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New York City Panel on Climate Change 2019 Report

Chapter 9: Perspectives on a City in a Changing Climate 2008–2018

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Introduction

Cities experience multiple environmental shifts, stresses, and shocks—such as air and water pollution—and a variety of extreme events simultaneously and continuously. Current urban programs have focused on limiting the impacts of these conditions through a portfolio of multifaceted strategies, such as regulations and codes, management and restoration projects, and citizen engagement. Global climate change represents a new environmental dynamic to which cities now have to respond.

While global climate change by definition has impacts worldwide, residents and managers of cities, like New York, typically perceive changes in their own local environments. In most cities, temperature is warming with increasingly hotter and longer heatwaves, and heavier downpours are leading to more frequent inland flooding. In coastal cities, sea levels are rising, exacerbating coastal flooding.

Analyzing and understanding the impacts of climate change on cities is important because of the dramatic growth in urban populations throughout the world. An estimated nearly 4.0 billion people reside in urban areas, accounting for 52% of the world's population (UN, 2017). That percentage will increase dramatically in the coming decades as almost all of the growth to take place up to 2050 will be in urban areas (UN, 2017).

The New York City metropolitan region (NYMR)—the five boroughs (equivalent to counties) of New York City and the adjacent 26 counties in the states of New York, New Jersey, and Connecticut—is an ideal model of an urban agglomeration. Approximately 8.6 million people live in the five boroughs and more than 15 million people live in the neighboring smaller cities, towns, and villages (City of New York, 2018a; US Census, 2017). The population of the five boroughs is projected to add 1 million people by 2030, while the total region is projected to reach 26.1 million (NYTC, 2015).

The original work on science-based assessments of climate change impacts in the NYMR began with *Climate Change and A Global City: The Metropolitan East Coast Regional Assessment of Potential Climate Variability and Change* (MEC Report) (Rosenzweig and Solecki, 2001a; Rosenzweig and Solecki, 2001b); (see also, Gornitz *et al.* (2002) and Major, (2003)).^a This foundational work laid the groundwork for a

^aEarly efforts at illustrating climate change challenges also included the Regional Plan Association's *Baked Apple* report (Hill, 1996) and the Environmental Defense Fund's *Hot Nights in the City* report (EDF, 1999).

stakeholder–scientist partnership to address climate change challenges in the region.

The objective of this chapter is to situate the third report of the New York City Panel on Climate Change (NPCC3) in the context of the role of cities in responding to climate change and the history of how New York City in particular has addressed climate change since the Metropolitan East Coast Assessment published in 2001 and the founding of the NPCC in 2008 (Rosenzweig and Solecki, 2001a; Rosenzweig and Solecki, 2010; Rosenzweig and Solecki, 2015).

The NPCC process has been both evolutionary and transformative. Its antecedents emerged in the late 1990s as the question of climate change and cities became first intertwined (e.g., EDF, 1999). From early on, there was recognition that new climate science, an understanding of how urban populations are vulnerable, and of how best to respond would emerge incrementally with occasional breakthroughs of new understanding as well as via significant trial and error.

The chapter presents an analysis of the how climate trends, projections, impacts, and responses have evolved over the past 20 years for New York City and its metropolitan region, and the contributions of the NPCC in the decade since 2008. It describes how these efforts can be expanded to provide future decision makers and practitioners in the city and region with the comprehensive knowledge foundation needed to guide and implement flexible adaptation pathways centered on resilience practice.

Flexible adaptation pathways are defined as a suite of mechanisms and actions that together enable meaningful responses to current climate risk while, as much as possible, also provide opportunities for a full suite of additional actions, which could be achieved via future adjustments and shifts in policy (Yohe and Leichenko, 2010).

As Co-Chairs of the NPCC over this period, we hope to define its advances and set them within the broader frame of climate change and cities in general as well as its future. This 10-year review of progress in building a knowledge base for risk-based response and adaptation pathways in NPCC1 (Rosenzweig and Solecki, 2010), for resiliency—NPCC2 (Rosenzweig and Solecki, 2015), and now with refined tools and methods—NPCC3, defines a point of departure for future co-development of New York City's response to climate change.

9.1. Leadership role of cities

New York City has engaged with and learned from other cities that also have been actively involved with climate change analysis and action.

City-to-city interactions

One of the ways New York interacts with Boston and Philadelphia on climate change is through the Consortium for Climate Risk in the Urban Northeast (CCRUN), an NOAA-funded Regional Integrated Sciences and Assessments (RISA) project. NOAA's RISA program supports research teams that help expand and build the nation's capacity to prepare for and adapt to climate variability and change. CCRUN's geographic domain includes Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, and Massachusetts, and is currently the only RISA team with a principal focus on climate change adaptation in urban settings.

New York City and Copenhagen are actively cooperating on sharing knowledge about responses to cloudbursts and heavy downpours. The NYC Department of Environmental Protection (DEP) is the lead agency on this project from New York. DEP launched the first phase of the "Cloudburst Resilience Planning Study" in 2016, based on the City of Copenhagen's Cloudburst Management Plan 2012. After a large event in Copenhagen in 2011, the city initiated 300 projects to drive storm water away from populated areas and to better manage flooding.^b

Applying this approach to Southeastern Queens where stormwater drains southward toward Kennedy Airport and Jamaica Bay, the New York study assessed risks, prioritized responses, and developed community-based solutions for managing local cloudbursts.^c Both cities sought to use a combination of blue-green and traditional infrastructure to manage flooding by replacing asphalt with grass to slow runoff, or by designing green spaces so that water flows into spaces where it can be stored temporarily, for instance by lowering basketball courts and playgrounds into the ground to catch rainwater. It is estimated that the total benefit of

^b<https://www.nytimes.com/2018/09/27/nyregion/new-york-flooding.html>

^chttp://www.nyc.gov/html/dep/html/about_dep/cloudburst.shtml

applying Copenhagen's Cloudburst Strategy to New York is \$603m USD.^d This partnership demonstrates how international collaboration among cities, and engagement between city governments, can result in more resilient cities.

The cities of New York and London, UK have long communicated with each other regarding their response to climate change. The London Climate Change Partnership, with connection to a wide group of organizations and the Greater London Authority as lead, has produced a series of studies and reports focused on metropolitan London (London Climate Change Partnership, 2002a,b). Early on in NPCC1, representatives from London presented to the panel and shared cutting-edge climate assessment advances such as flexible adaptation pathways.

Overall, the United Kingdom central government has been a leader with respect to developing the science of assessing climate change impacts on cities, such as through the Adaptation and Resiliency in the Context of Change^e network, which was established by the UK Climate Impacts Program. A number of regional studies have already been undertaken there. For example, the ASCCUE Project (Adaptation Strategies for Climate Change in the Urban Environment) conducted research in Manchester, England, specifically on the integrity of structures and the vulnerability of communities in the face of flooding (ASCCUE, 2003; Handley and Carter, 2006). In the Mayor's London Plan, response to climate change includes objectives for green roofs, managing flood risk, sustainable buildings, and reducing waste (Greater London Authority, 2011).

City Networks

There are several networks of cities that help to enable urban decision makers to respond to climate change in regard to both adaptation and mitigation. The C40 Cities Climate Leadership Group, established in 2005, connects about 100 of the world's cities, representing more than 550 million people and one quarter of the global economy. Created and led by cities, C40 is focused on tackling climate

change and driving urban actions that reduce greenhouse gas emissions and climate risks while increasing the health, wellbeing, and economic opportunities of urban citizens.

ICLEI—Local Governments for Sustainability is a leading network of more than 1500 cities, towns, and regions committed to building a sustainable future. By helping the ICLEI network to make their cities and regions sustainable, low-carbon, resilient, biodiverse, resource-efficient, and healthy with a green economy and smart infrastructure, ICLEI impacts more than 25% of the global urban population. ICLEI's mission is to build and serve a worldwide movement of city governments to achieve tangible improvements in global sustainability, with a specific focus on addressing climate change through cumulative local actions.

The Rockefeller Foundation 100 Resilient Cities (100 RC) initiative (<http://www.100resilient-cities.org/>) is another example of a climate change and cities network. This network was built through grants to cities to fund resiliency officer positions and conduct resiliency planning and programs. New York City is a 100RC member and through the network has been able to share advances and lessons learned with other cities.

9.2. Climate change in the New York metropolitan region

New York City is representative of the kinds of climate change challenges that may be experienced by other cities around the world, especially those located in emerging metropolitan conurbations. How the region is impacted by global climate change and how it will respond to the many-faceted challenges may be seen as a bellwether for other similar urbanized regions in both developed and developing countries.

In the New York metropolitan region, income growth has increased in recent years, and environmental threats such as the risk of hurricane damage (as clearly evidenced in the past decade), air pollution and heat stress, and water pollution persist. Although urban and suburban land uses have increased dramatically in the past several decades, approximately 60% of the land is still covered by farms and forests including the extensive NYC drinking water supply watershed region (Cox, 2014).

^dhttps://www.c40.org/case_studies/cities100-new-york-city-and-copenhagen-cities-collaborating-on-climate-resilience

^e<https://www.arcc-network.org.uk/>

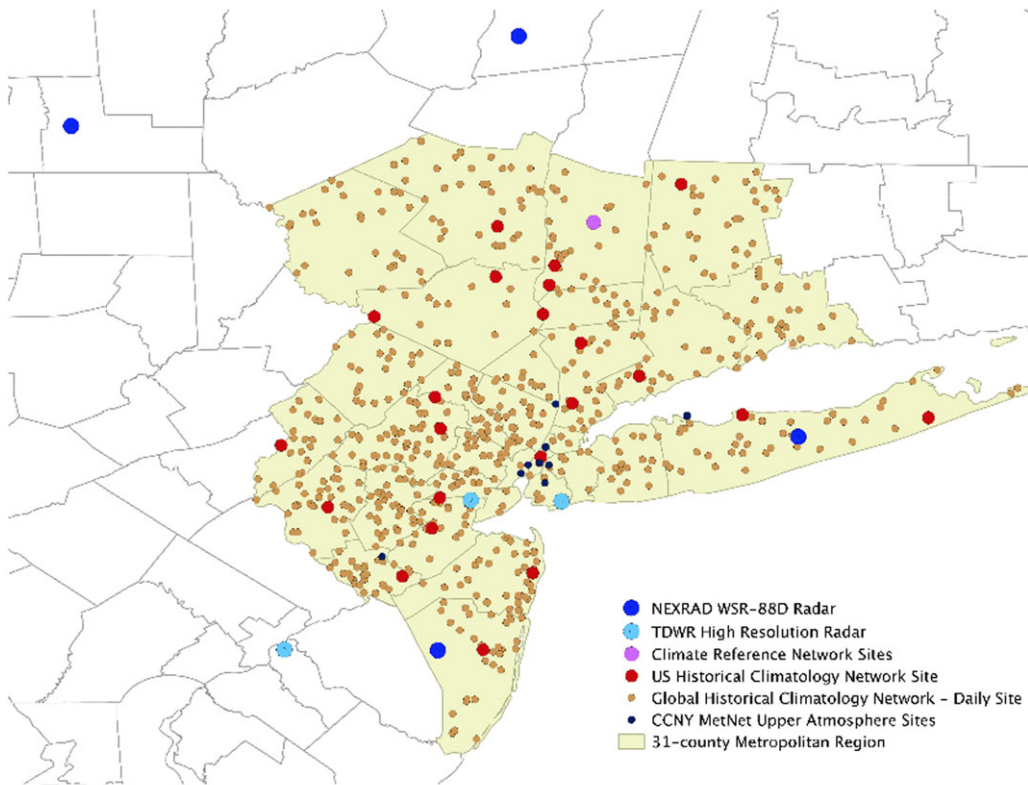


Figure 9.1. Sites important in supporting climate change monitoring in the New York Metropolitan Region. These include NOAA's Historic Climatology Network (HCN) and Climate Reference Network (USCRN), the City College of New York Upper Atmosphere Monitoring Sites, and Weather Radar Sites operated by the National Weather Service and the Federal Aviation Administration. *Image Source:* NPCC, 2015.

In the case of NYC and its history of climate change projections and assessments, stakeholders and decision makers in the region now understand climate warming as a range of diverse and interrelated impacts, as well as the need for dedicated climate change monitoring (Fig. 9.1) (see Chapter 8, Indicators and Monitoring; Solecki and Rosenzweig, 2014). This growing recognition and understanding has emerged over the past decade and an half, especially since the release of the 2001 Metropolitan East Coast Assessment report.

9.3. NPCC as an ongoing assessment process

As the MEC Report (Rosenzweig and Solecki, 2001a) concluded:

The complex nature of potential climate change impacts in urban regions poses tremendous challenges to urban managers to respond cooperatively, flexibly, and with far longer decision-making timeframes than currently prac-

ticed. Given the already fragmented nature of urban environments and jurisdictions, the political and social responses to the global climate issue in cities should begin at once. Transforming urban management to better prepare for climate change will safeguard against negative feedbacks in the Metro East Coast Region and around the world.

An intense rain event in early August of 2007, which flooded large portions of the NYC subways followed two similar events, precipitated additional focus on climate vulnerability, impacts, and adaptation issues. Two and a half inches of rain fell in one day. This extreme event brought the potential for climate-related disruption to the attention of the city and state, as well as to the Metropolitan Transportation Authority (MTA).

The New York City Panel on Climate Change (NPCC) was commissioned by then Mayor Michael Bloomberg in August, 2008. It came shortly after the launching of the PlaNYC Sustainability Plan (City of New York, 2007). Between the end of the MEC

Assessment and the founding of NPCC in 2008, the New York City DEP actively continued to work on climate change vulnerability and impacts assessment efforts (NYC DEP, 2008). At the same time, the Mayor's office began efforts to consider climate mitigation strategies for the city as part of PlaNYC.

The NPCC initiated work in August of 2008 and released its first assessment on climate change in New York City in 2010 (referred to here as NPCC1), incorporating new methods for predicting climate changes (Rosenzweig and Solecki, 2010).

Since 2008, the NPCC has essentially functioned as a *sustained assessment* for the city and metropolitan region of New York. According to the 2014 National Climate Assessment, a sustained assessment, in addition to producing assessment reports as required by law, recognizes that the ability to understand, predict, assess, and respond to rapid changes in the global environment requires ongoing efforts to integrate new knowledge and experience (Hall *et al.*, 2014).

This is accomplished by (1) advancing the science needed to improve the assessment process and its outcomes, building associated foundational knowledge, and collecting relevant data; (2) developing targeted scientific reports and other products that respond directly to the needs of federal agencies, state and local governments, tribes, other decision makers, and end users; (3) creating a framework for continued interactions between the assessment partners and stakeholders and the scientific community; and (4) supporting the capacity of those engaged in assessment activities to maintain such interactions (Hall *et al.*, 2014).

The NPCC has provided an essential enabling condition for New York to proactively and flexibly adapt to changing climate conditions. The challenge now is to sustain this function into the future under even more challenging climate change conditions. In August 2012, the City Council of New York passed Local Law 42 that codifies the NPCC, requiring it to present updated climate risk information and communication at least once during each mayoral administration.

The NPCC released its second assessment on climate change for the City of New York in 2015, referred to here as NPCC2 (2015). NPCC2 incorporates up-to-date climate observations and projections, impacts research, and policy analysis, as well

as lessons learned as a result of Hurricane Sandy in 2012.

Mayor de Blasio convened the third NPCC (NPCC3) in June, 2015. NPCC3, published in 2019, builds on the foundations of NPCC1 (2010) and NPCC2 (2015) and extends its framing and range of activities to focus on extreme events and new methods for analyzing them. Importantly, NPCC3 addresses the essential role of communities in preparing for climate change.

The NPCC, in its three iterations, has served as a knowledge provider to the Climate Change Adaptation Task Force (CCATF) that was founded at the same time. The CCATF body, also convened by the Mayor, brings together resource managers of the critical sectors in the city and region to coordinate development of resilience to climate change.

One of the main functions of the NPCC has been to develop a unified scenario process that resulted in "climate change projections of record" for the CCATF, the city more broadly, and the region to use in its resilience projects. For example, the NYC Climate Resiliency Design Guidelines^f use the NPCC projections, and were created to help ensure that city capital projects are designed to withstand the impacts of climate change.

Over the period since its founding in 2008, three questions emerge from the NPCC assessments:

1. Have climate change projections for NYC changed over time?
2. What has the NPCC learned about observed and projected climate change impacts?
3. How do stakeholders use the evolving NPCC information?

9.4. Regional climate and projected change

To assess the impacts of climate change and to study climate–society interactions in New York City, researchers use historical climate trends, current climate extremes, and future climate change scenarios (Rosenzweig and Solecki, 2001a; Rosenzweig and Solecki, 2010; NPCC, 2015). NPCC2 found that

^fThe NYC Climate Resiliency Design Guidelines, Version 2.0, 2018, can be accessed at: https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v2-0.pdf.

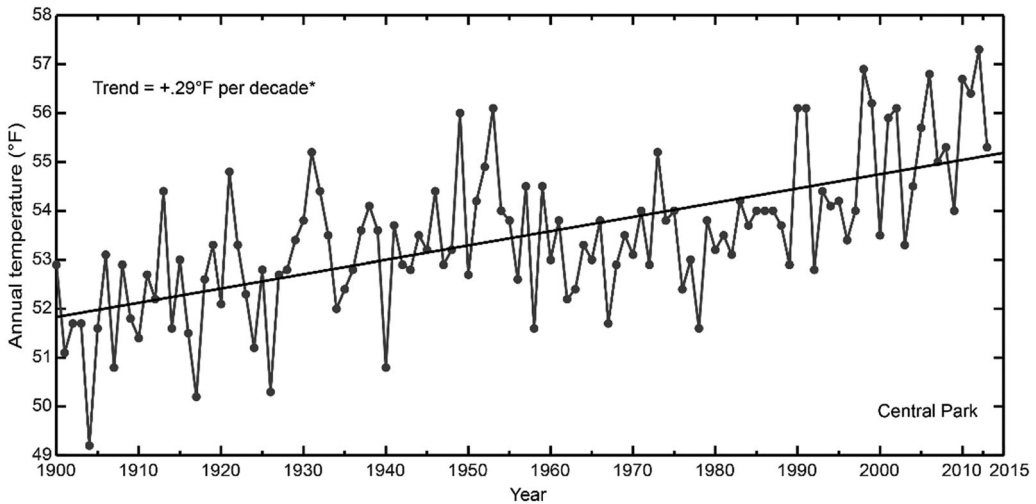


Figure 9.2a. Average annual temperature in New York City (Central Park), 1900–2013 (NPCC2, 2015).

historically, average annual temperatures in NYC have increased about 3°F (1.6 °C) between 1900 and 2013 (Fig. 9.2a). Overall, the warming has been greatest in the winter months compared to the annual average increase (Rosenzweig and Solecki, 2010; Rosenzweig *et al.*, 2011a).

Precipitation levels in the NYMR have increased by roughly 0.8 inches per decade between 1900 and 2015, with the amount of year-to-year variation greater than for the temperature data (Fig. 9.2b). According to NPCC2, the variation in precipitation has increased over the past century, especially since the 1970s, with a standard deviation of 6.1

inches in year-to-year precipitation from 1900 to 1956, increasing to 10.6 inches from 1957 to 2013 (NPCC, 2015).

Over the period of the MEC Report and the NPCC, several striking examples of climate extremes in New York City have hit the region since the late 1990s, including Hurricanes Floyd (1999), Irene (2011), and Sandy (2012). These episodes have been used as important “case studies” that presented opportunities for evaluating climate impacts and responses in the region.

For New York City, global climate models predict that climate change will bring higher temperatures

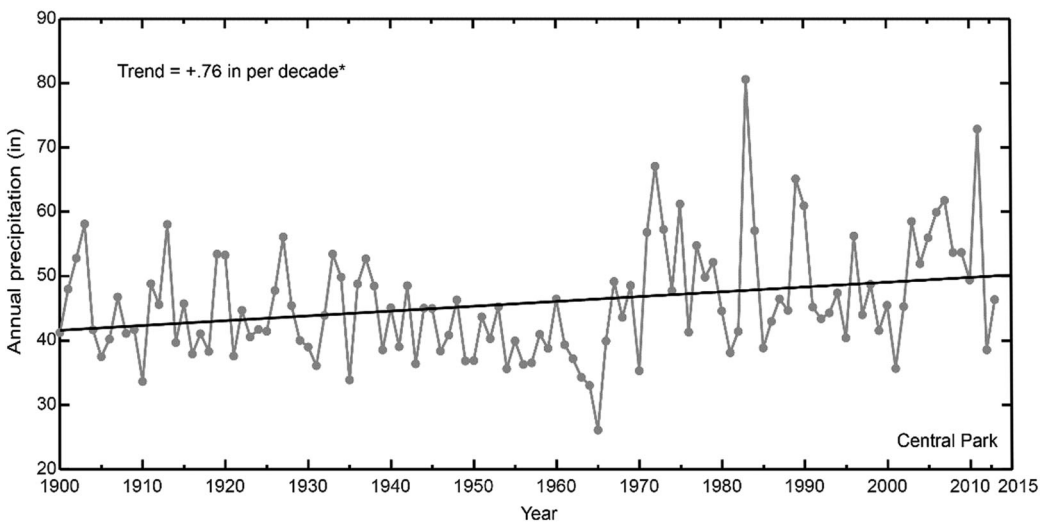


Figure 9.2b. Annual precipitation in New York City (Central Park), 1900–2013 (NPCC2, 2015).

all year long, more heat waves in the summer, rising sea levels, shorter coastal flooding recurrence periods, and inland flooding due to more frequent intense rainfall events. The number of droughts may increase by the end of the century, especially during the warm months, although drought projections are marked by a large amount of uncertainty (Shaw *et al.*, 2011). The question arises, Have these projections changed over time as new observations and models have emerged? This leads to another question: Do changes in projections make it difficult for decision makers and practitioners?

Climate scenarios

For the MEC assessment in 2001, future climate change scenarios could be viewed as “practice climates” for urban decision makers. They were defined as plausible combinations of climatic conditions that may be used to project possible climate impacts and to evaluate responses to them (Rosenzweig and Solecki, 2001a). They were a heuristic tool that began the process of social learning around the potential directional change in climate, which decision makers had previously viewed as unchanging or static.

As the NPCC advanced and uptake by NYC decision makers increased, the climate scenarios have become “projections of record” that are used as key inputs in resilience programs and projects. After the NPCC2 2015 projections were developed, the city began using them widely in resilience projects, culminating in the NYC Climate Resiliency Design Guidelines (City of New York, 2018b).

When NPCC3 began considering the development of a new set of projections to be published in 2019, discussions were held with regard to the state of the science because new scenarios for the IPCC 6th Assessment Report were not yet widely available. Further, the incorporation of the NPCC 2015 projections in resilience projects was still very much in progress. Therefore, no new climate projections were developed by NPCC for the 2019 Report. NPCC3 confirms NPCC2 projections for temperature, precipitation, and sea level changes as those of record for New York City.

NPCC climate scenarios are based on observed climate data and downscaled projections from global climate models (GCMs). Since 2001, climate change projections for New York City have been derived from evolving GCMs. They are mathemat-

ical models that simulate future temperature and precipitation changes in response to trajectories of greenhouse gas concentrations in the atmosphere, as well as trends in sulfate aerosols and other radiative forcings. Early GCMs projected climate responses at relatively coarse-scaled gridbox resolutions of $\sim 2.5^\circ \times 3.75^\circ$ lat. \times long. (or $\sim 175 \times 200$ miles) (Rosenzweig and Solecki, 2001a), but these have improved over time. Since the MEC assessment, NPCC 2010 used slightly refined GCM gridbox resolutions at $\sim 160 \times 190$ miles, and more refined resolutions of $\sim 125 \times 115$ miles for NPCC 2015.

In all three of the series, projections were developed for the 2020s, the 2050s, and the 2080s, with the addition of 2100 in the most recent projections of NPCC 2015. For the first time, the NPCC3 discusses post-2100 changes, especially in regard to the potential for continuing sea level rise. The methods for projecting climate change in the NYMR over the past decade are summarized in Table 9.1.

The evolution of these projections is presented in Table 9.2 for temperature and Table 9.3 for precipitation. While the projected changes in temperature as a result of climate change have shifted slightly as methods have developed over the past decade, they are generally consistent, showing temperature change projections ranging between 4°F and 10°F for the 2080s. Precipitation changes were projected to range between -2% and 30% in the earlier MEC study, but the more recent projections by NPCC 2010 and NPCC 2015 with larger numbers of newer GCMs narrowed that range to 5–13%.

Sea level rise

The rate of sea level rise in the city since 1900 has averaged approximately 1.2 inches per decade, with some regional and temporal variation (see Chapter 3, Sea Level Rise). This rate is approximately twice the rate of the global average rise due to regional land subsidence linked to isostatic rebound of formerly glaciated land to the north of the city (Rosenzweig and Solecki, 2001a; NPCC, 2015). Climate change will exacerbate sea level rise as glacial ice continues to melt (i.e., in the Greenland and West Antarctic ice sheets), because of thermal expansion of the upper layers of the ocean, and other factors.

Methods for projecting sea level rise have become more refined over the past decade and now utilize a complex set of global and regional inputs from scientific literature, GCMs, and expert

Table 9.1. Methods for calculating New York City climate change projections from MEC, NPCC 2010, and NPCC 2015

Publication	Year	# of GCMs	Greenhouse gas emissions scenarios	Ranges presented
Metropolitan East Coast Assessment (MEC)	2001	Two GCMs	Five scenarios Current trends, ^a HCGG, ^b HCGS, ^c CCGG, ^d and CCGS ^e	Lowest to highest
New York Panel on Climate Change 2010 (NPCC 2010)	2010	16 GCMs Seven for sea level rise	Three scenarios A2, ^f A1B, ^g and B1 ^h	Minimum value Central range (middle 67% of values) Maximum value Literature-based rapid Rapid ice-melt scenario (for sea level rise projections only)
New York Panel on Climate Change 2015 (NPCC 2015)	2015	35 GCMs 24 for sea level rise	Two scenarios RCP 4.5 ⁱ and RCP 8.5 ^j	Low estimate (10th percentile) Middle range (25th–75th percentile) High estimate (90th percentile)

^aProjection of historical temperature and precipitation trends (1900–1999).

^bHadley Centre, with forcing from greenhouse gases.

^cHadley Centre, with forcing from greenhouse gases and sulfate aerosols.

^dCanadian Centre, with forcing from greenhouse gases.

^eCanadian Centre, with forcing from greenhouse gases and sulfate aerosols.

^fFrom the IPCC Special Report on Emissions Scenarios (2000), the A2 emissions scenario assumes that relatively rapid growth and limited sharing of technological change combine to produce high greenhouse gas levels by the end of the 21st century, with emissions growing throughout the entire century.

^gFrom the IPCC Special Report on Emissions Scenarios (2000), the A1B emissions scenario assumes that the effects of economic growth are partially offset by the introduction of new technologies and decrease in global population after 2050. This trajectory is associated with relatively rapid increases in greenhouse gas emissions and the highest overall CO₂ levels for the first half of the 21st century, followed by a gradual decrease in emissions after 2050.

^hFrom the IPCC Special Report on Emissions Scenarios (2000), the B1 emissions scenario combines the A1 and A1B population trajectory with societal changes tending to reduce greenhouse gas emissions growth. The net result is the lowest greenhouse gas emissions of the three scenarios, with emissions beginning to decrease by 2040.

ⁱFrom Moss *et al.* (2010), the Representative Concentration Pathway (RCP) 4.5 refers to an emissions scenario where the total concentration of carbon dioxide equivalent (CO₂e) in the global atmosphere grows to 650 ppm by 2100, and then stabilizes thereafter. RCP 4.5 is typically seen as a medium scenario.

^jFrom Moss *et al.* (2010), the RCP 8.5 refers to an emissions scenario where the total concentration of CO₂e in the global atmosphere grows to greater than 1370 ppm in the year 2100, with no signal of halting growth. RCP 8.5 is typically seen as a high end—business-as-usual scenario.

elicitation. Projections for sea level rise in New York City over the past decade are summarized in Table 9.4.

As with temperature and precipitation, no new average annual sea level rise projections were developed for NPCC 2019, but an Antarctic Rapid Ice Melt (ARIM) scenario was developed to raise awareness of the growing risk at high end of the distribution. Recognizing the increasing risks from recent observations that ice melt has been occurring more

quickly than previously thought (Shepherd *et al.*, 2018; Sweet *et al.*, 2017; Slangen *et al.*, 2017), the NPCC saw a need for gaining an improved understanding of the potential upper limits to global mean sea level rise by 2100 as an important scientific objective to aid in critical and long-lived infrastructure decisions. The NPCC therefore developed a high-end scenario for sea level rise incorporating the effects of rapid ice melt from the Antarctic—the ARIM scenario.

Table 9.2. Evolution of temperature projections over the 21st century for New York City from MEC, NPCC 2010, and NPCC 2015

Publication	Baseline	Range	2020s ^a	2050s ^a	2080s ^a	2100 ^a
Metropolitan East Coast Assessment, 2001	50°F 1961–1990	Lowest to highest	+1.7°F–+3.5°F	+2.6°F–+6.5°F	+4.4°F–+10.2°F	–
New York Panel on Climate Change, 2010	55°F ^b 1971–2000	Minimum value	+0.5°F	+2.5°F	+3.0°F	–
		Central range (middle 67%)	+1.5°F–+3.0°F	+3.0°F–+5.0°F	+4.0°F–+7.5°F	–
		Maximum value	+3.5°F	+7.5°F	+10.0°F	–
New York Panel on Climate Change, 2015	54°F ^b 1971–2000	Lowest (10th percentile)	+1.5°F	+3.1°F	+3.8°F	+4.2°F
		Middle (25th–75th percentile)	+2.0°F–+2.9°F	+4.1°F–+5.7°F	+5.3°F–+8.8°F	+5.8°F–+10.4°F
		Highest (90th percentile)	+3.2°F	+6.6°F	+10.3°F	+12.1°F

^aTemperature projections are shown for the 2020s (2010–2039), 2050s (2040–2069), 2080s (2070–2099), and 2100.

^bDifferent sets of weather stations were used for NPCC 2010 and NPCC 2015, resulting in slightly difference baseline values.

NOTE: No new average annual temperature projections were developed by NPCC (2019).

Table 9.3. Evolution of precipitation projections over the 21st century for New York City from MEC, NPCC 2010, and NPCC 2015

Publication	Baseline	Range	2020s ^a	2050s ^a	2080s ^a	2100 ^a
Metropolitan East Coast Assessment, 2001	46.5 inches 1961–1990	Lowest to highest	+1%–+9%	–16%–+14%	–2%–+30%	–
New York Panel on Climate Change, 2010	46.5 inches ^b 1971–2000	Lowest value	–5%	–10%	–10%	–
		Central range (middle 67%)	+0%–+5%	+0%–+10%	+5%–+10%	–
		Highest value	+10%	+10%	+15%	–
New York Panel on Climate Change, 2015	50.1 inches ^b 1971–2000	Lowest (10th percentile)	–1%	+1%	+2%	–6%
		Middle (25th–75th percentile)	+1%–+8%	+4%–+11%	+5%–+13%	–1%–+19%
		Highest (90th percentile)	+10%	+13%	+19%	+25%

^aPrecipitation projections are shown for the 2020s (2010–2039), 2050s (2040–2069), 2080s (2070–2099), and 2100.

^bDifferent sets of weather stations were used for NPCC 2010 and NPCC 2015, resulting in slightly difference baseline values.

NOTE: No new average annual precipitation projections were developed for NPCC (2019).

Table 9.4. Evolution of sea level rise projections over the 21st century for New York City from MEC, NPCC 2010, and NPCC 2015

Publication	Baseline	Range	2020s ^a	2050s ^a	2080s ^a	2100 ^a
Metropolitan East Coast Assessment, 2001	0 inches 1961–1990	Lowest to highest	5.4–9.5 inches	8.6–20.1 inches	16.7–37.5 inches	–
New York Panel on Climate Change, 2010	0 inches 2000–2004	Lowest value	1 inch	5 inches	9 inches	–
		Central range (middle 67%)	2–5 inches	7–12 inches	12–23 inches	
		Highest value Rapid ice-melt scenario	6 inches 5–9 inches	14 inches 19–29 inches	26 inches 41–55 inches	
New York Panel on Climate Change, 2015	0 inches 2000–2004	Lowest (10th percentile)	2 inches	8 inches	13 inches	15 inches
		Middle (25th–75th percentile)	4–8 inches	11–21 inches	18–39 inches	22–50 inches
		Highest (90th percentile)	10 inches	30 inches	58 inches	75 inches
New York Panel on Climate Change, 2019	0 inches 2000–2004	Antarctic Rapid Ice Melt (ARIM) scenario ^b			81 inches	114 inches

^aSea level rise projections are shown for the 2020s (2020–2029), 2050s (2050–2059), 2080s (2080–2089), and 2100.

^bARIM 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. The ARIM scenario is based on DeConto and Pollard (2016), Kopp *et al.* (2014; 2017), and informed expert judgments about maximum plausible ice loss rates from Antarctica (Sweet *et al.*, 2017). However, uncertainties remain regarding ice sheet processes and atmosphere, ocean, and ice sheet interactions.

Mean sea level rise associated with global warming will increase the flooding area in low-lying coastal areas throughout NYC and represents a key threat (Table 9.5). Heightened flood potential due to sea level rise during future hurricanes and nor'easters will cause the most substantial damage.

Given the projected rates of sea level rise, NPCC 2015 estimates by the 2080s, a coastal storm event comparable to a current flood level with a 1 percent chance of annual occurrence could occur 10 to 15 times for often under the worst-case emissions scenario. In more extreme although less certain esti-

mates, a current flood level with a 0.2 percent chance of annual occurrence could increase to a 2 percent chance of annual occurrence (NPCC, 2015).

Even more moderate scenarios have the potential for destructive impacts. For example, the scenario with the lowest projected sea level rise implies that a current 100-year coastal flood could potentially occur every 25–30 years by the 2080s (NPCC, 2015).

As demonstrated by Hurricane Sandy and other recent storms highlighted in Table 9.6, the risks to many of the region's most significant infrastructure will be amplified as a result of sea level rise and the

Table 9.5. Shifting future 1% (100-year) and 0.2% (500-year) flood elevation areas in New York City with increasing sea level rise through 2100. Projections are for the high estimate (90th percentile)

	Area (mi ²)
100-year flood scenario	
FEMA 2013 Preliminary FIRM	50
Projected 2020s, 10"	59
Projected 2050s, 30"	72
Projected 2080s, 58"	85
Projected 2100s, 75"	91
500-year flood scenario	
FEMA 2013 Preliminary FIRM	66
Projected 2020s, 10"	76
Projected 2050s, 30"	84
Projected 2080s, 58"	94
Projected 2100s, 75"	99

Source: NPCC, 2015.

associated augmentation in storm surges (NPCC, 2015). Standard practice in public policy has been to place the necessary, yet locally unwanted land uses (LULUs,) on marginal lands. One example of this is placing transportation infrastructure near wetlands, bays, and estuaries, which has engendered some unintended consequences.

The Hackensack Meadowlands in northern New Jersey, located some 5 km west of New York City, is a model case of this practice. This area is a low-elevation, degraded wetland harboring critical ship, train, air, road, and pipeline infrastructure that crisscrosses the terrain; these intertwining components are at increased risk of flooding due to sea level rise. The storm surge associated with Hurricane Sandy, for example, caused significant flood damage in the Meadowlands, and the Federal Department of Housing and Urban Development is providing \$150 million to restore these wetlands and strengthen their resilience to future coastal storms (Leichenko and Solecki, 2013; U.S. Department of Housing and Urban Development, 2014).

9.5. Climate change impacts

Climate change presents challenges and opportunities for the socioeconomic and ecological systems of New York City. The climate stresses described above, in turn, are likely to inundate coastal wetlands, threaten vital infrastructure and water supplies, raise summertime energy demand, and affect

public health, all at the same time. These concurrent impacts could also result in other yet-to-be realized impacts on the local quality of urban life and economic activity. Hurricane Sandy revealed the potential for difficult-to-predict, system-level cascading impacts that could occur with climate change-enhanced extreme events. Given the region's prominent position in the global urban economic hierarchy and potential disruption of business activities, the effects of these local extreme events could be felt at national and international scales.

In this section, we discuss some of the direct and indirect impacts of climate change and how these will interact and, in the regional context, create secondary and tertiary effects. The impacts of climate change are becoming increasingly tangible and fall into a number of nonmutually exclusive categories (direct, indirect, interactive, and integrative) (Table 9.7). Furthermore, the skill in predicting regional climate has sharpened over the past 10 years (see Section 9.4).

Simultaneously, a dynamic process has developed between climate change scientists and public policymakers in cities throughout the world (Rosenzweig *et al.*, 2018). Policymakers and practitioners are being challenged to understand the implications of climate shifts for their cities and to devise adaptations and adjustments to these emerging conditions.

These include physical changes in infrastructure such as higher seawalls for coastal cities (Dawson *et al.*, 2018) and the restructuring of water supply systems (Vicuña *et al.*, 2018); changes in decision making such as coordinating management strategies among overlapping jurisdictions (Romero-Lankao *et al.*, 2018); incorporating urban planning and design (Raven *et al.*, 2018); and far-reaching societal shifts such as disinvestment in highly vulnerable coastal sites and increased support for at-risk populations such as the poor or elderly (Reckien *et al.*, 2018). These responses will inevitably also interact with other ongoing processes of societal and ecological transformation in large urbanized zones (Solecki *et al.*, 2013; McPhearson *et al.*, 2018).

Coastal wetlands

The vulnerability of the New York metropolitan region's remaining coastal wetlands to climate change was first documented in the MEC study (Hartig *et al.*, 2001). There are few remaining marsh

Table 9.6. Extreme coastal storm events in New York City from 1999 to 2012

Coastal storm	Date	Description
Hurricane Floyd	September 16–17, 1999	<ul style="list-style-type: none"> • Category: TS-1 • Central pressure: 974 mb • Wind speed: 70 mph • Major inland riverine flooding with 24-h rainfall totals between 10 and 15 inches in upstate New Jersey and New York
Hurricane Irene	August 27–29, 2011	<ul style="list-style-type: none"> • Category: TS^a • Central pressure: 959 mb^b • Wind speed: 65 mph^c • 3–6 foot storm surge above normal tide levels^d • NYC issued its first ever mandatory evacuation of coastal areas, covering 370,000 residents^e • NYC subway service suspended evening of August 27th, not fully restored until August 29th^f • Estimated \$100 million in damages^g • One attributed death in NYC^h
Hurricane Sandy	October 29–30, 2012	<ul style="list-style-type: none"> • Category: TSⁱ • Central pressure: 965 mb^j • Wind speed: 74 mph^k • Storm surge reached 9.4 feet above normal tide levels and storm tide reached 14.06 feet above Mean Lower Low Water (MLLW) at The Battery, flooding lower Manhattan^l • NYC issued its second-ever mandatory evacuation of coastal areas^m • Estimated \$19 billion in damage to the cityⁿ • At least 52 attributed deaths in NYC^o • 800,000 customers lost power in NYC^p
November 2012 Nor'easter	November 7–10, 2012	<ul style="list-style-type: none"> • Followed in wake of Hurricane Sandy, bringing strong winds and downed power lines to areas recovering from previous storm • Central Park recorded 2.8 inches of snowfall, setting new daily record,^q with snow affecting those in temporary shelters due to Hurricane Sandy

^ahttp://www.nhc.noaa.gov/data/tcr/AL092011_Irene.pdf^bhttp://www.nhc.noaa.gov/data/tcr/AL092011_Irene.pdf^c<http://www.nytimes.com/2011/08/29/nyregion/wind-and-rain-from-hurricane-irene-lash-new-york.html?smid=pl-share>^dhttp://www.nhc.noaa.gov/data/tcr/AL092011_Irene.pdf^ehttp://www.nyc.gov/html/oem/html/hazards/storms_hurricanehistory.shtml^f<http://www.nws.noaa.gov/om/assessments/pdfs/Irene2012.pdf>^ghttp://www.nyc.gov/html/oem/html/hazards/storms_hurricanehistory.shtml^hhttp://www.nhc.noaa.gov/data/tcr/AL092011_Irene.pdfⁱhttp://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf^jhttp://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf^khttp://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf^lhttp://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf^mhttp://www.nyc.gov/html/oem/html/hazards/storms_hurricanehistory.shtmlⁿhttp://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf^oSeil *et al.*, 2016.^phttp://www.nyc.gov/html/recovery/downloads/pdf/sandy_aar_5.2.13.pdf^qhttp://usnews.nbcnews.com/_news/2012/11/07/14987947-noreaster-snow-layers-sandy-destruction-more-evacuations-more-power-outages?lite

areas, all of which function to provide critical habitat for wildlife, particularly migratory waterfowl species. The wetlands also provide ecosystem services to coastal communities by inhibiting coastal storm surges onto developed lands and by naturally

purifying water systems. In addition, the encroachment of land development on wetlands has prevented the ecosystem from naturally responding to sea level rise through accretion and in-migration (Solecki and Rosenzweig, 2001).

Table 9.7. Categories of potential climate change impacts

Impact type	Description
Direct	Direct connection of climate change to a local environmental change, e.g., global climate warming contributing to local sea level rise
Indirect or dependent	Multistep process through which direct impacts eventually result in an effect, e.g., increased droughts leading to a decline in drinking water supplies
Interactive or interdependent	Two or more climate-related changes causing an impact, e.g., increased energy demand due to more heat waves leading to electrical blackouts and brownouts, in turn resulting in greater heat stress for those left without air conditioning
Integrative	One or more climate change-related changes becoming integrated with ongoing, local-scale environmental changes such as global temperature change exacerbating a city's existing urban heat island

Severe wetland loss in the region has already been recorded. The marsh islands in the Jamaica Bay National Wildlife Refuge in Brooklyn and Queens decreased approximately 10% in area from 1959 to 1998 (Hartig *et al.*, 2001), and research has shown that a significant amount of this loss is likely to have resulted from 20th century sea level rise (Hartig *et al.*, 2002). Future climate scenarios illustrate that the rate of sea level rise will likely exceed the accretion rate of these wetlands by 2050, resulting in even more rapid loss. In addition to this, the increasing rate of summer evapotranspiration and water deficits that are projected for the mid-to-late century further signify that the total extent of wetlands is likely to be reduced (Wolfe *et al.*, 2011).

Water supply

Managers of the NYC water supply system will face challenges from increased climate variability and climate change (Major, 2003). Periods of extreme rainfall followed by periods of drought are projected in future climate scenarios for the region (see Chapter 2, Climate Science). While changes in future precipitation are less certain than temperature changes, climate projections indicate that there will likely

be greater hydrologic variability (Rosenzweig and Solecki, 2010; Rosenzweig, *et al.*, 2011a).

Expected sea level rise will interact with the region's water supply infrastructure. Many features in the region, including pumping stations, treatment facilities, and intake and outflow sites, are now vulnerable to storm-surge flooding, and under conditions of climate change will be directly subject to more frequent flooding. Still under investigation is the potential increased threat of salt-water intrusion into regional groundwater supplies and at surface water withdrawal sites, such as the Chelsea pump station on the Hudson River where NYC would get supplemental water during periods of extreme drought (Major and Goldberg, 2001; Shaw *et al.*, 2011).

Research that began in 2001 has indicated that the New York City water supply system—one of the largest in the world with a storage capacity of 570 billion gallons—should be able to respond to both the expected increase in annual temperatures and greater variability in the rainfall (Major and Goldberg, 2001; Shaw *et al.*, 2011; NAS, 2018). However, shifts in the pattern of supply to New York City watersheds could potentially overwhelm the response capacity of smaller systems in the region.

More recently, researchers have begun examining the interdependent vulnerabilities between the water supply system and other critical infrastructure systems, such as the electricity supply system (Zimmerman and Faris, 2010; see Chapter 7, Critical Infrastructure). As noted in Chapter 2, Climate Science, of this report, while there has not been a major drought since the 1960s in the New York metropolitan region, analysis based on tree-rings from the last 250 years shows that 10-year or longer droughts have occurred, and therefore the possibility of future drought events should be considered in planning.

Energy demand

Climate change will have direct impacts on energy demand in the region. Demand for winter energy will decrease as seasonal temperatures become warmer, while cooling demand will rise significantly in the summer due to more frequent and intense heat extremes (Hammer *et al.*, 2011). Summer demand could be especially strong during heat waves as illustrated by the set of heat waves described in Table 9.8. In 2002, the temperature rose

Table 9.8. Extreme heat wave events in New York City from 1999 to 2013

Heat waves		
11-day heat wave	July 23–August 2, 1999	<ul style="list-style-type: none"> • Second-longest heat wave on record (longest was 12 days in 1953) • Preceded by two heat waves (4 and 5-day) earlier in July that were responsible for at least 27 heat-related deaths city-wide^a
4 successive heat waves	July–August, 2002	<ul style="list-style-type: none"> • Temperature rose higher than 90°F 25 times and exceeded 100°F twice • 8-day heat wave; 9-day heat wave
3-day heat wave	July 25–27, 2005	<ul style="list-style-type: none"> • 3 consecutive days with temperatures reaching 90°F or higher • Con Edison broke its energy use record, with 13,059 MW^b
10-day heat wave	July 27–August 5, 2006	<ul style="list-style-type: none"> • 10 consecutive days with temperatures reaching 90°F or higher • 140 attributed deaths in NYC deaths (direct and indirect)^c • Con Edison broke its energy use record, with 13,103 MW^d
4-day heat wave	July 21–24, 2011	<ul style="list-style-type: none"> • 4 consecutive days with temperatures reaching 90°F or higher; 2 consecutive days with temperatures reaching 100°F or higher • Con Edison broke its energy use record, with 13,189 MW of energy^e • Temperatures in Central Park reached 104°F (108°F in Newark NJ) on July 22nd, hottest day since July 21, 1977 • 24 heat-related deaths reported^f
7-day heat wave	July 14–20, 2013	<ul style="list-style-type: none"> • 7 consecutive days with temperatures reaching 90°F or higher • 2 consecutive days with > 100°F temperatures^g • Con Edison broke its energy use record, with 13,214 MW of energy^h • NY State ISO broke its energy use record, using 39,955 MW of powerⁱ • 19 heat-related deaths; approximately 140 natural cause deaths related to extreme heat, during the 2013 warm season^j

^a<https://www.nytimes.com/1999/07/10/nyregion/heat-wave-toll-climbs-to-27-dead-in-new-york-city.html>

^b<http://www.nytimes.com/2006/08/01/us/01cnd-heat.html>

^chttp://www.nytimes.com/2006/11/16/nyregion/16heat.html?_r=0

^d<http://www.nytimes.com/2006/08/01/us/01cnd-heat.html>

^e<http://www.foxnews.com/weather/2013/07/20/nyc-breaks-power-usage-record-during-heat-wave/>

^f<http://online.wsj.com/articles/a-summer-of-normal-temperatures-for-new-york-with-few-scorchers-1408756894>

^g<http://www.bloomberg.com/news/2013-07-19/heat-wave-may-peak-with-temperatures-near-or-at-100-in-new-york.html>

^h<http://www.bloomberg.com/news/2013-07-19/heat-wave-may-peak-with-temperatures-near-or-at-100-in-new-york.html>

ⁱ<http://www.bloomberg.com/news/2013-07-19/heat-wave-may-peak-with-temperatures-near-or-at-100-in-new-york.html>

^j<https://www1.nyc.gov/assets/doh/downloads/pdf/epi/databrief47.pdf>

above 90°F for 25 days during July and August, and went over 100°F twice.

Climate change scenarios in NPCC 2015 project that the average number of days at or above 90°F will increase three- to fourfold by the 2080s (NPCC, 2015). An indication that extreme heat is already impacting New York City energy demand is that in each of the four major heat waves from 2005 to 2013, Con Edison broke a new energy-use record (Table 9.8). On average, during each warm season in NYC, there are 13 heat stroke deaths, 150 hospital

admissions, and 450 emergency department visits for heat-related illness; an average of 115 natural-cause deaths are associated with extreme heat each year.^g

During a heat wave of 1999 that occurred as the MEC Report assessment was underway, the region

^g<https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6231a1.htm> 2); <https://www.ncbi.nlm.nih.gov/pubmed/27081885>

experienced a record peak demand for electrical power that precipitated brownouts and an extended blackout during the heat wave (July 6th) in largely minority sections of the city (upper Manhattan and the South Bronx) (Rosenzweig and Solecki, 2001a). Residents and local politicians argued that the blackout revealed that the local power authority (Consolidated Edison) had not properly maintained the equipment serving these neighborhoods putting the populations of color at comparatively higher risk.

Although a Public Service Commission review found that this was not the case (State of New York, 2000), this type of integrative impact highlights the need for focus on disadvantaged communities so that they are not disproportionately affected by similar future events (Wilgoren and Roane, 1999). Such events might foreshadow future extreme electricity demand events, and real or perceived inequities that might arise in the face of environmental risk exposure.

Public health

Inequity and the spatial and demographic unevenness of climate change impacts are probably no better expressed than in the risks to the public health sector in urban regions (Kalkstein and Greene, 1997). Typically, direct and integrative impacts occur under these circumstances. Populations in urbanized places like New York City are likely to experience increased exposure to heat stress conditions, greater potential of water-borne or vector-related disease outbreaks, and higher concentrations of secondary air pollutants resulting in increased frequency of respiratory ailments and attacks, such as asthma (Kinney *et al.*, 2011; see Chapter 6, Community-Based Adaptation). The poor, elderly, very young, and immuno-compromised will be at greatest risk. New York City, like other large cities, has significant populations of these individuals. Recent studies of the effects of Hurricane Sandy have highlighted the vulnerability of impoverished populations in critical flood zones (Lane *et al.*, 2013; Kinney *et al.*, 2015).

Interactions between electric energy demand and health effects are likely to occur under conditions of climate change. For example, heat stress and heat-related mortality are projected to a major direct health impact of climate change (NPCC, 2015). Populations at heightened risk of heat stress and heat-

related mortality will be those without access to air conditioning. Already, air conditioning access is not equitably distributed at the individual and neighborhood level, with wealthier people and neighborhoods having greater access (NYC DOHMH, 2014).

Air conditioning use, though, could become especially problematic during summer heat waves that result in increased cooling demand and possible, subsequent electricity blackouts unless actions are taken to ensure that people who need air conditioning to safeguard health have access while others, including businesses, use air conditioning responsibly during extreme heat events (Lane *et al.*, 2013; NYC DOHMH, 2014). Risk of morbidity and mortality in New York becomes severe if blackouts occur during an extreme heat event (Dominianni *et al.*, 2018) (Kinney *et al.*, 2015).

As found in the MEC report and other studies, heat waves will also exacerbate secondary air pollution problems in the region (Kinney *et al.*, 2001; Knowlton, 2004). Peak electricity demand and fossil fuel burning during heat waves result in an increase of primary air pollutants, for example, nitrogen oxides (NO_x). These pollutants are then converted into secondary air pollutants, like ozone. Increased concentrations of secondary pollutants are associated with higher numbers of respiratory-related health attacks and hospitalizations.

Vector-borne diseases are spread by organisms such as ticks and mosquitoes, and disease incidence is influenced by climate factors (Kinney *et al.*, 2015). Early in the MEC assessment, summer events of 1999 provided evidence of integrative climate change-related health impacts (Rosenzweig and Solecki, 2001a). Throughout the late summer of that year, birds starting dying throughout NYC. By September, a few people in the region came down with unusual flu-like illnesses. Within a few weeks, several victims had died, and the region erupted in a full-fledged public health crisis. Within weeks, the cause had been narrowed to two species of freshwater mosquitoes, and eventually the specific viral strain that they were carrying was isolated as West Nile-like Virus—recorded for the first time in North America.

While the process by which the mosquitoes became infected was unclear, how the mosquitoes' populations were able to grow so dramatically in late summer is illustrative of the society's vulnerability

to climate variability (Kinney *et al.*, 2011). A likely scenario is that early summer drought warning had forced homeowners in suburban Queens to temporarily stop using their backyard pools. The pool water remained stagnant for several weeks and was followed by heavy end-of-summer rains. Mosquito experts later stated that this was the ideal condition under which to promote the growth of the two species of mosquito later defined as the virus carriers. Though the number of mosquitos infected with West-Nile virus is not directly caused by increasing climate change, the number of total mosquitos is likely to rise with a warmer and wetter climate; this makes the potential for an elevated risk of mosquito-borne diseases such as West-Nile virus in New York a legitimate concern.

Community resiliency

The NPCC3 report presents key findings related to community resiliency in New York City (see Chapter 6, Community-Based Adaptation). The Community-Based Assessments of Adaptation and Equity Work Group investigated patterns of spatial vulnerability to climate change across neighborhoods and communities in New York City. This task, which draws attention to issues of *distributional equity* in vulnerability (i.e., spatial or temporal differences), was accomplished through compilation, review, and assessment of recent vulnerability mapping studies conducted in New York and elsewhere in the United States.

The aim of NPCC3 Chapter 6 was to identify common patterns and indicators of spatial vulnerability and to provide guidance on methods and indicators that can be used to monitor and track neighborhood vulnerability over time.

The Work Group also developed case studies of climate change risks, vulnerability, and adaptation in socially and economically disadvantaged communities. This task, which incorporates the consideration of *contextual equity* (i.e., communities with multiple stresses), was accomplished in collaboration with three community-based organizations (CBOs)—WE ACT for Environmental Justice in Harlem, THE POINT CDC in Hunts Point, and UPROSE in Sunset Park. All of these CBOs are situated in predominantly minority and low-income neighborhoods, and all have either developed or are in the process of developing climate adaptation plans for their communities.

An examination of community-based adaptation planning efforts was conducted in several New York City neighborhoods. The task, which was accomplished through collaboration with CBOs and New York City planners, explored how *procedural equity* (i.e., imbalance with respect to access to the decision-making process) is incorporated in development and implementation of adaptation plans.

An examination of current practices for incorporating equity in urban adaptation planning efforts is the final step. This task was accomplished via comparative investigation of how New York and other cities in the northeastern United States incorporate principles of distributive, contextual, and procedural equity into community adaptation planning.

9.6. How stakeholders use NPCC3 information

The NPCC has developed a range of new types and formats of information in a co-generation process with stakeholders. These include new climate data and projections as well as tools and methods to foster communication and situate these data and information products into a variety of resiliency and adaptation strategies.

Interactions with stakeholders and users of climate information have been emphasized throughout the NPCC process from the beginning in 2008. Most recently, NPCC3 members interacted with a variety of stakeholders, including scientists, members of city government agencies, infrastructure managers, and communities to “co-generate” the information that is presented in this report. In the NPCC context, the term “co-generation” refers to an iterative process of discussion and development of climate science information between scientists and stakeholders conducted to improve decision making.

These interactions included (1) discussion of relevant science needs that decision makers had; (2) communication via email, phone calls, and in-person meetings or workshops; and (3) reviews of draft report data, figures, and text. Throughout this process, NPCC3 scientists responded to and incorporated stakeholder feedback into its work, culminating in the final NPCC3 Report.

NPCC portfolio approach to resilience

In regard to responses to increasing climate risks, the city has adopted a wide range of strategies, in

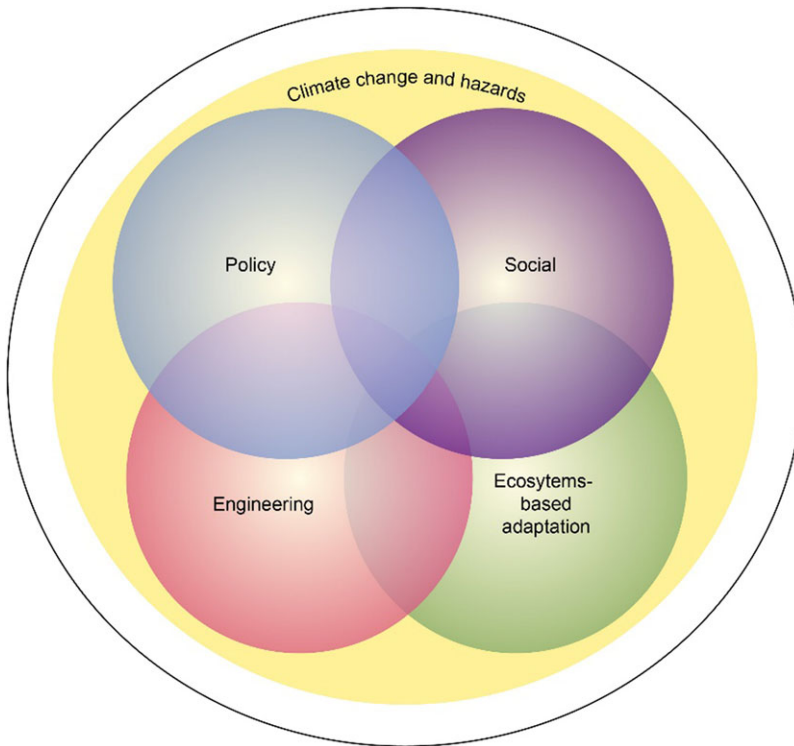


Figure 9.3. Portfolio approach to resilience.

essence taking a “portfolio approach” that includes programmatic, social, engineering, and nature-based adaptive initiatives (Fig. 9.3).

The NPCC has embedded this portfolio approach to resilience within its flexible adaptation pathways framework whereby each resiliency action can be set within a set of adaptation steps highlighted in NPCC1 as an eight-step process (see Chapter 1 Introduction). Over time, it has become increasingly clear that adaptation strategies take on a variety of conditions and contexts from small and discrete (e.g., a single wetland restoration effort to promote storm surge wave attenuation) to large and widespread (e.g., a series of actions to promote resiliency of the New York City transit system).

Some adaptation strategies represent policy regime shifts that once made are difficult to undo and limit return to an earlier state or adjustment to an alternate policy position (i.e., adaptation lock-in) (Ürge-Vorsatz *et al.*, 2018). The consideration of a large-scale storm surge barrier across the New York harbor is one such large, “game-changing” proposal. As described in NPCC1, the position of NPCC has been to recommend a comprehensive assessment of

potential physical, biophysical, and socioeconomic outcomes before any such activity is undertaken.

As an additional consideration, the NPCC presents the following typology of evaluation and assessment for this and other potential future adaptation strategies (see Fig. 9.4). In the typology, as the flexibility of the adaptation strategy decreases and its relative size increases, the need for assessment and analysis increases.

9.7. Policy recommendations and outcomes

Policy recommendations in each of the NPCC reports have helped to engage New York City decision makers in crafting long-term adaptation plans that have evolved through time. Assessment recommendations have contributed to the establishment of the Consortium for Climate Change Risk in the Urban Northeast (CCRUN) and the ongoing NPCC, which is now mandated by law to provide climate risk information to each successive mayoral administration. Recommendations from these assessments and their outcomes are described in Table 9.9.

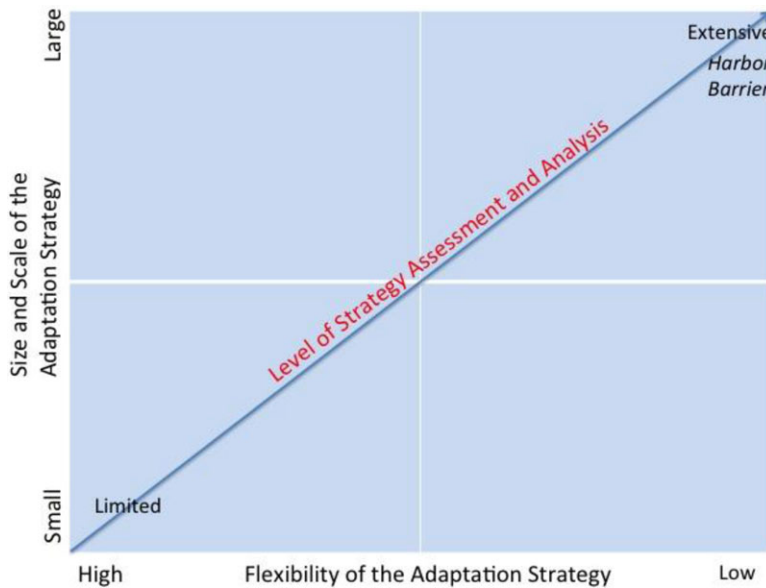


Figure 9.4. Adaptation assessment typology and required level of assessment.

9.8. Scoping NPCC's next phase: regional integration

The first decade of NPCC has yielded a series of important findings and lessons, and sets forth a pathway to consider some next steps. For example, it seems pressing that part of the evolution of the NPCC assessment should focus on assessing vulnerability, tracking impacts, evaluating adaptation measures, and providing a guide for coordinated resilience action across the entire New York metropolitan region.

Such a regional approach would benefit from incorporating a full range of sectors, and from taking the full range of dependencies and interdependencies into account in order to avoid siloed responses across multiple levels of government, as well as agencies and departments. The assessment process should create a unified set of scenarios to be used throughout the region and should include a benchmarked analysis of indicators from the proposed New York City Climate Change Resiliency Indicators and Monitoring system (NYCLIM) presented in Chapter 8 of this report (see NAS, 2018).

Such an ongoing regional assessment process can help to further important discussions about challenging issues such as potential land use change and strategic relocation in the region, given the increasing risks to coastal areas. For example, the

NPCC could facilitate a region-wide discussion of strategic relocation by convening a Climate Change Summit once during each administration so that responses to this and other key issues could be explored and coordinated.

Funding and resources

A key challenge for the ongoing NPCC process is funding its activities. The Rockefeller Foundation funded the first NPCC. The NPCC2 was funded by the City of New York for new projections following Hurricane Sandy. The New York City DEP and FEMA through the New York City Emergency Management partially funded NPCC3. Throughout NPCC2 and NPCC3, the NOAA-funded RISA program through its CCRUN provided technical support. NASA has contributed to the NPCC efforts through the Climate Impacts Group at NASA Goddard Institute for Space Studies. Going forward, it is essential that consistent resources and the means to provide them are developed for the NPCC scenario development, assessment, and monitoring functions.

9.9. Perspectives

The climate assessments for NYC produced since 1999 elicit several observations regarding the evolving character of climate change and its implications as an emerging type of environmental

Table 9.9. Policy recommendations and outcomes from MEC, NPCC 2010, and NPCC 2015

Policy recommendations	Outcomes
Metropolitan East Coast Assessment	
<p>A regional Climate Awareness Program would be effective to inform decision makers and the general public about current climate processes, lessons learned in responding to climate extremes, and future climate change</p>	<ul style="list-style-type: none"> • Northeast RISA—Consortium for Climate Risk in the Urban Northeast (CCRUN)—was established in 2010 with funding from NOAA to provide stakeholder-driven research from Boston to Philadelphia
<p>A regional Climate Inter-Agency Task Force should be formed to identify potential climate-related events and conditions (e.g., coastal infrastructure at risk, disease outbreaks, and water supply vulnerabilities) and proactively propose responses. The taskforce should also consider events that would require emergency actions and/or large-scale societal responses</p>	<ul style="list-style-type: none"> • Climate Change Adaptation Task Force (CCATF) was convened in 2008 by NYC Mayor Michael Bloomberg
New York Panel on Climate Change 2010	
<p>Create a mandate for an ongoing body of experts that provides advice and prepares tools related to climate change adaptation for the City of New York. Areas that could be addressed by this body include regular updates to climate change projections, improved mapping and geographic data, and periodic assessments of climate change impacts and adaptation for New York City to inform a broad spectrum of climate change adaptation policies and programs</p>	<ul style="list-style-type: none"> • Local Law 42 codified the New York Panel on Climate Change as an established, ongoing body of New York City government (2012)
<p>Conduct a review of standards and codes to evaluate their revision to meet climate challenges, or the development of new codes and regulations that increase the city’s resilience to climate change. Develop design standards, specifications, and regulations that take climate change into account, and hence are prospective in nature rather than retrospective. New York City should work with FEMA and NOAA to update the FIRMs and SLOSH maps to include climate change projections</p>	<ul style="list-style-type: none"> • NYC Special Initiative for Rebuilding and Resilience (2012) • Building Resiliency Task Force formed after Hurricane Sandy • Climate Resiliency Design Guidelines released in 2018
New York Panel on Climate Change 2015	
<p>Coordinate with state and federal partners on climate change projections and resiliency programs. Specifically, 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 resilience strategies</p>	<ul style="list-style-type: none"> • FEMA FIRMs update process initiated to include new flood risk projections • NOAA Coastal Mapper utilized NPCC2 projections • Amendment to Executive Order 11988 to use “best-available and actionable science” for flood hazards and community exposure^a

^a<https://obamawhitehouse.archives.gov/the-press-office/2015/01/30/executive-order-establishing-federal-flood-risk-management-standard-and->

challenge within cities. These considerations include (1) the need to provide information to stakeholders on how key decision-relevant variables may change at finer temporal (i.e., seasonal, monthly, daily, and subdaily) rather than annual timescales and spatial scales; (2) the interactive and integrative character of the impacts; (3) the importance of the onset speed of changes and impacts; (4) the critical need to understand uncertainty and predictability in regard to both projections and impacts; and (5) the trans-

formative trajectory toward integrated implementation of both mitigation and adaptation strategies (Rosenzweig and Solecki, 2018).

Finer-scale projections

The first observation is that it is essential to understand the level of variation within aggregate climate trend and forecast data sets. For example, yearly forecasts of climate conditions often mask seasonal variations that could be important with respect to

certain impacts and affected groups. In NYC, a focus on the steady rise in observed mean annual temperatures hides the fact that the temperature increases have been especially pronounced during the winter months, which is particularly relevant for water managers who look toward this time of year for reservoir recharge.

Other data variations include the spatial heterogeneity of the potential changes, which increasingly are being revealed through the application of finer-scale regional climate modeling. This is addressed in the climate science chapter of this NPCC3 Report (see Chapter 2, Climate Science), which tests the use of RCMs for use in future NPCC assessments. RCMs operate at a much finer spatial scale than GCMs (i.e., tens of kilometers versus hundreds of kilometers in scale) and as a result can portray climate change processes not resolved in the GCMs (Horton *et al.*, 2011).

In the case of NYC, for example, the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) RCM results illustrate a much wider range of temperature shifts between coastal and inland locations (Lynn *et al.*, 2004). This difference was largely driven by the moderating near-shore influence of the Atlantic Ocean and coastal sea breezes, a phenomenon not simulated by the coarser-scale GCMs, but captured by the MM5 RCM. However, regional climate modeling adds additional uncertainty due to sensitivity to model configurations (Lynn *et al.*, 2010).

Observed and projected impacts

Another critical observation is that documenting the urban impacts of recent climate change (e.g., during the past century and especially since the 1970s when the recent period of rapid warming began) is helpful in understanding the potential impacts of future climate change on cities. This is addressed in the Indicators and Monitoring chapter of this report (see Chapter 8), the MEC Report (Rosenzweig and Solecki, 2001a) and the first two NPCC Reports as well (NPCC1, Rosenzweig and Solecki, 2010; NPCC2, Rosenzweig and Solecki, 2015). Impacts on both critical infrastructure (see Chapter 7) and on communities (see Chapter 6) are also analyzed by NPCC3.

Climate change has already engendered associated impacts in cities. Documenting these impacts is important for developing a more informed concep-

tion of possible future shifts. Recent IPCC Working Group II reports analyze climate change impacts currently underway (IPCC, 2007; IPCC, 2014). At the moment, there are relatively few detailed observed climate impact assessments for urban areas that document recent changes and attribute them to the changed climate.

Urban region integrated assessments

In regard to future urban impacts, a systematic set of comparative climate change assessments needs to be done for varying classes of cities (e.g., coastal cities versus inland cities, mid-sized cities versus large cities, middle-latitude versus tropical cities, etc.). A key variable distinguishing cities is whether they are classified as low-, medium-, or high-income. This effort has now been taken on by the Urban Climate Change Research Network (UCCRN) through its assessment reports on climate change and cities (ARC 3.1 and ARC 3.2) (Roseznweig *et al.*, 2011c; Rosenzweig *et al.*, 2018 and see www.uccrn.org).

Prominent example assessment studies other than NPCC either completed or underway include climate proofing in Rio de Janeiro, Brazil; New Orleans, Louisiana lessons from Hurricane Katrina; Mexico City, Mexico's Virtual Center on Climate Change; Santiago, Chile's water management and spatial planning; and Sydney, Australia's Sustainability Framework for its urban transportation system (Rosenzweig *et al.*, 2011b). These assessments help illustrate similarities and differences among and between the cities and potentially reveal pathways for meaningful response.

A crucial element of these studies is specifying the interaction between current and potential climate change impacts and the existing pattern of environmental change within each city. Climate change may be viewed as yet another stress for a city where dense population and intensive economic activity already have put tremendous demand on local and non-local land, water, and energy resources.

In the case of NYC, the New York metropolitan region has been dramatically altered, particularly in the older urban and suburban areas. Approximately 40% of the metropolitan land area has been fully converted to urban uses, with significant reduction in vegetative cover, loss of wildlife habitat, and

degradation of environmental quality. The rate of land conversion has accelerated in the past several decades although the rate of population growth has slowed (Yaro and Hiss, 1996; Cox, 2014). These have set off a significant amount of local and regional environmental change and dramatic reduction of ecosystem service provision capacity (McPhearson *et al.*, 2013; Elmqvist *et al.*, 2013), separate from global climate change.

Defining the connection between exogenous (e.g., global climate warming) and endogenous environmental changes (e.g., suburbanization) often is hampered by limited information on the rate and character of local environmental alterations and on baseline conditions (Leichenko and Solecki, 2013).

An example of a significant interaction between these different scales of environmental change is illustrated by connection between global climate change and the local urban heat island effect (UHI). Local land use alters the energy balance causing increased temperatures to which urban residents are exposed. When evaluating the rate of temperature increases in an urban area, it is important that the observer distinguish between the UHI signal and the global climate change signal and to understand how they might be interacting. While UHI is a known phenomenon, a crucial question remains as whether global climate change will lessen or enhance the heat islands of cities. Clearly, there will be interactions (Rosenzweig *et al.*, 2005), yet the overall net effect of the impacts is not yet clear.

Uncertainty

Another important aspect of understanding global climate change as a local urban environmental challenge is addressing the associated levels of uncertainty and predictability. As a primary assertion, one needs to recognize that climate models such as GCMs and RCMs do not produce predictions of future climate conditions but instead present scenarios of future climate conditions based on specific sets of assumptions. Climate model results do not represent data for any specific day, season, or year in the future.

The standard protocol for the use of climate models for local down-scaled projections, beyond extensive calibration and validation with observed data at regional scales, is the definition of the range of variation across a set of models and

scenario assumptions. In the case of NYC climate assessment research, numerous separate GCM model results of future temperature and precipitation changes have now been compared (NPCC, 2015). A cutting-edge issue within climate assessment work is the development of statistical methods, often performed through the use of Bayesian approaches, to better numerically define and communicate the amount of variation within the run results of one model or results across a set of models.

Tipping points, thresholds, and transformations

A central challenge is to better understand the possibility of gradual change shifts over time or possible sudden, more rapid changes. The analogy of the dimmer switch versus the on-off light switch and the identification of associated system-level tipping points have been introduced into climate change science discourse (U.S. National Research Council, Committee on Abrupt Climate Change, 2002; Lenton and Ciscar, 2013). While these are presented within the context of global-scale phenomena such as the thermohaline circulation (i.e., sudden shifts in Atlantic Ocean currents), the implications for cities and the possibility of facing rapid shifts as well as gradual ones have important implications for impact assessment and policy response.

A crucial remaining question is how well the institutions in cities, such as those present in the New York metropolitan region, will be able to respond to climate change as a local environmental challenge (Bulkeley *et al.*, 2015; Solecki *et al.*, 2013). For most urban areas, barriers typically exist to effective regional institutional response to climate change and such problems are often inherent in urban environmental management (Rosenzweig *et al.*, 2014). More than a thousand political jurisdictions, home rule, and a splintered political landscape characterize the NYMR. Besides federal and regional designations, the region is divided jurisdictionally across 3 states, 31 counties, and hundreds of municipalities. In this setting, short-term political concerns tend to dominate.

Policy responses to climate change are also hampered by the generally reactive nature of management organizations. Institutional action is often directed at immediate and obvious problems. Issues

that might emerge fully only after several decades are perceived as less pressing.

Another set of barriers reflects the complications associated with climate change itself. In most cases, environmental and natural resource agencies and organizations already have defined their own basic assumptions regarding the nature and rate of environmental change in the region. These institutions need to incorporate the highly dynamic environment that could be associated with climate change into their *modus operandi*. The multidimensional nature of the potential impacts and resulting interactive and integrative effects and the scientific uncertainty regarding climate change also make responses difficult.

These conditions are challenging decision-making agencies and institutions to address some of these basic assumptions regarding urban systems and how they are managed. The complexity of the situation is compounded when it is realized that truly effective management responses should include both adaptation (i.e., lessen the overall effect of the impacts) and mitigation (i.e., lessen the rate and magnitude of global climate change by reducing greenhouse gas emissions).

While it is unclear how cities will respond to climate change impacts as they unfold over time, how they have responded to local environmental change in the past reveals some insights. Cities often have been sites of environmentally sustainable action (McGranahan *et al.*, 2001), and some scholars now present the argument that they are leading the way with regard to developing and implementing transformative climate pathways (Rosenzweig *et al.*, 2010; Rosenzweig, 2011; Kousky and Scheider, 2003; Rosenzweig and Solecki, 2018).

Environmental change and threats in previous eras were typically ignored or held in check until the issue became a significant crisis of some sort—economic, social, and/or health related (Solecki, 2012). It is during these moments that new policies can be implemented. In the case of New York City's pursuit of a stable water supply, the city faced shortages and minor problems for almost half a century until a series of disease outbreaks forced local officials to develop a copious source of drinking water. This became the first significant step in the construction of the extensive water supply system now in place (Gandy, 2003).

The response to Hurricane Sandy is another example, bringing explicit recognition that increasing climate risks must be brought into decision-making related to recovery and rebuilding (Rosenzweig and Solecki, 2014).

While the typical response of cities has been to seek solutions to their environmental problems by going beyond their borders, either in search of resources (via an ecological footprint) or as a location to dump wastes (see as example Tarr, 1996), the case of responding to climate change impacts is following a different pattern, with cities taking responsibility for both reducing their own greenhouse gas emissions and for developing the resilience needed to minimize impacts on their most vulnerable communities (Rosenzweig, 2011).

9.10. Conclusions

Throughout its 10-year history, the NPCC has functioned as a sustained assessment for the city and metropolitan region of New York. This knowledge platform has provided an essential enabling condition for New York to proactively and flexibly adapt to changing climate conditions.

Climate change is already affecting and will continue to affect people in cities multidimensionally. In the case of New York City, heightened frequencies of storm surges will damage major infrastructure in addition to already-threatened coastal wetlands. Health impacts of climate change will be intertwined with the effects of augmented heatwaves on energy demand and extent of equitable access to air conditioning (Rosenzweig and Solecki, 2001a).

The analysis of New York City and its actions on climate change resiliency presented in this chapter demonstrates a strong and socially beneficial relationship between science-based assessments benchmarked through time and policy outcomes. Over the last 10 years, explicit regional assessments that document evolving climate trends, present state-of-the-art climate change projections, and provide detailed impacts and adaptation strategies for key sectors such as energy, water, and health have led to the implementation of a wide range of climate resilience measures. The case of Hurricane Sandy, highlighted throughout the chapter, further shows the role that major extreme climate events can play in catalyzing resilience action in cities.

Urban growth and economic development, by definition, have been major agents of local

environmental change. These two processes have brought the relative reach of cities to all corners of the globe. At the same time, both contribute to global climate change, which increasingly has the potential to significantly impact cities.

Cities then, more and more, are the sites where the mediation of climate change as local *and* global environmental change is taking and will take place. Observations from New York City reveal that effective responses by cities to these intertwined processes can be facilitated by the engagement of local experts with stakeholders to undertake assessments that are benchmarked through time. This ensures that a city's implementation of climate change responses may be based on recent analyses of climate trends, state-of-the-science climate projections, accurate representation of potential impacts and vulnerabilities as they are distributed across the urban area, and adaptation strategies that have been carefully examined by local experts.

The NPCC is a testament to the foresight of the City of New York. Its ongoing activities show that the city recognizes that climate change is a “moving target” and that responding to its challenges requires knowledge to be continuously created, synthesized, and shared.

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