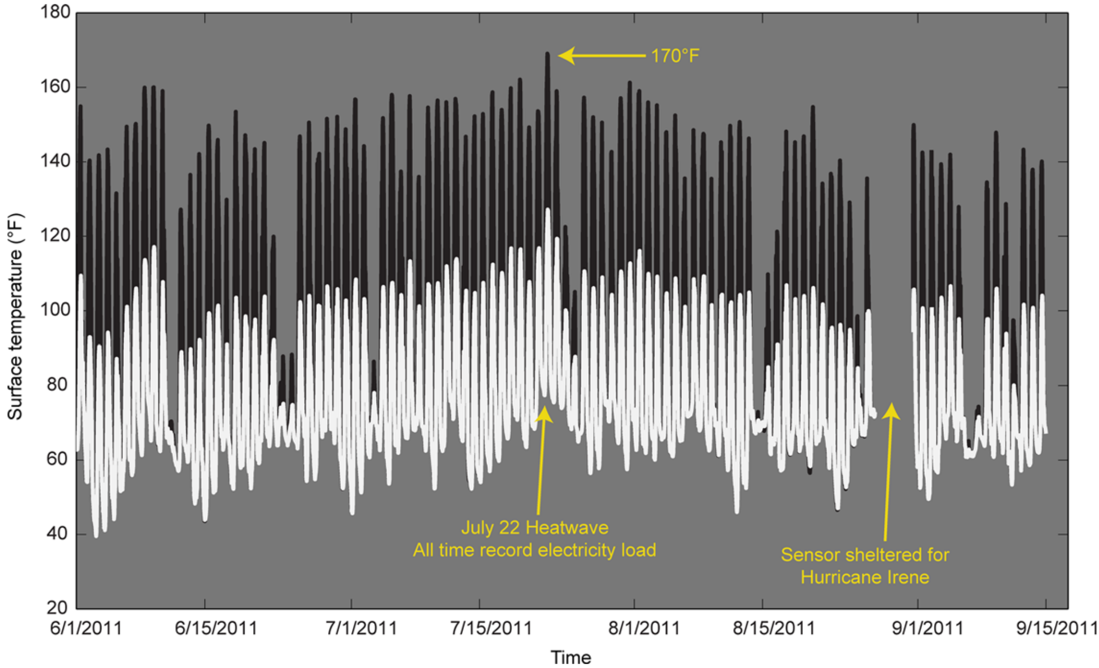

Figure ES.6. Surface temperatures for a freshly painted white roof compared to those of a control black roof at the Museum of Modern Art, Queens, NY. Source: Gaffin *et al.*, 2012.

relationships among the different sea level rise components as well as the relationships between those sea level rise components and coastal storm risk in the Northeast. An additional key area of study is how coastal storms may change in the future.

Static coastal flood mapping

Future work should focus on quantifying the sources of uncertainty in the datasets used to develop flood maps, on the mapping process, and on displaying these uncertainties on the maps themselves. An overall flood vulnerability index that combines both social and biophysical vulnerability should be utilized because it can characterize site-specific levels of risk to flood hazards. This will also help to identify communities in the New York metropolitan region that may require special attention, planning efforts, and mobilization to respond to and recover from disasters and hazards.

Dynamic coastal flood modeling

More research should be done on historical events and on probabilistic hazard assessment methods to identify and reduce the uncertainty in defining flood hazards for the New York metropolitan region. Investigations are needed of the local geographical and storm conditions that lead to different flood heights in static and dynamic models. Studies should explore the comparability between the use of the static and dynamic approaches to projecting coastal zone flooding.

Public health impacts and resiliency

Additional knowledge will be essential for New York City to anticipate and avoid future health impacts from extreme weather events in a changing climate. Key areas include understanding the factors that lead to unhealthy levels of exposure to heat inside New York City apartment buildings, where most deaths occur during heat events. Research is needed to analyze the health impacts resulting from climate adaptation and mitigation measures, including effects on indoor air quality. Actions that result in climate adaptation and mitigation co-benefits including positive health outcomes are particularly important to identify.

Indicators and monitoring

Studies are needed to identify opportunities where existing monitoring systems in the New York metropolitan region can easily be enhanced for climate change and situations where more extensive adjustments are needed. Focused analyses should be conducted on the identification of urban system tipping points in response to stresses in order to enhance capacity for early action.

Recommendations for climate resiliency

Although there remain significant uncertainties regarding long-term climate change, the NPCC 2015 report supports the large body of evidence indicating that decision-makers are better served by consideration of the future climate risks rather than reliance on the climate of the past in development of resiliency and rebuilding programs. Specific recommendations for climate resiliency include:

- Continue to follow the risk-based Flexible Adaptation Pathways approach to climate resiliency, set forth by the NPCC in 2010. This approach enhances the ability of the region to periodically assess, adjust, and tailor future development plans under changing climate conditions, updated by the NPCC as mandated by New York City's Local Law 42.
- Make progress on achieving the initiatives in *A Stronger, More Resilient New York* (City of New York, 2013). Because of the short- and long-term challenges posed by increasing risks of temperature extremes, heavy downpours, and coastal flooding, these need to be strengthened and expanded to the entire New York metropolitan region.
- An integrated approach that includes engineering, ecosystems, and social strategies is vital to ensuring climate resiliency in the coming decades. Land use planning for sustainable infrastructure systems, particularly in coastal zones and low-lying areas, is especially important.
- At the same time, develop and support programs and policies (such as *One City: Built to Last*; City of New York, 2014) that work to reduce GHG emissions in order to limit the rate of future climate change and the magnitude of the associated risks. Consider co-benefits of adaptation and mitigation.
- Establish the New York City Climate Resiliency Indicators and Monitoring System. Associated Working Groups should be convened to develop and analyze key information for decision-making on critical infrastructure, ecosystems, and health. Build wider networks to monitor indicators and actively support their operation and long-term maintenance throughout the New York metropolitan region.
- Coordinate with state and federal partners on climate change projections and resiliency programs such as Rebuild by Design and the U.S. Army Corps of Engineers North Atlantic Comprehensive Study. FEMA should incorporate local sea level rise projections into its coastal flood methodology and mapping. This enables residents as well as planners to utilize the best available information as they develop and implement climate resiliency strategies.
- While the 100-year coastal flood is widely used to inform decision-making, other risk thresholds should be examined to improve risk-reduction decisions in the future. The goal is dynamic performance-based risk management across a range of probabilistic hazards established for current and future climates.

Throughout all of the above activities:

- It is essential to facilitate an ongoing and continuous process of stakeholder–scientist interactions, with cross-linkages between the NPCC, other experts, the City, the other municipalities of the New York metropolitan region, New York State, relevant agencies of the federal government, and the U.S. National Climate Assessment.

Collaboration across multiple scales of government will help to ensure that the climate science developed for the New York metropolitan region informs and draws from the best available information, thereby positioning residents and planners to confront expected future changes in the most effective way possible.

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