Climate Risk and Equity: Advancing Knowledge Toward a Sustainable Future - Introduction

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Abstract

This Introduction to NPCC4 provides an overview of the first three NPCC Reports and contextualizes NPCC4's deliberate decision to address justice, equity, diversity, and inclusion in its collective work with special attention on incorporating racial equity in its own practices, procedures, and methods of assessment. Next it summarizes the assessment process, including greater emphasis on sustained assessment. Finally, it introduces the NPCC4 chapters and their scope.

Recommended Citation:

Balk, D., Braneon, C., Leichenko, R., Moss, R., Towers, J. (2024). Climate Risk and Equity: Advancing Knowledge Toward a Sustainable Future: Introduction. New York City Panel on Climate Change. https://climateassessment.nyc

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1 Introduction

Climate change presents urgent, immediate, and long-term challenges to New York City (NYC). The New York City Panel on Climate Change (NPCC) was established in 2008 and codified in Local Law in 2012 to regularly assess the current state of the science on climate change and provide actionable policy-relevant recommendations for adaptation and resilience. This chapter introduces the 4th assessment report of the New York City Panel on Climate Change, NPCC4.

NPCC4 builds on groundbreaking climate assessment work at the state level (e.g., New York State Climate Impacts Assessment (New York State Energy Research and Development Authority, 2024)) and in the region , especially the Metro East Coast Study (C. Rosenzweig & Solecki, 2001) and the City's ongoing commitment to science-based policymaking informed by NPCC assessment reports associated with NPCC1 (C. Rosenzweig & Solecki, 2010), NPCC2 (C. Rosenzweig & Solecki, 2015), and NPCC3 (C. Rosenzweig & Solecki, 2019) as well as shorter special reports focused on climate risk information (C. Rosenzweig et al., 2009, 2013). NPCC4 includes new "*climate projections of record*" for NYC and grounds those climate futures in the social fabric of the city (Braneon et al., 2024). NPCC4 extends prior panels' commitment to equity, engagement, and transparency of processes across the assessment report.

The first NPCC Report introduced risk management frameworks for the city and region via flexible adaptation pathways. NPCC2 developed climate projections of record that were embedded in the City of New York resilience programs and regulations. NPCC3 introduced the concept of "co-generation" to the assessment process. NPCC4 builds on and deepens these innovations.

> *"The NPCC3 2019 Report co-generates new tools and methods for the next generation of Climate risk assessments and implementation of region-wide resilience. Co-generation is an interactive process by which stakeholders and scientists work together to produce climate change information that is targeted to decision-making needs. These tools and methods can be used to observe, project, and map climate extremes; monitor risks and responses; and engage with communities to develop effective programs. They are especially important at "transformation points" in the adaptation process when large changes in the structure and function of physical, ecological, and social systems of the city and region are undertaken" (C. Rosenzweig & Solecki, 2019)*

2 A Dynamic Context

On December 19, 2019, the Mayor of New York appointed a group of five academics, researchers, and practitioners as co-chairs to lead the 4th New York City Panel on Climate Change. Providing expertise in climate science, engineering, social science, policy, design, and planning, the NPCC4 leadership team was convened with the ambition to support catalytic change during this next, and perhaps most crucial, decade of climate response in NYC. The co-chairs began meeting regularly with the Deputy Director for Climate Science and Risk Communication in the Mayor's Office of Resiliency[1], now the Mayor's Office of Climate and Environmental Justice (MOCEJ). Together, they established a set of goals for the assessment, including identifying near, intermediate, and long-term quantitative and qualitative climate trends; assessing potential impacts of climate change on the city's communities, vulnerable populations, public health, natural systems, critical infrastructure, and buildings; and expanding ways to use climate research to inform decision-making. From the outset, NPCC4 committed to strengthening participation by agencies and the public in the assessment process (see Section 4). The co-chairs and the Deputy Director then turned to identifying candidates to recommend to the Mayor to complete the full panel ensuring NPCC would meet its mandate to provide authoritative, actionable information on future climate change and its potential impacts in support of science-based decision-making by the City. However, between late December 2019 and June 2020, when the full panel was charged by the Mayor, the novel SARS-CoV-2/COVID-19 pandemic emerged in full and, in a trauma that would lay bare the modern brutality of structural racism in the United States, George Floyd's murder in police custody was filmed in a live-streamed video that quickly spread worldwide. Other systemic shocks would follow, including an

[1] The key office for coordination with NPCC was the Mayor's Office of Resiliency (MOR), which then became the Mayor's Office of Climate Resiliency (MOCR) in April 2021, and then the Mayor's Office of Climate and Environmental Justice (MOCEJ) around January 2022. Adam Parris was the Deputy Director for Climate Science and Risk Communication in that office when NPCC4 was empaneled. Emilie Schnarr, Victoria Cerullo, and Hayley Elsasz subsequently held that or a similar post and acted as a key partner with the co-chairs in the 4th Assessment.

extreme rainfall and flooding event associated with the remnants of Hurricane Ida and the 13 deaths in NYC (and more than 45 deaths in the New York metropolitan region) that lay in its wake. As events continued to confirm that the context of the 4th assessment was shifting in real-time, the full panel went to work assuring NPCC4 would produce a report in support of the City's initiatives to build resilience and equity into climate adaptation.

The profound system-level shock of COVID-19 revealed additional challenges to the City's resilience that will likely be exacerbated by current and future climate change. Climate change, like COVID-19, demands the full attention and commitment of the city government and the cooperation of local, state, federal, and global government, NGO, and private entities alike. Layering the impacts of significant, and likely, climate related system-level perturbations such as a hurricane or a sustained heat wave that threatens electrical grid capacity on top of a public health crisis, multiplies the complexity of the management challenge in the acute moment of impact, and complicates the long-term economic and ecological recovery. Advanced planning, dynamic and sustained adaptation, environmental and climate justice, as well as a commitment to ongoing assessment that reflects the state of emerging science are the hallmarks of a resilient city and the bedrock commitment of the NPCC.

Incorporating lessons from the SARS-CoV-2/COVID-19 pandemic is consistent with the NPCC's mandate. Projected increases in the frequency and intensity of extreme events pose particular challenges to NYC in the short-term and over the course of the 21st century. Public health (and other) emergencies intersect with and amplify climate-related health impacts. Current data indicate that NYC neighborhoods that had the highest rates of positive COVID-19 cases also have higher proportions of service workers, rent-burdened households, and people of color (Do & Frank, 2021; Friedman & Lee, 2021; Marcotullio & Solecki, 2021; Mustafa et al., 2021; Ortiz et al., 2022).

NPCC3 concluded that there is a need for further investigation into optimal methods to track social vulnerability to climate change and resilience at the community scale (Foster et al., 2019). In addition, the report concluded that illustrative indicators of energy sector transmission and distribution under extreme heat and humidity are needed. Furthermore, the report highlighted the critical importance of including attention to equity in all phases of climate adaptation efforts. In response, NPCC4 has incorporated equity considerations to a greater extent across all chapters.

The altered context of climate hazards assessed in NPCC4 is not limited to the uneven geography of race and health. At the municipal, state, and national level, a rapidly changing policy environment including the recently released PlaNYC, LL97 of 2019, changes to NYC coastal zoning, the New York State Climate Impact Assessment, Justice40, the Inflation Reduction Act of 2022, and Infrastructure Investment and Jobs Act, to name only a few, demonstrate the unique opportunity amid the urgency of the climate crisis that NPCC4 seeks to highlight. In addition, the City of New York commissioned new Climate Vulnerability, Impact, and Adaptation Analysis (VIA) research (McPhearson et al., 2024) that has provided new information on biophysical climate and flooding science, the economic impacts on health from climate change, and the social-spatial geography of flood vulnerability. Much of the VIA work has been incorporated in NPCC4.

What follows in this report is an assessment that offers policymakers, stakeholders, and communities a framework for centering equity, building flexible adaptation pathways, and incorporating sustained assessment processes that continue to evaluate and improve adaptation and mitigation of climate change.

The workgroups in NPCC4 were responsive to this dynamic environment. The groups were formed based on meetings and input from city agencies about key and emerging climate risks for the city and on the expertise and capacities of the panel. Initially six workgroups were formed focusing on topics including flooding, health, equity, futures and transitions, climate science, and shared methods (see Figure 1). Climate science has been the backbone of all NPCC assessments including NPCC4. Health and Equity workgroups were introduced in NPCC2 and NPCC3, respectively. While tracing their origins to points of emphasis in prior NPCC assessments, the Flooding, Futures and Transitions, and Shared Methods workgroups represent new directions for the Panel in NPCC4. The workgroups were each led by two co-chairs and included panel members as well as external participants.

Figure 1, showing a hand-drawn visual recording of a NPCC4 all-hands meeting in June 2021, reveals early aspirations for the content scoping of the workgroups. Over the course of the Assessment, these workgroups expanded to involve additional experts, met regularly, to define and write chapter(s), and to obtain input and feedback from a variety of stakeholders (see Section 4 below). Workgroups were designed to be cross-fertilized so that some panel members would participate in multiple groups. This approach fostered connections between workgroups and allowed for the fluid development of content. For example, the role of energy poverty on health and well-being was a clear focus of the health workgroup (see Figure 1); yet as aspects of the energy transitions were also developed in the Futures & Transition workgroup, it become evident that Energy and Energy Insecurity would be best addressed in a separate chapter. As Figure 2 makes clear, NPCC4 aimed to center equity throughout the work of the Assessment from its earliest stages. Figure 2 (reflecting NPCC4's kick-off meeting) also centers Co-Production of the Assessment with MOR (now MOCEJ). NPCC4 created hand-drawn visual recordings to document and reflect on the diversity of perspectives at various early meetings when the work of the full panel was getting underway. These drawings were produced in real-time during the meetings and redrawn upon reflection to capture and distill the key concepts, comments, people, and conclusions from each gathering. As participation in these meetings was entirely virtual, the note taking as shown in Figure 2 shows the active exchanges that occurred through chat (noted by the rectangular call-out boxes shown in the margins) as a feature of these meetings.

In addition to this introduction and a concluding chapter, these efforts have resulted in six substantive chapters in this 4th Assessment (See Section 5) along with the *NYC Climate Risk Information 2022: Observations and Projections* (Braneon et al., 2024), in addition to plain-language summaries that highlight the Assessment's key findings.

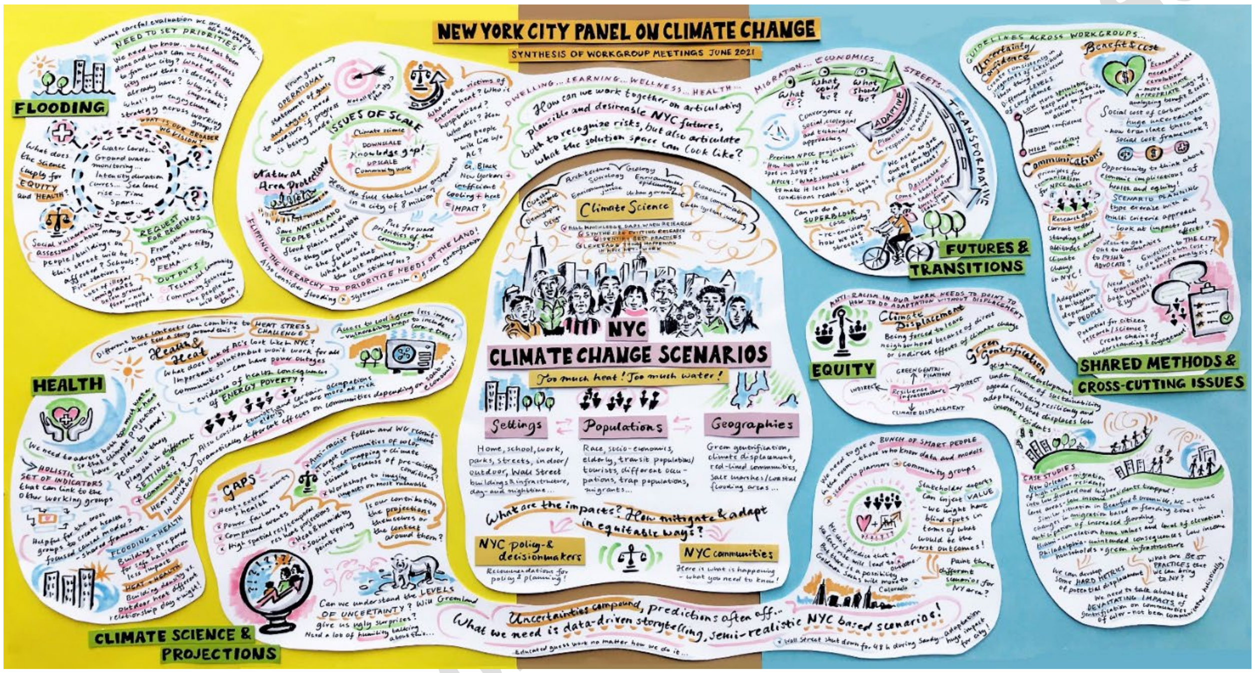

Figure 1. Johanna Tysk. Visual Notes from NPCC4 All Hands Meeting, June 2021

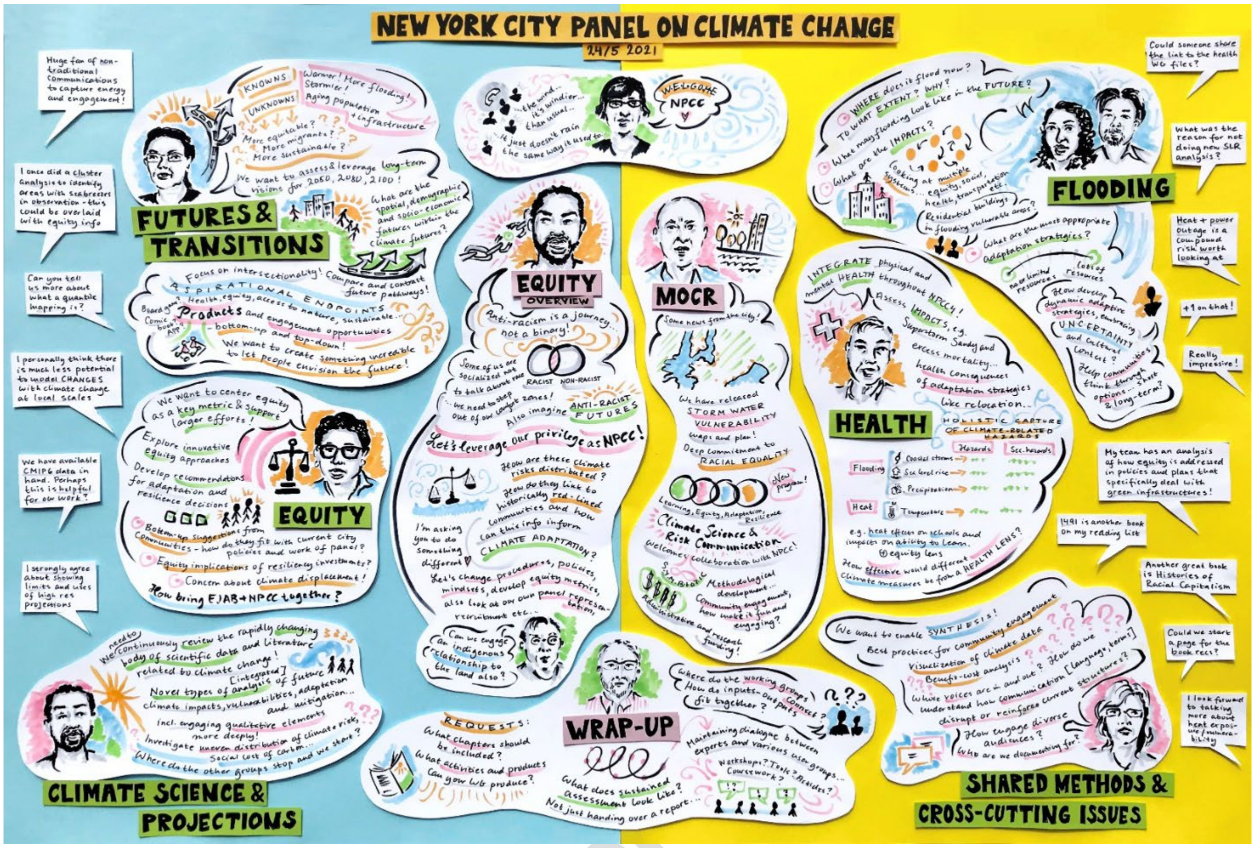

Figure 2. Johanna Tysk. Visual Notes from NPCC4 Kick-off Meeting, May 2021.

3 Centering Equity

The NPCC brings expertise in climate science, engineering, architecture, social science, public health, policy, design, and planning to the work of the 4th Assessment. Efforts to center equity in NPCC4 began with the panel's formation. The full NPCC, with 20 members when seated in the spring of 2020, was more diverse than prior panels, in terms of gender, age, career stage, and racial and ethnic composition. Full membership, with the inclusion of additional external members (researchers, students, practitioners) to the workgroups, is even more diverse. Notably, this panel offers a much wider range of disciplinary expertise than prior panels – including climate scientists, geographers, demographers, economists, health experts, architects, ecologists, and planners among others – from which new framings for the work of the assessment, including centering the assessment on equity, can emerge.

NPCC3 (2019) produced the first NPCC assessment report to devote a chapter of the report to questions surrounding equity in community vulnerability and adaptation (Foster et al., 2019). These efforts, which included development of a framework for incorporation of equity into the city's climate adaptation planning efforts, were co-produced through collaboration between NPCC panel members, representatives from community-based environmental justice groups, and representatives from the City (Foster et al., 2019; Leichenko et al., 2023). Building upon NPCC3, NPCC4 incorporates consideration of the equity implications of climate change adaptation in every chapter of the report.

NPCC4 also made a deliberate decision to address justice, equity, diversity, and inclusion in its collective work with special attention on incorporating racial equity in its own practices, procedures, and methods of assessment. To this end, each NPCC4 working group completed an interim report outlining the status of their work as it related to racial equity in the fall of 2022. Further, most panel members participated in a two-part racial equity training session (See

Figure 3) that was developed and led by BlackSpace Urbanist Collective, Inc.[2] (https://blackspace.org/) in partnership with Luis Alejandro Tapia (https://www.louknows.com/).

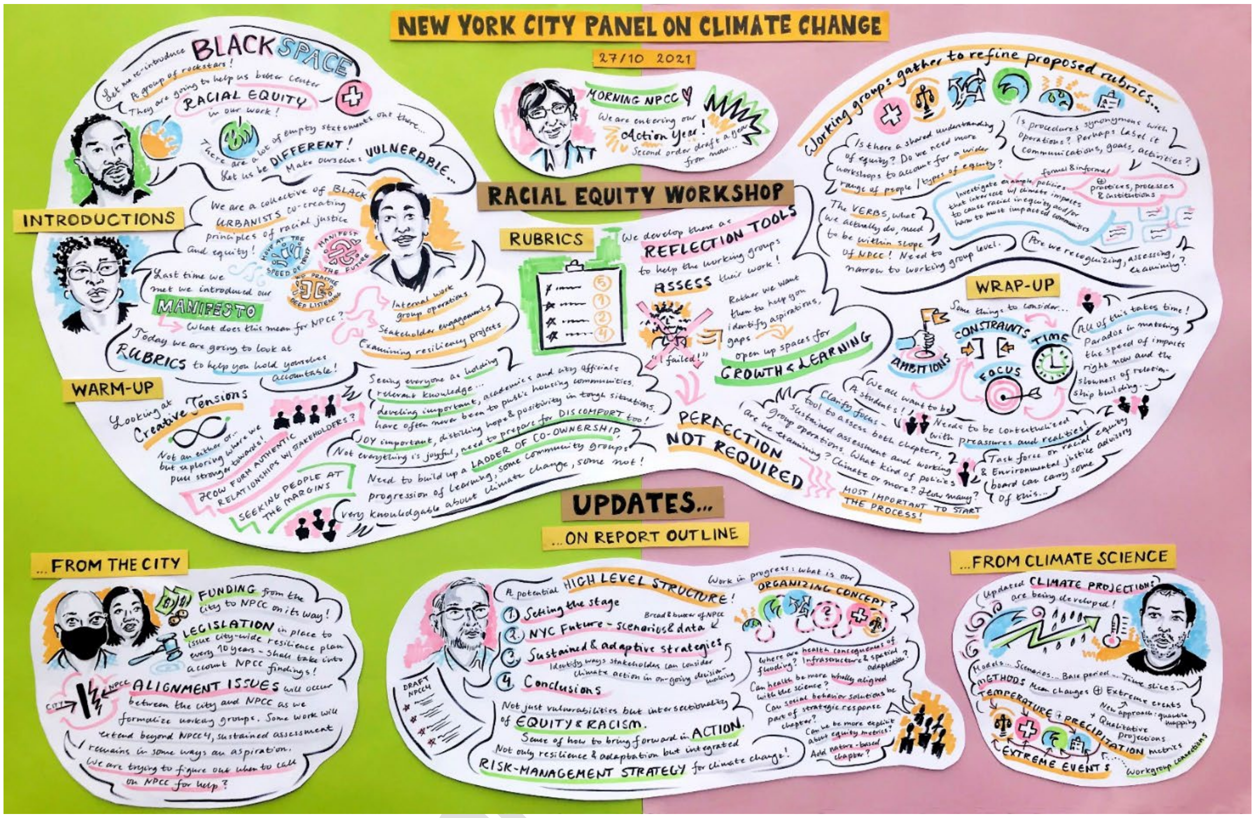

Figure 3. Johanna Tysk. Visual Notes from NPCC4 from Racial Equity Workshop and All-Hands Meeting, October 2021.

The training sessions included panel members along with members of the City's Environmental Justice Advisory Board (EJAB). The work included development of specific commitments to incorporate racial equity in workgroup operations and activities, and development of a rubric for assessment of each workgroup's equity efforts. This rubric was used internally by each workgroup, first in 2022 to assess its practices and early chapter development efforts, and again in 2023 to assess its first order draft. The rubric entailed qualitative and quantitative assessment of the workgroup's incorporation of equity[3] into its internal processes and procedures, impact and policy analysis, and recommendations. The rubric draws from the work of Ibram X. Kendi (2019) as well as insights and suggestions from the BlackSpace team. The following topics were included in the rubric:

- Integration of equity and antiracism into internal processes and procedures.
- Acknowledgement of racial inequity as a problem of racist structures (including but not limited to historic and current policy, regulations, procedures, norms, and institutions); not just people with racist views.
- Reference to data and literature from racially and gender diverse sources, taking into consideration alternative forms of knowledge (i.e., Indigenous knowledge, storytelling, experiential knowledge).
- Identification of how climate impacts and policies intersect with racial inequity in any of its manifestations.

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[2] BlackSpace Urbanist Collective, Inc. is an interdisciplinary collective of Black urbanists committed to acknowledging, affirming, and amplifying Black presence in the built environment.
[3] Antiracism is a powerful collection of antiracist policies that lead to racial equity and are substantiated by antiracist ideas. An antiracist idea is any idea that suggests the racial groups are equals in their apparent differences—that there is nothing right or wrong with any racial group. Antiracist ideas argue that racist policies are the cause of racial inequities (Kendi, 2019).

- Investigation of policies, structures, and institutions causing racial inequity that intersect with climate impacts.
- Identification or creation of antiracist climate measures/strategies that aim to reduce and ideally eliminate racial inequity.
- Recommendation of strategies to monitor the impacts that antiracist climate measures/strategies have on reducing and eliminating racial inequity.
- Recommendation of strategies to support new antiracist climate actions and policies (and prevent actions and policies that reinforce racial inequity).
- Use of bias-free language and visuals that are culturally and racially sensitive (i.e., all appropriate groups are represented, visuals reflect lived experiences), providing definitions and clarification when necessary.

The internal assessment was facilitated by an NPCC intern, Georgia Grzywacz, who also provided feedback to each workgroup based on her interaction with the group and her review of the first order chapter drafts. This process was designed to be inward-facing for each workgroup in order to provide opportunities to reflect on its equity-focus efforts and to adjust practices, processes, and assessment work as needed.

4 Elements of the Assessment Process

Transparency and accountability, along with scientific rigor, are cornerstones of any sustained assessment process. Thus, to guide the work of the panel, the co-chairs created a “Principles and Processes” document that was shared with all panel members (see BOX 1), edited by the full panel, and endorsed by all persons working on NPCC4. Sustained assessment refers to an ongoing process that engages researchers, professional practitioners, and stakeholders to share and apply knowledge and experience relevant to adaptation and mitigation solutions (Buizer et al., 2016; Moss et al., 2019). The concept was applied at the national scale in the third U.S. National Climate Assessment (NCA) (Hall et al., 2014; Melillo et al., 2014) as an approach to improve assessment outcomes and address expanding needs for decision-relevant information. Sustained dialogue with users is needed to identify information needs and decision contexts, establish useful communications formats, diversify products and communications, and build capacity to use available science and technical information in taking action. It has the potential to promote collaborative learning and establish leading practices (i.e., professional standards) for climate risk management strategies so that available knowledge is tailored for specific environmental, socioeconomic, and cultural contexts.

BOX 1. NPCC4 Principles and Processes

In general, the products and activities of the Panel will analyze and present the knowledge necessary for decision making and implementation of climate change policies and actions. The Panel's products will inform New York City's efforts to address the climate crisis. They will identify key gaps in climate knowledge and research needs relevant to these efforts. In addition, the Panel seeks to enhance accountability for translation of climate knowledge to action through effective engagement and communication on climate-related issues with a range of audiences. Some of the key principles and processes for the 4th cycle of the Panel's work are described below.

Deliberation and use of information:

- NPCC4 will operate in a transparent, accountable, and rigorous fashion. This includes transparency in its public meetings and decision-making processes.
- Adoption of the Panel's work plan, approval of reports and summaries for public release, and other major decisions will be made by consensus of the Panel. Members are expected to work towards consensus in good faith, but if during the process of approving reports and other materials consensus cannot be reached, dissenting opinions may be noted.
- The Co-Chairs may make decisions on behalf of the Panel for routine procedural matters or when more rapid decisions are needed in between Panel meetings. The Co-Chairs commit to the rest of the Panel to consult with them on any major issues that could call into question Panel members' roles or judgment.
- The NPCC will address justice, equity, diversity, and inclusion in its work. This commitment extends to bringing to light how systemic racism and injustice intensify the impacts of climate change and how anti-racist policies can be integrated into climate action to promote a just, resilient, sustainable, and more vibrant future.

Traceable accounts:

- NPCC will strive to make its products accessible and useful to decision-makers and the general public. It will engage with the intended audiences and users of Panel products, adopting a "co-production" or "sustained assessment" approach to its work. This approach will facilitate the relevance, credibility, and legitimacy of Panel products and activities.
- The Panel will reach its conclusions collectively. Individual panel members do not speak "for the NPCC" except when they represent agreed findings or decisions.
- NPCC4 will adopt a consistent framework and process for assessing and reporting on levels of confidence and significant sources of uncertainty. This will facilitate effective communication with users.
- The Panel will rely on published, peer-reviewed sources of information whenever possible. However, the Panel recognizes that invaluable information relevant to its work may come from non-peer reviewed sources. NPCC4 will use standards on information quality and transparency to provide open-source documentation of all data used in its products.

An important component of sustained assessment is co-production. Much of NPCC4's success has been predicated on embracing a co-production approach (see Box 2)– that is, by engagement between members of the panel and many stakeholders in local agencies from city government to other public and private organizations (Foster et al., 2019; C. Rosenzweig et al., 2011; C. Rosenzweig & Solecki, 2019). Co-produced climate assessments are increasingly recognized as a means of improving the effective generation and utilization of climate information to inform decision-making and support adaptation to climate change. However, as scholars and practitioners have illustrated, co-production does present potential pitfalls (e.g., transactional costs) for scientists, decision-makers, and community members (Cvitanovic et al., 2019; Lemos et al., 2018). NPCC has weathered these potential pitfalls and, as the appointment of NPCC4 suggests, co-production remains a cornerstone of the City's climate response.

NPCC outlined a framework for co-production and partnership between the City of New York, principally the Mayor's Office of Resiliency (now MOCEJ), and NPCC specifically for the 4th assessment cycle of NPCC (i.e.,NPCC4). The actions outlined in BOX 2 were intended to allow for an agile and authoritative process (and are not listed in order of priority or emphasis).

BOX 2. Co-Production: Actions and Accountability

Action	Description
Action 1	Form an Executive Committee including leadership from MOR and NPCC.
Action 2	Facilitate coordination between NPCC, the Climate Change Adaptation Task Force (CCATF), and the Environmental Justice Advisory Board (EJAB), including potentially a joint working group or committee.
Action 3	Form a Fundraising Committee for NPCC with joint leadership from MOR and NPCC.
Action 4	Develop scenario planning and climate knowledge briefs as collaborative projects between MOR, NPCC, and partners.
Action 5	Create an MOR-NPCC Fellows Program.

Progress was made on all five actions, to varying degrees.

Actions 1, 4 and 5 were fully implemented for NPCC4, and future NPCC assessments may choose to maintain and build on those efforts. For example, the MOR-NPCC Fellows Program (City of New York Mayor's Office of Resiliency, 2021) (Action 5) was responsive to the City's current internship programs (i.e., that they must be paid or receiving academic credit) and, consistent with Action 3, may need future resourcing to meet NPCC's inclusivity objectives.

Because panel members of NPCC, like IPCC and NCA, work on a volunteer basis, the issue of resourcing the assessment (both administratively and substantively) -- that is, Action 3 -- was identified as an important area to be developed. NPCC4 made important progress on Action 3 via resource allocation that was essential to its mandate. Funding for report administration, support, and production was allocated by NYC. Although these funds were identified late in the process (almost three years after the panel was seated) the final report critically relied on the support from the administrative contract after a competitive Request for Proposals (RFP) process.

In addition, as noted above, NYC commissioned new Climate Vulnerability, Impact, and Adaptation Analysis (VIA) research during the timeframe of NPCC4 through an open RFP process. Though not predicated on NPCC, the City's commitment to original research significantly advanced NPCC4 and future panels.

As for Action 2, NPCC4 met with CCATF virtually in November 2021. With about 150 persons representing government and quasi-government agencies, this was the only meeting organized by MOCR/MOCEJ between CCATF and NPCC4. There were no further engagements with CCATF because it has not been convened since 2021. Because the City valued multiple touchpoints with NPCC, it developed a broad Interagency Climate Assessment Team (ICAT) -- comprising about 16 individuals representing 8 agencies -- to foster engagement with city agencies and the NPCC workgroups.

These actions established principles for NPCC4 to ensure an iterative and meaningful stakeholder engagement for shared learning and collaboration – that is, co-production and sustained assessment activities (Lemos & Morehouse, 2005; Meadow et al., 2015; Vincent et al., 2018) -- in order to align its work with just and resilient climate action.

To ensure access and uptake to NPCC4 products, NPCC has produced a website [https://climateassessment.nyc] with access to data, plan-language summaries for each chapter, and a variety of other climate-change related resources.

Co-production in the NPCC4 occurred at the level of the Panel's workgroups in several ways. In some cases, the workgroups identified ongoing consultations and efforts that engaged communities, relevant professionals, and scientists to discuss future hazards, their impacts, and what can be done to prepare (e.g., OneNYC2050 and NYC Adaptation Scenarios 2100 (Cook et al., 2022). While gaps and challenges remain, these engagements offered an opportunity for building out more effective dialogue about future climate action in the city. In other cases, the workgroups reviewed information needs identified through the Climate Knowledge Exchange 2021 report (City of New York, 2022) and offered suggestions for the City to convene communities of practice to dive deeper and develop required information. And in some cases, the workgroups convened public meetings focused on issues of concern (e.g., stormwater management or displacement) identified in their chapters. While resources available to the NPCC were not sufficient to convene and sustain these processes, these discussions provide ideas for the future, particularly for sustained assessment and ongoing collaborations. The Climate Knowledge Exchange (2024) continues to provide a forum for sharing scientific climate information, receiving input from diverse stakeholders, and co-producing climate research priorities. Finally, all chapters engaged with relevant members of ICAT (See Box 2) in the drafting process of their chapters.

5 Organization of NPCC4 Assessment Report

The 4th Assessment is divided into the following six chapters, in addition to this Introduction, a Conclusion with recommendations for next steps, and the Climate Science Special Report (Braneon et al., 2024):

1. Tail Risk, Climate Drivers of Extreme Heat, and New Methods for Extreme Event Projections | (Ortiz et al., 2024)
2. Climate Change and New York City's Flood Risk | (B. Rosenzweig et al., 2024)
3. Advancing Climate Justice in Climate Adaptation Strategies for New York City | (Foster et al., 2024)
4. Climate Change and New York City's Health Risk | (Matte et al., 2024)
5. Climate Change, Energy, and Energy Insecurity in New York City | (Yoon et al., 2024)
6. Concepts and Tools for Envisioning New York City's Futures | (Balk et al., 2024)

Ortiz et al. (2024) document recent observed climate trends and confirm new temperature and precipitation projections of record for NYC; new sea level rise projections of record are confirmed in Braneon et al.(Braneon et al., 2024). Foster at al., (2024) build on the findings and recommendations to the City from the NPCC3 equity workgroup to identify additional metrics and adaptation efforts that can advance climate justice. Rosenzweig et al., (2024) provide a comprehensive description of the different types of flood hazards facing NYC and provide climatological context that can be utilized, along with climate change projections, to support flood risk management (FRM). Balk et al., (2024) synthesize the state of knowledge on social-demographic, economic, transportation, housing, health futures, and many other subsystems of the complex system of NYC that will all interact to determine the City's futures. Matte et al., (2024) update evidence since the last NPCC health assessment in 2015 as part of NPCC2 (Kinney et al., 2015) and address climate health risks as well as vulnerabilities with an emphasis on heat and flooding. Yoon et al.,(2024) provide an overview of energy trends in NYC and the State, considers challenges and barriers in energy transition, and implications for energy insecurity, which can have profound and inequitable impacts on human health and wellbeing. Through this collection of technical reports (e.g. Balk et al.(2024), Braneon et al.(2024), Foster et al.(2024), Matte et al.(2024), Ortiz et al.(2024), and Yoon et al.(2024)), NPCC4 continues its mandate of providing NYC with essential climate information while centering that knowledge in the dynamic socio-ecological environment of today.

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Acknowledgements

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The assessment does not represent the policy position of any agencies whose staff are co-authors.

We also acknowledge the NPCC4 panel members for their helpful comments on this chapter, and our home institutions (noted in our affiliation) for supporting our work on this Assessment in myriad ways.

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Abstract:

We summarize historic New York City (NYC) climate change trends and provide the latest scientific analyses on projected future changes based on a range of global greenhouse gas emissions scenarios. Building on previous NPCC assessment reports we describe new methods used to develop the projections of record for sea level rise, temperature, and precipitation for the City, including using projections across multiple emissions pathways and the issue of the "hot models" associated with CMIP6 and their potential impact on NYC's climate projections. We describe the state of the science on temperature variability within NYC and explain both the large scale and regional dynamics that lead to extreme heat events, as well as the local physical drivers that lead to inequitable distributions of exposure to extreme heat. We identify three areas of tail risk and potential for its mischaracterization, including the physical processes of extreme events and effects of a changing climate. Finally, we review opportunities for future research, with a focus on the hot model problem and the intersection of spatial resolution of projections with gaps in knowledge in the impacts of the climate signal on intra-urban heat and heat exposure.

Key Words: *Climate Science, Extreme Events, Climate Risk, Climate Justice and Equity, Tail Risk*

Recommended Citation:
Ortiz, L., Braneon, C., Horton, R., Bader, D., Orton, P., Gornitz, V., Rosenzweig, B., McPhearson, T., Smalls-Mantey, L., Sheerazi, H., Montalto, F., Golkhandan, M.R., Evans, C., Degaetano, A., Mallen, E., Carter, L., McConnell, K., Mayo, T., Buchanan, M. (2024). NPCC4: Tail Risk, Climate Drivers of Extreme Heat, and New Methods for Extreme Event Projections: Interim Report. https://climateassessment.nyc

Table of Contents

1 Chapter Summary

This chapter summarizes historic New York City (NYC) climate change trends and provides the latest state-of-the-art science information on potential future changes based on a range of global greenhouse gas emissions scenarios. This chapter further describes the drivers and consequences of climate change in NYC related to sea level rise, extreme heat, and precipitation. Projections of annual averages, the frequency of extreme temperatures and precipitation are presented, refining methods used in previous New York City Panel of Climate Change (NPCC) reports.

1.1 Key Messages

***Key Message 1 -** NPCC4 analysis of the impact of hot models on the CMIP6 ensemble found no statistically significant difference between the temperature and precipitation projections of record and alternative projections that do not include models with equilibrium climate sensitivity outside the expected range. The CMIP6 climate model ensemble used to create the temperature and precipitation projections of record contains three models that display higher-than-expected sensitivity of temperatures to greenhouse gases. These so-called "hot models" lead to higher global mean temperatures. However, the impact of high climate sensitivity appears small with our approach to developing local projections for NYC. Nevertheless, more research is needed to better understand (1) the impact of the high climate sensitivity on the representation of key large scale climate processes, (2) the model physics leading to high sensitivity in the first place, and (3) the constraints on the planet's equilibrium climate sensitivity.*

***Key Message 2:** The high tail end of sea level rise will be governed by the future stability of the ice sheets, and in particular, that of the West Antarctic Ice Sheet (WAIS), with ~3 m of SLR potential if all its marine-based ice melted, and also that of the Greenland Ice Sheet (~7 m SLR equivalent) throughout the 21st century and beyond. Troubling signs of ice shelf thinning and ocean warming around WAIS and an approaching temperature tipping point over Greenland raise the possibility of faster and higher sea level rise than projected by most climate models, increasing the risks associated with coastal flooding. Additional research is needed to gain a better understanding of all the processes governing ice sheet behavior with rising temperatures. Stakeholders concerned with long-term planning need to examine plausible scenarios at the extreme upper tail of the sea level rise distribution.*

***Key Message 3:** While occurrence of extreme heat events in NYC is governed in great part by climatic events taking place at large spatial scales, local urbanization patterns play a key role in the spatial distribution of temperatures within the city. These local patterns, which include a range of factors like distribution of green spaces and urban geometry, play the most significant role in the generation of physical process that lead to the urban heat island (UHI). Moreover, extreme heat events exacerbate this intra-urban excess temperatures, increasing exposure to deadly heat of populations without access to adaptive measures and cooling infrastructure (e.g., cooling centers, tree shade). Future work is needed to assess the impact of a warming climate on intra-urban heat variability in order quantify the effect of climate change on spatial inequities of heat exposure.*

2 Introduction

While every NPCC assessment report has included a chapter on the state of climate science and projections for NYC, this chapter includes a strengthened emphasis on the equity implications of climate change adaptation (Boeckmann & Zeeb, 2016; Foster et al., 2019). In addition, this chapter addresses emerging issues related to higher-than-expected equilibrium climate sensitivity (ECS) in several ensemble members from the 6th Climate Model Intercomparison Project (CMIP6), which simulate higher than expected global mean temperatures. Finally, the chapter describes the changing tail and compound risks associated with climate change.

2.1 Chapter Scope and Context

Anthropogenic climate change is fundamentally linked to the rapid increase in greenhouse gas (GHG) emissions propelled by the Industrial Revolution and the European colonial systems that enabled it. "Raw materials from colonies across the British Empire fueled the Industrial Revolution" (Easton et al., 2022), land dispossession and forced migration facilitated colonial expansion, and chattel slavery provided unpaid labor to build the British colonies as well as the new American nation[1] (Baker, 2019; Foster et al., 2024, sec. 3.1; Munshi, 2022; Park, 2022). In addition, the "political arithmetic" of global trade prompted extreme extraction from the New York metropolitan region's biodiversity into the Atlantic world trading system (Tchen, 2001). Consequently, humanity's climate crisis has its roots in land dispossession, forced migration, as well as human and natural resource extraction orchestrated by European colonial powers. Furthermore, the tremendous variability in vulnerability to climate change (among and within regions) is driven by "patterns of intersecting socio-economic development, unsustainable ocean and land use, inequity, and marginalization" as well as "historical and ongoing patterns of inequity such as colonialism" and structural racism (e.g. Home Owners Loan Corporation redlining in NYC's five boroughs) (Braveman et al., 2022; Egede et al., 2023; Farrell et al., 2021; Lynch et al., 2021; Pörtner et al., 2022; Sultana, 2022).

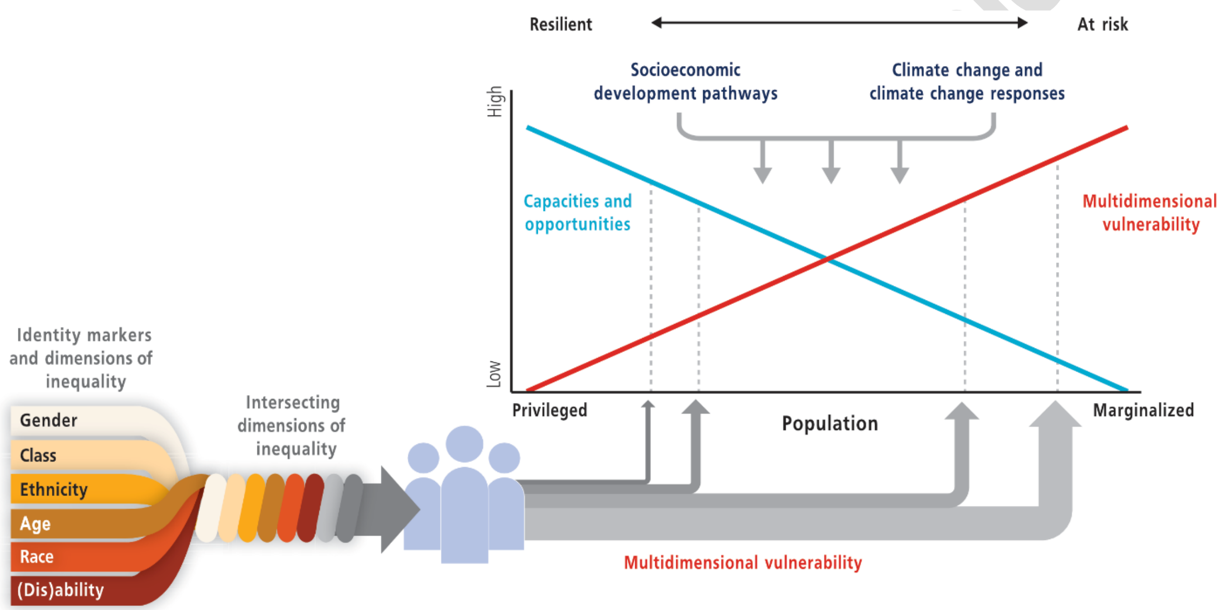

Figure 1: Schematic Depicting the Relationship between Marginalization, Vulnerability, and Resilience. Source: Field et al.(2014)

Vulnerability to climate hazards and stressors (Figure 1) (Field et al., 2014, p. 49) is unequally distributed across NYC as "high levels of social vulnerability are consistently found in areas with lower incomes", aging populations, and higher proportions of Black and Latinx/Hispanic residents (Foster et al., 2019). For example, NYC is among urban hotspots in the country where ambient temperatures can be 5 to 20 degrees Fahrenheit hotter in neighborhoods with low income households and more residents of color (Hoffman et al., 2020). NYC also has the largest number of affordable housing units exposed to extreme water levels in the country (Buchanan et al., 2020).

Local Law 42 (2012) mandates that the New York City Panel on Climate Change (NPCC) meet at least twice a year for the purpose of (i) reviewing the most recent scientific data related to climate change and its potential impacts on the City's communities, vulnerable populations and public health[2] as well as the City's natural systems, critical infrastructure, buildings and economy; and (ii) advising municipal staff (e.g. the Mayor's Office of Climate and Environmental Justice) as well as the NYC Climate Change Adaptation Task Force (CCATF). Further, the Panel[3] is mandated by LL42 to make recommendations regarding (i) the near-, intermediate and long-term quantitative and

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[1] The U.S. share of global GHG emissions is currently around 15 percent (Sachs, 2020).
[2] Vulnerable populations are defined here as persons or communities at increased risk of harm as a direct or indirect consequence of climate change based on one or more of the following risk factors: (i) proximity to disproportionally impacted areas; (ii) age, including senior citizen or minor status; (iii) income level; (iv) disability; (v) chronic or mental illness; and (vi) language. Public health is defined here as impacts on physical health, mental health and social well-being and public or private services that treat and prevent disease, prolong life and promote health.
[3] The Panel is currently led by a team of four co-chairs who possess a broad spectrum of disciplinary expertise including climate science, demography, civil and environmental engineering, geography, vulnerability analysis, global change, architecture, and urban planning. Both the full NPCC and its leadership team were selected to ensure a diversity of backgrounds, research disciplines, and fields of technical practice.

qualitative climate projections (i.e. "projections of record") for the City of New York; and (ii) a framework for stakeholders to incorporate climate projections into their planning processes (Rosenzweig & Solecki, 2015).

In 2023, NPCC published a brief assessment report that aimed to mirror its 2013 report See Rosenzweig et al., (2013). It establishes new sea level rise projections of record for NYC and introduces interim climate projections associated with temperature and precipitation. Further, the climate science synthesis focused on sea level rise that is presented by NPCC4 in *NYC Climate Risk Information 2022: Observations and Projections* (Braneon et al., 2024) addresses recommendations from NPCC3 to (a) "monitor trends in sea level rise and in the processes contributing to sea level rise in the New York metropolitan region", (b) "study trajectories of potential sea level rise that continue after 2100 in light of the sea level rise commitment on longer timescales", and (c) "examine the consequences of long-term sea level rise scenarios on coastal flooding, including those stemming from low-probability, high-end scenarios" (Gornitz et al., 2019).

This chapter presents the finalized projections of record[4] associated with temperature and precipitation. These projections use new methods that derive expected changes in NYC's temperature and precipitation from global climate models, both in terms of average conditions as well as climate extremes. The projections use the newest generation of climate models from CMIP6, which include significant advances in the representation of the process that form the climate system and the impacts of anthropogenic emissions. New methods for downscaling these global projections are introduced which account for changes to not only the mean state of local climate but also in the variability of temperature and precipitation.

The chapter also describes potential impacts of climate change on intra-urban heat variability. While the chapter does not update the projections of NPCC3 that mapped temperatures at the neighborhood scale for select future periods of time (González et al., 2019), it describes the local and global drivers of extreme heat in the city. Moreover, new projections of compound heat and humidity are presented. A new section also describes growing evidence of global climate change leading to stronger urban heat islands (UHIs) as well as physical interactions that may exacerbate the City's UHI.

2.2 Chapter Organization

This chapter contains three sections that describe changing climate risks in NYC. Section 3 builds on previous NPCC assessment reports by describing the latest climate science and data, while describing new methods used to develop the projections of record for sea level rise, temperature, and precipitation for the City. This section also describes the approach followed by NPCC4 for using projections across multiple emissions pathways. Finally, Section 3 also discusses the issue of the "hot models" associated with CMIP6 and their potential impact on NYC's climate projections. Section 4 describes the state of the science on temperature variability within the city. This section explains both the large scale and regional dynamics that lead to extreme heat events, as well as the local physical drivers that lead to inequitable distributions of exposure to extreme heat. Section 5 describes the physical processes and the impact of a changing climate on *tail risks* and extreme events. Finally, Section 6 reviews opportunities for future research, with a focus on the *hot model problem* and the intersection of spatial resolution of projections with gaps in knowledge in the impacts of the climate signal on intra-urban heat and heat exposure.

3 Sustained assessment and CMIP6

This report follows prior NPCC assessments that developed climate projections for NYC. Presented here is a summary of the methods and how the key components of the projections have changed over time. Braneon et al., (2024) and the New York State Climate Impacts Assessment (NYSCIA) (New York State Energy Research and Development Authority, 2024) provide a more detailed description of the analytic methodology. The NYSCIA contains a detailed breakdown of the differences in each "element" of the projections (e.g., baseline period, number of models used, emissions scenarios).

[4] Based on climate analyses, regional and global trends, and a review of scientific literature, NPCC confirms which climate projections of temperature, precipitation, sea level rise, and coastal flooding (i.e. projections of record) are most appropriate for use in resiliency planning for the city and region.

3.1 Identifying the Differences/Updates in the Climate Projections

Changes in the projections in this NPCC4 report include 1) the use of new emissions scenarios and global climate models, 2) updated historical baseline period and future time slices for projections, and 3) new methods for projections of quantitative extreme events and sea level rise.

3.1.1 Emissions scenarios and global climate models

The newest climate science available is associated with Coupled Model Intercomparison Project Phase 6 (CMIP6); its shared socio-economic pathways (SSPs) are part of a new scenario framework (Ebi et al., 2014; O'Neill et al., 2016), established by the climate change research community to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. The updated climate projections for NYC utilize data (both monthly and daily) from the CMIP6 ensemble of global climate models. For a specific description of the methods used, refer to Braneon et al. (2024).

CMIP6 global climate models have, in general, a higher spatial resolution than CMIP5 (the previous iteration of models utilized by the IPCC); grid box sizes for many models are on the order of approximately 70 miles by 70 miles horizontally, whereas a common resolution for CMIP5 was approximately 140 miles by 140 miles. CMIP6 models also feature more advanced characterization of key system components, such as stratospheric chemistry, and more dynamic coupling across system components. The climate sensitivity—a measure of how sensitive global average temperatures are to changes in greenhouse gas concentrations—is higher in approximately one-fourth of CMIP6 models than in CMIP5 and earlier CMIP generations (Zelinka et al., 2020) In addition to presenting projections for NYC based on CMIP6, this chapter also examines the potential impact of these so-called "hot models".

3.1.2 Historical base period and future timeslices

The historical baseline periods for the climate projections are updated for NPCC4. Projections of temperature are expressed relative to a baseline period of 1981 to 2010 for temperature and precipitation while the baseline period is 1995 to 2014 for sea level rise. In addition, projections are now provided for each decade from the 2030s through the 2080s (See Braneon et al (2024) for more details). The methods still use a 30-year average for the time periods (10-year average for sea level rise) to reduce the noise of year-to-year variability while the climate change signal remains.

3.1.3 New methods for extreme events and sea level rise

For the projections in NPCC4, new methodologies are used for quantitative extreme events and sea level rise. Full details of these methods can be found in Braneon et al., (2024), however, this section identifies some of the key updates.

In NPCC4, quantile mapping is used to combine the daily outputs from the global climate models (GCMs) with historical climate data to develop future climate projections that include daily extremes like hot days, defined as days with maximum temperature above 90°F and days with heavy rainfall, defined as days with at least 1 inch total precipitation. Quantile mapping represents an advance from prior NPCC work, which used the delta method based on monthly rather than daily data from GCMs. Whereas the delta method largely retains the distribution of temperatures from the historical observed data--only adding a mean, or 'delta' uniformly to the historical data, quantile mapping of daily data retains changes in the distribution of temperatures with climate change, as simulated by GCMs. For example, if a model has its top one percent of hottest days warming more than other days, quantile mapping will lead to projections with larger increases in hot day frequency and intensity than would be generated by the delta method (Panofsky & Brier, 1968).

The downscaling technique used in this work is one of many used in climate research, and while all are generally considered to render 'value added' projections (by addressing GCM biases and adding finer spatial resolution), the methods do not produce identical results. The downscaling technique used here should not be considered inherently superior to other possible downscaling choices.

The development of a comprehensive approach to sea level rise in the latest IPCC report (AR6) offered the opportunity to rely on methods and data generated by the IPCC rather than recreating data already available. For NYC, outputs are taken directly from the IPCC data set for the Battery for three scenarios; SSP2-4.5-medium confidence, SSP5-8.5-medium confidence, and SSP5-8.5-low confidence (Kopp et al., 2023). Because this data is available for years at the start of each decade (e.g., 2050), we interpolated the values to the middle year (e.g., 2055) of the decade, to align with the decadal time periods (e.g., the 2050s) previously used for NPCC sea level rise projections. Sea level rise projections are computed for all decades from the 2030s to the 2090s and then 2100 and 2150.

3.1.4 Additional methodological changes and advances

The observed rate of mean sea level rise of 4.3 ± 1.08 mm/yr (1992-2021) at the Battery in NYC (National Oceanic and Atmospheric Administration (NOAA), 2023; National Oceanography Centre, 2023) remains higher that of the observed rate of global mean sea level rise (GMSLR) of 3.3 [2.8-2.2] mm/yr (1993-2018) (Fox-Kemper et al., 2021, tbl. 9.5). This higher relative, or local rate of sea level rise (RSLR) derives from a combination of glacial isostatic adjustment (GIA) related subsidence, enhanced thermal expansion, and increasing distant land ice mass losses (see also Braneon et al., 2024; Section 4.1.1).New hotspots of highly localized land uplift and subsidence in NYC that cause variations in RSLR have been recently identified by interferometric synthetic aperture radar and other satellite data (Buzzanga et al., 2023). Most of these hotspots are situated on land fill or on heavily modified ground. The very localized variations in RSLR may produce highly differential coastal flood risk across the city. In addition, there is some evidence that the Atlantic Meridional Overturning Circulation (AMOC) weakening in the future, which would lead to higher RSLR along much of the East Coast and increase the likelihood of higher coastal flooding (Little et al., 2019; Volkov et al., 2023). In addition, the AMOC plays a role in a “domino effect” of tipping points, which may add uncertainty its role in RSLR (Wunderling et al., 2021) and other changes throughout the climate system.

Sea level rise and coastal flooding pose growing risks to the population and major economic assets along and beyond NYC's waterfront. Rising sea level is leading to an increased frequency of coastal flooding in New York City and elsewhere in the United States (e.g. Sweet et al., (2022). Future sea level rise will exacerbate high tide flooding as well as the destruction caused by storm surges (Strauss et al., 2021).

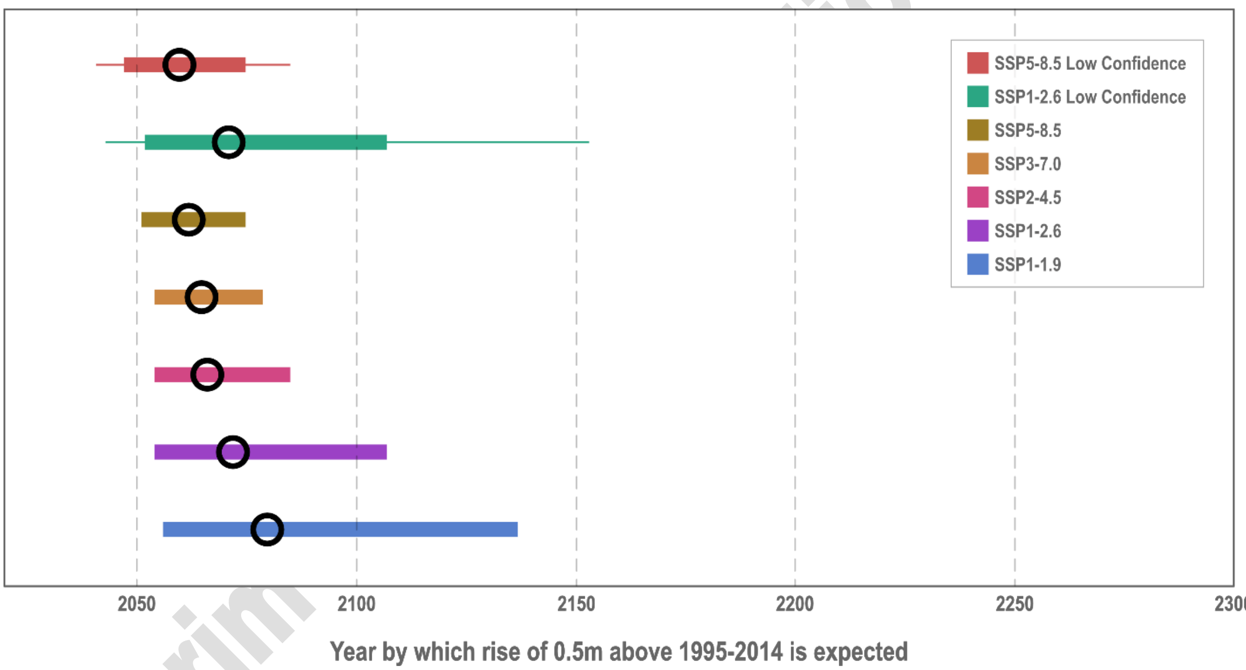

Figure 2: Projected Timing of Selected Sea-Level Rise Milestone Under Different Scenarios at The Battery in New York City. Thick bars show 17th-83rd percentile ranges, and black circles show median value. Thin bars also show 5th–95th percentile ranges for SSP1-2.6 Low Confidence and SSP5-8.5 Low Confidence scenarios that indicate the indicate the potential impact of deeply uncertain ice sheet processes. Source: National Aeronautics and Space Administration (2023)

While the “ambiguity” associated with ice-sheet instability limited the ability of NPCC3 (and earlier Panels) to generate quantitative sea-level projections of record (Gornitz et al., 1982; Kopp et al., 2023; Mercer, 1978; Oppenheimer et al., 2019) that explicitly account for this, NPCC4 utilizes sea level rise projections from the National Aeronautics and Space Administration (NASA) Sea Level Projection Tool (Fox-Kemper et al., 2021; Garner et al., 2021; National Aeronautics and Space Administration, 2023) to present a broad range of plausible outcomes that explicitly account for ice sheet processes[5] (Bamber et al., 2019; DeConto et al., 2021) that are deeply uncertain (Bassis, 2021; Braneon et al., 2024). The tool allows users to view both global and regional sea level projections from 2020 to 2150, along with how these projections differ depending on future scenario or warming level (See Figure 2 from NASA (2023).

While the sea level rise projections available from the NASA Sea Level Projection Tool for NYC are consistent with the assessment of equilibrium climate sensitivity (ECS) described in IPCC's Sixth Assessment Report (AR6) (See Box 9.3 and Sections 9.6.3 and 9.7 in Fox-Kemper et al., (2021), some members of the climate science community (e.g. Hausfather et al., (2022) have begun developing different approaches (e.g. "model culling" or rejecting some models' projections) for projecting local temperature and precipitation changes that explicitly address the fact that some GCMs' transient warming lies outside the bounds of the IPCC AR6 assessed "likely" range of ECS or transient climate response (TCR) (Table 1 in Rypdal et al., (2021) shows a TCR span of 1.3–3.0°C in the CMIP6 experiments). A consequential aspect of the model culling approach is that "rejecting models is akin to applying a binary weighting scheme to the CMIP6 ensemble, with zero weight applied to the culled models", and model democracy" (e.g. equal weighting) for the remaining ensemble members (Massoud et al., 2023). As model culling (or unequal weighting) results in eliminating (or significantly reducing) consideration of the information provided by a significant portion of the model ensemble, NPCC4 has elected to conduct data-driven analyses to understand if the so-called "hot model" problem (Hausfather et al., 2022) has a statistically significant impact on the bias-corrected temperature and precipitation projections presented in Braneon et al. (2024; Massoud et al., 2023; Weigel et al., 2010).

"In climate science, one of the most fundamental pursuits is determination of the significance of differences between two states or sets of conditions" (Lanzante, 2021). Multiple statistical tests were conducted with the ensemble of GCM means that is used to develop the temperature and precipitation projections that are found in Braneon et al., (2024). Kolmogorov–Smirnov tests results reveal that there is no statistically significant difference at the significance level of 0.01 for any of the metric distributions when the three GCMs with TCR values greater than 2.2 degrees C are removed (See Table 1 for 2080s results). NPCC4 affirms the temperature and precipitation projections presented here (and also in Section 6.4 of (Braneon et al., 2024) as projections of record for the City of New York. See Appendix A for boxplots comparing 960-member ensembles (16 GCMs x 2 scenarios x 30 years) of annual projections with 780-member ensembles (13 GCMs x 2 scenarios x 30 years) that exclude GCMs with TCR values greater than 2.2 degrees C.

Table 1. Difference in ensemble means for the 2080s for temperature and precipitation metrics. Kolmogorov-Smirnov (KS) tests comparing the 32-member ensemble (16 GCMs x 2 scenarios) of model mean projections (i.e. mean of 30 years of annual projections) for the 2080s with a 26-member ensemble (13 GCMs x 2 scenarios) that excludes GCMs with TCR values greater than 2.2 degrees C. No statistically significant differences are found for any metric at the 0.01 level.

Metric	Decade	Difference in Means
Days/yr >= 90 degrees F	2080s	4.12
Days/yr >= 95 degrees F	2080s	3.43
Days/yr >= 100 degrees F	2080s	2.65
Days/yr <= 32 degrees F	2080s	-4.64
Days/yr >= 1 inch	2080s	0.24
Days/yr >= 2 inches	2080s	0.08
Days/yr >= 4 inches	2080s	0.03

[5] To indicate the potential impact of deeply uncertain ice sheet processes, about which there is currently a low level of agreement and limited evidence, low confidence projections are also provided for SSP1-2.6 and SSP5-8.5. For both the Greenland and Antarctic ice sheets, the low confidence projections integrate information from the Structured Expert Judgement study of Bamber et al. (2019). For the Antarctic ice sheet, the low confidence projections> projections also incorporate results from a simulation study that incorporates Marine Ice Cliff Instability (DeConto et al., 2021).

3.1.5 Temperature trends and projections

Annual average air temperatures, as measured by long-term ground stations in the Global Historical Climatological Network – daily (GHCN-daily) (Menne et al., 2012) have increased at stations across the NYC metropolitan area over the last 70 years. Although the data records' length varies between stations, the warming rates are similar. During their overlapping period of observations (1949-2022), annual mean temperatures have increased at rates between 0.24°F to 0.41°F per decade (Figure 3) for the period where observations overlap across the stations. This increasing trend can be observed across the entire observation record of each station, with Central Park temperatures growing at a pace of 0.28°F per decade since 1870. Both daily minimum and maximum temperatures have increased throughout this period (Figure 4). In general, nighttime minimum temperatures have increased at faster rates than daytime maximum, except at John F Kennedy (JFK) Airport. As in annual average temperatures, similar trends are observed in both daily minima and maxima when the records are extended beyond their temporal overlap, with Central Park station daily minimum and maximum growing by .26 and .31 °F per decade since the first observations in 1870.

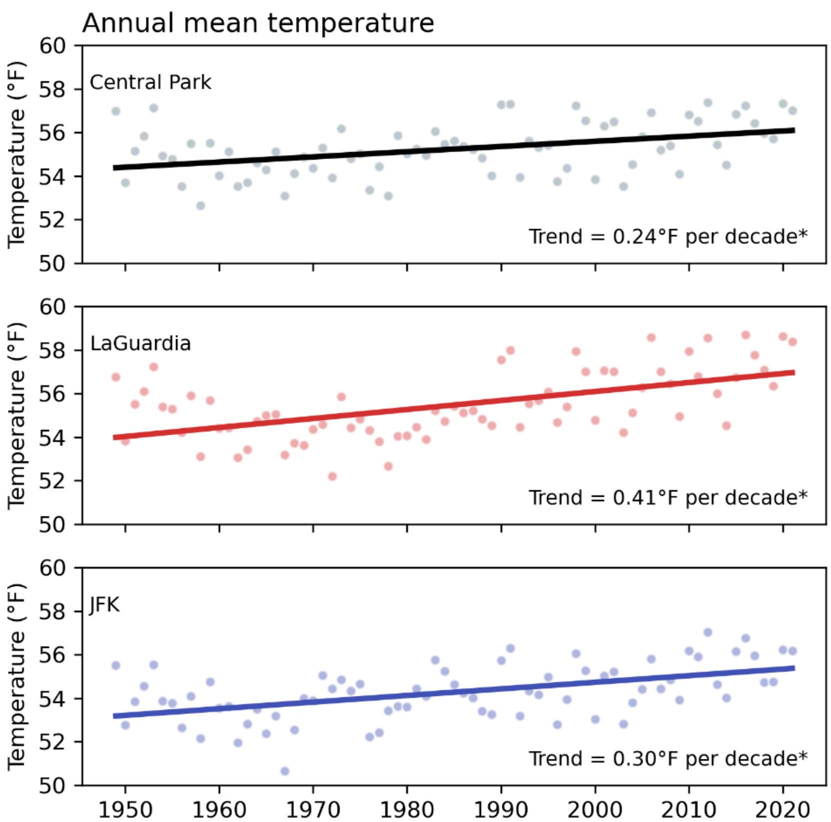

*Figure 3. Annual mean temperature recorded at Central Park, LaGuardia, and JFK Airports (1949-2022). Solid line represents linear trend. *Trend is significant at the 99% confidence level tested with a non-parametric Spearman Correlation. Source: Global Historical Climatology Network-daily.*

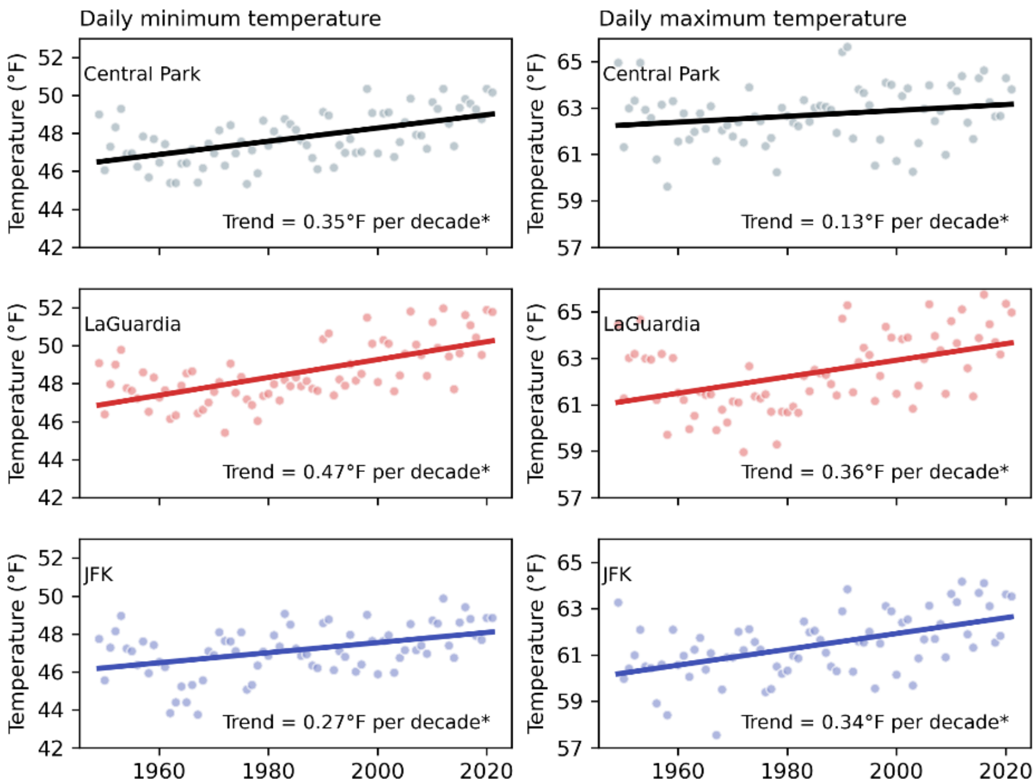

*Figure 4. Annual daily minimum (left column) and maximum (right column) temperature recorded at Central Park, LaGuardia, and JFK Airports (1949-2022). Solid line represents linear trend. *Trend is significant at the 95% confidence level tested with a non-parametric Spearman Correlation. Source: Global Historical Climatology Network-daily*

Climate change is extremely likely to bring warmer temperatures to the New York metropolitan region. Global climate models predict mean annual average temperatures increases between 2.7 to 3.9°F by the 2030s, 4.0 to 6.0°F by the 2050s, and 5.6 to 9.8 °F by the 2080s relative to a baseline period of 1981 to 2010. The total number of hot days and nights in NYC is projected to increase between 15 to 52 days by midcentury. The frequency of heat waves is expected to increase by a factor of 2 to 4 times the current baseline, with their average duration increasing by up to 50% by the 2050s. By the 2080s, the projected number of days per year with maximum temperatures at or above 82 degrees F (which occur on average 69 days per year in the current climate) nearly doubles. By the 2080s, the upper end of projected number of days per year with minimum temperatures at or above 80 degrees F (which occur on average about 1 day per year in the current climate) increases 10-fold.

3.1.6 Heat index projections

In order to maintain biological function, humans must keep a body temperature of close to 37°C (98.6°F). However, humans gain heat through a variety of mechanisms such as metabolic activity and from interactions with the environment. In order to maintain body temperatures near 37°C, the human body sheds heat via convection, evaporation of surface sweat, and respiration. Of these, evaporation is most important as it accounts for close to 75% of heat dissipation (Koppe et al., 2004). However, evaporation of surface skin sweat is dependent on the properties of moist ambient air. As ambient air around a person becomes saturated with moisture, evaporation becomes more difficult, leading to reduced heat dissipation. This reduced cooling capacity can be particularly dangerous during periods of extreme heat, when humans are most reliant on evaporation for shedding heat.

Although there are several methods to quantify the impact of combined temperatures and humidity on human wellbeing, the United States National Weather Service (US NWS) relies on the heat index as defined by Steadman (1979) and codified into an equation by Rothfusz (1990)[6].

Table 2 shows the baseline (1981-2010) and projected changes to the occurrence of extreme heat index days throughout the 21st century. In the recent historical record, NYC experiences, on average, 38 and 6 days with heat index above 85°F and 95°F, respectively. These heat index thresholds are labeled by the US NWS as periods where *Caution* and *Extreme Caution* are warranted. By mid-century (2050s), the number of heat days with heat index larger than 95°F are projected to increase sixfold to 37. (the 50th percentile value of the model-based projections). Meanwhile, end of century days with heat index above 95°F increase close to a factor of 9 (50th percentile).

These results build on work presented in NPCC3 (González et al., 2019) by introducing a full set of projections of record of compound humid heat occurrence for the first time in NPCC. These projections leverage sub-daily data from CMIP6 and the quantile mapping method used for the other projections on model air temperatures and relative humidity estimates to present data consistent with projections of temperature, precipitation, and their extremes.

Table 2. Projections of heat index days per year for 30-year periods centered around the 2040s, 2050s, 2060s, 2070s, and 2080s.

	Baseline Period (1981 - 2010)	10th	25th	50th	75th	90th
2030s						
Days with HI > 85°F	38	57	61	69	74	84
Days with HI > 95°F	6	17	18	23	29	37
2040s						
Days with HI > 85°F	38	60	67	77	84	92
Days with HI > 95°F	6	19	23	29	36	44
2050s						
Days with HI > 85°F	38	68	74	83	93	102
Days with HI > 95°F	6	23	30	37	46	57
2060s						
Days with HI > 85°F	38	72	81	92	100	112
Days with HI > 95°F	6	27	33	46	54	70
2070s						
Days with HI > 85°F	38	77	86	97	109	121
Days with HI > 95°F	6	31	37	50	65	82
2080s						
Days with HI > 85°F	38	81	89	101	118	132
Days with HI > 95°F	6	34	39	55	77	97

3.1.7 Precipitation trends and projections

Annual precipitation has increased since 1959, as recorded across all three long-term weather stations in NYC. The Central Park and LaGuardia stations exhibit similar statistically significant positive trends of 1.61 and 1.35 inches

[6] A recent study by Lu and Romps (2022) found that the NWS formula used to calculate heat index may lead to negative biases when applied to future climate scenarios. This paper was not available at the time when the climate projections were updated.

more rain per decade. Meanwhile rainfall at JFK airport station exhibits a slightly lower and not statistically significant trend of 0.93 inches more rain per decade.

Total annual precipitation will likely increase, although precipitation projections are less certain than temperature projections. Mean annual precipitation is projected to increase by approximately 2 to 7 percent by the 2030s, 4 to 11 percent by the 2050s and 7 to 17 percent by the 2080s relative to a baseline period of 1981 to 2010. 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 (i.e. compared to the 1981 to 2010 baseline period).

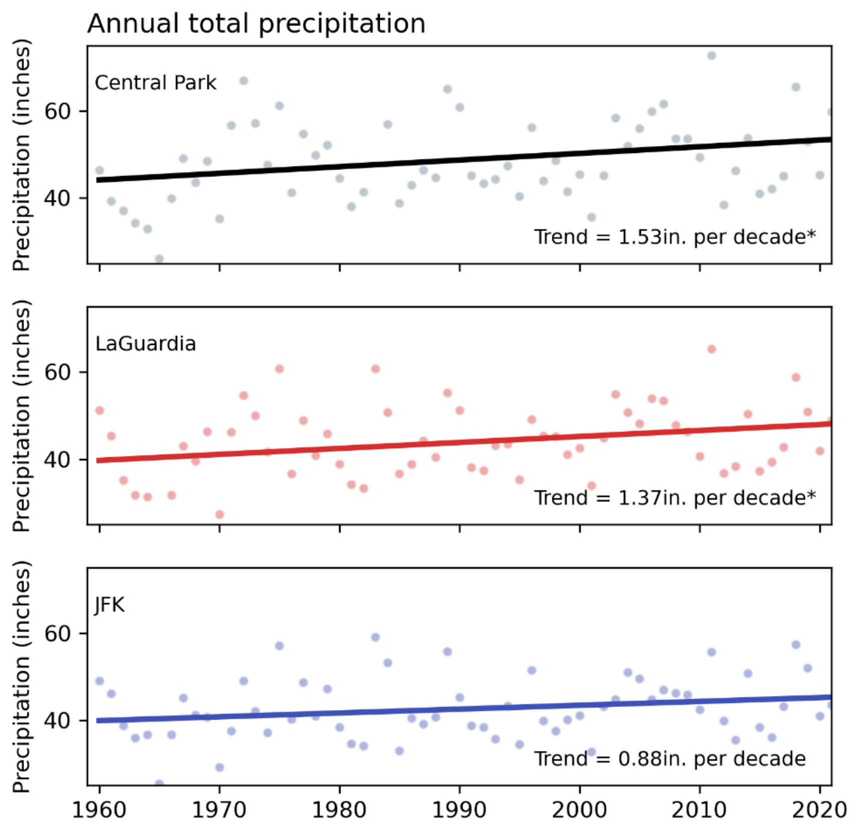

*Figure 5. Annual total precipitation recorded at the Central Park, LaGuardia, and JFK stations for their overlapping period of observations (1960-2022). Solid line represents linear trend. *Trend is significant at the 95% confidence level. Source: Global Historical Climatology Network-daily*

3.1.8 New analyses of historical trends and future projection for subdaily precipitation

Along with changes in annual precipitation, climate change will impact patterns of precipitation at subdaily time scales with implications for flooding, harbor water quality, as well as the design and maintenance of building systems and infrastructure. To evaluate historic trends in subdaily precipitation, a 68-year study of historical precipitation was conducted using hourly precipitation data from The NCEI Hourly Precipitation Dataset (HPCP; 1955-2013) (National Centers for Environmental Information (NCEI), 2023a) and Local Climatological Dataset (LCD; ID NCEI DSI 3505; NCEI 2005; 2014-2022) (National Centers for Environmental Information (NCEI), 2023b). The analysis included three NYC metropolitan area gages (Central Park, LaGuardia Airport, and Newark Airport), with JFK Airport excluded due to long periods of missing hourly data.

During this period record, it should be noted that the observing technology used transitioned. Unshielded Universal (or Freiz) weighing rain gages were in use during the earliest part of each station's record. A tipping-bucket type rain gage was used at Central Park from 2000-2004, at LaGuardia from 1996-2004 and at Newark from (2000-2005).

These transitioned to an NWS all-weather precipitation accumulation gage in the later part of the record. Wind shielding was added to the gage at LaGuardia in 2010 and Newark in 2019. It is likely that rainfall measured by the tipping bucket gages was underestimated, especially when intensity was high. The addition of wind shields likely resulted in a more accurate rainfall measurement. Although these potential biases are an artifact of the entire U.S. national hourly precipitation record, established methods to adjust for these discontinuities are not available.

For these analyses, discrete events were defined by at least a 4-hour period without rainfall (Restrepo-Posada & Eagleson, 1982; Yu et al., 2018) and characterized in terms of the peak hourly intensity observed during the event, the event total accumulation, the event duration, and the average intensity (defined as event total accumulation/duration). The number of events that occurred for each year and each gauge were computed and extreme precipitation events, defined as the number of exceedances of the 95th and 99th percentile values in the full record, were identified. The non-parametric Mann-Kendall test was employed (Hussain & Mahmud, 2019). This test was used to identify statistically significant upward and downward trends using a p-value threshold of 0.05. The results from these analyses are summarized in Table 3. Significant increasing trends in the 95th percentile peak hourly intensity and event total intensity were observed at all 3 sites.

*Table 3: Precipitation Trends (1955-2022). Intensity-Duration-Frequency Curves calculated based on observations from 1950-1986 and 1986-2022. The recent period values are statistically different from the earlier period, especially at the longer recurrence intervals. * Trend is significant at the $p < 0.05$ level. Source: Franco Montalto and Mobin Rahimi Golkhandan, Drexel University.*

	Newark Airport	Central Park	LaGuardia Airport
Annual Accumulated Precipitation	**Increasing ***	**Increasing ***	**Increasing ***
Annual number of events			
Peak hourly intensity	**Increasing ***	**Increasing ***	**Increasing ***
Frequency of long-term 95th percentile peak hourly intensity exceedances	**Increasing ***	**Increasing ***	**Increasing ***
Frequency of long-term 99th percentile peak hourly intensity exceedances	**Increasing ***		
Event total precipitation accumulation	**Increasing ***		**Increasing ***
Frequency of long-term 95th percentile event total precipitation accumulation exceedances	**Increasing ***	**Increasing ***	
Frequency of long-term 99th percentile event total precipitation accumulation exceedances			
Event Duration		**Decreasing ***	**Decreasing ***
Frequency of long-term 95th percentile event duration exceedances			
Frequency of long-term 99th percentile event duration exceedances			
Average hourly intensity	**Increasing ***	**Increasing ***	**Increasing ***
Frequency of long-term 95th percentile average hourly intensity exceedances	**Increasing ***	**Increasing ***	**Increasing ***
Frequency of long-term 99th percentile average hourly intensity exceedances	**Increasing ***	**Increasing ***	

Urban stormwater and other critical infrastructure systems are designed to withstand a defined intensity and duration of rainfall, known as the 'design storm'. For any given rain event, the intensity of rainfall (defined as rainfall depth over a given duration) is associated with an annual probability of occurrence, usually described by its reciprocal return period. Accurate representation of the probability of rainfall intensity is thus critical for stormwater management and flood resilience planning and design. This information is presented in site-specific Intensity-Duration-Frequency (IDF) curves, developed based on frequency analysis of historic rainfall at specific locations and under the assumption of stationarity - the idea that natural systems fluctuate within an envelope of variability that is unchanging with time (Milly et al., 2008). With projections of amplified precipitation intensity through the 21st century due to global climate change (Allan & Soden, 2008; Fowler et al., 2021; Pfahl et al., 2017), the appropriateness of this approach to urban drainage design has recently been called into question (National Oceanic and Atmospheric Administration, 2022) .

Two sets of Partial Duration Series (PDS; 1950-1986 and 1986-2022) were constructed separately using hourly precipitation data from the sources described above. For each PDS in the array, IDF curves (Figure 6) describing rainfall amounts corresponding to annual recurrence probabilities of 50%, 20%, 10%, 4%, 2% and 1% (i.e. 2-, 5-, 10-

25-, 50- and 100-year storms) were computed by simulating the methodology used in NOAA Atlas 14 (Perica et al., 2019). As shown in Figure 6, changes between the 1950-1986 and the 1986-2022 IDF curves vary with rain event duration and recurrence probability, with substantially greater changes observed for the 1-12 hour events at recurrence intervals greater than 25-years. For example, at the Central Park weather station (Figure 6), the 50-yr return period the change in the 1-hour duration is 40%, while for the 24-hr duration rain event it is only 15%.

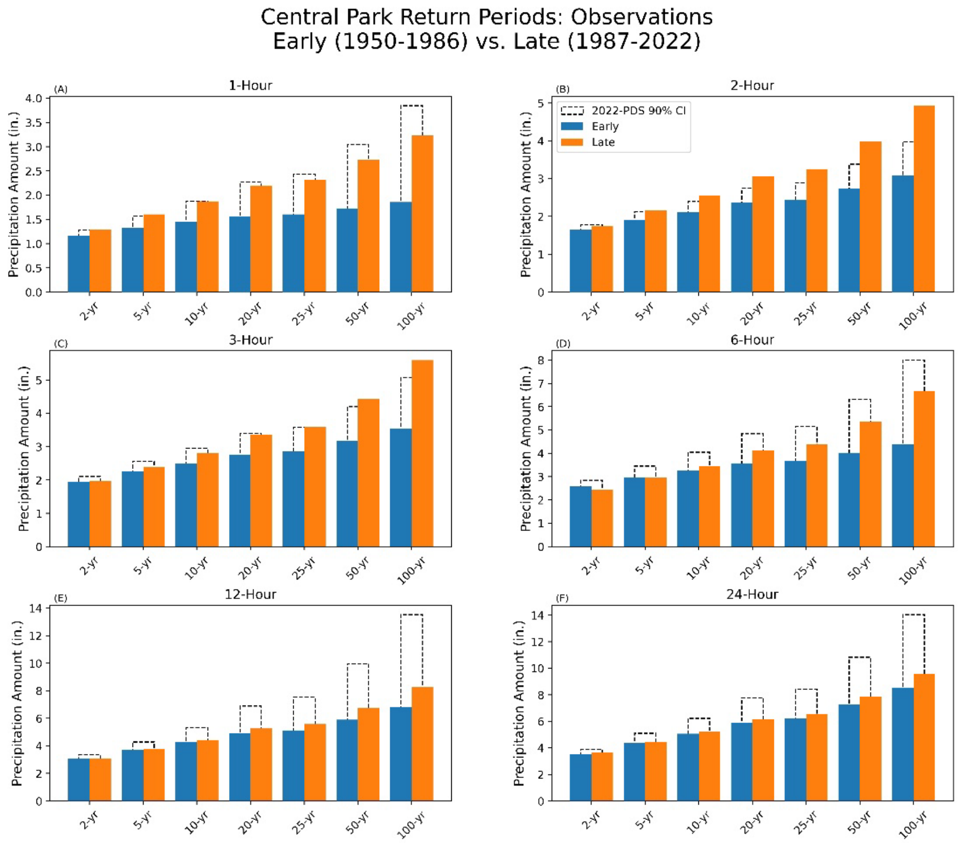

Figure 6. Intensity-Duration-Frequency chart created from two sets of Partial Duration Series (PDS): early (1950-1986, blue) and late (1987-2022, orange) for differing hourly durations (Panels A-F) and return periods (x-axis). The 90% confidence interval based solely on the 1950-2022 POR is plotted in black. Source: Colin Evans, Cornell University.

3.1.9 Sea level rise projections

Sea level rise (SLR) in NYC is projected to continue to exceed the global average and is very likely to accelerate as the century progresses. A recent study based on statistics and oceanographic data warns of a potential collapse of the AMOC an important branch of the global ocean circulation system, as early as the 2050s under current greenhouse gas emissions (Ditlevsen & Ditlevsen, 2023). Most experts only anticipate a future slowing of the AMOC as opposed to a complete collapse (Liu et al., 2020); a weakening of the AMOC could lead to increased thermal expansion, and redistribution of ocean water mass shoreward especially in the mid-Atlantic region, including New York City (Krasting et al., 2016; Yin & Goddard, 2013), as well as increased frequency of coastal flooding in the Southeast U.S. (Volkov et al., 2023).

Projections for SLR in NYC are 14 to 19 inches (0.36-0.48 m) by the 2050s and 25 to 39 inches (0.64-0.99 m) by the 2080s when compared with a 1995 to 2014 baseline period; SLR could reach as high as 5 feet (1.5 m) by 2100. Full details of the methods used to develop these projections with the scenarios shown in Figure 7(2023) can be found in Braneon et al., (2024). Under the ARIM scenario presented in 2019 by NPCC3, accelerated loss of land-based ice could lead to sea level rise of up to 81 inches (2 m) by the 2080s and 114 inches (2.9 m) by 2100 under a plausible 'worst-case' scenario that cannot entirely be ruled out.

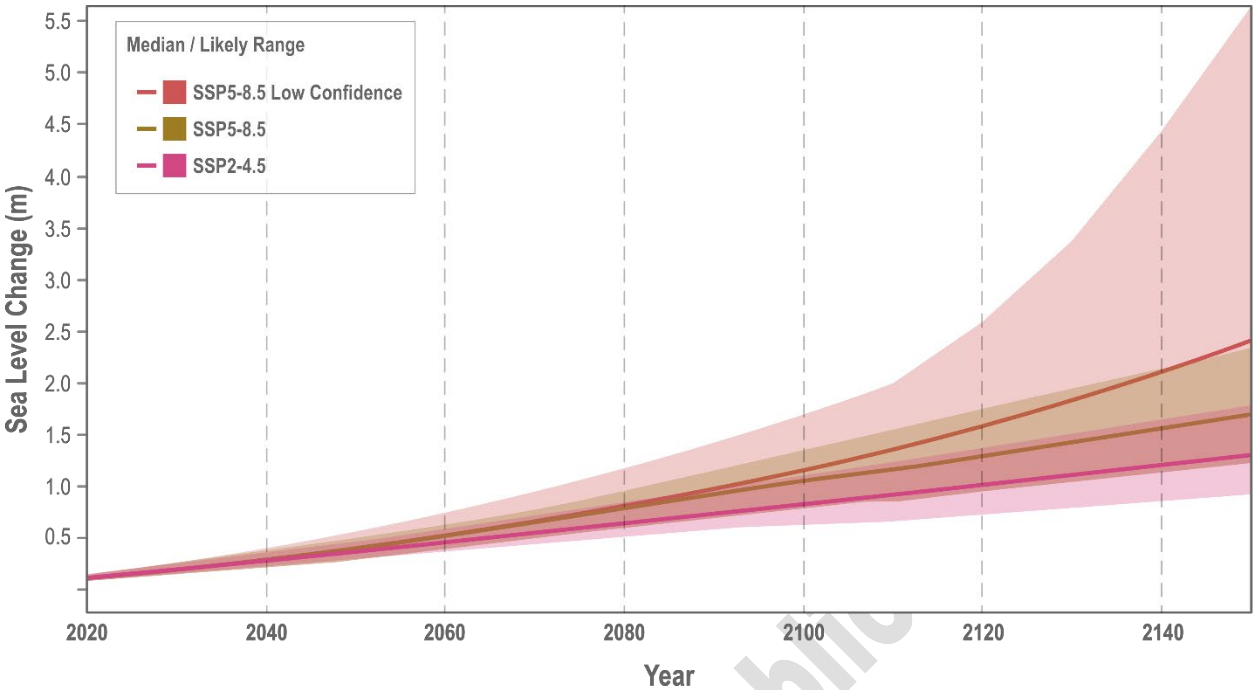

Figure 7. Projected Sea Level Rise Under Different Scenarios at The Battery in New York City. Median values for three scenarios are shown with solid lines and shaded regions show the 17th-83rd percentile ranges presented in the IPCC Sixth Assessment Report. Projections are relative to a 1995-2014 baseline. Source: National Aeronautics and Space Administration (2023)

4 Drivers of Extreme Heat

4.1 Large-scale Drivers

Extreme heat in NYC is driven both by large scale climate processes and local characteristics of its land cover. At the large scale studies show that that changes in global mean temperatures have led to an increase in the frequency, intensity, and duration of extreme heat events (Coumou & Robinson, 2013; Habeeb et al., 2015). A review of global drivers of extreme heat by Horton et al (2016) found that several dynamical climate mechanisms impact the occurrence and intensity of extreme heat events such as (1) land-atmosphere feedbacks, (2) atmospheric blocking events, and (3) planetary-scale atmospheric waves. While there is evidence to support that warmer climates may enhance land-atmosphere feedbacks and their impact on heat extremes, there are still open questions on the other aforementioned mechanisms' sensitivity to global climate change.

There is evidence, however, of increasing trends in large scale circulations linked to extreme heat as a result of global climate change. Horton et al (2015) found increasing trends over North America in the occurrence of warm season atmospheric blocking, often dubbed heat domes for their warm air trapping effect, finding that increases in temperature extremes are impacted not only by thermodynamic changes but also increased incidence of regional flow regimes. Climate models, however, may have biases in their representation of the incidence of these large-scale flows, which may lead to uncertainties in future projections of extreme heat (Jeong et al., 2022). Meanwhile, evidence from extreme heat events in Europe indicates that the cooling capacity of soil moisture through evaporation may be depleted by high temperatures, which in turn allows for even higher temperatures due to lack of cooling – a positive feedback loop (Miralles et al., 2014). Nevertheless, increased temperatures, including in NYC, are one of the strongest signals in climate projections as a function of increasing greenhouse gas emissions (Calvin et al., 2023).

4.2 Local Drivers

Local landcover characteristics drive surface and air temperature in the urban built and natural environment. The urban built infrastructure refers to streets, sidewalks, and buildings and is primarily comprised of impervious surfaces of varying material types, reflectance, and thermal capacities. Throughout the day these surfaces retain, store, and emit heat from incoming solar radiation. The rate and magnitude at which the built infrastructure transfers heat impacts the surrounding air and surface temperature of the environment. For example, surfaces that have a low albedo or reflectivity (e.g. asphalt streets) typically absorb and store more heat during the day releasing it slowly as sensible heat in the afternoon (Oke, 1982). The release of sensible heat warms the surrounding environment. The installation of impervious surfaces in an urban environment such as NYC can also limit natural cooling processes such as evaporation, evapotranspiration and wind speed and direction (Mallen et al., 2020). Tall buildings can create an “urban canyon” effect that can prevent ventilation and trap heat (Oke, 1982). Anthropogenic heat from human activity like traffic, industrial processes and air conditioning is an additional source of heat commonly found in the urban environment which can elevate urban air temperature (Oke, 1982). The natural environment is mainly comprised of pervious surfaces characterized by vegetation like shrubs, grasses, and trees. Vegetation cools the environment through shade and evapotranspiration. The natural environment stores less heat during the day and releases heat at a faster rate than the built environment.

The urban and natural environment store and retain heat from incoming solar radiation throughout the day and commence releasing heat as the sets in the afternoon. The slower release of heat from the built environment creates a temperature differential with areas containing more of the natural environment creating a phenomenon called the urban heat island (UHI) (McConnell et al., 2022) effect characterized by an urban heat island intensity (UHII) (Memon et al., 2009). The UHII is traditionally reported as a temperature difference between the urban and surrounding rural environment. The highest UHII is commonly observed during the late afternoon through nighttime period. In recent years other characterizations of UHII have been used in literature (Almeida et al., 2021; Wang, 2022) as a comparison to include parks (Cai et al., 2023; Yao et al., 2022), airports (Gough & Leung, 2022; Wan et al., 2022) and land classification zones (Zhou et al., 2020). In NYC neighborhoods contain varying amounts of the built and natural infrastructure causing some neighborhoods to maintain warmer temperatures (Hamstead et al., 2016). Equitable heat mitigation and adaptation policies seek to reduce neighborhood temperature heterogeneity, while reducing local citywide temperature (Broadbent et al., 2022; Heger, 2022; Shi et al., 2023).

UHII in NYC has been studied for several decades, with observations of urban-rural temperature differences of 3.22°F on average and as high as 5.4°F reported by (Bornstein, 1968). More recent observations based on longer study periods found that the NYC UHII averaged between 4°C in the summer and 5.4°C in the winter and spring, with significant variability due to the time of day and prevalent weather conditions (Gedzelman et al., 2003).

The spatial distribution of the NYC UHI is linked to both characteristics of the land surface and larger scale prevailing wind conditions (Raven et al., 2022). The NYC UHI is impacted significantly by afternoon sea breezes, which move its core inland towards The Bronx and New Jersey in the afternoon, while nighttime land breezes may move its core over Brooklyn and Queens. Studies have found that contributions from NYC’s built surface varied significantly due to the characteristics of the urban surface as well as distance to the southeastern coastline where sea-breezes typically come from, and that these contributions extended several hundred meters above ground (Bauer, 2020; Ortiz et al., 2018).

Studies have quantified the impacts of landcover on air temperature in the urban environment. Characteristics of the built environment are more closely associated with nighttime air temperature variance compared to daytime air temperature (Alonzo et al., 2021; Shiflett et al., 2017; Zekar et al., 2023; Ziter et al., 2019). Minimum (nighttime) air temperature is influenced by building height (Chen et al., 2020; Konarska et al., 2016). Research using land use regression modeling have observed a non-linear relationship between temperature and canopy cover and greenness, requiring a threshold of canopy cover associated with decreases in air temperature, and with diminished cooling as distance increases from tree canopied areas (Johnson et al., 2020; Ziter et al., 2019). Decreases in nighttime temperatures were found to be associated with a 32% threshold in a 200 m buffer (Johnson et al., 2020) and a greater than 40% threshold in a 60-90m buffer (Ziter et al., 2019).

The relationship between urban land cover (i.e. tree canopy, building height/area, impervious land cover) and temperature is made more complex by intra and inter-variability based on the time of day (Raven et al., 2022). Pedestrian (ground) level air temperature monitoring offers a means to observer hyper-local variability to assess and explore microscale interactions between land cover and temperature, which can lead to changes in how humans interact with the environment thus impacting day-to-day human health.

BOX 1. Temperature monitoring in NYC

In 2018 as a part of Cool Neighborhoods NYC, a comprehensive heat adaptation and mitigation plan (City of New York Mayor's Office of Resiliency, 2017), the city launched a 2-year hyper-local temperature monitoring effort installing nearly 500 air temperature sensors in medium to high HVI neighborhoods (see Braneon et al. (2024), Figure 11, for HVI distribution map (2024). These HVI neighborhoods were identified based on the prevalence of vegetative cover, air conditioning and demographic prevalence, daytime surface temperature, median income, and demographic prevalence. Intra (within) site variability in NYC med-high neighborhoods was observed to be larger during the afternoon when UHII is highest compared to the nighttime (*Figure 8*a). In contrast inter (between)-site (between sites) variability is higher at night compared to the afternoon. The magnitude of temperature variability is larger for observations representing higher temperature ranges for the afternoon and nighttime periods (*Figure 8*b). The site with the highest afternoon variability is Central Harlem, Manhattan adjacent to Marcus Garvey Park. The lowest variability was observed in Stuyvesant Heights Brooklyn. Reducing intra and inter neighborhood variability is important when considering equitable heat adaptation and mitigation policies within NYC communities. The thresholds used were based on the 2023 NYC Heat mortality report prepared by the NYC Department of Health (City of New York Department of Health and Mental Hygiene, 2023).

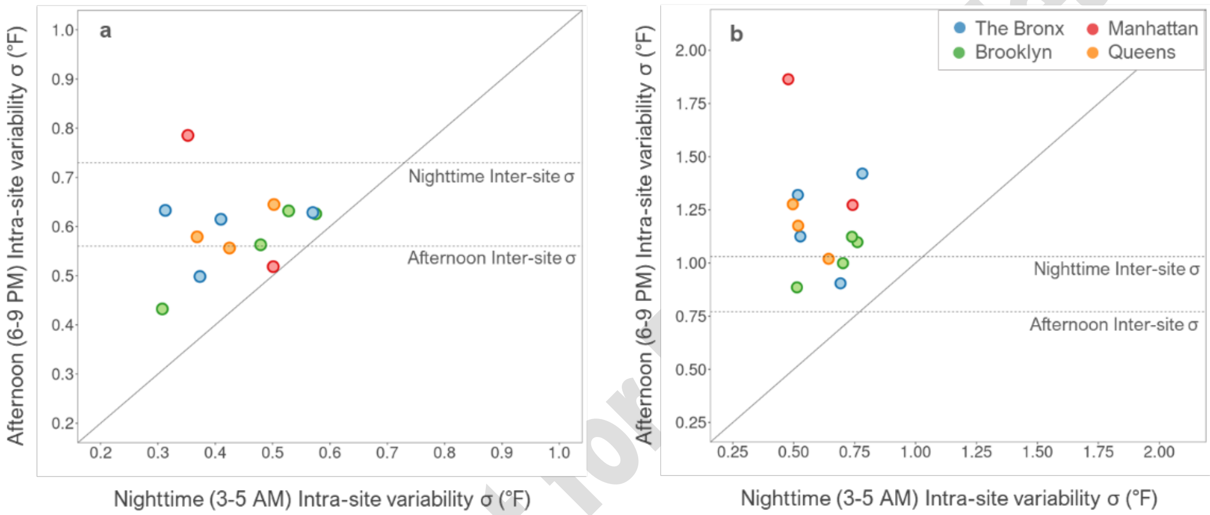

Figure 8. Estimates of intra-site under tree canopy air temperature variability (standard deviation (σ)) per borough for (a) summer period (July-August) (b) upper threshold temperature (>82 °F nighttime, 90°F afternoon). Dotted line denotes the inter-site variability. Solid line is the 1:1 line. Source: NYC DOHMH

BOX 2. Interactions between heat waves and UHIs

UHIs are the product of dynamical interactions between the land surface and the atmosphere, as well as urban planning decisions that dictate the form and material properties of urban landscapes. There is significant evidence of UHI intensification during periods of extreme heat due to so-called synergistic interactions (Li & Bou-Zeid, 2013). These synergies arise due to (1) the impact of extreme heat on soil moisture availability, which significantly affects the ability of the surface to cool via evapotranspiration, as well as (2) increased intake of heat in built-up surfaces. Studies have found these synergies to also occur in NYC (*Figure 9*) from Ortiz et al., (2018), with UHI intensification of over 5°C during a heat wave due to limited cooling and enhanced heat storage (Ortiz et al., 2018; Ramamurthy et al., 2017).

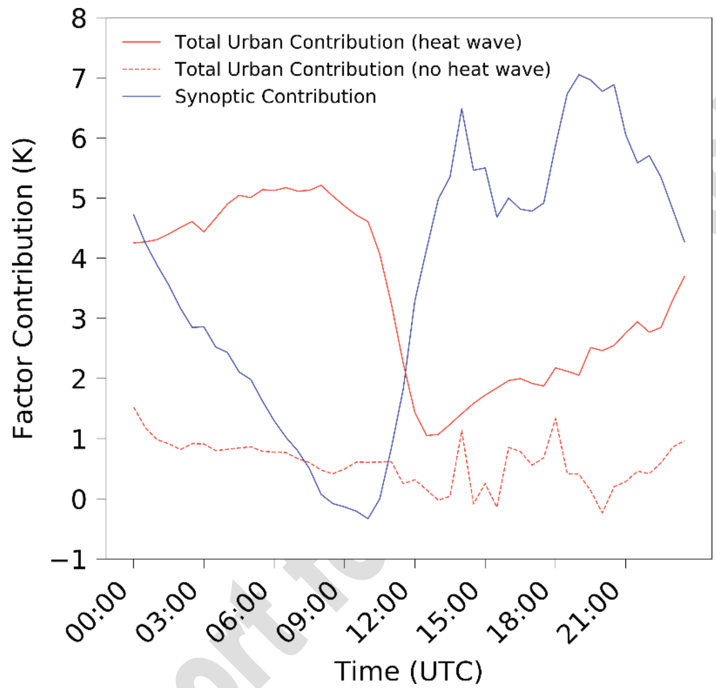

Figure 9. Contribution of urban surfaces to near surface temperatures before and during a heat wave event in NYC. Reproduced from Ortiz et al (2018).

5 Tail Risk Implications and Challenges

Low-probability extreme weather and climate change scenarios that have high consequences are referred to as “tail risk”. When assessing the risks associated with natural hazards and climate change, tail risks (i.e. low-probability extreme events) often play a much larger role than the probability of climate hazards alone might indicate (Quiggin, 2018). Tail risk is important to quantify, as it entails low-probability scenarios that have high consequences.

Tail risk for extreme weather is often underestimated because the historical record is insufficient to include a good characterization of extreme events. Tail risk for climate projections is often not revealed, due to a focus on the scenarios with moderate greenhouse gas emissions (e.g., SSP2-4.5) or by considering 90th percentiles as worst-case scenarios. Uncertainties in tail risk need to be reduced through deeper exploration of historical data, modeling of synthetic events, and climate downscaling simulations. When assessing extreme flooding, tail risk can also be reduced by more careful extreme value assessment that explores separation of tropical cyclone event data from other events.

Underestimating tail risk can lead to repeatedly being caught by surprise by events like Sandy and Ida and potentially other hazards such as extreme winds. Climate change impacts can have high tail risk, such as the ARIM scenario. Baseline (present-day) hazards can also have high tail risk, such as events like Hurricane Sandy. Sandy can be considered more of a baseline hazard, given that a similar storm surge had occurred in the historical record in 1821 (Orton et al., 2016) and research has only found anthropogenic climate change to have contributed to 13% (7.5-23%) of the damages (Strauss et al., 2021). However, FEMA and NOAA assessments of extreme coastal water levels at the time of Sandy's impact suggested it was a very unlikely event with a 1570-year return period (Federal Emergency Management Agency, 2007; Sweet et al., 2013). Reasons why the tail risk of extreme events such as Sandy and Ida could be underestimated are revealed below.

5.1 Extreme Precipitation Implications

The most direct mechanism of precipitation intensification results from the thermodynamic relationship between atmospheric temperature and the saturation vapor pressure of water, which is known as the Clausius-Clapeyron (CC) Relation ('warmer air holds more moisture'). Under the temperature conditions relevant to weather, the amount of water vapor in the atmosphere at saturation will increase 6-7% per degree Celsius warming. From this thermodynamic relationship alone, it would be expected that precipitation would occur less frequently when the supply of atmospheric moisture is limited, since more moisture would be required for the atmosphere to reach saturation, condense, and precipitate. However, when large-scale weather conditions provide a source of atmospheric moisture, there would be more precipitable water and, in turn, higher rainfall rates once saturation is reached (Trenberth et al., 2003).

Along with this direct thermodynamic effect, climate change can also influence short-duration precipitation extremes through several key atmospheric processes that take place at micro- to global spatial scales. At a global scale, a fundamental effect of global warming will be the thermal expansion of the warming troposphere and stratospheric cooling, resulting in an increase in the height of the tropopause. Increased tropospheric heights will allow for deeper convection and increased precipitation rates when local conditions are favorable (Lenderink et al., 2017; Loriaux et al., 2017; Santer et al., 2003).

Global warming can also influence precipitation patterns through changes in the continental-scale atmospheric circulation patterns that determine the transport of moisture across the globe. In the eastern United States, the climatology of large-scale moisture transport can be described by 16 spatially distinct atmospheric transport patterns, each with a distinct frequency and seasonality (Teale & Robinson, 2020). Anthropogenic climate change could potentially alter the frequency or seasonality of these patterns, with implications for local moisture availability and the probability of extreme precipitation in the future.

Large scale patterns associated with tropical cyclones (including tropical depressions, and hurricanes) also play an important role in the climatology of extreme precipitation in the northeast. This includes events associated with direct rainfall from tropical cyclones passing over, or very close to NYC. It also includes extreme rainfall that results from the remnants of tropical storms, such as the cloudburst associated with the remnants of Hurricane Ida in 2021, or changes to atmospheric dynamics such as lifting, instability, or moisture availability induced by tropical cyclones hundreds of kilometers away (Barlow, 2011).

In an observational analysis study of the continental United States, Barlow (2011) found that over most of the Northeast, more than two-thirds of all extreme daily rainfall events between 1975 and 1999 were linked to tropical cyclone-related activity. In terms of the dynamics underlying the forcing of extreme precipitation, Barlow's study found that the relationship between tropical cyclones or their remnants on large-scale lift was much greater than the relationship with moisture availability and buoyancy. It recommended further study of the interactions of tropical cyclones with large-scale circulation patterns that induce lift, such as the jet stream. This is notable, since large-scale lift induced by a powerful jet streak and associated upper-level divergence was a key contributor to the extremely intense precipitation observed during the Ida-remnants cloudburst in NYC in 2021 (National Oceanic and Atmospheric Administration, 2023b, fig. 4).

The influence of climate change on mesoscale storm processes also has the potential to result in more intense short-duration precipitation. Convective precipitation can occur in isolated thunderstorm cells or as part of organized clusters described as Mesoscale (10s to 100s of kilometers) Convective Systems (MCSs), which are often embedded into larger scale circulation such as squall lines or Nor'Easters. Organized convection is associated with increased precipitation efficiency - the ratio of moisture that falls to the surface as precipitation to total condensed moisture within a storm - and more intense precipitation (Fowler et al., 2021). Mosely et al. (2016) found that increased surface temperatures resulted in enhanced convective organization and more extreme precipitation and that, more broadly, the interactions amongst convective cells could be strongly influenced by large-scale changes in climate.

Historically, flash flooding in the northeast has been more commonly associated with disorganized, localized convective cells rather than organized MCSs, especially when compared to other regions of the United States (Jessup & Colucci, 2012). The significance of potential changes in convective organization in more extreme precipitation with climate change remains uncertain and is still in early stages of investigation (Pendergrass, 2020), however, some initial studies indicate that the storm areas may be larger and more organized under climate warming (Lenderink et al., 2017; Lochbihler et al., 2019). In a climate modeling study simulating an unmitigated global warming scenario (RCP 8.5), Prein et al. (2017) found that the total volume of summertime precipitation increased with global warming due to both increased precipitation rates and increases in the area over which precipitation occurs in organized MCSs.

Within individual thunderstorms, the increased moisture from warmer temperatures will increase the release of latent heat, creating more instability and stronger updrafts within thunderstorms and increasing precipitation rates beyond what would be expected from the increase in moisture availability alone. Assuming that latent heat within a thunderstorm is proportional to precipitation intensity and that kinetic energy of rising air within a thunderstorm increases proportionally with latent heating, precipitation intensity would be expected to increase at a rate twice that predicted by the CC relationship alone (2CC-scaling (Lenderink et al., 2017).

Changes in microphysical dynamics within thunderstorm clouds can also influence precipitation efficiency and convective precipitation rates. Precipitation efficiency is determined by the size distribution of hydrometeors (water and ice droplets) within thunderstorm clouds and the extent to which these hydrometeors re-evaporate or are re-entrained in updrafts before falling as precipitation to the ground. Singh and O'Gorman (2015) found that climatic warming resulted in an increase in the fall speed of water and ice droplets within clouds. Higher fall speeds reduce the probability that a water droplet will evaporate or be reëntrained in updrafts within the thunderstorm, resulting in higher precipitation efficiency within any given storm. However, the fall speed of water droplets within clouds can also influence updraft velocities, and in-turn precipitation rates (Bao & Sherwood, 2019; Parodi & Emanuel, 2009). Understanding the changes in these microphysical processes are most significant for sub-hourly precipitation rates (Singh & O'Gorman, 2015): studies on the contribution of tropical cyclones to subdaily rainfall in the New York City Metropolitan region are not yet available in the academic literature.

5.2 Sea Level Rise Implications

A key remaining uncertainty around the tail risk of future sea level rise is the future stability of the ice sheets and the Antarctic Ice Sheet as it holds the equivalent of 58.3 m of global mean sea level rise (GMSLR) if all its ice melted. The West Antarctic Ice Sheet (WAIS) is potentially subject to two instabilities: the Marine Ice Sheet Instability (MISI) and Marine Ice Cliff Instability (MICI) (Braneon et al., 2024, section 4.1.1). Therefore, in NPCC3, Gornitz et al. (2019) also considered one high end, low probability scenario—ARIM scenario, which includes these potential instabilities. DeConto et al. (2021), in a revised extreme upper tail GMSLR scenario which also includes these instabilities, found that by 2025, the median contribution of the WAIS to GMSL approaches 1 m and by 2150 rates exceed 6 cm. By 2300, Antarctica could contribute 9.6 m of GMSLR under RCP8.5 due to sustained CO2 emissions increases that extend past 2100.

A new study finds that projected 21^{st} century ocean temperature increases in the Amundsen Sea region of WAIS point to inevitable widespread basal ice shelf thinning and melting in most greenhouse gas emissions scenarios (Naughten et al., 2023). With weakened ice shelf buttressing, accelerated rates of ice-shelf melting would become inevitable even for moderate future climate policies, with adverse implications for the stability of WAIS.

The Greenland Ice Sheet, which holds the equivalent of 7 meters of sea level rise is also potentially vulnerable to abrupt ice-sheet loss beyond a global mean temperature threshold of 1.7 °C to 2.3 °C above preindustrial levels (Bochow et al., 2023). This ice loss can be substantially reduced if global mean temperature change reverts to less than 1.5°C above preindustrial levels within a few centuries. Nevertheless, even temporarily overshooting the 1.5°C temperature threshold, still leads to a peak in SLR of up to several meters even if ice sheets return to nearly historical normals.

5.3 Potential Mischaracterization of Tail Risk from Tropical Cyclones

A fundamental challenge with storm-related hazard assessments for the U.S. Mid-Atlantic and Southern New England is that Tropical Cyclones (TCs) (defined as including hybrid storms and post-TCs) are responsible for the largest events (e.g. Sandy and Ida) but occur infrequently during the typical detailed observation record (e.g. 75 years for hourly rainfall data from 1948-2022). Therefore, TC hazard data are typically under-sampled, leading to difficulty in constructing extreme value distributions. As a result, despite large differences in TC and extratropical cyclone (ETC) maximum storm intensities judged by pressure drop or maximum sustained wind speed, observation-based assessments of surge, wind and rain hazards typically merge data from TCs with far more numerous data from ETCs. An alternative solution to this problem has been model-based assessments that create synthetic TC events to enable separate extreme value analyses of TCs and ETCs (e.g. Gori et al., 2022; Orton et al., 2016). For the NYC area, these model-based assessments that separate data by storm type have at times found substantially higher estimates of water level extremes (Cialone et al., 2015; Federal Emergency Management Agency, 2014; Orton et al., 2016). However, such model-based hazard-assessments have a high epistemic uncertainty and are challenging to independently validate. This approach has rarely (or never) been applied for wind and rain hazard assessments for

NYC, which have continued to use merged observational data, potentially underestimating the baseline natural hazards and societal “tail risk”.

A recent analysis is summarized here that evaluates the differences between merged and separate extreme value analyses for TC and ETC storm tides (McPherson et al. 2024, section 2.9). Storm tide return level data are created for a range of US Mid-Atlantic and Northeast Coast TC and ETC coastal storm tide climates (e.g. Lin et al. 2012; Orton et al. 2016; Dullart et al. 2021). The TC peak storm tide exceedance curves follow the Gumbel distribution with a range of nine different slopes. A single ETC peak storm tide exceedance probability curve is utilized based on the Generalized Extreme Value (GEV) distribution that represents water level extremes for NY Bight and southern New England (e.g. Orton et al., 2016; Dullart et al., 2021).

Stochastic storm tide event sets for TCs and ETCs are created by sampling from these distributions to create synthetic historical periods of 100 years, similar to that available from NOAA for New York City at the Battery tide gauge. One thousand Monte Carlo simulations are performed for each storm tide climate and Extreme Value Analysis (EVA) is applied to each synthetic historical period. In each simulation, EVA is performed on both merged versus separated TC and ETC populations, and the results are compared. Three analysis methods are utilized -- (1) fitting combined TC/ETC datasets annual maximum storm tide (AMST) with Generalized Extreme Value (GEV) distributions as has recently been standard practice (National Oceanic and Atmospheric Administration, 2023a; Sweet et al., 2013); (2) Using a peaks-over-threshold approach and Generalized Pareto Distribution (GPD) with mixed ETC and TC events, as done in many hazard assessment types (e.g. Atlas-14; others), and (3) Using approach #1 for ETC and #2 for fitting TC storm tide distributions.

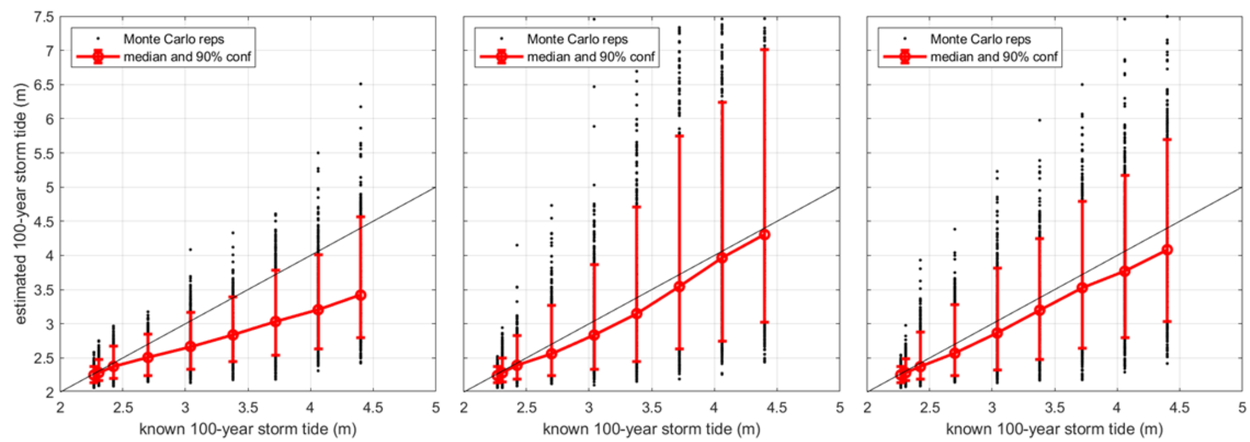

Figure 10. Results of a series of Monte Carlo simulations of Extreme Value Analyses of estimated 100-year storm tides for synthetic data for 100-year datasets, across a range of environments with different a priori known 100-year storm tides. EVA approaches studied include (left) GEV distribution fitting of mixed data, (middle) GPD distribution of mixed data, and (right) separated TC and ETC distribution fitting. Error bars show 90% variability ranges of the results.

Results show that fitting GEV distribution to AMST from mixed storm tide populations often leads to underestimated 100-year storm tides (Figure 10 left panel). The GPD approach greatly reduces the low bias (middle panel), but the GPD focus only on the tail of the distribution tail raises the uncertainty higher than that for separated EVA. The separate analysis of TCs and ETCs has moderate uncertainty but minimizes the low bias (right panel).

The results of these analyses demonstrate some of the challenges of quantifying tail risk. Small numbers of extreme events that predominantly come from TCs lead to either low bias or high uncertainty in estimated 100-year extremes, illustrated in Figure 10. These same challenges likely apply to storm surge, wind and rainfall, and separated EVA should be explored for all these coastal storm related hazards. These challenges point to the importance of not over-relying on quantitative projections, given deep uncertainties and limitations to model based projections; more qualitative approaches, grounded in decision making under uncertainty, are likely to be instructive for these and other uncertainties described in this chapter and throughout this report.

5.4 Limitations Associated with GCM Resolution and Downscaling Methods

Many recent studies (DeGaetano & Castellano, 2017; Kunkel et al., 2020; Miro et al., 2021; National Weather Service, 2022) have employed a quantile delta approach to develop climate-change informed IDF curves. Quantiles are discrete segments within a probability distribution, in this context corresponding with the recurrence intervals associated with IDF curves of a given duration (Miro et al., 2021). The ensemble of downscaled GCM outputs are used to calculate delta change factors, the relative change between the present and the future precipitation frequency estimates for each quantile. The delta change factors between historic and future values are calculated separately for each quantile within the IDF probability distribution. This approach is quasi-stationary, with constant delta change factors applied for each future time interval. Time intervals are typically 30 years or more, allowing for representation of multidecadal climate conditions. The delta change factors are then used to adjust IDF curves based on past observations so that they represent future non-stationary climate.

A key advantage of applying the quantile delta change method to calculate the rate of increase of future estimates is that the inherited bias of the climate model data is reduced when applied as ratios. These rates of increase of the future estimates can be applied along with the current period, which is based on more reliable spatial and temporal characteristics of the historical observations (National Weather Service, 2022). Also, with this approach, the relative changes in all modeled quantiles are accounted for rather than only relative changes in the modeled mean (Cannon et al., 2015).Future intensity duration frequency (IDF) curves were generated using downscaled precipitation data from the Localized Constructed Analogs version 1 (LOCA1) (Pierce et al., 2014) and version 2 (LOCA2) (Pierce et al., 2023) and compared. An ensemble of 21 CMIP5 GCM models is the basis of the LOCA1 dataset, while 27 CMIP6 GCM models, with up to ten of their ensemble members, are used in LOCA2. Only a single downscaling method was considered given LOCA2 was the only available downscaled CMIP6 dataset available at the time, and due to the desire to reflect data used in the U.S. National Climate Assessment. The two main differences between LOCA1 and LOCA2 are the input GCM data and the precipitation training data - LOCA1 downscaled CMIP5 model outputs whereas LOCA2 downscaled the CMIP6 models' outputs to generate high resolution (6km) future projections of precipitation. LOCA1 used an observational dataset from (Livneh et al., 2015). However, additional analyses on this dataset discovered a bias in the strength of daily rain extremes which resulted in unrealistically weak values (Pierce et al., 2023). LOCA2 uses Pierce et al. (2021), which is believed to correct the bias seen in (Livneh et al., 2015) and better represent daily rain extremes (Pierce et al., 2023). Differences in downscaling methodology including the observational data used in bias correction, are a source of uncertainty in the resulting projections. Maimone et al. (2023) examined the influence of such uncertainty and concluded that despite differences associated with various approaches (including the method used here) the range of future extreme rainfall projections was comparable and provided practical planning-level data.

Overall, a total of six GCM experiments were analyzed. For CMIP5, the historical period covers 1950-2005. Its future climates are based on the representative concentration pathways (RCP) scenarios that represent medium-low emissions (RCP4.5) and high emissions (RCP8.5) future climates. For CMIP6, the historical period covers 1950-2014, and its two future scenarios (2015-2099) under the shared socio-economic pathways (SSP) that represent low emission (SSP245) and high emission (SSP585) future climates.

Across the four stations (Central Park, JFK Airport, LaGuardia Airport, and Newark Airport), the extremes seen in LOCA2 downscaled CMIP6 projections tend to be larger than those in LOCA1 downscaled CMIP5 values in both the lower and high emissions scenarios (Figure 11 b & d). This is particularly evident at the longer return periods. For Central Park (which is representative of JFK and LaGuardia), the CMIP6 change factors are similar to those from CMIP5 for the 2-yr return period, but for return periods >5 years, the CMIP6 values exceed the 50% confidence interval of the CMIP5 (LOCA1) values in the majority of cases (Figure 11 a & b). The results for Newark are similar (Figure 11 c & d). Like Central Park, the CMIP6 2-yr return period change factor is marginally lower than that of CMIP5, but for the remaining returning periods the CMIP6 values exceed those from CMIP5. However, Newark is the only station where all CMIP6 change factors are within the 50% confidence interval of CMIP5 (Figure 11 c&d). It should be noted that these differences can arise from both the underlying global climate models as well as the differences in methods used in LOCA1 and LOCA2.

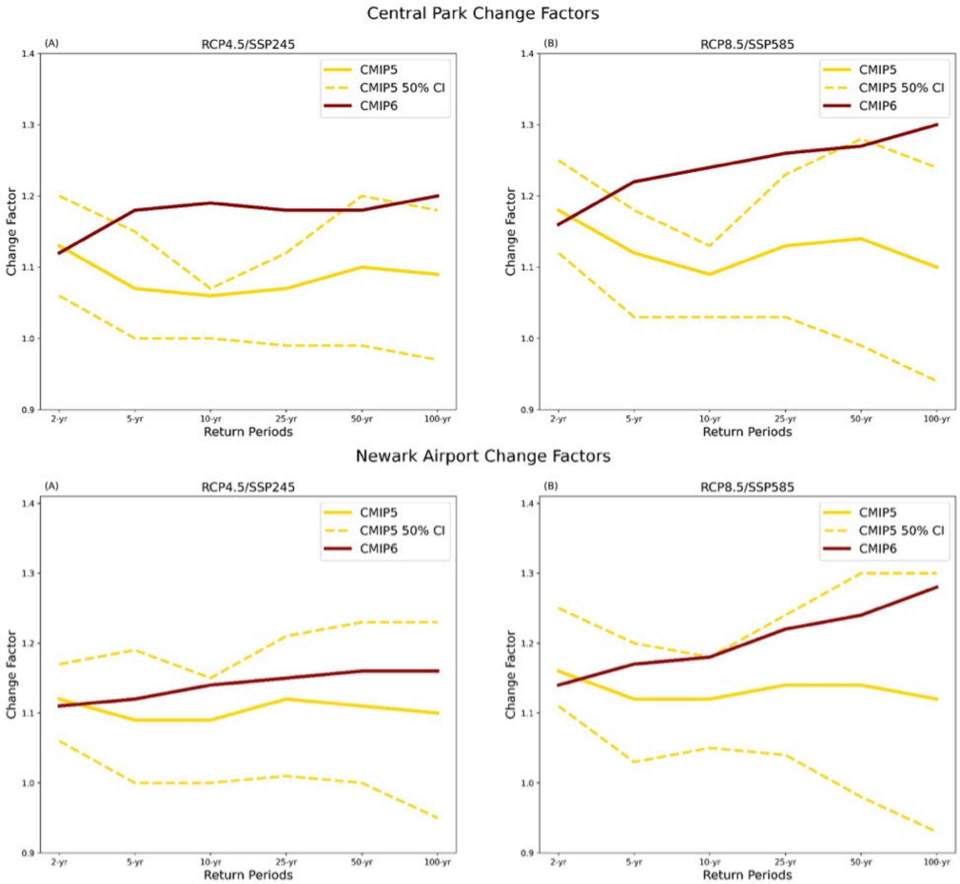

Figure 11. Comparison of CMIP5 and CMIP6 extremes for multiple return periods and across medium-low (RCP4.5) and high (RCP8.5) emissions scenarios. Solid lines denote ensemble means, while dashed lines show the ensemble 50% confidence interval Source: Colin Evans, Cornell University

The GCMs downscaled to develop the delta change factors are able to represent the dynamics of large-scale atmospheric processes and their interactions across the globe. But they are unable to represent the dynamic processes described in Section 5.2.1 that take place at finer-spatial scales (Table 4)(Maimone et al., 2019; Yu et al., 2018). While statistical downscaling provides a means to represent the finer-scale spatial structure of precipitation, it is based on historical patterns that may not be representative of future climate. For example, the observed changes in annual probability for extreme subdaily precipitation at the Central Park Weather Station are substantially greater than those for daily precipitation (Table 3). Such changes may not be represented in current projections based on downscaled GCMs if they result from finer-scale processes.

As an alternative, Convection Permitting Regional Climate Models (CPRCMs) are RCMs run at < 4km spatial resolution. At this resolution, deep convection parameterization is no longer required since the convective dynamics within rainstorms - and their potential changes with global warming - can be explicitly simulated (Kendon et al., 2017). In addition, these models are better able to represent details of the land surface, which might be particularly important in highly urbanized areas like New York City (Luo et al., 2022; Luong et al., 2020). But while CPRCMs have the potential to provide important insight on how climate change will impact extreme precipitation, no single CPRCM can accurately represent future climate on its own and studies utilizing an ensemble of CPRCM outputs are needed to generate robust projections for subdaily precipitation (Ban et al., 2021; Pichelli et al., 2021). The computational expense of CPCRM remains a challenge and such studies have only been piloted in a small number of regions across the world over the last four years (Kendon et al., 2021). At the time of writing, an ensemble of CPCRM forecasts needed to conduct such a study is not yet available for NYC.

Table 4. Representation of multiscale precipitation processes in climate models

Climate Model Type [spatial resolution]	General Circulation Model (GCMs) [25 - 100 km]	Tropical Cyclone Permitting GCMs [20 - 50km]	Regional Climate Model (RCMs: e.g. NA-CORDEX) [25 - 50km]	Convection Permitting RCMs [1 - 4km]
Thermodynamic Processes	CC-scaling with global covariates (radiative forcing, mean global temperature anomaly)	CC-scaling with global covariates (radiative forcing, mean global temperature anomaly)	CC-scaling with local covariates (local temperature, dewpoint, precipitable water)	CC-scaling with local covariates (local temperature, dewpoint, precipitable water)
Increased tropopause height	Represented in convection parameterizations	Represented in convection parameterizations	Represented in convection parameterizations	Represented in model simulations
Large (continental)-scale atmospheric circulation patterns and moisture transport	Represented in model simulations	Represented in model simulations	Provided as lateral boundary conditions from GCMs	Provided as lateral boundary conditions from GCMs
Tropical cyclones	Insufficiently represented	Represented in model simulations	Represented in model simulations	Represented in model simulations
Mesoscale changes to convective organization	Not directly represented	Not directly represented	Not directly represented	Represented in model simulations
Within-storm convective processes	Not directly represented	Not directly represented	Not directly represented	Represented in model simulations

6 Opportunities for Future Research

There remain key gaps in the understanding of changing climate risks in NYC. In this section, we present a non-exhaustive list of research gaps that may inform important impacts of a changing climate in NYC, tied to the topics covered here. Additional research gaps related to climate and its changing impacts may be found in Braneon et al. (2024). While projections for extreme heat were updated in this chapter, they focused on outdoor conditions as modeled by climate models in CMIP6. However, indoor heat exposure remains the most common site for the onset of heat related mortality and hospitalizations (Matte et al., 2024). Addressing this gap will need an interdisciplinary research agenda that studies not only the physics of the climate systems but also its interactions with human infrastructure (e.g., homes, the urban canopy). Another gap related to extreme heat is the lack of spatially explicit projections for air temperature. NPCC3 (González et al., 2019) described new methods that could fill this gap using methods like dynamical downscaling, but high computational costs and uncertainties around future changes to the city's urban landscape have made robust application prohibitive. Downscaled projections to the neighborhood and higher levels could provide invaluable information on the physical interactions between a changing climate and the unjust distribution of heat-resilient spaces that lead to inequitable exposure to extreme heat in cities like NYC due to decades (Chakraborty et al., 2019; Foster et al., 2024; Matte et al., 2024; Wilson, 2020).

Another key gap relates to the treatment of CMIP6 models with ECS outside of the likely range. Although analysis presented in this chapter describes the existing differences between the so-called "hot models" and the rest of the CMIP6 ensemble, there may be larger scale physical processes that may be poorly constrained in these models. Additional research may be needed to better understand the relationships between increased ECS and the frequency and intensity of weather extremes in NYC. Moreover, because of the complex nature of the climate system and the models that try to quantify their processes the causes of enhanced ECS are poorly understood. A research agenda that includes out-of-sample tests from paleoclimate records and modeling may provide insights into the constraints needed in the next generations of earth systems models (Burls & Sagoo, 2022a). Similarly, data collection on key processes related to large scale drivers of climate change and sea-level rise may inform constraints on existing models and improve estimation across a range of impacts. As an intermediate solution, future NPCC assessments could elect to present projections across global warming levels (e.g., 2°C, 3°C) to avoid some of the potential influences from the hot models in the CMIP ensemble.

7 Traceable Accounts

Key Message 1	NPCC4 analysis of the impact of hot models on the CMIP6 ensemble found no statistically significant difference between the temperature and precipitation projections of record and alternative projections that do not include models with equilibrium climate sensitivity outside the expected range. The CMIP6 climate model ensemble used to create the temperature and precipitation projections of record contains three models that display higher-than-expected sensitivity of temperatures to greenhouse gases. These so-called "hot models" lead to higher global mean temperatures. However, the impact of high climate sensitivity appears small with our approach to developing local projections for NYC. Nevertheless, more research is needed to better understand (1) the impact of the high climate sensitivity on the representation of key large scale climate processes, (2) the model physics leading to high sensitivity in the first place, and (3) the constraints on the planet's equilibrium climate sensitivity.
Description of Evidence	Many models that make up the CMIP6 experiment and serve as the basis of NPCC projections of record are more sensitive to greenhouse gas forcing than previous generations of models, leading to hotter global average temperatures (Zelinka et al., 2020). This higher sensitivity is often attributed to stronger positive cloud feedbacks from decreasing extratropical low cloud coverage and albedo (Zelinka et al., 2020). Analysis by NPCC4 found non statistically significant differences between projections of record when hot models are removed.
New Information and Remaining Uncertainties	Although high sensitivity models are still within the likely ECS range as supported by evidence (Masson-Delmotte et al., 2021), there is evidence from the paleorecord indicating that such high values are unrealistic (Zhu et al., 2020). New evidence from paleoclimate records and simulations may be needed to better constrain the newer generation of earth system models (Burls & Sagoo, 2022b).
Assessment of Confidence based on the Evidence	Given the analysis performed by NPCC4, there is high confidence that the projections of record presented in Braneon et al., (2024)are not significantly impacted by the "hot model problem". There is medium confidence that the representations of all physical process relevant to the climate of NYC are not significantly impacted by these high ECS models.

Key Message 2	The high tail end of sea level rise will be governed by the future stability of the ice sheets, and in particular, that of the West Antarctic Ice Sheet (WAIS), with ~3 m of SLR potential if all its marine-based ice melted, and also that of the Greenland Ice Sheet (~7 m SLR equivalent). Troubling signs of ice shelf thinning and ocean warming around WAIS and an approaching temperature tipping point over Greenland raise the possibility of faster and higher sea level rise than projected by most climate models, increasing the risks associated with coastal flooding. Additional research is needed to gain a better understanding of all the processes governing ice sheet behavior with rising temperatures. Stakeholders concerned with long-term planning need to examine plausible scenarios at the extreme upper tail of the sea level rise distribution.
Description of Evidence	MISI may develop because much of WAIS lies on land below sea level, on reverse slopes that tilt toward the continental interior--an inherently unstable topographic configuration. An ice stream or glacier on a reverse slope near the grounding line undergoing MISI accelerates, calving more and more ice until the bed slope flattens or rises landward (e.g. Figure 3.5 in Gornitz et al., (2019; Milillo et al., 2022). A more controversial process is the Marine Ice Cliff Instability (MICI) in which the exposed cliff face of a high ice cliff (>100 m (~328 ft) above sea level) may become structurally weakened and collapse after thinning and removal of a buttressing ice shelf. Furthermore, in a warmer climate, larger meltwater pools on top of an ice cliff during summer would propagate down crevasses and cut through ice until reaching bottom in a process known as hydrofracturing. Ice cliff retreat is accelerated as large ice masses calve. Several regions of WAIS face high vulnerability to (Marine Ice Shelf Instability) MISI. In particular, the Thwaites Glacier would become “unstoppable” once it passes beyond two ridges (Morlighem et al., 2020). If current rates of retreat persist, the Thwaites Eastern Ice Shelf could unpin from the seafloor in less than a decade. The collapse of Thwaites Glacier, which holds the equivalent of more than half a meter of global sea level rise potential, could also destabilize neighboring glaciers that hold another 3 m of sea level rise potential. Three other glaciers near Thwaites show rapid retreat within the last decade (Milillo et al., 2022).
New Information and Remaining Uncertainties	A recent study confirms the ongoing rapid retreat of the Thwaites Glacier’s grounding line, in particular, near a pinning point mapped in 2014 (Wild et al., 2022). New underwater surveys of the Thwaites Eastern Ice Shelf (TEIS) between 2011 to 2020 also reveal favorable submarine topography that promotes enhanced melting near the ice base and entry of warmer ocean water leading to sustained grounding line retreat (Schmidt et al., 2023). On the other hand, negative feedbacks, such as glacial rebound or a weakened gravitational attraction may mitigate the full extent of MISI (e.g. Barletta et al., 2018; Gomez et al., 2015). MICI may be delayed by slower retreat of ice shelves (Clerc et al., 2019), rates and degree of effectiveness of hydrofracturing (Robel & Banwell, 2019), and lack of evidence for an observed MICI either at present or in the geological past (Edwards et al., 2019).
Assessment of Confidence based on the Evidence	Recent ice sheet observations raise renewed concerns over the long-term stability of both the WAIS and Greenland Ice Sheet with continued climate warming. Glaciers and ice sheets combined are now the dominant contributors to global mean sea level rise with very high confidence. Further, sea level is projected to rise for centuries and remain elevated for thousands of years with very high confidence.

Key Message 3	While occurrence of extreme heat events in NYC is governed in great part by climatic events taking place at large spatial scales, local urbanization patterns play a key role in the spatial distribution of temperatures within the city. These local patterns, which include a range of factors like distribution of green spaces and urban geometry, play the most significant role in the generation of physical process that lead to the urban heat island (UHI). Moreover, extreme heat events exacerbate this intra-urban excess temperatures, increasing exposure to deadly heat of populations without access to adaptive measures and cooling infrastructure (e.g., cooling centers, tree shade). Future work is needed to assess the impact of a warming climate on intra-urban heat variability in order quantify the effect of climate change on spatial inequities of heat exposure.
Description of Evidence	The NYC UHI has been studied for decades, with measurements of urban-rural temperature differences going back decades (Bornstein, 1968). There is significant following evidence of the impact of urban surfaces on temperatures in NYC, with values often ranging between 0.5 to 5 depending on time of year and prevailing weather conditions (Childs & Raman, 2005; Gedzelman et al., 2003). Further, there is significant evidence of positive feedbacks between the NYC UHI and extreme heat events (Ortiz et al., 2018; Ramamurthy et al., 2017).
New Information and Remaining Uncertainties	Although most studies have shown intensification of UHIs during extreme heat events, some have found no such intensification in the observation record (Scott et al., 2018). Further, there are robust projections of intra-urban heat in NYC that account for local physics across model ensembles and climatologically relevant temporal scales.
Assessment of Confidence based on the Evidence	Given the significant modeling and observational evidence, there is very high confidence in the existence and magnitude of the NYC UHI. There is also high confidence of synergistic interactions between extreme heat and UHIs, although the extent of these interactions remains a topic of research.

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Acknowledgements

The authors are grateful for the constructive remarks of Drs. Richard Moss and Jack Tchen. The authors are thankful for the funding for interns, fellows, and workshops that was provided by Columbia University, The New School, Sarah Lawrence College, Rutgers University, and the City University of New York. Dr. Timon McPhearson acknowledges funding from the National Science Foundation (grants #1444755, #1927167, and #193493). Dr. Christian Braneon acknowledges funding from the AXA Research Fund.

Dr. Kathryn McConnell was supported by the National Science Foundation Human-Environment and Geographical Sciences (HEGS) and Sociology Programs through award number 2117405, titled "Analysis of Impacts of Environmental and Natural Hazards on Human Migration" (awarded to E. Fussell, Brown University, J. DeWaard, Population Council and University of Minnesota, K. Curtis, University of Wisconsin-Madison, and J. Schroeder, University of Minnesota). She was further supported by the Population Studies and Training Center at Brown University through the generosity of the Eunice Kennedy Shriver National Institute of Child Health and Human Development (P2C HD041020). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF or NASA.

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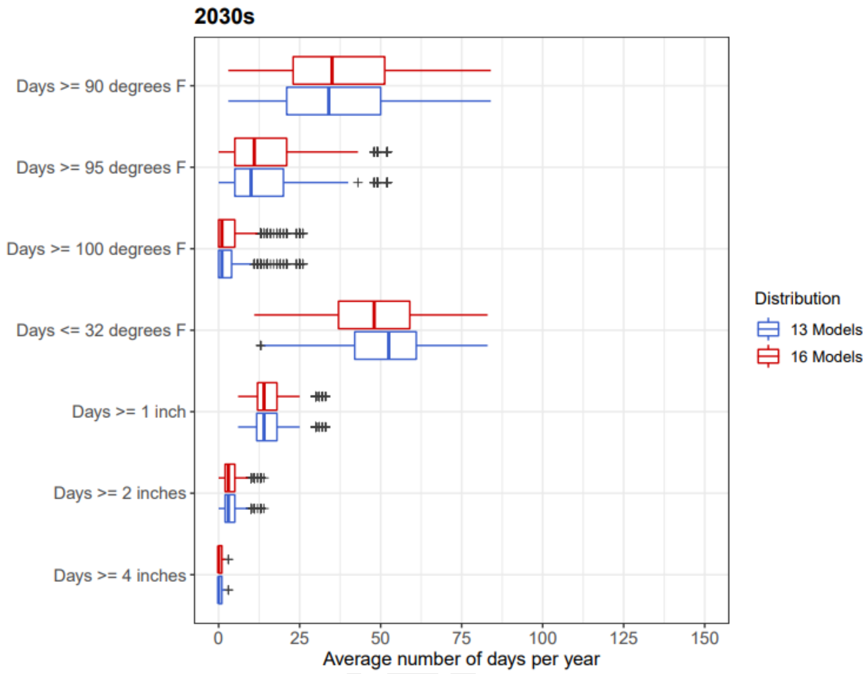
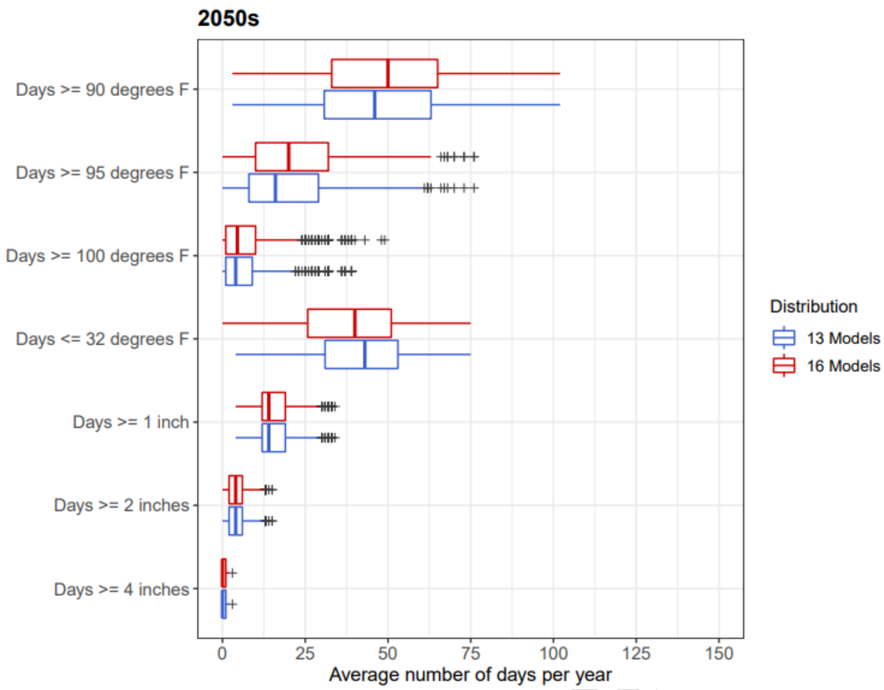
Appendix A.

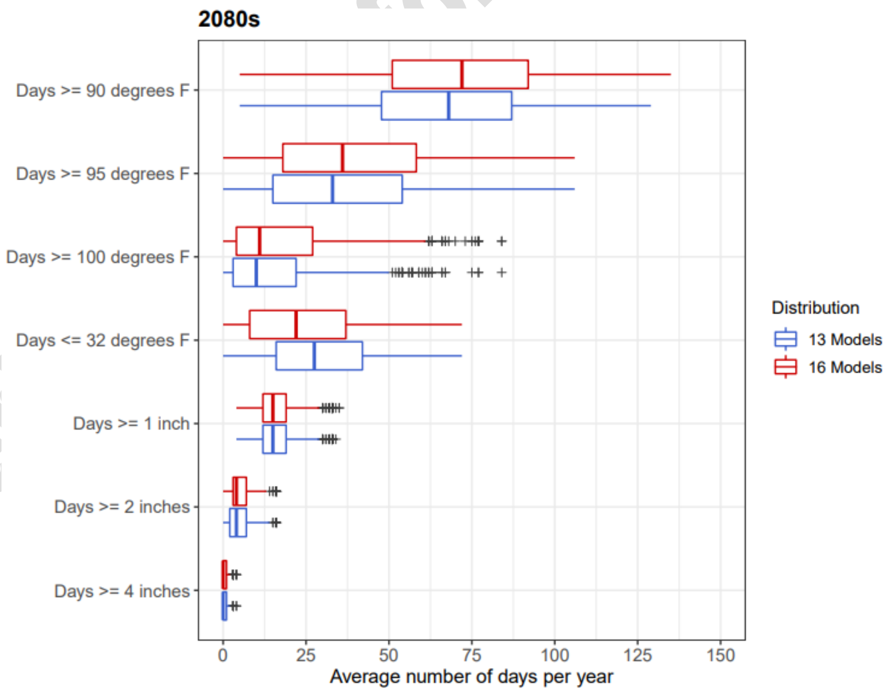
Boxplots comparing 960-member ensembles of annual projections with 780-member ensembles that exclude GCMs with TCR values greater than 2.2 degrees C.



Appendix Figure A-1. Boxplots comparing the 960-member ensemble (16 GCMs x 2 scenarios x 30 years) of annual projections for 2021 to 2050 with a 780-member ensemble (13 GCMs x 2 scenarios x 30 years) that excludes GCMs with TCR values greater than 2.2 degrees C.



Appendix Figure A-2. Boxplots comparing the 960-member ensemble (16 GCMs x 2 scenarios x 30 years) of annual projections for 2041 to 2070 with a 780-member ensemble (13 GCMs x 2 scenarios x 30 years) that excludes GCMs with TCR values greater than 2.2 degrees C.



Appendix Figure A-3. Boxplots comparing the 960-member ensemble (16 GCMs x 2 scenarios x 30 years) of annual projections for 2071 to 2100 with a 780-member ensemble (13 GCMs x 2 scenarios x 30 years) that excludes GCMs with TCR values greater than 2.2 degrees C.

Advancing Climate Justice in Climate Adaptation Strategies for New York City

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Abstract:

The Advancing Climate Justice in Climate Adaptation Strategies for New York City (Equity) chapter of NPCC4 builds on the findings and recommendations from NPCC3 to identify additional metrics and adaptation efforts that can advance climate justice. First, the chapter assesses the efforts of the city to incorporate equity into climate adaptation efforts since NPCC3 and describes how the communities profiled in NPCC3 have implemented and evolved their approaches to addressing the intersecting climate, environmental, and social stressors that they continue to face. Second, it adds to the historical context of climate inequity by linking the bioregion's history of colonization, land dispossession, and slavery building on emerging evidence demonstrating how historical and contemporary land use patterns and decisions shape present and future climate risks and social vulnerability, including climate displacement. Third, it recommends a NYC focused metric to identify areas of the city that are most vulnerable to the intersection of climate hazards, social vulnerability, and displacement. Finally, it highlights approaches to more equitable and just climate adaptation drawn from local, national, and international examples. As such, the chapter offers best practices that prioritize community-driven climate resilience approaches that are integrated, more equitable, and racially just.

Keywords:

Equity, Social Vulnerability, Colonization, Climate Displacement, Community-Driven Climate Resilience, Racial Justice, NPCC4

Recommended Citation:

Foster, S.R., Baptista, A., Nguyen, K.H., Tchen, J., Tedesco, M., Leichenko, R. (2024). Advancing Climate Justice in Climate Adaptation Strategies for New York City: Interim Report. New York City Panel on Climate Change. https://climateassessment.nyc

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1 Introduction

Equity is an essential part of climate adaptation and resilience efforts for cities. The NPCC3 report featured equity dimensions of climate adaptation using several metrics and case studies applicable to New York City (NYC). The NPCC3 report metrics included well-established social vulnerability indices and a tripartite framing of climate equity using distributive, procedural, and contextual concepts. NPCC4 builds on this climate equity approach and expands it to reflect the developing literature on climate justice. Climate justice is defined in the IPCC as "[j]ustice that links development and human rights to achieve a human-centered approach to addressing climate change, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its impacts equitably and fairly" (IPCC, 2022). The term implies that climate adaptation and mitigation efforts must account for differential impacts and equitable allocation of benefits and burdens that considers drivers of climate change, including global economic systems dependent on resource extraction, as well as legacies of colonialism and racism. To advance climate justice, NYC must attend to how historical legacies of discrimination and bias drive climate risks and unequal vulnerability to those risks.

1.1 Key Messages

Key Message 1: The City's climate-related equity work since 2019 has become more explicitly focused on redressing environmental injustice and racial disparities. *Over the past five years, the City has embarked on four interrelated sets of actions to foster and advance equity in its approach to climate adaptation: (1) adoption of multiple laws and programs to address equity issues related to climate change impacts, (2) internal institutional reforms in the provision of city services; (3) development of indicators and metrics and digital, interactive, and mapping platforms that are publicly accessible to track and monitor city agencies' progress; and, (4) incorporation of equity into ongoing climate risk assessments and in sustainability and resilience planning.*

Key Message 2: The City's climate-related equity work would benefit from more comprehensive data on disaggregated climate risks at the local level and tracking of city-sponsored climate adaptation projects and resilience investments. *There is limited understanding of climate change impacts and adaptation needs at the community or neighborhood level and limited systematic data exists on city-sponsored adaptation projects and resilience investments. More disaggregated climate risk data and systematic tracking of city-sponsored climate investments are needed.*

Key Message 3: Some of the city's most marginalized communities have evolved their approaches to combat a variety of environmental, climate, and social stressors. *The organizations profiled in NPCC3's equity section report that they are implementing dynamic approaches to address the various risks they face while providing multiple benefits to their communities. These benefits include expanding access to solar energy and providing upgrades for cooling residences experiencing high heat and air pollution exposure.*

Key Message 4: The climate change challenges that New York City faces are inextricably linked to the bioregion's early history, including slavery and land dispossession. *Understanding the impacts of this history is vital for formulating effective policies and strategies to mitigate and adapt to climate change. An appreciation of the historical legacy of climate impacts on the region, and on certain communities, also necessitates a commitment to reparations and restorative justice. By recognizing Indigenous knowledge, seeking restorative justice, and reconceptualizing our relationship to land, the City can forge a future that respects the environment, promotes social justice, and ensures the well-being of all communities.*

Key Message 5: Climate risks for the most socially vulnerable populations are linked to both past and present land use decisions and patterns and their underlying inequities. *Although the relationships between historical land use and climate risk are complex and context-dependent, they often have similar underlying mechanisms such as past discriminatory land use and siting decisions, redlining and disinvestment, and lower land costs in hazard-prone areas. Many of these land use issues—past and present—reinforce one another and create future risks and vulnerabilities. Without the creation of climate mitigation, adaptation, and resilience policies and practices that promote racially equitable procedures and outcomes, the City will risk perpetuating these inequities in new forms.*

Key Message 6: Climate displacement is an important dimension of social vulnerability to climate change and should be measured by the City. *The City's ability to measure the risks of climate displacement at an appropriate scale, such as at the neighborhood level, could help determine whether and how new infrastructure or infrastructure investments designed to help the city adapt to climate impacts might risk displacement and identify ways to mitigate that risk. Use of a combined climate displacement and social vulnerability (CDSV) score is proposed to integrate socio-economic, climate risk, and evictions and housing data to better measure the risks of climate displacement at the census-tract level.*

Key Message 7: Without anti-displacement strategies in place, resilience-promoting investments can have inequitable outcomes. *These strategies require several key approaches: (1) incorporating contextual equity and understanding the history of places down to the neighborhood level; (2) taking a holistic approach to reducing racialized vulnerability to climate shocks, including inseparable issues like housing and transit access; and, (3) recognizing that the cost burdens of climate adaptation (e.g., higher energy costs, insurance premiums, relocation) affect people differently—particularly when considered in light of homeownership and wealth gaps—and can result in increased displacement risks.*

Key Message 8: Key to achieving equitable climate adaptation is to prioritize community-driven climate resilience approaches. *As an example of successful approaches, community-based organizations featured in NPCC 3 have implemented climate adaptation initiatives that were attentive to the intersecting nature of climate risks and other health vulnerabilities, including the COVID-19 pandemic. These initiatives include climate mitigation strategies and provide multiple benefits including equitable access to renewable energy, affordable and efficient housing, and economic development strategies that promote equitable green, adaptation economies.*

Key Message 9: Best practices from around New York City and the world highlight the importance of integrated, affirmatively anti-racist, equitable, and just approaches to tackling climate risks. *The three broad categories of best practices identified for more equitable and racially just climate adaptation approaches are: (1) integrative approaches to climate resilience that seek out opportunities to advance just transitions and adaptive economies; (2) community-**led** planning processes that make adaptation plans more successful in the face of intersecting housing and climate displacement risks; and, (3) collaborative development of goals, programs, policies by leveraging relationships between communities, civic organizations, and state and local government offices and programs.*

1.2 Chapter Scope and Context

The Advancing Climate Justice in Climate Adaptation Strategies for New York City (Equity) chapter builds on the findings and recommendations to the City from the NPCC3 equity workgroup to identify additional metrics and adaptation efforts that can advance climate justice. The NPCC3 report (Foster et al., 2019) found that social vulnerability to climate change stressors is unequally distributed across African American and Hispanic residents. The report also found, based on qualitative case studies of communities with high levels of social vulnerability, that those communities also face intersecting stressors such as disproportionate pollution exposure and gentrification pressures, which are aggravated by climate change impacts (Anguelovski et al., 2019). Finally, the report found that these same communities are involved in many forms of adaptation planning and implementation to address this intersection of stressors, but that they desire a deeper engagement with the city via the use of fully collaborative, coproduction planning approaches.

Based on these findings, the NPCC3 report recommended to the city actions that would incorporate all forms of climate equity—distributional, contextual, and procedural—into its adaptation efforts, particularly if those efforts are focused at the neighborhood level. On the distributional dimension, the report recommended future tracking of social vulnerability through index-based methods like the social vulnerability index (SoVI (*SoVI® - College of Arts and Sciences | University of South Carolina*, n.d.) or SVI (*CDC/ATSDR Social Vulnerability Index (SVI)*, 2024)), through the use of individual variables, and/or through a combination of approaches. On the contextual dimension, the report recommended that the city involve local communities much earlier and more often in adaptation planning to ensure that local context and knowledge is appropriately accounted for in that planning. Additionally, the report also recommended that adaptation projects should contain a stronger focus on community development to reduce the potential of displacing longtime residents and to promote the social sustainability of local communities. For procedural equity, the report recommended that city officials work side by side with communities at the outset to co-design and co-implement neighborhood-based adaptation projects (Foster et al., 2019).

This Equity chapter builds on those findings and recommendations in the following ways. First, the chapter assesses the efforts of the city to incorporate equity into climate adaptation efforts since the NPCC3 report. It also describes how the communities profiled in that report have implemented and evolved their approaches to addressing the intersecting climate, environmental, and social stressors that they continue to face. Second, the chapter adds to the historical context of climate inequity in NYC by linking it to the bioregion's history of colonization, land dispossession, and slavery. The chapter importantly builds on an emerging body of empirical evidence demonstrating how historical and contemporary land use patterns and decisions shape present and future climate risks and social vulnerability, including climate displacement.

Third, to better respond to the ways that history shapes climate risks and social vulnerability for local communities, the chapter recommends a NYC-focused metric to identify areas of the city that are most vulnerable to the intersection of climate hazards, social vulnerability, and displacement. This scoring is utilized for multiple climate hazards in NYC and measures the sensitivity of certain populations to the intersection of various risks. Finally, the chapter highlights a number of practices and approaches to more equitable and just climate adaptation drawn from local, national, and international examples. These examples presuppose, based on the evidence gathered in the chapter, that in the absence of anti-displacement strategies in place, the city's resilience-promoting investments risk entrenching existing or creating new inequities by race, ethnicity, and income. As such, the chapter offers best practices that prioritize community-driven climate resilience approaches that are integrated, more equitable, and racially just.

1.3 Chapter Organization

This Chapter includes five substantive sections. Section 2 provides an overview of progress on climate equity goals since NPCC3 (Foster et al., 2019) including NYC's engagement with and adoption of equity considerations for climate-related initiatives across multiple City agencies and functions. The section also includes a review of community-led climate equity approaches for the three organizations who co-produced case studies featured in NPCC3 (Foster et al., 2019). Section 3 explores climate equity in the context of NYC's historical context from pre-colonial times to European colonization to present day and historic racialized land use practices. This section offers a framework for understanding the relationships between historic land use practices, climate risk, contemporary land use patterns, and social vulnerability. Section 4 reviews the emerging evidence and indicators of climate displacement and gentrification. This section also includes an approach for combining climate risks, social vulnerability, and displacement risk into a combined index for NYC. Section 5 offers a sample of best practices for equitable, racially just, climate adaptation from NYC and beyond. The case studies feature collaborative and intersectional approaches to climate adaptation by community-based climate justice organizations from NYC, the City's efforts in Edgemere, Queens, and the non-profit PUSH Buffalo in upstate New York.

2 Progress Toward Climate Equity in New York City Over the Past 5 Years

2.1 The City's Progress Toward Climate Equity Since NPCC3

In its last report, the NPCC made recommendations for the enhancement of equity in the City's climate adaptation planning, particularly at the neighborhood or community level (Foster et al., 2019). This section of the report will review NYC's engagement with equity in its climate-related work since the NPCC3 report was published in 2019, and specifically how the findings of NPCC3 have influenced the city's work in this area. Our methods include interviews with city officials and former city officials who have worked on climate change and equity efforts. We also reviewed numerous publicly available documents including executive orders, laws, policy and planning reports, and city-sponsored websites.

Prior to 2019, the City's equity-related climate change efforts largely focused on environmental justice (Foster et al., 2019). The NPCC3 report offered a framework for how the city might approach climate equity in its adaptation planning processes. The NPCC3 Equity Framework consists of three interrelated concepts: distributive equity, procedural equity, and contextual or recognitional equity. Contextual equity emphasizes the social, economic, and political factors and processes that contribute to uneven vulnerability and shape adaptive capacity (McDermott et al., 2013). Distributive equity emphasizes disparities across social groups, neighborhoods, and communities in vulnerability, adaptive capacity, and outcomes of adaptation actions (McDermott et al., 2013). Procedural equity emphasizes the extent and robustness of public and community participation in adaptation planning and decision making, such as community engagement during buyout processes (McDermott et al., 2013).

The assessment in this section reflects a review of online content, relevant reports, as well as semi-structured interviews with key informants with relevant knowledge of NYC's past and current equity strategies. Interviews were conducted between late 2022 and early 2023 using snowball sampling methods to recruit participants with knowledge of City initiatives, including representatives from the Mayor's Office of Climate and Environmental Justice (MOCEJ), the Mayor's Office for Economic Opportunity (NYC Opportunity) and the NYC Department of City Planning (Miles & Huberman, 1994).1 A total of five interviews were conducted using questions that focused on (1) approaches to environmental justice and equity within the context of climate adaptation planning, (2) programs and policies developed to address EJ and equity concerns, (3) awareness of the NPCC3 equity framework and whether it was incorporated into planning and decision-making process, and (4) challenges associated with implementation. These interviews were designed to explore current equity-related initiatives including PovertyNYC, EquityNYC, and the Comprehensive Waterfront Plan. The interviews were confidential, and the resulting summaries were member-checked as each interview participant reviewed them prior to inclusion in the report. Interviewees suggested that the NPCC3 equity framework and recommendations were well received by agency staff but applied unevenly across city agencies. Some reported not being aware of the framework, others consulted it but found it too technical/academic, only useful as background research or thinking, or not useful at all, while some agencies and offices consulted with it and used it to inform city plans/policies.

In general, the City's climate-related equity work since 2019 has become more explicitly focused on racial disparities. The theme of racial equity is especially prominent within NPCC4: Climate Assessment for New York City (Balk, Braneon, et al., 2024) and following the changed social and political context since 2019 (e.g., racial disparities in exposure and illness that were revealed by the COVID pandemic, racial justice awareness following the police murder of George Floyd in Minneapolis and the Black Lives Matter (BLM) movement). As such, this Report's discussion of climate-related equity efforts can be situated within a broader discussion of the City's increasing engagement with racial and social equity issues in other areas such as housing, policing, and public health.

Over the past five years, the City has embarked on four parallel and somewhat interrelated sets of actions to foster and advance equity:

(1) legislative and programmatic efforts addressing equity issues related to climate change impacts. These included adoption of several new local laws such as LLs 60 & 64 (Local Law 60, 2017; Local Law 64, 2017), which established the Environmental Justice Advisory Board, EJNYC Report, and EJ Mapping Tool (Environmental Justice Interagency Working Group, 2021), and EJNYC Plan (City of New York Mayor's Office of Climate & Environmental Justice, 2023), LL 78 (Local Law 78, 2021), which required the creation of a citywide equitable development data tool and racial equity reports for land use applications, and LL 122 (Local Law 122, 2021), which mandated a citywide climate adaptation plan;

(2) internal institutional reforms in the provision of city services (e.g., Executive Order 45 (City of New York Office of the Mayor, 2019b) which required the creation and tracking of social equity metrics and indicators);

(3) development of interactive digital and mapping platforms that are publicly accessible designed to track and monitor city agencies' progress (e.g., online Hazard Mitigation Plan (*Plan for Hazards - Hazard Mitigation - NYCEM*, n.d.), and Community Risk Assessment Dashboard (*CRA Dashboard – NYC Hazard Mitigation*, n.d.), EquityNYC (City of New York Mayor's Office for Economic Opportunity, 2023b), Equitable Development Explorer (City of New York Department of City Planning & City of New York Housing Preservation and Development, 2023));

(4) ongoing efforts to ensure equity in climate risk assessment and sustainability and resilience planning (e.g., NPCC4 (*New York City Panel on Climate Change (NPCC)*, n.d.), AdaptNYC (City of New York Mayor's Office of Climate & Environmental Justice, 2022a), Climate, Vulnerability, Impact and adaptation (VIA) Analysis (McPhearson et al., 2024), PlaNYC: Getting Sustainability Done (City of New York Office of the Mayor, 2023b).

Snowball or chain sampling involves utilizing well informed people to identify critical cases or informants who have a great deal of information about a phenomenon (Miles & Huberman, 1994)

2.1.1 Legislative and programmatic efforts addressing equity issues related to climate change impacts

As discussed in the introductory section, prior to the last NPCC3 report, the City was already committed to advancing equity with respect to addressing climate change impacts and developing place-based adaptation strategies, especially in the aftermath of Hurricane Sandy (2012). These efforts included initiatives such as *OneNYC: The Plan for a Strong and Just City* (City of New York Office of the Mayor, 2019a) the Resilient Neighborhoods studies (*Resilient Neighborhoods*, n.d.), and the Cool Neighborhoods (City of New York Mayor's Office of Resiliency, 2017) program. At the same time, environmental justice and social advocacy organizations had expressed that the City needed to do more for under-resourced groups and communities of color. This included more directly addressing the needs of vulnerable populations, improving community-based evacuation and disaster response, and supporting community-based resilience planning, specifically for neighborhoods adjacent to the Significant Maritime and Industrial Areas (SMIAs) (Bautista et al., 2016). Additionally, several EJ organizations and the New York City Council felt that the City's vision for coastal resilience, as previously laid out in the NYC Special Initiative for Rebuilding and Recovery (SIRR) plan, was too Manhattan-centric and did not account for unique challenges in each of the five boroughs and diverse communities across NYC, nor did it prepare them for the next superstorms (Iqbal, 2019; S. Maldonado, 2021; Sandy Regional Assembly, 2013).

In response, the City has increased efforts to understand community risk profiles, especially with a focus on historically disadvantaged and environmental justice communities. In particular, the City Council and local representatives from EJ organizations have emerged as key players in advancing and institutionalizing environmental justice and equity in the City's long-term climate adaptation planning efforts. Key legislations and activities adopted by the City Council that have resulted in the actions undertaken by the Mayor's Office, specifically MOCEJ, and other city agencies include:

- Local Law 60 required a comprehensive EJ report and Local Law 64 an EJ advisory board and an EJ interagency working group (Local Law 60, 2017; Local Law 64, 2017). These laws subsequently resulted in the establishment of the Environmental Justice Advisory Board (EJAB) and the convening of the Environmental Justice Interagency Working Group (EJ IWG) (City of New York Mayor's Office of Climate & Environmental Justice, 2023). Led by MOCEJ, EJ IWG is responsible for the development of the EJNYC report, the EJ Web-based Portal and Mapping Tool, and the EJNYC Plan. In December 2021, MOECJ and the EJ IWG released the Environmental Justice for All Scope of Work Report, which provided a roadmap for the development of the EJNYC report, mapping tool, and comprehensive plan (Environmental Justice Interagency Working Group (EJ IWG), 2021). These products are designed to systematically analyze EJ concerns citywide, to identify communities that are disproportionately impacted by environmental burdens and may not experience the benefits from green and climate resilient investments, and to inform city-level decision-making processes and programmatic initiatives that can advance climate and environmental justice.

- In 2020, the City Council released its own climate action agenda, Securing Our Future: Strategies for NYC in the Fight against Climate Change (New York City Council, 2020). This report included strategies for climate resiliency planning, GHG emission reduction, clean energy transition, waste reduction and circular economy, and workforce development for green jobs.

- Local Law 78 required a citywide equitable development data tool and racial equity reports for certain land use actions (Local Law 78, 2021). This legislation has resulted in the creation of the Equitable Development Data Explorer (EDDE) tool (City of New York Department of City Planning & City of New York Housing Preservation and Development, 2023) and a displacement risk map by the NYC Department of City Planning (DCP) and Department of Housing Preservation and Development (HPD) (City of New York Department of City Planning & City of New York Housing Preservation and Development, 2023). The EDDE is an interactive resource that provides analysis about the social, economic, and housing conditions in communities across NYC. The displacement risk map measures levels of displacement risk for neighborhoods citywide based on factors such as population vulnerability, housing conditions, and market pressure. This legislation also required Racial Equity Reports for certain land use actions, and applicants must include a study that analyzes the area's demographic conditions, quality of life, and displacement risk (ANHD, 2023). These initiatives sought to address growing concerns about gentrification and displacement linked to land use changes, rezonings, and real estate development trends that are happening in NYC.

- Local Law 122 mandated the creation of a citywide climate adaptation plan to protect every neighborhood from a wide range of hazards and prioritize the most vulnerable areas and EJ areas (Local Law 122, 2021). This legislation has resulted in the establishment of the AdaptNYC (City of New York Mayor's Office of Climate & Environmental Justice, 2022a) and Climate Strong Communities (City of New York Mayor's Office of Climate & Environmental Justice, 2022b) programs, both of which are overseen by MOCEJ. AdaptNYC is an online program that identifies climate change hazards that pose the greatest threats, populations and neighborhoods that are most at risk, and the adaptation and resiliency measures that the City is currently taking to protect residents, property, and infrastructure. Climate Strong Communities is a neighborhood-based resiliency and sustainability planning program in which MOCEJ identifies vulnerable communities and engages local stakeholders to implement infrastructure and other measures that address adaptation needs. MOCEJ has already started working with communities in Brownsville and Canarsie, Brooklyn; Corona, Queens; East Harlem, Manhattan; Port Richmond, Staten Island; and Soundview, the Bronx (City of New York Office of the Mayor, 2023b).

2.1.2 Fostering internal institutional reforms to advance racial equity and social justice

In the past few years, the City has increased efforts to advance racial equity and social justice within city agencies. In 2018, NYC joined the Government Alliance for Racial Equity (GARE), a network of municipal governments that provides strategies for combating racism and promoting racial equity within city governments (Government Alliance on Race and Equity, 2023). Staff from then Mayor de Blasio's Office of Climate Resiliency (predecessor to MOCEJ) employed GARE's Racial Equity Assessment Tools, a step-by-step analysis of equity goals, stakeholder and community engagement, and outcomes (Office of Climate Resiliency, personal communication, December 2, 2022). The tool also provided staff members with relevant language to discuss environmental and climate justice issues. City staff consulted with and received feedback from other municipal government representatives to better understand how racial equity can be operationalized within the city. Highly motivated staff members formed an internal Equity Work Team, which functioned as a centralized think-tank for developing racial equity policy, fostering internal changes, building institutional capacity and mechanisms for hiring people, soliciting buy-in and feedback from leadership, promoting horizontal collaboration, and breaking down bureaucratic silos. These efforts culminated, in part, in the creation of an anti-racism city charter, hiring protocols that address racial justice, and the incorporation of environmental justice and racial justice into the fabric of the city's work (Office of Climate Resiliency, personal communication, December 2, 2022).

In 2019, Mayor de Blasio signed Executive Order 45 (EO45) (City of New York Office of the Mayor, 2019b, p. 45), which mandated the annual creation of the Social and Equity Indicators Report by the Mayor's Office for Economic Opportunity (now referred to as NYC Opportunity) (City of New York Mayor's Office for Economic Opportunity, 2023b; Executive Order 45, 2019). The report, which exists as an interactive digital platform EquityNYC, is intended to measure the social, economic, and environmental health of the city. It analyzes equity outcomes in eight policy domains including: (1) core infrastructure and environment, (2) diverse and inclusive government, (3) economic security and mobility, (4) education, (5) empowered residents and neighborhoods, (6) health and well-being, (7) housing, and (8) personal and community safety. It also includes standardized equity metrics that measure city agencies' work through equity lens such as (1) city services, (2) service locations, (3) workforce diversity, (4) M/WBE contract distribution, and (5) internal equity practices. Data for equity outcomes and standardized equity metrics must be collected, analyzed and disaggregated by race/ethnicity, gender identity, income, and, where available, sexual orientation. The dataset for EquityNYC is publicly available through NYC Open Data (City of New York Mayor's Office for Economic Opportunity, 2023b).

Additionally, as part of EO45, staff members from Mayor's Office of Climate Resiliency participated in a 9-month training program hosted by the Mayor's Office of Operations to learn how to institutionalize Results-Based Accountability (RBA) and incorporate racial and social equity principles into long-term strategic planning processes within the agency and with communities (Mayor's Office of Climate and Environmental Justice (MOCEJ), personal communication, July 27, 2023). This effort helped conceptualize the early development of the Climate Strong Communities initiative (City of New York Mayor's Office of Climate & Environmental Justice, 2022b).

In the past year, NYC Opportunity has developed a series of mapping platforms that help the public visualize distribution of equity outcomes, city services, and city service locations (City of New York Mayor's Office for Economic Opportunity, 2023b). The office continues to partner with city agencies to routinely collect data on service programs, examine equity strategies, and develop new programs and policies that aim to reduce service disparities (Office for Economic Opportunity, personal communication, January 5, 2023, p. 4). Since 2020, over 40 city agencies (City of New York Mayor's Office for Economic Opportunity, 2023b) have completed an annual online survey (City of New York Mayor's Office for Economic Opportunity, 2023b) that inventories internal equity practices such as formation of working groups to reduce social and racial inequality, specialized training on equity-related concepts and skills, strategies to promote equitable hiring processes, training and mentorship programs to support career advancement for individuals from traditionally underrepresented groups, and contracting with equity consultants or third party vendors to support social and racial equity work (City of New York Mayor's Office for Economic Opportunity, 2023a). These EquityNYC-related initiatives represent a concerted effort to provide transparency and accountability about the City's equity work, which is key for addressing service disparities and tailoring policy responses (Office for Economic Opportunity, personal communication, January 5, 2023, p. 4).

Other city-level agencies and entities have also developed initiatives to promote internal reforms and racial equity. In 2020, the Department of Health and Mental Hygiene (DOHMH) released the Race to Justice Action Kit (City of New York Department of Health and Mental Hygiene, 2023), an initiative that evolved from earlier efforts started in 2016(Human Impact Partners, 2019) to address racism in healthcare. The Race to Justice Action Kit provides an overview of the effects of racism on historical and contemporary health, communication tips for staff, a language use guide, and a community engagement framework. Additionally, with strong support from DOHMH, in 2021, the NYC Board of Health adopted a resolution to declare racism a public health crisis (City of New York Department of Health and Mental Hygiene, 2021a). Furthermore, in 2020, the NYC Commission on Human Rights released a report on "Black New Yorkers on Their Experiences of Antiblack Racism," which included recommended strategies for internal and structural reforms and for advancing racial equity among city agencies and offices (City of New York Commission on Human Rights, 2019). In spring 2022, Mayor Eric Adams created the Mayor's Office of Equity, which oversees multiple equity-related offices and commissions including the Commission on Gender Equity, the Racial Justice Commission, the Pay Equity Cabinet, the Unity Project, the Young Men's initiative, and the Taskforce on Racial Inclusion and Equity (City of New York Mayor's Office of Equity, 2023).

In the latest NYC Comprehensive Waterfront Plan (CWP) (City of New York Department of City Planning, 2021b), language relating to equity, racial justice, environmental justice, and climate justice was consistently deployed (City of New York Department of City Planning, 2021b; Office of Climate Resiliency, personal communication, January 12, 2023). In the previous version developed under Bloomberg (i.e., Vision 2020 (City of New York Department of City Planning, 2011), these terms did not make a single appearance. In the current CWP (City of New York Department of City Planning, 2021b), equity is conveyed as one of the three guiding values and climate justice as the driving principle (City of New York Department of City Planning, 2021b). The CWP explicitly recognizes the historical legacy of structural racism, marginalization, discrimination, and economic inequality, as well as the disproportionate impacts of climate change on low-income communities and communities of color. It also features examples of initiatives related to just transition (e.g., Edgemere Community Land Trust, Sunset Park Solar) and includes language expressing commitments to racial equity (City of New York Department of City Planning, 2021b). The usage of these terms, particularly references to racial inequity and injustice, represents a shift in the City's approach to addressing equity and climate change. In another example, the NPCC3's climate equity framework was applied to inform the development of MOCEJ's Neighborhood Coastal Protection Planning Guidance, which provides best practices for siting of city-level capital coastal protection projects (City of New York Mayor's Office of Climate Resiliency, 2021).

2.1.3 Development of indicators and metrics to track progress on equity and digital and interactive mapping platforms to foster transparency and accountability

Over the past decade, the City, specifically through NYC Opportunity, has increased efforts to track and monitor progress on reducing poverty rates as well as spatial and socio-demographic disparities in city-funded provisions. NYC Opportunity leads multiple initiatives to develop indicators and metrics for social and racial equity (described in the section above) (*Social Indicators Report - NYC Opportunity*, n.d.) and performance measures for poverty reduction (*Poverty Measure - NYC Opportunity*, n.d.) and equitable workforce development (*Workforce Data Portal*, n.d.) See Table 1: Indicators and Metrics for City-Funded Provisions. Performance measures are designed to assess outcomes of specific policy interventions, for example, to determine the effects of anti-poverty initiatives (e.g., tax credit programs, food stamps, nutritional assistance programs) on poverty rates or who benefits from city-sponsored career development and employment services. To provide users with a more complete picture of city-provided activities, NYC Opportunity routinely collects data from city agencies and partner organizations, which can date back to the year 2000 and up to the present, and disaggregates them by race/ethnicity, gender, and income. Data on social and racial equity and workforce development, along with data stories and related programs, are accessible through online platforms and digital navigators such as EquityNYC (City of New York Mayor's Office for Economic Opportunity, 2023b), Workforce Data Portal (*Workforce Data Portal*, n.d.), Jobs NYC (*Jobs NYC*, n.d.), and AccessNYC (*ACCESS NYC*, n.d.).

Table 1: Indicators and Metrics for City-Funded Provisions

Details	Agency	Sources
Social Equity Indicators	NYC Opportunity	https://www.nyc.gov/site/opportunity/reports/social-indicators-report.page
Poverty Measures	NYC Opportunity	https://www.nyc.gov/site/opportunity/poverty-in-nyc/poverty-measure.page
Workforce Metrics	NYC Opportunity	https://workforcedata.nyc.gov/en

The development of publicly accessible online platforms is part of a larger effort across city agencies to communicate progress and activities on the external facing side (Office for Economic Opportunity, personal communication, January 5, 2023, p. 4). These new tools are intended to build a culture of transparency and accountability and employed to justify the City's decisions to address social, economic and health disparities in underserved areas (Office for Economic Opportunity, personal communication, December 8, 2022, p. 2). In recent years, city agencies have created multiple tools to visualize data on population, land use and zoning, and environmental risks and vulnerability, and data sources for many of these tools are available for download on NYC Open Data (City of New York, 2022, see Table 2).

Specifically, there has been an increase in spatial visualization platforms designed to promote and/or enhance planning at the community or neighborhood level. City agencies and community-based organizations can find community-level data on demographic information, land use, and flood and heat vulnerability. They can also compare distributions of city services, facilities, zoning applications, broadband access, and mitigation and resilience projects among the City's 59 community districts.

To integrate environmental justice concerns into citywide spatial planning, MOCEJ, in collaboration with EJAB and EJ IWG, is set to release a public, web-based portal and mapping tool detailing environmental and climate data; this action is a direct result of the passage of Local Law 60 and 64 in 2017 (Local Law 60, 2017; Local Law 64, 2017). To address growing community concerns regarding housing development and displacement risks, the NYC DCP and HPD created the Equitable Development Data Explorer (EDDE) (City of New York Department of City Planning & City of New York Housing Preservation and Development, 2023) as a response to Local Law 78 in 2021 (Local Law 78, 2021). The EDDE provides analysis of the demographic, social, economic, and housing conditions along with displacement risks for NYC communities and can be used for community advocacy purposes and/or inform planning decisions on affordable housing, capital investments, and land use. To complement the EDDE, DCP also developed two interactive platforms that examined the dynamics of racial/Hispanic composition (City of New York Department of City Planning, 2021a) and stability and change in NYC neighborhoods (City of New York Department of City Planning, 2023b). The creation of an EJ mapping tool, the EDDE, and other neighborhood-based visualization tools is consistent with growing nationwide recognition of the need to address historic inequities in the most at-risk communities. NYC-level data can be cross-referenced with other relevant spatial data visualization tools such as the US Environmental Protection Agency's Environmental Justice Screening Tool (US EPA, 2014) and the national Climate and Economic Justice Screening Tool (Executive Office of the President of the United States Council on Environmental Quality, 2023).

In addition, an increasing number of policy and planning documents are available online in digital and interactive formats that can be changed and updated over time, with some functioning as "living" documents rather than static ones. Examples include the NYC Hazard Mitigation Plan (City of New York Office of Emergency Management, 2019), the 2021 Comprehensive Waterfront Plan (City of New York Department of City Planning, 2021b), EquityNYC (City of New York Mayor's Office for Economic Opportunity, 2023b), AdaptNYC (City of New York Mayor's Office of Climate & Environmental Justice, 2022a), and OneNYC 2050 (City of New York Office of the Mayor, 2023a).

Table 2: Visualization mapping platforms encompass multiple categories including demographic data, land use, hazard risks and vulnerability, and other.

Category	Description of web-based visualization platforms	Name	Agency	Website
Population	City-level census data	Population Factfinder	NYC DCP	https://popfactfinder.planning.nyc.gov/#12.25/40.724/-73.9868
	Community-based socio-demographic data	Community District Profiles	NYC DCP	https://communityprofiles.planning.nyc.gov/
	Environmental Justice	Environmental Justice Areas	MOCEJ	https://nycdohmh.maps.arcgis.com/apps/instant/lookup/index.html?appid=fc9a0dc8b7564148b4079d294498a3cf
	Neighborhood composition	Dynamics of Racial/Hispanic Composition in NYC Neighborhoods (2010-2020)	NYC DCP	https://storymaps.arcgis.com/stories/46a91a58447d4024afd00771eec1dd23
		Stability & Change in NYC Neighborhoods (2010-2020)	NYC DCP	https://storymaps.arcgis.com/stories/c7bf9175168f4a2aa25980cf31992342
Land Use and Zoning	Land use	ZoLa (Zoning & Land Use)	NYC DCP	https://zola.planning.nyc.gov/about/
	City-based facilities	NYC Capital Planning Explorer	NYC DCP	https://capitalplanning.nyc.gov/facilities/
	Zoning applications	Zoning Application Portal	NYC DCP	https://zap.planning.nyc.gov/projects
	Development planning	Equitable Development Data Explorer	NYC DCP & HPD	https://equitableexplorer.planning.nyc.gov/map/data/district
		Displacement Risk Map	NYC DCP & HPD	https://equitableexplorer.planning.nyc.gov/map/drm/nta https://equitableexplorer.planning.nyc.gov/map/drm/ntac
Environmental Risk and Vulnerability	Flood vulnerability	NYC Flood Hazard Mapper	NYC DCP	https://dcp.maps.arcgis.com/apps/webappviewer/index.html?id=1c37d271fba14163bbb520517153d6d5
	Heat vulnerability	NYC Heat Vulnerability Index	NYC DOHMH	https://a816-dohbesp.nyc.gov/IndicatorPublic/beta/key-topics/climatehealth/hvi/
	Emergency preparedness	NYC Hurricane Evacuation Zone Finder	NYCEM	https://maps.nyc.gov/hurricane/#
	Mitigation and resilience projects	NYC Mitigation Actions Map	NYCEM	https://nychazardmitigation.com/documentation/mitigation/actions/
	Community-level hazard risks	Community Risk Assessment Dashboard	NYCEM	https://cra.nychazardmitigation.com/
	Community resources for hazard mitigation	Community Hazard Mitigation Resources	NYCEM	https://nychazardmitigation.com/documentation/community/
Other	City-funded services and provisions	EquityNYC	NYC Opportunity	https://equity.nyc.gov/
	Broadband access for NYCHA residents	NYC Big Apple Connect	NYC OTI	https://www.nyc.gov/assets/bigappleconnect/

2.1.4 Ongoing efforts to incorporate equity in climate risk assessments and in sustainability and resilience planning

The City continues to incorporate equity in ongoing efforts to conduct climate risk assessments (e.g., Climate Vulnerability, Impact, and Adaptation Analysis project) and in sustainability and resilience planning (e.g., PlaNYC: Getting Sustainability Done). At present, MOCEJ is currently sponsoring the Climate Vulnerability, Impact, and Adaptation Analysis (VIA) study (McPhearson et al., 2024), an 18-month interdisciplinary initiative to develop a comprehensive analysis of future potential climatic conditions and associated socio-economic impacts in NYC. VIA-related projects include (1) high-resolution climate projections for heat risk and exposure, storm surge, and coastal flooding, (2) characterizing current and future extreme heavy rainfall, (3) systematic assessment of health-related economic costs from climate sensitive events, and (4) a creation of a Flood Vulnerability Index to identify areas with the highest vulnerability to coastal storm surge, tidal, and pluvial flooding. The VIA research has the potential to advance equity by providing key information and tracking tools on populations facing the brunt of climate impacts now and in the future. Together with the EJNYC report, the VIA research will also inform other efforts to develop forward-looking adaptation strategies and plans that prioritize vulnerable populations and EJ areas.

In April 2023, the City, led by the Adams administration, unveiled its latest vision for sustainability and resiliency called PlaNYC: Getting Sustainability Done (City of New York Office of the Mayor, 2023b). This plan functions as an update and successor to de Blasio's OneNYC: A Strong and Just City (City of New York, 2015). Building on the previous administration's focus on equity, the new sustainability plan centers environmental justice and health equity as core components for near-term and long-range climate action planning. It proposes multiple climate resiliency initiatives that prioritize vulnerable populations (e.g., NYCHA residents, low-income and moderate-income households, basement apartment dwellers) and environmental justice communities. Example initiatives include piloting Resilience Hubs in areas that are exposed to flood- and storm-related hazards and across NYCHA campuses and Cool Corridors in areas that are disproportionally affected by the urban heat island effect with a focus on environmental justice communities (City of New York Office of the Mayor, 2023b). Others include the Climate Strong Communities program designed to identify climate resilience investments in communities that were left out by Hurricane Sandy recovery funding and the FloodHelpNY and the HomeFix programs to help low- and moderate-income homeowners with acquiring flood insurance coverage, repairs, and resilience retrofits (Center for NYC Neighborhoods, n.d.; City of New York Department of Housing Preservation and Development, 2024; City of New York Mayor's Office of Climate & Environmental Justice, 2022b). The plan also addresses equity in terms of access to sustainability and green economy investments by prioritizing historically underserved communities. Example initiatives include creation of multi-purpose green infrastructure (e.g., nature-based stormwater management solutions, greenways, greenspace), bike lanes, urban farms and community gardens, community brownfield planning grants, electrification and efficiency upgrades for NYCHA housing, and workforce development and training for green and circular economy sectors.

In combination with municipal capital spending, the City is counting on new federal and state funding streams to develop and implement its sustainability and resiliency initiatives (City of New York Office of the Mayor, 2023b). The latest PlaNYC outlines ambitious strategies for leveraging these sources of funding, which include the Bipartisan Infrastructure Investment and Jobs Act (IIJA), the Inflation Reduction Act (IRA), the New York State (NYS) Environmental Bond Act as well as from other sources such as the Federal Healthy Street Programs, Federal Emergency Management Agency (FEMA)'s Building Resilience Infrastructure and Communities (BRIC) program and Pre-Disaster Hazard Mitigation Assistance program, and other grants from federal and state agencies (City of New York Office of the Mayor, 2023b). The City is pursuing federal and state funding to implement efforts including the Climate Strong Communities program, Resilience Hubs, Cool Corridors, stormwater management projects, clean energy projects, municipal fleet electrification, green workforce training, and other climate and environmental projects. It has recently called on the federal government to provide $8.5 billion in pre-disaster mitigation funding to implement unfunded resiliency projects (*Mayor Adams Commemorates 10th Anniversary of Superstorm Sandy*, 2022). In terms of advancing equity, grants and programs funded by the IIJA and IRA are subjected to the Justice40 initiative, an provision inspired by and similar to the environmental justice provision in the NYS' Climate Leadership and Community Protection Act (CLCPA) (New York State Climate Leadership and Community Protection Act, 2019), requiring that "40 percent of overall benefits of certain federal investments flow to disadvantaged communities that are marginalized, underserved, and overburdened by pollution" (The White House, 2022, p. 40). Tracking how the CLCPA's EJ provision (New York State Climate Leadership and Community Protection Act, 2019) and the Justice40 initiative (The White House, 2022, p. 40) are implemented and how climate investments are distributed at local and neighborhood levels requires further research.

While the City has developed numerous plans, policies, and programs to advance equity in climate adaptation planning, efforts to track and monitor equity issues with respect to climate resilience investments are in early stages. Existing efforts include the Sandy Funding Tracker (City of New York Office of Emergency Management, 2023b) and the NYC Emergency Management (NYCEM)'s Mitigation Actions Map (*Actions Map – NYC Hazard Mitigation*, n.d.), but these tools do not provide a complete picture of the City's spending on climate resilience or on the status of completed and planned projects. For example, while the Sandy Funding Tracker provides information about how much federal grant money has been spent, it does not include the status or anticipated completion dates for federally funded projects nor include information about the City's capital contributions to these projects (Yeung & Levers, 2022). On the other hand, while NYCEM's Mitigation Actions Map conveys the status and location of the City's capital investments in hazard mitigation projects, without a clear picture of community-specific strategies for climate risks and vulnerability, it remains difficult to determine whether local adaptation needs are being met. It may be noted though that, at the least, the NYCEM's Climate Risk Assessment Dashboard (City of New York Office of Emergency Management, 2023a) includes a Risk Report feature for each neighborhood, assisting in understanding local adaptation needs and providing information on community programmatic resources. Efforts to develop community-level climate risk assessment and resilience strategies such as the US Army Corps of Engineers (USACE)'s NY & NJ Harbor & Tributaries Coastal Storm Risk Management Study (NYNJHATS), the VIA project, and the Climate Strong Communities are only now underway. In the Ten Years after Sandy: Barriers to Resilience report (Yeung & Levers, 2022), the New York City Office of the Comptroller found that as of June 2022, the City has only spent 73 percent of the $15 billion of federally appropriated grants for Sandy recovery and resilience (Yeung & Levers, 2022). Slow progress can be attributed to complexity of projects, lengthy coordination and approval requirements by federal agencies, and challenges associated with community engagement (S. Maldonado, 2022).The Comptroller office recommended that the City accelerates the pace of resiliency spending and improve public transparency of capital project tracking, particularly by establishing the Capital Project Tracker that provides accessible neighborhood-level information about resiliency projects with details such as budgets, timelines, and management entities (Yeung & Levers, 2022). The City established the NYC Capital Projects Dashboard in 2023 in response to the Comptroller's recommendation (City of New York Mayor's Office of Operations, 2024).

In the last few years, MOCEJ has increased efforts to communicate the City's progress on climate action in clearer and more accessible manners. Its website has been updated and streamlined to convey information about climate hazards and ongoing work on climate change adaptation, sustainability, and environmental justice. The agency recently created a webpage (City of New York Mayor's Office of Climate & Environmental Justice, 2022c) that compiles key coastal infrastructure studies and projects that are taking place across five boroughs. While Manhattan is home to many large-scale projects funded by federal post-Sandy recovery and rebuilding grants (e.g., the East Side Coastal Resiliency project, the Battery Coastal Resilience Project, the Battery Park City Resilience projects, the Brooklyn –Bridge-Montgomery Coastal Resiliency project), others such as the Interim Flood Protection Measures Program (IFPM), Living Breakwaters, Raised Shorelines, Red Hook Coastal Resiliency, and other USACE-led resiliency projects are being implemented in other boroughs.

Another mechanism that can potentially enable transparent tracking of sustainability and resiliency funding and spending is the climate budgeting initiative (Khan & Adams, 2023). Together with the City of London, New York is among the first to adopt a systematic approach "that incorporates science-based climate considerations into the budget decision-making process by evaluating how actions and spending today contribute to meeting longer-term climate targets" (City of New York Office of the Mayor, 2023b; Khan & Adams, 2023). The initiative is led by the Mayor's Office of Budget and Management (OMB)'s Environmental Sustainability and Resiliency Taskforce in partnership with MOCEJ, who are working to include resilience, sustainability, and equity indicators when reviewing budget proposals from city agencies. Information about the process will be documented in an annual publication, to be released in April 2024, which highlights the City's investments and provides a snapshot of progress on meeting long-term climate goals (City of New York Office of the Mayor, 2023b).

2.1.5 Remaining equity concerns

Since the publication of the NPCC3 report in 2019, the City's framing of equity has broadened from initially focusing on environmental justice to later including racial justice and climate justice. There has also been a shift in usage of language and concepts about equity in planning discussions. City-level efforts aimed to address the institutional foundation for advancing social and racial equity, starting with an explicit recognition of the legacy and persistent effects of structural racism on health, income, and access to services as a first step to operationalizing racial equity and social justice. The development of digital visualization tools and mapping platforms, as well as making city-level data more accessible and available, enables city agencies to better communicate progress and foster a culture of transparency and accountability (and thus trust) with the public. Recently adoption of laws such as LLs 60 & 64 in 2017 and LL 78 &122 in 2021 (Local Law 60, 2017; Local Law 64, 2017; Local Law 78, 2021; Local Law 122, 2021) ensures that consideration for environmental justice and equity in climate adaptation planning efforts will be key priorities for subsequent mayoral administrations and that these priorities will continue beyond the usual political cycles.

At the same time, several key equity concerns remain:

- The City has numerous initiatives to assess and characterize climate risks including the SIRR initiative (City of New York Office of the Mayor, 2013), Heat Vulnerability Index (City of New York Department of Health and Mental Hygiene, 2022a), Flood Hazard Mapper (City of New York, 2023a), Comprehensive Waterfront Plan (City of New York Department of City Planning, 2021b), and Community Risk Assessment Dashboard (*CRA Dashboard – NYC Hazard Mitigation*, n.d.) but there is a need to develop more adaptation strategies and plans that reflect the unique context and address challenges of each of the five boroughs, 59 community districts, and/or specific neighborhoods. To date, the Resilient Neighborhood studies (*Resilient Neighborhoods*, n.d.), Cool Neighborhoods NYC (City of New York Mayor's Office of Resiliency, 2017), Lower Manhattan Coastal Resilience Projects (*Lower Manhattan Coastal Resiliency (LMCR)*, n.d.), and the Resilient Edgemere Community Plan (City of New York Department of Housing Preservation and Development, 2017) are among the few city-sponsored community-based adaptation plans. While Climate Strong Communities initiative is designed to address local equity and adaptation concerns, it is in the early stages of implementation. A better understanding of how specific climate risks (e.g., flooding, heat) affect individual communities and neighborhoods will allow the City to tailor policy responses and resource allocation, develop mechanisms for soliciting inputs and buy-in, and document benefits and outcomes.

- As the City works with state and federal agencies to develop climate adaptation and resilience projects, there is a need to systematically document and track climate investments to ensure communities are prioritized equitably and their adaptation needs are met. The Sandy Funding Tracker,(City of New York Office of Emergency Management, 2023b) NYCEM's Mitigation Actions Maps,(*Actions Map – NYC Hazard Mitigation*, n.d.) and the Comptroller's Climate Dashboard are web-based platforms that allow users to see what and where climate investments are sited. City agencies need to assess equity impacts of climate investments, particularly the effects of these investments on existing social, economic, and housing conditions in neighborhoods and ensure that new projects reflect local stakeholders' goals, visions, and desires. City-sponsored adaptation projects should be developed in synergy with existing community-led planning efforts, particularly those by local EJ and community advocacy organizations, to ensure concrete community benefits and equitable outcomes. The work by OMB and MOECJ on climate budgeting can ensure transparency and equity when tracking climate investment spending. In response to the Comptroller's recommendation, the City developed the NYC Capital Project Dashboard (City of New York Mayor's Office of Operations, 2024) to monitor how resiliency is being integrated into capital projects (Yeung & Levers, 2022). Further research is needed to understand how city agencies and land use applicants comply with Local Law 78 (Local Law 78, 2021), which requires racial equity reports for certain land use actions, and whether this regulation results in meaningful outcomes for communities facing displacement risks.

- Through the EquityNYC initiative, the City has developed robust equity metrics and indicators that capture multiple dimensions of governance, but this effort is largely focused on disparities in city-funded services (i.e., distributive equity) (City of New York Mayor's Office for Economic Opportunity, 2023b). Development of indicators and metrics that can capture other dimensions of equity such as procedural or contextual equity is a more difficult task. It will require further research and consultation with local stakeholders to ensure that city-level datasets reflect on-the-ground reality and service disparities have improved. Similarly, future efforts to track equity progress and visualize spatial data should include a public and/or community engagement component. On the other hand, limited efforts exist in developing equity indicators and metrics regarding climate adaptation and resilience planning. The City, specifically city agencies such as MOCEJ, DCP, NYCEM, and NYC Opportunity along with NPCC, can expand upon the EquityNYC initiative and NPCC3's New York City Climate Change Indicators and Monitoring Systems (NYCLIM) framework (Blake et al., 2019; City of New York Mayor's Office for Economic Opportunity, 2023b) and develop community-specific indicators and indices that can capture dimensions such as social and health vulnerability, disparate exposure, adaptive capacity, mobility, and housing. Available resources for consultation include the City of San Diego's Climate Equity Index and the City of Cincinnati's Climate Equity Indicators for Neighborhoods (City of San Diego Sustainability Department, 2019; Even et al., 2021).

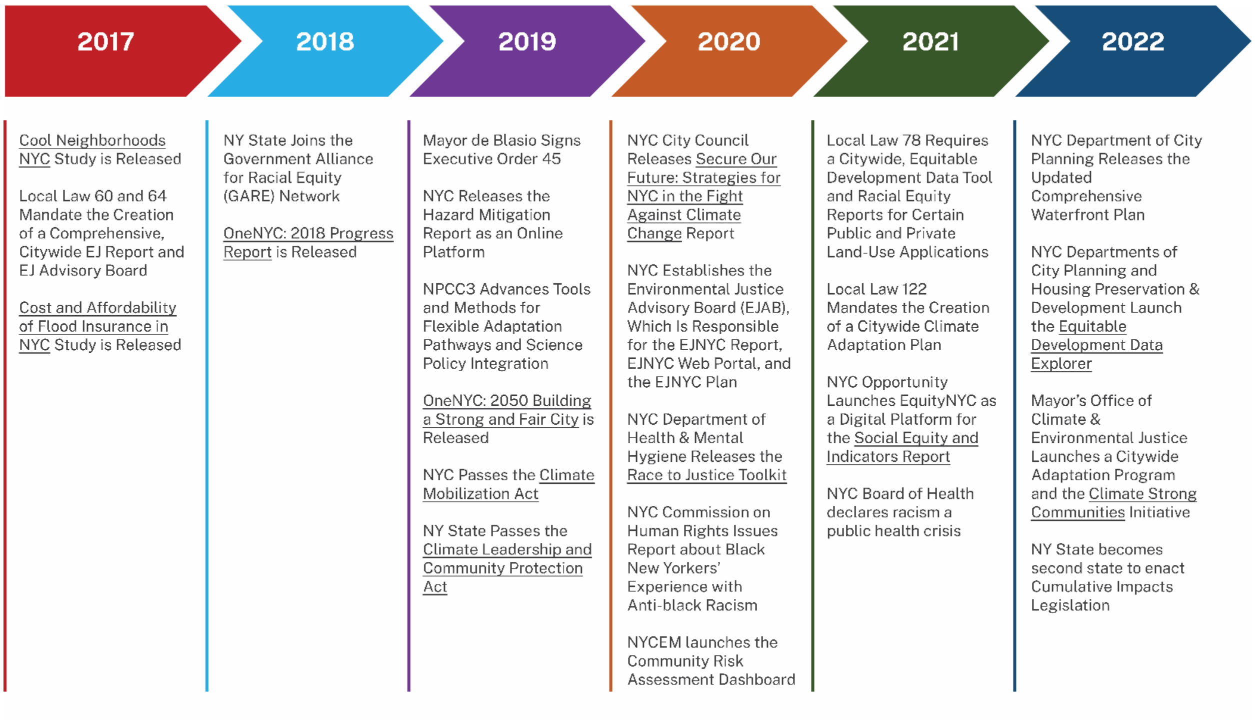

Figure 1: Timeline of City's climate-related equity actions.

2.2 Community-level Action and Progress Toward Climate Equity

The NPCC3 Chapter: Community-Based Assessments of Adaptation and Equity (2019) featured three case studies co-produced with environmental justice organizations, including WEACT for Environmental Justice in northern Manhattan; UPROSE in Sunset Park, Brooklyn; and The Point CDC in Hunts Point, in the Bronx. These case studies included a review of environmental, climate, and social stressors as well as climate action plans developed by these groups. In NPCC3 (2019) Chapter on Equity, section 6.5.1 *Community-based adaptation initiatives and projects*, a review of each organization's climate adaptation projects and their approach to community engagement were summarized. Since the release of NPCC3, these communities have continued to both implement and evolve their approaches to climate, environmental and social stressors. The impact of the COVID-19 pandemic on communities represented by these organizations and increasing climate change-related extreme weather events like Hurricane Ida have also required dynamic approaches to meet the needs of their respective communities.

Table 3 summarizes updates to some of the climate-related projects that were featured in NPCC3.

The updates reflect a review of each organization's website and other online sources, as well as information from semi-structured interviews conducted with Sonal Jessel (Director of Policy) from We Act and Elizabeth Yeampierre (Executive Director), and John Fleming (Development Director/Project Manager) of UpRose. We were unable to reach The Point CDC for interviews, thus updates reflect the information found online.

Table 3: Climate-Related Projects Featured in NPCC3

Cases	Updates from NPCC3 Projects
UPROSE, Sunset Park Brooklyn	■ Climate Justice Youth Summit was last held in 2019 and then paused due to Covid. UPROSE continues to organize youth and intergenerational groups of residents in "Learning Circles" that entail climate adaptation discussions. ■ Block Captains, a program that trains volunteers to contribute to resilience work in the Sunset Park neighborhood, was put on hold and shifted to a campaign focused on land use proposals for Industry City. ■ The Sunset Park Climate Justice Center hosted town hall meetings to facilitate community-based resiliency planning with residents. Participants gave input on climate adaptation measures that can also combat displacement and reflect just transition opportunities for local wealth creation. ■ Sunset Park Solar is a 685-kilowatt solar project to be built on the Brooklyn Army Terminal rooftop. The cooperative will include 200 community solar subscribers who receive 15% savings on their monthly energy bills. Project construction was delayed due to the pandemic but leasing and financing agreements are being finalized and construction is expected to begin this year.
WE ACT	■ Northern Manhattan Climate Action Plan (NMCA) is a community-informed agenda for addressing climate change in northern Manhattan, with strong energy democracy principles. The plan targets publicly owned power, renewable energy generation, sustainable housing, and a resilient built environment. ■ Solar Uptown Now (SUN) project is now complete, with 415 KW of installed solar on Housing Development Fund Corporation (HDFC) co-operatives in northern Manhattan. ■ Community Solar project installed solar on three NYCHA buildings and trained over 100 NYCHA residents in solar installation. ■ The NYCHA Villages report (de Hoz & Abreu, 2019) was issued by WeAct on *Healthy and Sustainable Public Housing. The report* addresses issues of mold, maintenance defects, pests, and power outages. This led NYDEC to fund the Inwood Climate Change & Health Project which expanded beyond Dyckman Houses to look at climate change and health initiatives throughout the Inwood neighborhood.
The Point CDC	The Point CDC was a project partner for *Hunts Point Lifelines*, a proposal funded by US HUD's Rebuild by Design program after Hurricane Sandy. Although the City convened a working group to solicit community input, residents raised concerns about limited input and the risk of displacement of proposed resiliency efforts (Foster et al., 2019). A 2020 Hunts Point Resiliency Feasibility study of the proposal recommended the energy components be considered for implementation, while issues like coastal flooding be deferred for future implementation ((NYCEDC, 2020). FEMA announced NYC EDC was a recipient of BRIC funding to dry floodproof two food facilities at Hunts Point that are most at risk of storm surge flooding (FEMA, 2022). The Point CDC was a member of the Hunts Point Forward Working Group, which supported development of the engagement process, recommendations, and implementation pathways for the Hunts Point Forward plan (NYCEDC, 2023) part of the City's $140 million investment in Hunts Point infrastructure. The Hunts Point Forward plan builds from EDC's first neighborhood-wide plan for the area, the 2004 Hunts Point Vision Plan .

3 Climate Equity in the Context of NYC's Historical Experience

3.1 Historical Dispossession of Land and Land Uses

The climate change challenges we currently face in NYC are inextricably linked to the bioregion's (see BOX 1) history of settler colonialism, extractivism, imperial trade, and slavery (The Public History Project, 2023). An understanding of this historical context is essential for formulating effective policies that address the rapidly changing climate. In addition, local Indigenous knowledge provides valuable ecosystemic insights that can help us all move toward repairing the broken human-environment relationship. Urban agriculture, land stewardship, and community gardens are three promising examples illustrating urban processes of relinking to nature.

BOX 1. The Great Tidal Ecoregion

The Algonquian term for what British colonialists boasted as the "Hudson River" is *Mahicannituk*[w] or "great tidal river." This "ecoregion", roughly the NYC metropolitan region, has been a thriving place where land, sea, and rivers converge. Compressed herein is an elaborate estuary in a relatively small area fostering thriving life energies.

At the southernmost boundary of the Wisconsin ice sheet of 20,000 years ago, this "end moraine" left a ridge elevation of mineral soil, gravel, sand, silt, and clay amidst a saltwater / freshwater habitat for shellfish, waterfowl, migrating fish, and Lunaape (Lenape) with allied Algonquian communities.

Upland forests, rich in nut bearing trees, provided additional food and shelter; and selective burning sustained forests and grasslands that extended the palette of plants and creatures used for dietary, cultural, and medicinal uses. This tending of native flora and fauna created a dynamic seasonal natural economy.

Figure 2: The Great Tidal Ecoregion. Courtesy of Kerry Hardy and the Public History Project

Dutch and British colonizers intent on maximizing their profits in local and global markets, took limited regard for the local ecosystems. By 1750, Dutch naturalist Pehr Kalm remarked how the forests of New Jersey were "already more ruined than any others." (Kalm, 1770, p. 50)

Well before industrial pollution, this attitude of endless "natural resource" extraction disrupted the regenerative and sustainable local cycle of tending, what Indigenous ethnobotanist Robin Wall Kimmerer frames as the tradition of the "honorable harvest" of "take only what you need and use everything you take." (Kimmerer, 2013, pp. 148, 179)

With recent IPCC acknowledgment of both Indigenous Local Knowledge (ILK) and Traditional Ecological Knowledge (TEK) it is increasingly possible to have a mutually respectful dialogue on how a dynamic ecology might be better balanced within the NY metro ecoregion within the larger bioregion.[2] Notably, NYC Greenmarkets interlinking local small farmers with NYC Parks, cobbled together by Robert Lewis over three decades is one such effort.(The WNET Group, 2007)

3.1.1 Pre-colonial landscape and land management

Roughly twenty thousand years ago, during the last peak of glaciation, NYC was sealed in a layer of ice thousands of feet thick (Stanford, 2010). As the ice melted in the following centuries, rivers were rerouted, channels were carved, and a brand-new landscape emerged.

For all beings of the Northeast coast, survival required adaptation to these post-glacial and climate fluctuations. Coast Algonquian communities cultivated a deep intimacy with their environments, moving around the area as the seasons shifted their protein sources (Bragdon, 2005).

The Munsee speaking Lunaape people referred to the river we now call the Hudson as "*Mahicannitukw*," meaning "the great tidal river" (The Public History Project, 2020). The makeup of the Mahicannitukw river—its waters fresh at the northern end but increasingly briny as it approaches the Atlantic—created the ideal habitat for salmon, shad, sturgeon, whales, and particularly the critical keystone species of oysters, along with a long list of dependent species in this food web. Additionally, post-glacial pond formations became home to beavers, turtles, waterfowl, plants with medicinal properties, and other flora and fauna valued by Indigenous people. These environments made the region a hub for human food, travel, and trade long before the first European settlers arrived (Lynch et al., 2012; Sanderson, 2009).

The Indigenous communities of our region shared in common a developed, nuanced language, and an understanding of the relationship between humans and the ecologies that nourished them (Goddard, 2010). They thrived in the region by "tending the wilderness"–employing sustainable harvesting and permaculture farming methods and by maintaining a delicate balance with their surroundings.

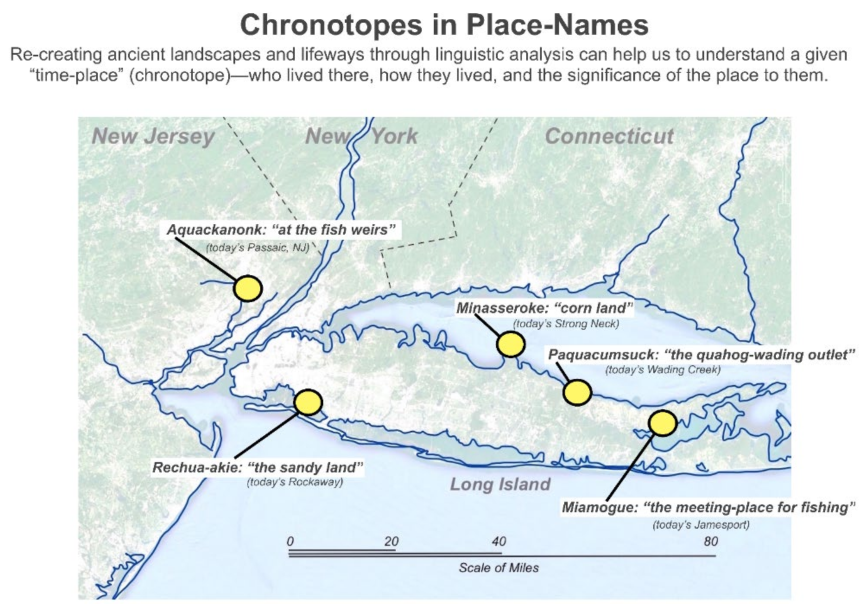

Figure 3: Chronotopes in Place-Names: Source: Public History Project (2023)

[2] "Bioregion" and "ecoregion" are formulations of nature/human relational places by systems ecologists that engage in a dialogue with ILK, TEK, and Western-trained scientists and systems theory. "*A bioregion is a self-reliant geographic unit defined through watersheds, ecoregions, hard physical boundaries and the cultures that stem within them. Bioregion is short for 'bio-cultural region' and are geographically based areas defined by physical traits; land or soil composition, watershed, climate, flora, and fauna; as well as the cultural traits of the inhabitants that live within them, and act upon them. Ultimately, they are defined by the people living within them.*"(Cascadia Department of Bioregion, 2024) (See also Thomashow (Thomashow, 2001))

Their practices included selective harvesting, which meant only taking what was necessary while allowing plants and wildlife to replenish themselves, along with controlled burning of the grasslands, which served many purposes. For instance, burning enriched the soil, which allowed strawberries to crop up in profusion, beckoning the animals they hunted, such as passenger pigeons and turkeys. These practices reflected their intimacy with the land as a living system and the understanding that their own well-being depended on ecosystem health and on practicing care for “all our relations,” animal and plant alike (LaDuke, 2016).

3.1.2 European colonization and ransacking the commons

The “discovery” of the Mahicannitukw river by Henry Hudson in 1609 set off an era of drastic change in the uses and abuse of our bioregion (Jennings, 1975; Kalm, 1770).

The arrival of European colonizers brought an extremist extractive mindset that failed to account for the long-term consequences of exploiting the land and its resources, as was noted with concern by visiting Finnish-Swedish botanist Pehr Kalm (Kalm, 1770). The Doctrine of Discovery enabled Christian appropriation of Indigenous lands, resulting in dispossession, ecological disruption, and the destruction of communal resources (Upstander Project, 2023).

The violent imposition of this privatized European economy in the 17th century introduced a capitalist trade and extraction-production structure that replaced Indigenous cultural systems, which centered a shared commons. It marked a shift from a society founded in Indigenous practices of “tending the wild” for sustenance and regeneration to a society where resources were harnessed primarily for their “exchange value” (K. Anderson, 2005; Bollier, 2013). Locale by locale, overexploitation depleted the massive oyster banks, disrupted fish runs, and contaminated groundwaters.

European settlers used extended credit for rum and other European goods to addict and lock Indigenous people in debt, and then used that debt to justify seizing Indigenous assets. In addition, the monetization of wampum gifting disrupted inter-Indigenous social dynamics; some Indigenous groups began demanding tribute in the form of wampum from other groups, even threatening to use violence if they failed to comply. The European trade of wampum also accelerated the depletion of beavers and other animals coveted for their fur.

In the 1630s and 1640s, English and Dutch settlers turned to an even more vicious strategy to occupy and gain land from Indigenous communities and crush resistance. There were at least nine colonial attacks in the region in the span of a decade that can be defined as genocidal massacres—unnecessary, indiscriminate killing of human beings, including children and pregnant women (Anonymous, 2013; Bailyn, 2013, p. 336; Brodhead, 1871, p. 391; de Vries, 2020, p. 173; Jameson, 2000; Melyn, 1850; O’Callaghan, 1848; van der Donck & van Tienhoven, 1856). Murder and subjugation became a regular economic development policy.

Beginning with the British mercenary-led Pequot War at Mystic, which paved the way for British conquest of much of Connecticut and parts of Long Island, followed by Dutch massacres at Corlears Hook (in present day Lower East Side), Pavonia (in present day Jersey City), Pound Ridge (in present day Westchester) and other settlements (Figure 4), the violence set off a series of battles between settlers and Indigenous peoples and would, over time, lead to further Indigenous land dispossession.

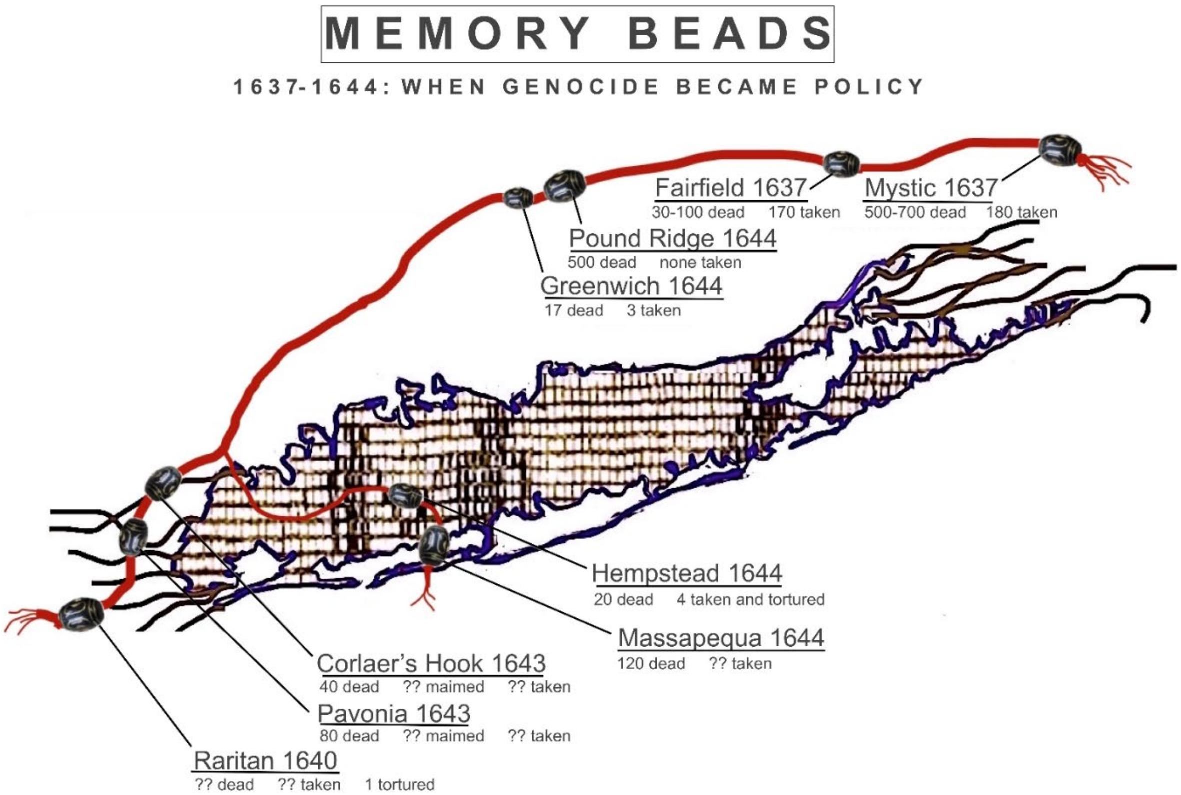

Figure 4: Memory Beads: Source Kerry Hardy and the Public History Project (2023)

Herein the Dutch and the British established a massive global economy based on an interlocking set of relations between money, power, and people spanning four continents (Lowe, 2015; Tchen, 2001). Imperial trade relied heavily on the extraction of resources from the so-called New World using these taken lands and forced labor, which escalated the demand for enslaved Indigenous people and Africans. When the English acquired New York and East and West Jersey from the Dutch in 1664, the shift further intensified the demand for slaves. Enslaved African people were brought to the region and forced to farm the fields formerly planted by Indigenous people and clear away forest to make more fields (Matthews, 2019, p. 9). The labor of enslaved people fueled the city's economy, while the concentration of lands and wealth in the hands of a few exacerbated social inequalities.

By the late eighteenth-century, many living beings in the region were depleted, including beavers, oysters, and whales. Extensive deforestation to clear land for agriculture and to produce fuel and building materials for the developing colonial cities had also destroyed atmosphere stabilizing carbon sinks (Cronon, 2003, p. 178). The ditching of tidal wetlands started as early as the 1600s to alter hydrology and optimize the production of salt hay and other products (Adamowicz et al., 2020; Dahl & Allord, 1996). In 1791, The Society for Establishing Useful Manufactures (SUM) was established by Alexander Hamilton to use the Great Falls at Paterson, NY, a longstanding site for Lunaape, to harness and eventually sell the waterpower to manufacturers (Cowen & Sylla, 2018). Additionally, alterations to waterways through canal construction and marshland reclamation disrupted wetlands, leading to increased flooding, erosion, and the loss of wetland habitats. Over the ensuing decades ,the Passaic River and the adjacent estuarial region became prime manufacturing real estate. Commodifying drained land accelerated the industrialization and pollution west of Manhattan Island – a pattern of land use development already established by King Charles II's massive state drainage policies (Mulry, 2021). These adapted US practices not only resulted in loss of biodiversity and the disruption of ecosystems, but also set the stage for the Industrial Revolution in the US. The fossil fuel emissions from this era now account for the historic accumulation of US emissions, the largest of any nation, still lingering in the atmosphere.

We cannot disregard the ways Dutch, English, and US abuses of the land have made the region and the planet more vulnerable to climate change. Furthermore, that settler-colonial, extremist extractive mindset continues to shape our society today. Ecological and environmental injustices persist, with Indigenous peoples, people of color, and low-income neighborhoods most affected (The Climate Reality Project, 2021; U.S. EPA Office of Land and Emergency Management, 2020). Marginalized communities are now at risk for the worst impacts of climate change (McDonald et al., 2021, tbl. S4; U.S. Government Accountability Office (GAO), 2021).

Eco-colonialism in the New York metro region is a legacy that will impact everyone in the bioregion and on the planet. It is not only prudent but also the moral duty of policymakers in our region today to recognize this inheritance and to address the inequities and ecological ruin perpetuated by systems that prioritized and fostered wealth accumulation.

3.1.3 Learning from the history and the historical stewards of the land

Climate change in NYC and its bioregion cannot be divorced from the history of colonialism, extractivism, and slavery. Understanding the impacts of these legacies is vital for formulating effective policies and strategies to mitigate and adapt to climate change. Furthermore, knowledge of our history also necessitates a commitment to restorative justice.

Indigenous peoples of North and South America have endured centuries of genocidal violence, leading to the extinction of over 2,000 nations (LaDuke, 2016, p. 1). Despite this immense loss, today there are still at least 3.7 million Indigenous people in the United States, or a total of 9.7 million people when including those who identify as both “American Indian/Alaskan Native” and another racial group (U.S. Census Bureau, 2020). While many of the original people of our bioregion have been dislocated to other parts of the U.S., some remain on the lands they have called home for centuries, including but not limited to the Ramapough Munsee Lunaape and the Sand Hill people of present-day New Jersey (The Public History Project, 2023). Both have recognition from the state of New Jersey but no federal recognition from the Bureau of Indian Affairs. Meanwhile, the Shinnecock, who received federal recognition in 2010, continue to own and occupy aboriginal homelands on the eastern end of Long Island (Shinnecock Nation, n.d.). Indigenous people of diverse nations from throughout the country have also made NYC their home. The city has the largest concentration of Indigenous peoples in the U.S., with the Manhattan-based American Indian Community House serving people from 72 nations (“About The American Indian Community House,” n.d.; First Peoples | The New York State Museum, n.d.).

Far from being “erased,” Indigenous groups in our bioregion and in North America at large continue to struggle for the return of land to Indigenous sovereignty (NDN Collective, 2021). A true commitment to principles of equity and justice require that today’s policymakers take seriously Indigenous movements for the right to steward their original homelands and for greater consent in decisions that impact their access to sustainable food, shelter, and more (Thompson, 2020).

Thinking locally, it may seem challenging to conceptualize how to bring a crowded, acutely privatized city like New York back into the hands of the Lunaape, especially given the dislocation of many Lunaape people and the Indigenous diversity of present-day NYC. Yet Indigenous advocates and allies are already articulating steps worthy of consideration. For instance, in Shinnecock Bay off the coast of Long Island, members of the Shinnecock, working with the Sisters of St. Joseph, have developed a kelp farm that is helping to absorb the excess carbon and nitrates in the water while also providing the Shinnecock with green jobs and a return to stewarding their coastal waters. Collaborating with knowledgeable Indigenous stewards has the dual benefit of respecting Indigenous sovereignty demands while also addressing our city’s environmental issues and caring for our vulnerable coastal areas (Kleczek, 2023; Leonard, 2021). In addition, the city can explore furthering investment in land stewardship models like the community land trust, which privileges a community’s needs—whether for affordable housing or climate resiliency infrastructure—over an individual’s potential to generate wealth (Dudley Street Neighborhood Initiative, 2023; NDN Collective, 2021; Thompson, 2020; United States Census Bureau, 2022). Policy-makers—and the public—must also be open to learning from Indigenous Land education (McCoy et al., 2017; Tuck et al., 2014). Those still on homelands possess profound insights into the bioregions they inhabit. Indigenous practices offer alternative models of relating to the land that ensures the well-being of both humans and our shared natural world and that can help us address the root causes of our disconnection from the environment and seek solutions for an inclusive, biodiverse future (United States Census Bureau, 2022). Collaborating with Indigenous communities and integrating these fundamental, embodied, long-memory insights into political decision-making processes can pave the way for more just and ecologically conscious policy approaches to climate action.

3.2 Historical and Contemporary Land Use Patterns and Climate Risk

Historical land use decisions contribute to climate risk today and to who bears that risk. Working to eliminate inequities in climate risk requires understanding this more recent history, as well as the ongoing practices that perpetuate them. There are clear linkages between past land use and present climate risk; at the same time, the characteristics of this relationship depend on local histories and context. Nevertheless, common themes emerge and can help explain patterns in New York today. To explore these relationships across a range of land use issues—

including zoning, development decisions, geography, and transportation—this section will use the following framework (See Figure 5). Past land use practices affect climate risk directly and indirectly through how they affect current land use patterns and social vulnerability. In turn, these climate risks also shape land use patterns.

- **Past land use practices affect climate risk directly.** For example, formerly industrial areas may still have contaminated soil or other health risks. Often, the areas develop into low-income residential neighborhoods because the land is relatively inexpensive. The residents are then more exposed to toxic contaminants during extreme weather events, such as storm surges.
- **Past land use practices affect current land use patterns, which affect climate risk.** Redlined neighborhoods typically have developed over time to have higher rates of impervious surfaces and less investment in green space, resulting in intensified heat waves.
- **A combination of current land use patterns and climate risk affects future land use patterns.** Low-income, high-elevation neighborhoods may see rising property values that lead to displacement and other changes in residential patterns.

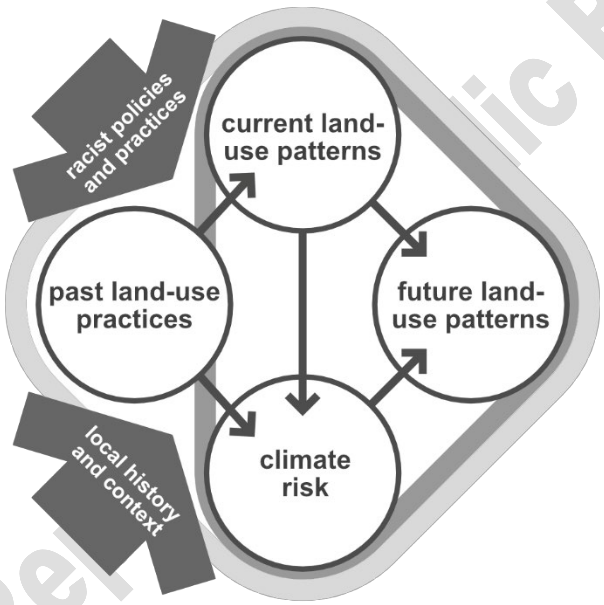

Figure 5: Framework for the relationship between Historic and Present Land Uses, Climate Risk, and Social Vulnerability |

Although many studies use a social vulnerability lens to understand each of these categories individually, such as showing that people of color face greater heat wave-related mortality in New York (Madrigano et al., 2015), fewer studies empirically lay out these series of relationships: past land use practices produce social vulnerability, leading to specific climate vulnerabilities, leading to future land use patterns with their own inequities. Notably, the Madrigano study used multiple factors spanning demographics and the physical environment to assess heat wave-related mortality risk. This led to a composite Heat Vulnerability Index that NYC has continued to use and refine (City of New York Department of Health and Mental Hygiene, 2022a).

The following sections will map out the state of the research across each of these relationships.

3.2.1 Zoning, land use planning, and climate risks

Zoning and land use planning have been powerful tools for creating and enforcing racial and class segregation in U.S. urban areas, including suburban neighborhoods within and surrounding city boundaries (Whittemore, 2021). In addition to these socio-demographic consequences, zoning also determines many physical characteristics of communities, such as where hazards are located, who has access to green space, tree canopy cover, and development patterns.

3.2.1.1 Redlining

Old government maps by the federal Home Owners' Loan Corporation (HOLC) outlined neighborhoods in more than 200 U.S. cities and rated them for inclusion in government home mortgage and lending programs (Aaronson, Faber, et al., 2021; Aaronson, Hartley, et al., 2021). These color-coded maps rated (and marked) neighborhoods from least risky to most risky — "A" through "D"; the "D" areas (red) were neighborhoods where Black residents lived. This practice is referred to as "redlining." The result was that Black homeowners could not qualify for home loans that were backed by government insurance programs, essentially zoning out Black neighborhoods from investment (Aaronson, Faber, et al., 2021; Aaronson, Hartley, et al., 2021). As such, while "redlining" was not technically a land use policy, the practice operated like a zoning map, designating areas where Blacks and whites could and should live based on their ability to secure a mortgage and other financing.

One consequence of governments and private entities' disinvesting in redlined neighborhoods over time is that these areas, even today, lack heat- and flood-mitigating infrastructure relative to neighborhoods with higher HOLC grades (Hoffman et al., 2020; Wilson, 2020). At the same time, redlining and other discriminatory housing policies (such as racial covenants) precluded people of color from moving to areas with fewer environmental risks and more resilient features. Although there is mixed evidence on to what extent formerly redlined areas have retained their original demographic composition (R. Best & Mejia, 2022; Perry & Harshbarger, 2019), many low-income residents and residents of color continue to live in formerly redlined areas today.

In NYC, spatial inequities have changed over time due to population migration, upzoning, urban renewal, and displacement–all making the influence of redlining and other historical land use issues more complex and less direct (City of New York Office of the Mayor, 2020). Although HOLC deemed 54 percent of Manhattan's land area as "hazardous" in the 1930s, some of these areas are now affluent neighborhoods; this relationship is further complicated by the neighborhoods' high but uneven prevalence of air conditioning, making redlining even less of a predictor for heat vulnerability today (City of New York Department of Health and Mental Hygiene, 2021b; *Not Even Past*, n.d.).

Nevertheless, formerly redlined neighborhoods appear to be more likely than non-redlined neighborhoods to be facing high flood risk, disproportionately impacting households of color (Katz, 2021). These discrepancies are much larger in a handful of U.S. metros, including Sacramento, New York, Boston and Chicago (Katz, 2021). In NYC, census tracts that had been graded "A" or "B" have significantly lower flood risk under four scenarios—extreme and deep contiguous flooding, extreme nuisance flooding, moderate deep and contiguous flooding, and moderate nuisance flooding—than those with "C" and "D" grades (Steinberg-McElroy et al., Forthcoming).

Moreover, these disparate risks are increasingly being quantified. One analysis of Los Angeles, California, found that between 197,000 and 874,000 people—and between $36 and $108 billion in property—within the 100-year floodplain are exposed to flooding greater than 30 centimeters (about 11.81 in), disproportionately so in non-Hispanic Black communities (Sanders et al., 2022). An earlier study of NYC found that the non-Hispanic Black population in 100-year floodplain (relative to what is expected based on population size) was nearly 60 percent higher in Manhattan, 40 percent higher in the Bronx, and nearly 100 percent higher in Queens, whereas the Non-Hispanic White population was approximately 100 percent higher in the Bronx and 40 percent higher in Brooklyn. The authors of the study attribute these differences to past and changing land use patterns (Maantay & Maroko, 2009; *Not Even Past*, n.d.). The history of redlining also contributes to inequities in disaster protection and recovery funding. For example, redlining has led to lower property values, which can result in fewer government flood-protection funds (Katz, 2021). It's worth noting that these lower-valued properties often retain disproportionately higher property tax assessments relative to their actual market values, thus increasing the financial burden on low-income people (Center for Municipal Finance, n.d.; Editorial Board, 2021). Some federal flood mitigation grants for homeowners require matching, often making them unaffordable particularly for residents who have not been able to build wealth through homeownership (Dorazio, 2022). Inequities in disaster relief also stem from many aspects of redlining: homes are likely less resilient to natural disasters and face more damage; lower property values result in fewer funds to cover damage; and a lack of previous repairs means that properties may not be eligible for certain programs (Dorazio, 2022; Sturgis, 2018).

Climate risk today—particularly with respect to climate gentrification—may influence how these spatial inequities continue to evolve. One study suggests that outmigration can concentrate low-income households in flood zones. When the housing market experiences a drop in demand and prices, high-income people who can accept lower offers leave the neighborhood, while only low-income people are able to stay—or even move into the neighborhood (de Koning & Filatova, 2020).

3.2.1.2 Exclusionary zoning

Historically, zoning regulations that favored single-family homes and larger lot sizes were designed to make neighborhoods less accessible and more exclusive (Trounstine, 2018). For this reason, single-family zoning is often referred to as "exclusionary zoning" because it emerged as a way to keep racial and ethnic minority groups out of the suburbs after explicit racial zoning was found to be unconstitutional (Trounstine, 2018). The exclusionary nature of many suburbs meant that low-income residents of color, including those who live in NYC, were locked out of these neighborhoods and consigned to segregated neighborhoods in the city (City of New York Office of the Mayor, 2020).

From a climate justice perspective, many of the places contributing to greenhouse gas emissions the most (per person), including the suburbs of New York, are more protected from climate impacts, while also receiving the most renewable energy and electric vehicle subsidies. According to one report, households in New York metropolitan area suburbs and exurbs have emissions footprints that are two to three times as large as those in parts of Brooklyn or Manhattan (Plumer, 2022). Residents of compact neighborhoods in the city, and particularly low-income residents, have a lower carbon footprint because of the density and everything it enables, such as public transit and walkability (Popovich et al., 2022).

Many suburbs have also remained greener and, therefore, cooler, and environmentally healthier due to policies that perpetuate exclusion today, such as single-family zoning, and a lack of enforcement of fair housing laws. When higher-risk geographies have lower housing costs, rapidly growing urban areas may develop these areas to accommodate a growing population. For example, one study of Austin, Texas, found that low property prices caused the proportion of low-income residents living in floodplains to increase between 1990 and 2000 (Lee & Jung, 2014). Since this is an emerging body of literature, more research is needed to understand how repeated climate shocks affect displacement and whether residents are more likely to move to areas of sprawl.

3.2.1.3 Hazardous and industrial land uses

Historically, zoning policies for industrial and hazardous land uses have either targeted less expensive land or reduced land value. Hazardous and industrial land uses are intertwined with segregation and expulsive zoning practices, resulting in greater exposure to certain pollutants in communities of color. Expulsive zoning targets low-income communities and communities of color with noxious uses, which not only expand industrial zones but also accelerate gentrification in nearby neighborhoods that do not have these uses. In 2022, the U.S. Department of Housing and Urban Development found that the city of Chicago has been instrumental in efforts to move industrial facilities from predominantly white to predominantly non-white neighborhoods—one example of how governments continue to use zoning and land use policies to intentionally facilitate environmental injustice (Nexus Media News, 2022).

Historically, under expulsive zoning, low-income people and people of color were disproportionately displaced to the more industrial neighborhoods or became unable to afford to move out of these neighborhoods (Maantay, 2002). Today, predominantly low-income neighborhoods remain more likely to be targeted for, or to host, environmental hazards (Mizutani, 2018). One recent study, for example, finds that racially segregated residential areas are more strongly associated with fine particulate metals from human activity (such as industrial emissions, vehicle engines and shipping emissions) than natural sources (City of New York Department of Health and Mental Hygiene, 2022b; Kodros et al., 2022). Higher-income, predominantly white populations may move away from newly introduced hazards, leaving lower-income residents with the greatest exposure. Additionally, these racially segregated residential areas also often have higher incidences of air pollution and urban heat island. See NPCC4, Matte et al (Matte et al., 2024).

Legacy pollutants common in current or formerly industrial zones persist in the soil and can be released during flooding and storms (Marlow et al., 2022), reflecting how past land use decisions directly affect residents' climate and environmental health risks today. Storms may increase contaminant transport near Superfund sites (2019), and two million people in the U.S. live within a mile of Superfund sites in areas prone to flooding or vulnerable to sea-level rise (Dearen et al., 2017). A review of sites within six metro areas found that socially vulnerable groups (taking into account demographics, socioeconomic status, and housing status) were disproportionately likely to live in areas with elevated flooding risks near former industrial sites. (Marlow et al., 2022). Moreover, more than 9,000 current federally subsidized housing properties currently sit within a mile of a Superfund site (Caputo & Lerner, 2021).

Indirectly, these past land use decisions can affect land use patterns today, which then have implications for climate risk. In New York, the creation of official Significant Maritime and Industrial Areas (SMIAs) in 1992 has resulted in the further siting and clustering of environmental hazards in predominantly low-income communities of color. These areas were created to encourage the protection and siting of industrial and maritime uses along the waterfront. Historically, industrial land was often on the waterfront due to the city's shipping history and low-income residents were often placed in public housing in industrial areas or moved there because of the availability of low-cost housing. One study finds that all six[3] SMIAs are in hurricane storm surge zones, leading to greater risks for residents in these

[3] There are now seven SMIAs.

neighborhoods (Bautista, Hanhardt, et al., 2015) [4]. According to this study, the creation of SMIAs also resulted in the further siting and clustering of environmental hazards in predominantly low-income communities of color.

At the same time, as neighborhoods shift away from hazardous and industrial uses, zoning decisions today can influence who bears greater risks of both climate impacts and climate gentrification in the future. When areas have transitional land uses and flexible zoning, combined with low exposure to climate impacts, they may be more likely to experience new development (Tedesco et al., 2022). These land use decisions not only affect neighborhoods differently but also the populations within each neighborhood. In the case of brownfield redevelopment in Manhattan, neighborhoods with certain amenities (such as waterfront property and public transit) experienced increased gentrification. The rising costs of living had the greatest impact on the elderly, renters, and those using government assistance (Pearsall, 2010).

3.2.2 Development and investment decisions

Development decisions have long-term repercussions. Similarly, investments in resilience, and disparities in those investments, have been a direct result of historical and modern-day land use decisions. Today, these types of investments play a role in climate gentrification. Large-scale investments in climate adaptation and resilience—ranging from green infrastructure to seawalls to buyouts—affect the development landscape and the climate riskscape.

3.2.2.1 Housing development

Large building complexes (including many federally subsidized buildings) were typically placed in areas with inexpensive land, which continue to be more affordable neighborhoods today. These buildings and their related infrastructure were constructed with heat-absorbing materials that intensify the urban heat island effect, continuing to disproportionately impact the predominantly low-income residents (Hoffman et al., 2020). In addition to the environmental effects of the construction materials, low-income renters of color are more likely to live in housing that is older, substandard, and less maintained; these quality issues increase the risk of structural collapse and damage to people and properties during extreme weather events (Burby et al., 2003; Cash et al., 2020; Fussell, 2015; Krause & Reeves, 2017; Rosenbaum, 1996). Moreover, housing continues to be built in riskier areas and with less resilient materials, including new construction of affordable housing (Hammett et al., 2018; Mervosh, 2019; Uhlmann, 2018).

In NYC, these effects are not as straightforward. Although densely developed neighborhoods with masonry and steel apartment buildings do have higher overnight minimum outdoor temperatures (Eliezer et al., 2019), the same structures can reduce heat exposure in several ways: by gaining heat more slowly (Urban Green Council, 2014); by being more energy efficient and having lower energy costs than single-family homes (U.S. Department of Energy Office of Energy Efficiency & Renewable Energy, n.d.); by having less exposure to outdoor heat or cold due to adjacent unit walls (U.S. Energy Information Administration, 2013); and, by helping to shade streets and sidewalks, thereby reducing daytime surface temperatures relative to outer boroughs (City of New York, n.d., 2021).

Multifamily buildings constructed with masonry and steel are more able to survive flooding than single-family homes with wood frames, as illustrated by the storm surge during Hurricane Sandy (Sandy Regional Assembly, 2013). However, residents of larger buildings were still affected by damage to electrical, heating, elevator, and water supply systems and would benefit from flood hardening and other resilience strategies (Lane et al., 2013).

The development of public and affordable housing also has a distinct relationship with climate vulnerability. Inexpensive land tends to be located in areas of environmental risk, which contributes to the government's decision to place public housing in these geographies. One early study of floodplain areas in Austin found that such areas have been developed for multi-family housing, mobile homes, and single-family housing in low-income neighborhoods between 1990 and 2000 (Lee & Jung, 2014). More recent studies continue to document the relationship between flooding risks and affordable housing. In fact, approximately 9 percent of all subsidized or public housing projects in the US are in 100-year or 500-year floodplains (Mervosh, 2019; Peri et al., n.d.; Rosoff & Yager, 2017) and the number of affordable units exposed to flooding and sea level rise in the United States is projected to more than triple by 2050 (Buchanan et al., 2020). Coastal states are estimated to have at least some affordable housing units exposed to flood risk events at least four times year, with the most vulnerable cities highly concentrated along the northeastern corridor and in California (Buchanan et al., 2020). In some of these cities, over 90 percent of their

[4] This pattern does not always hold. For example, contaminants can also exist in neighborhoods that have undergone significant land use and demographic change. In New Orleans, formerly industrial sites have been converted to other uses, most commonly in predominantly White neighborhoods. (Frickel & Elliott, 2008)

relatively smaller affordable housing stocks are expected to be exposed to flooding. However, the study finds, NYC remains the most vulnerable in absolute terms (Buchanan et al., 2020).

In New York, 17 percent of the New York City Housing Authority's buildings are in the 100-year floodplain or Special Flood Hazard Area (SFHA), and this is expected to rise to 26 percent over the next few decades due to sea level rise (Yeung & Levers, 2022). NYCHA's Climate Adaptation Plan recognizes the need to prioritize the protection of critical infrastructure in these developments (New York City Housing Authority, 2023). Additionally, not all areas that flood are within FEMA-designated floodplains (See NPCC4, Rosenzweig et al., (Rosenzweig et al., 2024)).

In addition to the impact of housing development decisions on climate risk, disasters have a range of inequitable consequences for housing. Redeveloping public housing into mixed-income units after a disaster exacerbates the existing shortage of public housing units, as happened in New Orleans after Hurricane Katrina; this also shapes whether residents can (or want to) return as their neighborhood changes (Fessler, 2015). These changes can also emerge over time. After Hurricane Katrina, the neighborhoods that were slower to recover—which typically also had greater social vulnerability—became the fastest growing neighborhoods in the early 2010s, with gentrification being one factor in the newly accelerated growth (Peacock et al., 2014). Plus, the housing shortages after disasters—even without redevelopment—and the resulting rise in prices can play a role in neighborhood change (Fussell et al., 2010; Peacock et al., 2014).

3.2.2.2 Buyouts

Similarly, buyout programs initiated in response to repeated disasters have a variety of disparate impacts on low-income residents and residents of color (Kraan et al., 2021).

Although nationally wealthier counties have implemented more buyouts, the affected properties within those counties tend to have lower incomes and greater racial diversity (Mach et al., 2019). One study finds that whiter counties and neighborhoods have more access to federal buyout assistance, but homeowners in neighborhoods of color are more likely to accept that assistance (Elliott et al., 2020). This helps to explain why non-white neighborhoods in predominantly white counties see the greatest demolition (Elliott et al., 2020). In another study, the majority of FEMA-funded buyouts were found to be located outside of zones that HOLC had assessed. For the areas HOLC had graded in historic urban cores, most buyouts were located in redlined districts (Zavar & Fischer, 2021). In addition to inequities in the buyout process itself, other issues include unequal access to information about the process, dislocation from social networks, and relocation costs.

Buyouts may also facilitate racial segregation. One recent study that traced the path of over ten thousand federally funded buyouts across the country finds that retreating homeowners in majority-white neighborhoods are willing to endure 30% higher flood risk before selling to the government and relocating than homeowners in majority Black neighborhoods. The study also finds that white families in neighborhoods that utilize FEMA buyout money move to wealthier and whiter areas, while residents of majority-minority neighborhoods were more likely to move to neighborhoods that are majority-Black or majority-Hispanic (Elliott & Wang, 2023).

At the same time, wealthier, whiter communities are more likely to receive support for seawalls, funding to elevate homes, or drainage infrastructure (Nance et al., 2022; Siders & Keenan, 2020). Without this protective infrastructure, residents in low-income communities may want buyouts. However, when properties are undervalued during the appraisal process, people who want to move may not be considered eligible for some buyout programs despite the climate risks they face. Equity issues with benefit-cost analysis methods can compound concerns about buyouts (See NPCC4, Balk et al, (Balk, McPhearson, et al., 2024)). To qualify for federal FEMA funds, the cost of flooding must exceed the cost of acquisition and demolition, which can disproportionately exclude residents of neighborhoods with low land values (Patterson, 2018). FEMA has introduced an alternative method for determining cost-effectiveness, but the impact remains to be evaluated (Association of State Floodplain Managers, 2022; Siders, 2019). Without transparency around buyout decision-making processes, residents do not know how home values are being appraised or how the buyouts are being allocated, leading to the feeling that relocation is the only financially viable option being offered (Shi et al., 2022). Although buyouts are intended to reduce vulnerability to climate impacts, this outcome is not guaranteed without significant changes to those programs (Kraan et al., 2021).

Moreover, in hot housing markets, many people cannot afford a comparable home and may not be able to move to a less risky neighborhood (Shi et al., 2022). One study of a buyout program in New York after Hurricane Sandy, the New York Rising Buyout and Acquisition Program, found that 20 percent of households studied relocated to an area with exposure to coastal flood hazards. And 99 percent relocated to an area with higher social vulnerability (McGhee et al., 2020).

To better understand and address these types of issues, a series of workshops in 2022 discussed shared challenges, lessons learned, and recommendations for improving buyouts, including how they can be fairer (*Innovations in Buyouts Workshops*, n.d.). Additional work will continue to be needed to prevent and remedy the inequities to which buyouts can and have contributed.

3.2.2.3 Resilience-promoting investments

Disparities in parks (Rigolon et al., 2018), tree cover, and other green infrastructure investments contribute to inequities in climate risk and resilience. For example, one study finds that the public right-of-way has less tree cover in neighborhoods with higher proportions of residents who are Black, low-income, or renters (Landry & Chakraborty, 2009). This is related to redlining nationally: in one study of 37 U.S. cities, formerly redlined areas (i.e., D graded) have about 23 percent tree canopy coverage, whereas areas with the highest grading (i.e., A and B) have about 43 percent coverage today (Locke et al., 2021). Because higher HOLC grades are associated with significantly higher percentages of tree canopy coverage today, these neighborhoods not only can better mitigate urban heat and flooding but also gain health, aesthetic, and other benefits (Namin et al., 2020).

These patterns, however, are not identical across cities. In Baltimore, Black residents have more access to parks within walking distance, but white residents have more acreage of parks within walking distance, which are less congested (Boone et al., 2009). Baltimore's historical *de jure* segregation created predominantly black neighborhoods without park access until a period of white flight and suburbanization changed settlement patterns throughout Baltimore, resulting in Black residents living closer to the parks from which they had previously been excluded. Contextualizing current land use patterns is critical for understanding the impact of amenities over time.

Access to parks within walking distance in NYC is relatively robust, with nearly 99% of New Yorkers residing within a 10-minute walk of a park, according to a recent study by the Trust for Public Land (Rozon, 2023). However, the ability to reach larger parks is more limited without a car, and fewer of these areas are transit-accessible or near public and affordable housing. As such, according to the study, in New York, residents living in neighborhoods of color have access to 32% less nearby park space than those living in white neighborhoods and residents living in lower-income neighborhoods have access to 19% less nearby park space than those in higher-income neighborhoods. Moreover, a report from Natural Areas Conservancy found that natural areas are significantly cooler than the rest of the city, and so disparities in park access have consequences for heat exposure and health (Crown et al., 2023).

Today, resilience-promoting investments can continue to create inequities through several channels, including maladaptation and climate gentrification. In one example of how maladaptation can increase physical risks, the protection of individual shoreline segments can increase flooding and damages in other areas, and in some cases regional flood damages (Hummel et al., 2021). Structural mitigation—as defined by physical construction or engineering to reduce or avoid impacts on structures, such as raising buildings—also raises the cost of coastal redevelopment, making coastal areas more expensive and more exclusive (Gould & Lewis, 2018). The demand for waterfront property in NYC continues to outweigh flooding concerns, leading to high demand real estate markets that are seen as better candidates for structural mitigation. The higher building costs are then passed on to those who can afford to live in and develop these neighborhoods (i.e., the resilience pathway of climate gentrification) (Gould & Lewis, 2018). However, in one example of equity-focused resilience-promoting investments, NYC's Climate Strong Communities program aims to invest in infrastructure within vulnerable communities that have received fewer resiliency investments historically or post-Sandy (For more information on this program, see section 2.1).

Resilience-promoting investments in multifamily affordable housing developments have the potential to address some of these inequities. For example, energy back-up systems–particularly those coupled with rooftop solar–can help residents vulnerable to climate impacts and their social-economic consequences maintain power during heat waves and coastal storms. Although residential clean energy subsidies have largely gone to more affluent households (Borenstein & Davis, 2016), there are currently efforts to bring the benefits of renewable energy–from phone charging to medical equipment to cooling and heating common rooms–to environmental justice communities within the city.

Most of the benefits of green infrastructure go to areas with wealthier, whiter and better educated residents (Shokry et al., 2020), and parks are typically associated with gentrification processes (with the exception of historically Black post-industrial cities experiencing disinvestment and high rates of vacant land) (Triguero-Mas et al., 2022). Without anti-displacement strategies in place, resilience-promoting investments can have inequitable outcomes.

3.2.3 Geography and displacement

Different geographies have advantages and disadvantages that affect land costs, amenities, and residential settlement patterns.

3.2.3.1 Elevation

Both historically and today, elevation has been a factor in land use decisions. However, the relationships among elevation, development, and social vulnerability depend on each locality's social and environmental context. For example, inland cities tend to have residential patterns in which income correlates with elevation, but coastal cities see the reverse pattern (Ueland & Warf, 2006). Low-lying waterfronts may serve as an amenity that drives up land costs or as a disamenity because of its potential for industrial uses. For individual cities, context is key to understanding elevation as a factor in climate risk and who bears that risk today.

In NYC, low-lying marshes were historically considered an environmental disamenity. Even after sanitation infrastructure was introduced, historical marsh sites have continued to be disproportionately low-income, with housing prices rising with distance from these sites (Villareal, 2013). One study suggests that relative elevation may better correlate with socioeconomic status in New York; it also recognizes that some high-elevation areas, such as in Staten Island, may also have unwanted land uses and predominantly low-income populations, potentially because these areas used to be more difficult to access (Brisbane, 2014). Even within NYC, these mixed patterns demonstrate how elevation can be a complex factor in land use decisions that does not have a straightforward relationship with social vulnerability.

In some cities, climate impacts are making high elevation more desirable, leading to climate gentrification and displacement. Empirically, flood depth and lower ground elevation have been shown to be inversely associated with gentrification, causing higher-elevation neighborhoods to become significantly whiter and higher income (Aune et al., 2020). In the example of Miami-Dade County, the rate of single-family home price appreciation is positively correlated with higher elevation, and price appreciation in the lowest-elevation cohorts have not kept up since 2000 (Keenan et al., 2018). The high-elevation neighborhood Little Haiti has historically had little investment but is now experiencing a development boom, partly because of its low land costs. The neighborhood is predominantly low-income and Black, and its rising housing prices are now displacing long-term residents (Campo-Flores & Kusisto, 2019; WLRN, 2019). The literature on climate gentrification and displacement is explored further in Section 4.1 below.

Although elevation can contribute to land use and demographic patterns, there is a range of different evidence across contexts (and even within cities), with no straightforward or single explanation. When considering the effects of elevation in NYC, these relationships are equally nuanced.

3.2.3.2 Waterfronts and coasts

In some cities, coasts serve as amenities that attract investment and have higher property values. Although wealthier residents in some cities may currently be more likely to live in these flood-prone areas, they also have more resources to cope with disruption and disasters (Collins et al., 2018). In New York, building codes for new housing were strengthened after Hurricane Sandy, making new development more resilient (even on the waterfront), but not necessarily more affordable. Like elevation, waterfronts and coasts have highly context-dependent effects on land use and climate risk.[5]

However, the link between waterfronts and high-income residents has not always been a consistent pattern over time. In NYC, both the land uses and population associated with waterfronts have changed. For most of its history, the city's low-lying waterfront was largely used for industrial purposes; it wasn't until the 1960s that New York's waterfront began to be reimagined as a recreational and/or residential space (Platt, 2009). Many of these areas were not rated by HOLC because, at the time, they were not residential. As they became desirable places for residential development (including some built on landfill, such as Battery Park City), plans for affordable housing have not kept up with market pressure (Jacobson, 2018). Today, New York's waterfront has become a special point of interest among environmental justice advocates, due to new high-end real estate developments on the waterfront which can displace local residents (Turan, 2018).

3.2.4 Transportation

Transportation planning has implications for both land use patterns and climate risk. Access to transportation options and transportation infrastructure itself affects people's capacity to evacuate, how much disruption they experience during and after disasters, and certain physical characteristics of their communities.

[5] One study takes this contextual approach to analyzing the process of racial coastal formation on Sapelo Island, Georgia. The authors identify land ownership, employment, and barriers to inclusion in adaptation planning as factors in vulnerability to seal-level rise on this waterfront.(Hardy et al., 2017)

3.2.4.1 Disruption and evacuation

Transit disruption particularly affects communities with already-low access to transit, even if they are farther from the worst climate impacts (Faber, 2015). In addition to unequal access to public transit, renter, single-parent, low-income, and non-white households tend to have less access to personal vehicles—one factor in the slower and lower evacuation rates observed. (Living near congested city centers also plays a role in these rates) (Cutter & Emrich, 2006; Van Zandt et al., 2012).

These inequities are clear in New York: among all households in the lower quintile of income in the state, vehicle costs are 18 percent of income, on average; more affluent households have more vehicles, which comprise a smaller share of their income, and also have greater flexibility in hours and remote work (U.S. Bureau of Labor Statistics, 2021).

Additionally, federal infrastructure policy continues to favor highways over infrastructure for transit. Even when transit infrastructure exists, it often faces its own climate vulnerabilities. The ongoing PROTECT program intends to address these vulnerabilities (*Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation Program (PROTECT) | US Department of Transportation*, n.d.). In NYC, 79 percent of transportation and utility land uses that support essential infrastructure—electric and gas utilities, rail yards, airports, docks and piers, bridges, tunnels, and highways—are in the 100-year floodplain (Yeung & Levers, 2022). These infrastructure vulnerabilities compound disruption and evacuation concerns.

3.2.4.2 Urban renewal

Focusing on the transportation-related aspects of urban renewal, federally incentivized roadways were often built through low-income neighborhoods—including many redlined neighborhoods that were divided by highways—thereby increasing the amount of heat-absorbing land cover (Hoffman et al., 2020). Like the construction of housing or large complexes, these materials intensify the urban heat island effect in the immediate communities where they are located. The interplay between roadways, development, and redlining has a cumulative effect on how extreme heat becomes concentrated in low-income communities and communities of color. Another aspect of these linkages is that exclusionary zoning near suburban railway hubs has limited the stock of affordable, transit-accessible housing in metropolitan areas–again compounding the effects of housing discrimination, transportation inequities, and mobility to and from "greenlined" areas (Regional Plan Association (RPA), 2017).

3.3 Conclusion

The research on historical land use patterns and present-day climate risk is growing (Table 4: Evidence-Supported Mechanisms Between Land Use, Climate Risk, and Social Vulnerability), but more research is needed on how these patterns and relationship influence social vulnerability in particular local contexts. As flood maps are updated and risk projections change, revisiting studies with new data will be useful. Although the relationships between historical land use and climate risk are complex and context-dependent, they often have similar underlying mechanisms, such as lower land costs in risky areas, eroded political capital in marginalized communities, race-based practices that are distinct from but often related to socioeconomic factors, and so on. Many of these land use issues—past and present—are related to and reinforce one another. Without intentional, anti-racist work toward climate mitigation, adaptation, and resilience, NYC will risk perpetuating these inequities in new forms. This requires several key approaches:

1. Incorporating contextual equity and understanding the history of places down to the neighborhood level,
2. taking a holistic approach to reducing racialized vulnerability to climate shocks, including inseparable issues like housing and transit access, and
3. recognizing that the cost burdens of climate adaptation (e.g., higher energy costs, insurance premiums, relocation) affect people differently—particularly when considered alongside homeownership and wealth gaps—and can easily result in increased displacement risks.

Table 4: Evidence-Supported Mechanisms Between Land Use, Climate Risk, and Social Vulnerability

Note: Examples of studies supporting these mechanisms are referenced. * = Studies specific to or inclusive of NYC.

Past and Present Land-Use Practices	Impact on Current and Future Land Use	Impact on Climate Risk and Social Vulnerability
Redlining and Exclusionary Zoning	■ Disinvestment in green and resilient infrastructure (Hoffman et al., 2020*; Wilson, 2020) ■ Restricted mobility to areas with green infrastructure (Rozon, 2023*)	■ Hotter land surface temperatures (City of New York Department of Health and Mental Hygiene, 2021b*) ■ Less tree canopy (Locke et al., 2021*) ■ Inequities in disaster protection and recovery funding (Katz, 2021)
Hazardous and Industrial Land Uses	■ Placement and concentration of hazardous land uses (Kodros et al., 2022) ■ Restricted mobility and greater racial segregation (Mizutani, 2018)	■ Compounded and cumulative environmental health risks (Marlow et al., 2022) ■ Legacy pollutants released during foods and storms (Ibid.)
Housing and Other Development Decisions	■ Inexpensive land tends to be located in areas of environmental risk (Hoffman et al., 2020) ■ Placement of public and subsidized housing in risky areas (Uhlmann, 2018) ■ Affordable housing built with less resilient materials (Cash et al., 2020)	■ High exposure of public subsidized housing units to flooding and sea level rise (Rosoff & Yager, 2017*) ■ Gentrification and displacement post-disaster (Peacock et al., 2014) ■ Change in the composition of homebuyers in less expensive, flood-prone areas (de Koning & Filatova, 2020)
Managed Retreat: Buyouts	■ High percentage of buyouts in formerly redlined neighborhoods (Zavar & Fischer, 2021) ■ Greater demolition in non-white and underinvested neighborhoods (Elliott et al., 2020)	■ Inequities in buyouts shape who stays and leaves (Elliott & Wang, 2023) ■ Relocation to areas with higher climate exposure and social vulnerability (Shi et al., 2022)
Resilience-Promoting Investments	■ Inequities in parks, tree canopy in low-income, black areas (Boone et al., 2009) ■ Shoreline armoring affects demand for waterfront properties (Gould & Lewis, 2021)	■ Maladaptation: protection of shoreline can increase flooding in other areas (Hummel et al., 2021) ■ Climate displacement and gentrification (Gould & Lewis, 2018)

4 Identifying Risks at the Intersection of Historical Patterns of Injustice and Climate Change

Based on the above analysis of the ways that historical and contemporary land uses and a host of other factors shape the risks of populations in NYC, the NPCC investigated potential metrics that could be used to assess the ongoing vulnerability of local populations to climate change. In its last report, NPCC3 examined and assessed methodological approaches used for social vulnerability analysis and mapping in NYC and elsewhere. In this iteration, NPCC4 proposes to capture another dimension of social vulnerability to climate change: climate displacement. It is evident that displacement is projected to be one of the most devastating and widespread impacts of climate change (Cash et al., 2020; Melix et al., 2023). However, it is not always clear what the relationship is between social drivers of displacement—whether as the result of eviction, unaffordable housing costs, or poor-quality housing (Citizens Housing Planning Council (CHPC) of New York City, 2002; City of New York, 2023b) and climate risks and hazards. Fortunately, an emerging body of research has added to our understanding of the ways that climate impacts and adaptations may contribute to changes in community characteristics and potential displacement of vulnerable residents through interactions with social and economic drivers of displacement (K. Best & Jouzi, 2022).

Understanding and quantifying the compounding effects of climate change, displacement, and socio-vulnerability is crucial for the ability of local governments to adopt mitigation and adaptation policies that do not entrench and further the kind of unjust land patterns and development that the previous sections detailed. In this section, we summarize the state of the science and research on climate gentrification, to situate the vulnerability of specific populations to displacement which results from a complex interaction of factors and forces. We then suggest that the City adopt a recently proposed Climate Displacement Social Vulnerability (CDSV) score that integrates socio-economic, climate risk, evictions, and housing data to better measure the risks of climate displacement at the census-tract level in NYC (Tedesco et al., 2024). If the City is able to measure the risks of climate displacement at an appropriate scale, such as at the neighborhood level, then it could determine whether and how new climate-resilient infrastructure or infrastructure investments might risk displacement and identify ways to mitigate that risk.

4.1 Defining and Understanding Climate Displacement and Gentrification

Displacement is most often defined as the involuntary movement of an individual or family from their home or neighborhood. This definition has traditionally not included the ways that climate impacts and adaptations can contribute to displacement of vulnerable populations (Farbotko, 2019; J. K. Maldonado et al., 2014; Shokry et al., 2020, 2022; Tedesco et al., 2022; Triguero-Mas et al., 2022), including bluelining (Fleming et al., 2022), and decreasing health conditions associated with climate hazards, such as flooding or heatwaves (Rocque et al., 2021). Several definitions have been used for climate displacement. However, as a general matter, climate displacement is understood as forced migration occurring entirely or partially from environmental events or from long-term changes related to climate change. (Tedesco et al, 2024). Connecting displacement and climate or environmental hazards is a complex task due to a multitude of environmental and climatic influences that impact the ability to stay in one place (Miller & Vu, 2021), to the relatively coarse spatial and temporal resolution of currently available datasets (de Sherbinin & Bardy, 2015), and because current assessment models miss the feedbacks among the socio-economic and climate systems (Rising et al., 2022).

4.1.1 Pathways to Climate Displacement

Keenan et al. (2018), in one of the most cited works on this topic, identify three types of climate gentrification: the "superior investment pathway," the "cost-burden pathway," and the "resilience investment pathway." Under the *superior investment pathway*, households move from high-risk geographies to low-risk ones in order to avoid climate hazards. This pathway is evident in Miami, Florida, for example, where price depreciation in coastal zones induce high- and moderate- income households to move into higher elevation areas, often displacing moderate- to low-income households in historical communities of color (Keenan et al., 2018). The *cost-burden pathway* describes scenarios in which only high-income households can afford to remain in high-risk but desirable (usually coastal) areas. As the cost of insurance, repairs, taxes, etc. rise, moderate and low-income households are forced to leave these areas (Knuth, 2020). In the *resilience investment pathway*, low-income households are similarly displaced as an unintended consequence of public investments in adaptation, such as green infrastructure, that lead to rising property values that price residents out (Shokry et al., 2020).

As this climate gentrification and displacement literature has developed over the past five years, researchers have further complicated these pathways, recognizing that climate gentrification is a dynamic process that varies across contexts and may result from a combination of the above "pathways" Best & Jouzi and Black et al (2022; Black et al., 2013), for example, characterize climate gentrification as "a multi-causal, multi-spatial process that involves dimensions of both natural and human systems…[and] happens across global and regional scales spatially and from the past to future temporally." Climate change has the potential to exacerbate other forces of displacement, such as neighborhood disinvestment, rising housing costs, and extreme weather events like flooding and heat (Gregg & Braddock, 2020). For example, Li & Grant (Li & Grant, 2022) find evidence that the major factor steering Miami homebuyers to higher ground are expensive flood insurance and the historical record of flooding, rather than scientific projections of sea level rise. On the other hand, coastal residents migrate to high elevation neighborhoods like Little Haiti in Miami, a once redlined community starved of investment for decades and only now targeted for accelerated investment through tax incentive programs.

4.1.2 Climate Displacement Metrics

Researchers have used a variety of measures to understand the potential drivers of climate displacement or gentrification: disproportionate price appreciation in high-elevation areas in Miami Dade County (Keenan et al., 2018); green resilient infrastructure siting and minority population in Philadelphia (Shokry et al., 2022); low-carbon infrastructure, housing prices, the number of lower-income and non-white residents in Seattle (Rice et al., 2019); and, agent-based modeling simulation of flood hazards and the outmigration of high-income households (de Koning & Filatova, 2020).

Aune et al. (2020) move beyond these single measures and creates a gentrification index based on education level, population above the poverty limit, and median household income. The authors use the index to identify gentrification-eligible census tracts in New Orleans before Hurricane Katrina. Of these tracts, the ones that did undergo gentrification by 2010 had experienced less flooding, were at higher elevations, and were more likely to have changed from majority black to majority white, among other demographic changes. The authors conclude that "High elevation, low-income, demographically transitional areas are at highest risk for future climate gentrification (Aune et al., 2020)." This study demonstrates the importance of examining how neighborhoods' physical characteristics and gentrification pressures interact with disasters.

Tedesco et al. (2022) develop another index, the Climate Gentrification Risk Index (CGRI), from data on rental properties, evictions, socioeconomic status, and environmental risk. The authors identify two neighborhoods, one in Miami and one in Tampa, with trends that are consistent with climate gentrification. In addition to previous studies' focus on demographics and climate hazards, this analysis points to transitional land uses and flexible zoning in low-exposure areas as potential drivers of climate gentrification.

Best et al. (2023) use machine learning to categorize U.S. East Coast counties into four typologies of social, housing, and environmental vulnerability. The researchers interpret each cluster as being defined by the superior investment pathway, disinvestment, affordable development, and a mixed typology. However, they recognize that these larger-scale patterns do not reflect heterogeneity within counties (such as at the tract level), and this method cannot speak to the exact relationship between climate change and gentrification.

Melix et al. (2023) use principal components analysis to quantify displacement pressures , focusing on demographic, socioeconomic, sea-level rise, and housing. Each component represents a combination of variables (e.g., "neighborhoods with low job proximity scores and low proficiency schools"), which they use to identify neighborhoods at risk of climate displacement. They find that high-displacement risk areas in three Florida cities also tend to be inland, making them likely to receive migrants from coastal areas, and designated as opportunity zones–two factors that may accelerate climate gentrification processes and ultimately displacement.

Finally, S. K. Kim & Park (2023) demonstrate that migration is responsive to climate risk, and that this migration to lower-risk areas leads to gentrification–in this case, both the in-migration of higher-income households and the out-migration of lower-income households and people of color. Unlike previous studies, this analysis is able to causally connect climate change, migration, and displacement (rather than illustrating displacement alongside climate impacts).

4.1.3 Gaps and Opportunities

From this body of literature, it is clear that climate displacement is a context-specific phenomenon that interacts with social, environmental, and land-use patterns. Displacement can happen alongside climate change, because of climate change, and intertwined with climate change. Displacement can result in the mobility of socially vulnerable populations to areas where they are likely to be more exposed to climate risks or are more socially vulnerable because they can only access less quality housing and neighborhoods. Displacement can occur on the heels of large-scale investments in climate adaptation and resilience —ranging from green infrastructure to seawalls to buyouts. Displacement often occurs when socially vulnerable and historically marginalized populations are priced out of a neighborhood or experience cultural displacement as neighborhood demographics and character changes. The existing research illuminates some of these aspects of climate displacement, but a more holistic measure remains necessary.

4.2 Measuring Climate Displacement Vulnerability for New York City

Tedesco et al. (2024) propose a metric that integrates socio-economic vulnerability, climate risk, evictions, and housing data to better measure the risk of climate displacement at the neighborhood level in NYC. Unlike previous climate gentrification measures, it directly speaks to the multi-dimensional factors that can inform displacement risks. To our knowledge, this is the first time that *multiple* climate hazards are studied *in conjunction* with displacement and socio-vulnerability for NYC. The CDSV is a starting point for future research on how to capture and assess the complex nature of climate displacement using multidimensional indices which are likely to lead a more robust evidence base to assess this risk in different areas of the country. Below we describe the proposed Climate Displacement Social Vulnerability (CDSV) score and assess its strengths and limitations as applied to NYC.

4.2.1 Data and methods

The proposed Climate Displacement and Socio-Vulnerability (CDSV) score for NYC (Tedesco et al., 2024) is designed to account for climate hazards, displacement risk, and social vulnerability factors based on publicly available datasets. These databases include the FEMA National Risk Index, New York City's Displacement Index, and the Social Vulnerability Index. Each is described below. The goal is to identify those areas where risk of the combination of the three factors is the highest (e.g., hotspots due to compounding effects). As such, for each climate hazard the CDSV score is computed from the linear combination of the three factors equally weighted in Equation 1

4.2.1.1 FEMA National Risk Index

The Climate Score (ClimSc) is based on a national dataset created by FEMA, the National Risk Index (NRI), to identify communities most at risk of specific climate hazards (FEMA, 2023). The NRI combines the frequency of natural hazards with social factors and resilience capabilities. Of the 18 natural hazards, the CDSV for NYC applies the NRI to evaluate the following hazard risks: 1) Coastal and 2) Fluvial Flooding; 3) Heatwaves; 4) Hurricanes and 5) Winter Weather (winter storm events in which the main types of precipitation are snow, sleet, or freezing rain). These hazards were chosen by Tedesco et al, (2024) because they have been previously identified as priority climate hazards for the City. One caution that the researchers note regarding the Climate Score (ClimSc), is that because it is based on national data set, it is not a substitute for more granular localized investigations of hazard risks that are available (see for example, NPCC4, Rosenzweig et al (2024) which presents more detailed discussion of coastal and fluvial flooding hazards). As a reference Figure 6 shows an example of the FEMA National Risk Index ranking for the five selected hazards in the CDSV for NYC.

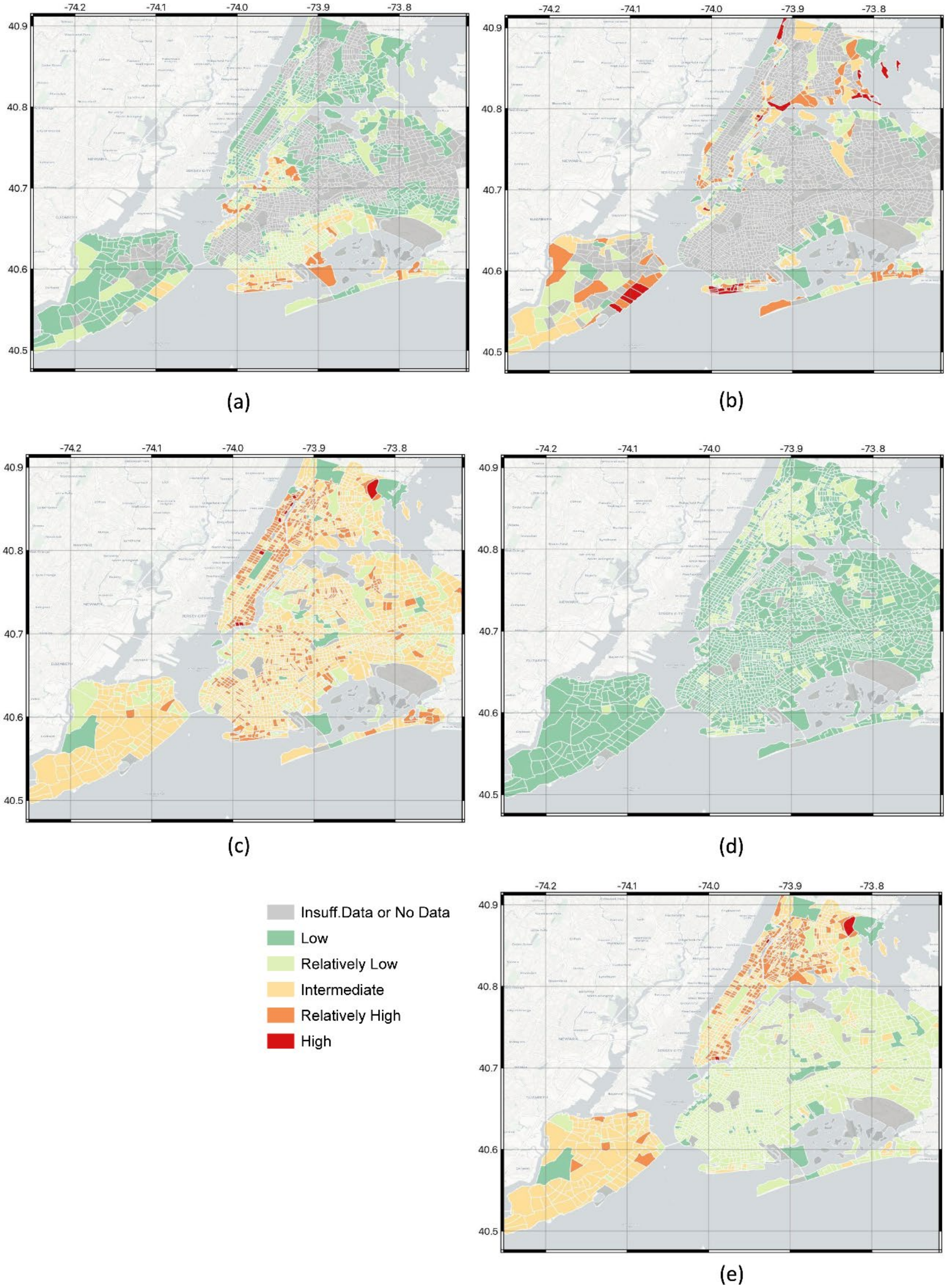

Figure 6: Risk ranking from the FEMA NRI dataset over NYC for the a) coastal flooding, b) riverine flooding, c) heatwaves, d) hurricanes and e) winter weather. Source: FEMA National Risk Index

4.2.1.2 NYC displacement risk dataset

The Displacement Score (DispSc) is constituted from displacement risk data obtained from the NYC Department of City Planning (City of New York Department of City Planning & City of New York Housing Preservation and Development, 2023). NYC defines displacement as the “involuntary movement of an individual or family from their home or neighborhood, whether as the result of eviction, unaffordable housing costs, or poor-quality housing”. The NYC displacement risk builds on variables listed in Local Law 78 (Local Law 78, 2021), which requires an online citywide equitable development data tool including data from six categories, disaggregated by race and ethnicity. Specifically, the Displacement Index uses three categories of data: Population Vulnerability, Housing Conditions, and Market Pressure. Population Vulnerability refers to the demographic and socioeconomic characteristics of a neighborhood's residents that may make them more susceptible to displacement. It includes factors such as race/ethnicity, income, and the share of a household's income spent on rent. Housing Conditions refer to the characteristics of housing in a neighborhood that can either help stabilize households or lead to greater instability. It includes variables such as the condition of the housing stock, whether a household rents or owns, and applicability of various programs or regulations limiting rent increases. Market Pressure refers to the broader conditions affecting neighborhoods that tend to make it harder for lower-income residents to remain or find new housing in the area and includes data points related to changes in the housing market and demographic composition of a neighborhood, among others.

The data is generated at the Public Use Microdata Area (PUMA) scale, a statistical area defined by the US Census (United States Census Bureau, 2023c). PUMAs in NYC generally approximate Community Districts, of which there are 59 (Tedesco et al., 2024). The Displacement Risk Map, which is not broken down by race and ethnicity, is generated at a smaller geography, Neighborhood Tabulation Areas (NTA) (City of New York Department of City Planning, 2023a). NTAs are groupings of census tracts that are designed to approximate neighborhoods. The index is obtained through the incorporation of several data sources that are surveys, such as the American Community Survey (ACS) (United States Census Bureau, 2023a) and the Housing and Vacancy Survey (HVS) (United States Census Bureau, 2023b), meaning the data are based on a sample and there is a margin of error (MOE) associated with each data estimate. As an example, Figure 7a shows the displacement risk used in this study. As in the case of FEMA NRI, the CDSV score for NYC converts the displacement risk categories into numerical values using the following correspondence: Very Low = 0; Relatively Low = 25; Intermediate = 50; Relatively High= 75; Very High= 100. We name this the Displacement Score (DsipSc).

4.2.1.3 SOVI

For the socio-vulnerability score (*SOVISc*) the CDSV uses the Social Vulnerability Index (SoVI) (Cutter et al., 2003). The index synthesizes 29 socioeconomic variables, which the research literature suggests contribute to reduction in a community’s ability to prepare for, respond to, and recover from hazards. The data are compiled and processed by the Hazards and Vulnerability Research Institute at the University of South Carolina and are standardized and placed into a principal components analysis to reduce the initial set of variables into a smaller set of statistically optimized components (*HVRI Data and Resources - College of Arts and Sciences | University of South Carolina*, n.d.). The CDSV normalizes the SoVI score value between 0 and 100 over the NYC area (Figure 7b).

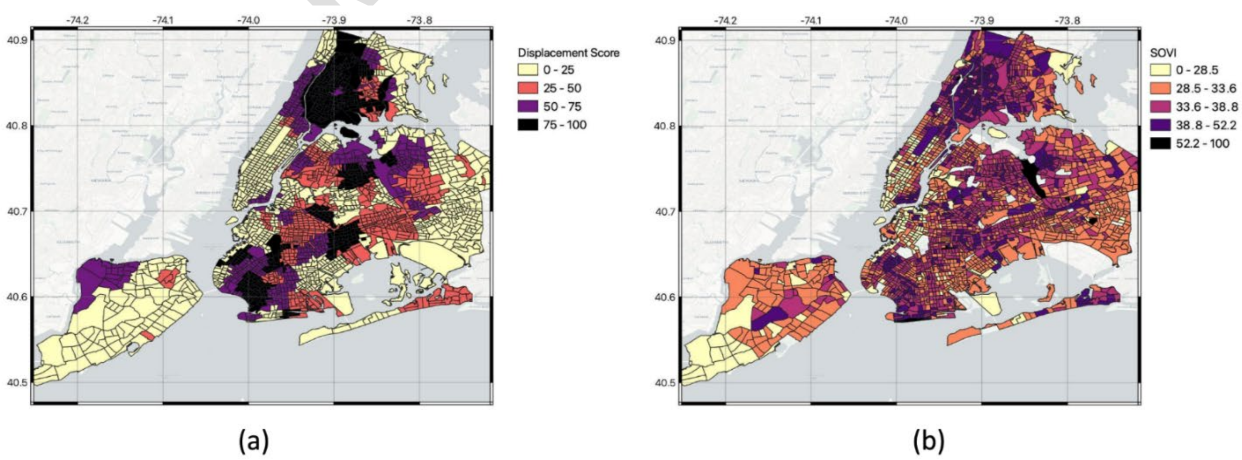

Figure 7: Displacement (a) and SOVI (b) scores over NYC. The SOVI score is normalized to the NYC values.

4.2.1.4 Computation of the Climate, Displacement and Socio-Vulnerability (CDSV) score

For each climate hazard e the CDSV score is computed from the linear combination of the three factors equally weighted in Equation 1 (Tedesco et al., 2024):

$$\mathrm{CDSV_i} = (\mathrm{ClimSc_i} + \mathrm{DispSc} + \mathrm{SOVISc})/3$$

Equation 1: Climate, Displacement and Socio-Vulnerability (CDSV) Score. V_i is the specific natural hazard. DispSC is displacement score based on the NYC Displacement Risk dataset. SOVISc is SOVI score based on (Cutter et al., 2003).

The subscript *i* refers to the specific natural hazard (e.g., coastal flood, heatwaves, etc.). The $\mathrm{CDSV_i}$ score can range between 0 and 100 with 0 being the lowest impact due to the combination of the three factors and 100 being the highest (Tedesco et al., 2024). The CDSV is also complemented by a Climate Displacement and Socio-Vulnerability Rank (CDSV_R) obtained by translating the numerical values into categories using k-means classification (Wu, 2012) and adopting the five different classes of *Very Low*, *Low*, *Intermediate*, *High,* and *Very High* (Tedesco et al., 2024).

4.2.2 Results

Figure 8 shows the CDSV scores obtained for coastal (a) and fluvial flooding (b) heatwaves (c) hurricanes (d) and winter weather over NYC (Tedesco et al., 2024). Figure 9 shows the relative contribution of socio-vulnerability (left column), displacement (middle column) and climate hazards (right column) to the CDSV in the case of the different climate hazards. Values can range between 0 and 1, with low values meaning that the particular factor under consideration weakly contributes to the CDSV and high values meaning that it is a dominant contributor. These figures illustrate, for example, a relative minor role over most of our study areas in the case of hurricanes (Figure 9 j, k, and l) where the socio-economic component plays a large role in south Staten Island and the Lower East Side of Manhattan. In contrast, in the case of heatwaves, all three factors tend to contribute to the computed CDSV in a more balanced way (Figure 9 g, h, and l), with displacement playing a negligible role in lower Manhattan and the climate factor playing a larger role in mid-Manhattan and, again, the southern portion of Staten Island.

In order to better identify the location of the areas at highest risk of exposure to the combination of climate, displacement, and socio-vulnerability factors, Tedesco et al (Tedesco et al., 2024) ordered the top 10 CDSV values for the five hazards. The tract with the highest occurrences of top 10 CDSV values is located along Harlem River Drive, near the subway station on 155th street. The 2016 Census (American Community Survey) reports 7,601 people for this tract with an unemployment rate of 27.7%, a poverty rate of 49.3 %, a per capita income (PCI) of $10,982. 34 % of the residents don't have a high school diploma, 30.2 % are younger than 17 years, 31.8 % are single parents and 99.8 % belong to a minority, with 85.3 % of the population not having a vehicle. As a comparison, the NYC average values for the same quantities are: 19.4 % (no high school diploma), 21.1 % (younger than 17 years), 10.7 % (single parent), 67.4 % (minority) and 43.4 % (no vehicle).

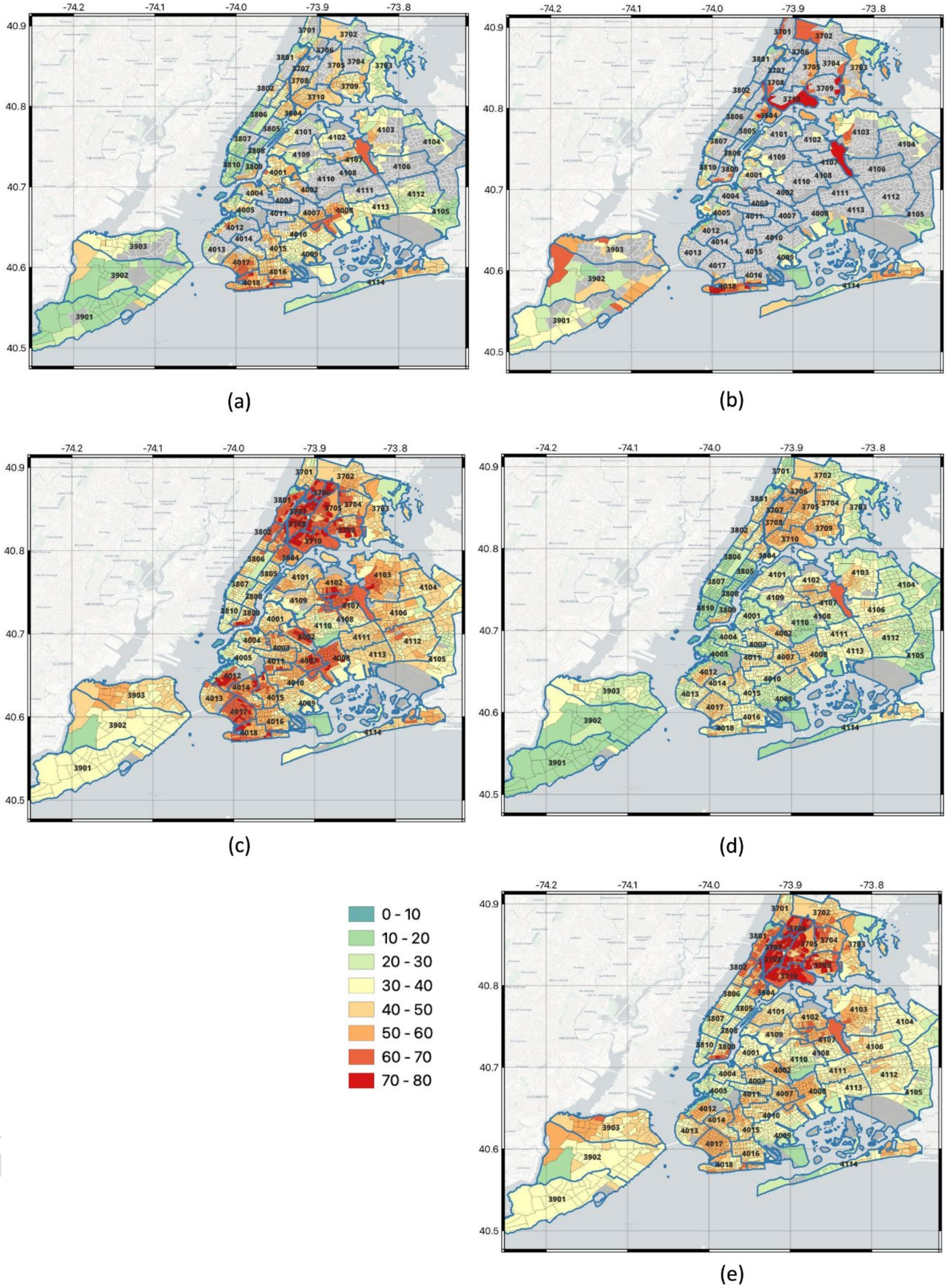

Figure 8: CDSV score for a) coastal and b) riverine flooding, c) heatwaves, d) hurricanes and e) winter weather for the five NYC boroughs. Thick lines and numbers represent PUMA areas and their extent.

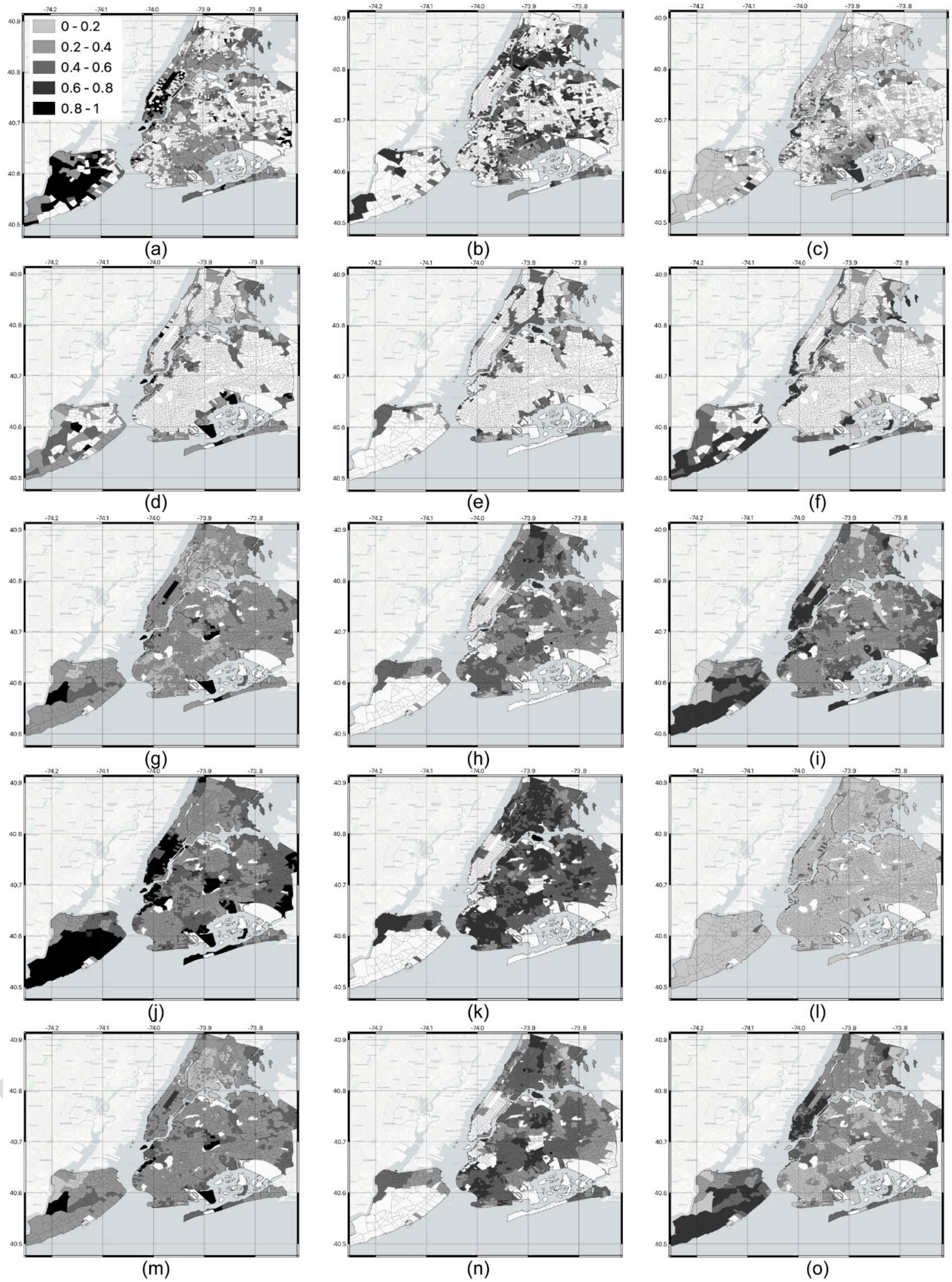

Figure 9: Relative contribution (ranging from 0 to 1) of the socio-vulnerability (first column), displacement (mid column) and climate hazards (right column) in the case of coastal (a,b,c) and riverine (d,e,f) flooding, heatwaves (g,h,i), hurricanes (j,k,l) and winter weather (m,n,o) to the computed CDSV score.

The second-highest ranked tract is located in the Bronx, containing the 182-183rd street subway station and it is home to 4,142 people. The PCI is $11,675, and more than half of the population (52.4 %) live below the poverty line. Similar to the case of the Ralph J Rangel Houses, roughly 30 % of the population is younger than 17 years of age with 82.2 % not having access to a vehicle. Also, as in the previous case, 99.3 % of the population belongs to a minority, 91 % lives in multi-unit, and 31.9 % has limited English skills, with 39.2 % not having a high school diploma.

A second tract ranked highly, according to CDSV top 10 values, is located in southeast Manhattan. This area is home to 10,765 people (according to the 2016 Census) of which 10.7 % are unemployed, 49.8 % have no high school diploma, 26.3 % are over 65 years of age, and 17.9 % are below 17 years of age. The PCI here is slightly higher than the other places, being $14,554 and with a percentage of 39.3% of the population who live below the poverty line. Similar to other areas ranking high in terms of combined top CDSV values overlapping from multiple hazards, 95.6 % of the population belongs to a minority, 81.2 % have no vehicle, and 43.8% speak limited English.

The census tract located in south Brooklyn (also within the top CDSV score) contains 2,460 people. The relative percentage of people belonging to a minority is smaller than in the previous cases (43.9 %) with the percentage of people living below the poverty line down to 27.3 % and a PCI of $22,011, almost doubling the one found for other areas discussed above. Here, the percentage of people with disabilities is relatively high (34.9 %), and so is the percentage of people older than 65 years of age.

The last tract where the CDSV has three top 10 values is located along Brighton Beach. This tract hosts 4,062 people with a PCI of $17,489, an unemployment rate of 15.7%, and a percentage of minority of 12.1%. Here, more than one third (37.2 %) of people are 65 years or older, and only 13.4% are younger than 17 years. The percentage of people with no high school diploma is relatively low (9.1%), but the percentage of people speaking limited English is relatively high (49.8%).

Building on data provided by the NYC's Mayor Office concerning changes in socio-economic and housing conditions for three different periods (2000, 2008-2012, and 2015-2019) (City of New York Department of City Planning & City of New York Housing Preservation and Development, 2023), Tedesco et al (Tedesco et al., 2024) additionally analyzed how such conditions have been changing for those areas where relatively high values of CDSV were obtained in order toto understand some of the socio-dynamic processes associated with or driving the combined risk of climate hazards and displacement and the populations at risk. To further this understanding, the study grouped the CDSV scores into 5 classes using a K-means based approach (Wu, 2012) and refer to the 5 classes as Very High, High, Intermediate, Low and Very Low.

Focusing the attention on those areas classified as Very High and High, for example, the study identified the following PUMA regions: # 3705 through #3710 in the South Bronx; # 4017 in South Brooklyn, # 4012 in Southeast Brooklyn, and # 4008 in Queens. The areas in the South Bronx showed a decrease in the Median Home Value between 2008-2012 and 2015-2019 up to more than 10 % (e.g., 3705 Figure 10) and a corresponding increase in rent of the same order of magnitude. These areas are characterized by a high percentage of Latin/Hispanic people (on average above 65 %). For the inland areas, the Latinx/Hispanics population has increased up to ~ 10 %, with the increase being smaller for the regions along shorelines (e.g., 3710). For some of the PUMA sectors, such as # 3706, the percentage of White people halved between 2000 and 2018 (from 11 % to 5.6 %) where for the PUMA # 3707 and 3708 the percentage of African Americans has reduced by 6-8 %. The increase in rent and the decrease in home values point to an increased financial stress for the already vulnerable populations living there.

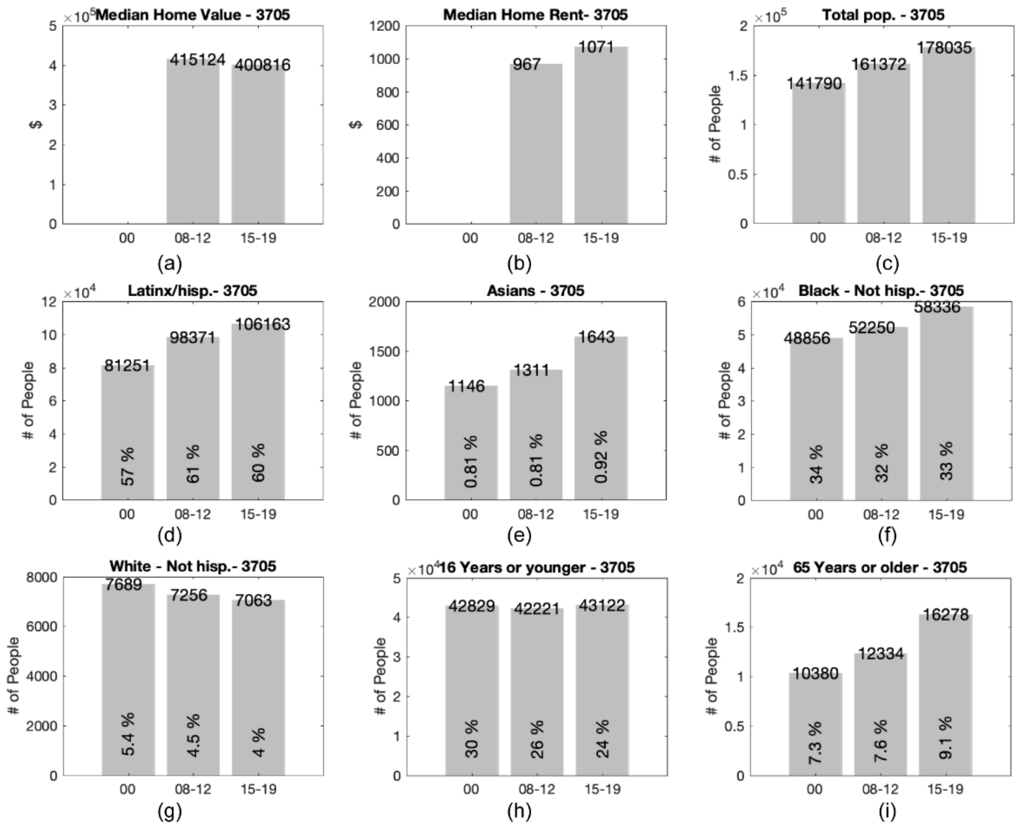

Figure 10: Changes in a) Total population, b) number of Black-Not Hispanics, c) Latinx/Hispanics, d) Asians, e) Whites, f) people who are 16 years or younger , g) people who are 65 years or older, h) Median Home Value and i) Median Home rent for the years 2000 , 2008-2012 and 2015-2019 for PUMA 3705. Percentage values within the gray bars in panels b through g represent the relative percentage of the population for the corresponding class with respect to the total population.

The PUMA sector in South Brooklyn (4017) shows, differently from the South Bronx areas, an increase in both the median value and the rent. The median value increased by roughly 20 % between 2008-2012 and 2015-2019. The increase for rental was a similar order of magnitude. For the PUMA #4017, the Latinx/Hispanic population has doubled from ~ 8 % in 2000 % to 16 % in 2015-2019 of the total population, similarly to Asians, whose percentage increased from 23 % in 2000 to 43 % in 2015-2019. For the same region, the number of White people drastically reduced from 65 % of the population in 2000 to 36 % in 2015-2019.

In the case of PUMA # 4008 the median home value did not considerably change between 2008-2012 and 2015 – 2019, with a relatively small increase in the median home rent. In this area, the study noted an increase of the Asian population, which tripled in terms of the number of people and doubled in terms of percentage relative to the total population. Such increase is even more substantial for PUMA #4012, in Southeast Brooklyn, showing almost doubling of Asians (from ~ 30,000 to ~ 55,000) with a change in the relative percentage from 22 % to 36 %. Differently from PUMA #4008, however, the studied noted a substantial increase in the median home value by 27 % from the period 2008-2012 to the period 2015–2019.

The study also investigated the relationships between the CDSV and racial, ethnic, and health factors to study potential linkages that could provide suggestions for future policies or recommendations. These included health data (e.g., number of adults with asthma and diabetes) and racial/ethnicity data obtained from the recently released Climate and Economic Justice Screening tool (Executive Office of the President of the United States Council on Environmental Quality, 2023) and spatially co-registered with the CDSV scores at census tract level. In the case of riverine flooding, the study observed a systematic decrease of the median value of the percentage of White people as the CDSV score increases. This is accompanied by a significant increase of the percentage of Latin/Hispanic people and also Black people.

In the case of heatwaves, the median value of the percentage of White people is minimum for low CDSV values, reaching a peak in the case of CDSV binned values between 30 and 40 and dropping considerably after reaching a

CDSV value close to 0. In the case of Latin/Hispanic people, the computed median values begin to increase after the CDSV binned values of 30-40. An increase is also observed in the case of Black people for this hazard.

Similar results were observed in the study for areas affected by hurricanes, winter weather, and heat wave outcomes showing the median value of the percentage of White people belonging to high CDSV values decreasing with CDSV scores and the percentage of Latin/Hispanic and Black people increasing, with the Latin/Hispanic people reaching the highest values.

The study observed more generally that the relationship between CDSV and the median value of the percentage of people belonging to racial/ethnic classes are not statistically significant in the case of coastal flooding. This is also true in the case of White people and heat waves CDSV score. The remaining cases showed statistically significant associations between median values and binned CDSV score (either at 95% or 99 % level). It is important to note that Tedesco et al. (Tedesco et al., 2024) focus on exploring linear relationships between the values reported on the y axes and those on the x axes of the different panels. Exploring other non-linear formulas, such as quadratic or polynomial of higher grade, might unveil other relationships that cannot be discovered with the linear approach, though it would require a deeper understanding of the processes driving such relationships to avoid the risk of overfitting the model to achieve a higher correlation without considering causality.

The percentage of White people exposed to CDSV riverine flooding and winter weather decreases, respectively, by 1.3 % (riverine) and by 1.12 % (winter weather) per CDSV value. The percentage of Black people increases with increasing CDSV values for all hazards but coastal flooding, with hurricanes showing the largest increase (1.35 %/CDSV), followed by riverine flooding (0.52 %/CDSV) and winter weather (0.34 %/CDSV) and heatwaves (0.37 %/CDSV). In the case of Latin/Hispanic people, the only negative trend (-0.92 %/CDSV) is found in the case of hurricanes. Trends are similar in the case of winter weather (0.99 %/CDSV) and heatwaves (0.84 %/CDSV), with a relatively lower value in the case of riverine flooding (0.66 %/CDSV).

Finally, in view of the compounding effects of heatwaves and health (Madrigano et al., 2015), which can lead to deteriorating health conditions or premature mortality, the study also analyzed the relationships between the CDSV in the case of heat waves and the number of people diagnosed with asthma and with diabetes. In both cases, the study observed a strong relationship between the CDSV computed values and the median number of people diagnosed with the two illnesses. This points out the potential risks of compounding effects on health for those who already have such conditions in areas where the combination of climate, displacement, and socio-vulnerability is the highest. The correlation coefficients between CDSV Heatwaves and median values of people above 18 years of age with asthma and diabetes are $R^2 = 0.82$ (asthma) and $R^2 = 0.92$ (diabetes), both statistically significant at a 99% level ($p<0.01$). In the case of the two illnesses considered here, we find an increase of 97.1 (diabetes) and 56.5 (asthma) people per CDSV value.

4.3 Conclusion and Limitations

As reported, Tedesco et al. (Tedesco et al., 2024) developed a Climate, Displacement, and Socio-Vulnerability (CDSV) score for multiple climate hazards (coastal and fluvial flooding, heat waves, hurricanes, and winter weather) over NYC. Following Tedesco et al. (2022), the researchers based the scores on publicly available datasets provided by FEMA, the NYC Dept. of City Planning, and the University of South Carolina. The score captures the relative contribution of climate hazards, displacement risk, and social vulnerability to the total score over the different areas of NYC and the ways that socio-economic and demographic conditions have changed starting in 2000 for those areas where the compounding effect of multiple risks and hazards is the highest. Such areas are located in the South Bronx, South Brooklyn, and Queens.

The study also quantifies linkages between the CDSV scores for the different climate hazards and health as well as for racial/ethnic indicators. The results indicate that, except for the case of coastal flooding, the percentage of White people decreases as CDSV scores increase where the percentage of Black and Latin/Hispanic people increases, with the latter showing the strongest correlation. The results also show a statistically significant relationship between the median number of people with asthma and diabetes and the CDSV score in the case of heat waves.

Given the results reported, the CDSV score might be used by the City to help inform decision-making about climate investments that account for both socio-economic vulnerability and displacement. It contains the potential to help guide where and how to target adaptation strategies and resilience investments to avoid or reduce the chance of maladaptation outcomes and climate gentrification (Tedesco et al., 2024). Importantly, the results demonstrate that the sensitivity of the population to the combination of climate hazards, displacement, and socio-vulnerability has been increasing over the past decades because of the evolution of socio-demographic factors and to the geographic regions where the combined effect is the highest. There appears to be a strong correlation between people belonging to specific racial and ethnic groups and the combined effects of the three factors accounted for in the scores, highlighting the racial reverberations of climate change impacts on those groups who are already carrying the burden of social and racial segregation. This is also true for illnesses such as asthma and diabetes, reinforcing the inter-generational climate justice aspect of climate change, with areas where the combined impacts are greater being home to a high number of ill people.

The proposed CDSV score and methodology, however, do contain limitations that can be addressed through further research. One limitation consists of the use of the specific datasets used in this study. First, as previously mentioned, the datasets used by FEMA to generate the NRI database are limited relative to what is known about some of the climate hazards, such as flooding, in NYC. The city can and should utilize climate data generated for this Report that is more specific regarding different types of flooding, for example, through the use of datasets at enhanced spatial resolution and accounting for local events that are missing from the NRI. This more granular data might improve the understanding of the spatio-temporal behavior of the CDSV. Similar granularity for the socio-vulnerability dataset would be valuable as well, akin to the recommendations made in the NPCC3 report to utilize specific SOVI indicators to better assess neighborhood vulnerability in NYC. In this regard, a revised version of the FEMA NRI which now includes the SOVI dataset and an analysis of the CDSV values obtained using the two distinct socio-vulnerability datasets would be a useful exercise to understand the robustness of the results reported in Tedesco et al.(Tedesco et al., 2024) and here discussed. Similarly, one drawback of incorporating all 29 SOVI indicators with New York City's displacement index is the likelihood of duplication in some of the vulnerability metrics. A more fine-tuned analysis, making use, for example, of Principal component Analysis (PCA) might reduce or eliminate the risk of duplication. Nevertheless, this is not straightforward as it is not clear how the socio-vulnerability terms are used by the City to generate the displacement index as we were not able to obtain such information. Finally, the study authors note that the assessment of their results in terms of margins of error (MOE) was not performed given the absence of MOEs with the currently available FEMA NRI. Although the FEMA NRI team is currently working to build this, and preliminary validation is underway using historical period, the authors note that the results reported in Tedesco et al.(Tedesco et al., 2024) might be relatively robust in terms of errors, given that most of the analysis is focused on the areas with the top CDSV values.

5 Best Practices for Climate Adaptation Planning and Investment

There are significant links between climate risks, adaptation investments, housing, socio-economic inequalities, and residential mobility (Section 4), that shape the equity outcomes of municipal resilience and recovery projects. Climate impacts and resiliency measures cannot be examined in isolation from other processes at play in a community. Because of this complexity, there is no singular approach to equitable climate resilience that is broadly applicable to NYC. Instead, diverse, multiple, and overlapping approaches must be developed with local input to adapt to the unique context of each community.

In a review of the literature relating to equitable climate adaptation planning, two general themes emerge as central to achieving equitable climate adaptation: community-driven climate resilience planning and approaches should be prioritized over traditional top-down, government or private sector led initiatives (Binder & Greer, 2016; Shokry et al., 2020). This sentiment was echoed in the interviews conducted with climate resiliency experts and city officials. Interviewees highlighted the importance of community engagement in every step of the process including the design of climate resiliency proposals. In addition, since a major concern of climate resiliency initiatives is the risk of displacement, multiple studies highlight infrastructure investments, particularly affordable housing, as a necessary component of equitable resiliency efforts (Rice et al., 2019; Shokry et al., 2020, 2022).

There is a diversity of innovative approaches to equitable and just climate resilience in NYC, throughout the region and globally. Since climate justice entails addressing intersecting systems that drive climate change and inequality, the responses must also reflect a depth and richness capable of attending to these multiple, interrelated systems. In addition to a review of the literature, this section is informed by insights from semi-structured interviews conducted with representatives from NYC-based environmental justice groups, including Sonal Jessel (Director of Policy) from WE ACT for Environmental Justice, Elizabeth Yeampierre (Executive Director) and John Fleming (Development Director/Project Manager) of UPROSE, Rami Dinnawi (Environmental Justice Campaign & Policy Manager) and Daniela Castillo (Program Manager, Green Light District) of El Puente, and Eddie Bautista (Executive Director) of NYC Environmental Justice Alliance. Many of the organizations and climate adaptation strategies that are described herein are also featured in the literature focused on case studies of just climate adaptation and resiliency planning. The following best practices can help guide climate adaptation planning and investment. The practices are designed to be illustrative, not prescriptive, enabling city governments, community groups, and other stakeholders to tailor them to their individual contexts.

5.1 Integrative Approaches to Climate Resilience

5.1.1 Seeking economic development opportunities that advance just transitions and adaptive economies

Climate resilience comprises not only physical protection from climate risks but also social and economic resilience in the face of disruption. Adaptation planning and infrastructure investments can serve as opportunities to strengthen local economies, make them more inclusive, and promote regenerative industries. A just transition approach to climate adaptation considers the overlapping opportunities for wealth generation and promotion of health and well-being, equitable access to renewable energy, and affordable, efficient homes (Sze & Yeampierre, 2017). One example of a just transition approach is the growing interest in "adaptation economies" sometimes also referred to as a green economy. Adaptation economies build on the need for adaptation investments, from workforce development to supply chain manufacturing, across multiple sectors and infrastructures. These investments can be leveraged by vulnerable communities to address legacy environmental and economic injustices as well as future climate risks.

People United for Sustainable Housing **(PUSH Buffalo)**, for example, is developing a 25-square block in Buffalo's West Side, focused on green and affordable housing, vacant land use, and quality jobs to build a "resilient and regenerative community." PUSH Buffalo created this Green Development Zone (GDZ) in 2008, and their neighborhood-scale work continues to enhance and preserve the community's local economy in a self-sustaining way, demonstrating how short-term community development opportunities can create green sectors and workforces that thrive in the long term. PUSH prepares people to work with development partners and a network of local contractors, and they directly employ local workers through their related enterprises, PUSH Blue and PUSH Green. PUSH's projects are designed to promote physical resilience–including green infrastructure installation, residential weatherization, and retrofits–while creating a thriving local economy (Hart & Magavern, 2017).

Similarly, **UPROSE**'s Green Resilient Industrial District (GRID) Plan aims to invest in green industries and job training for low-income residents of Sunset Park, securing this economic base for a neighborhood that faces both climate and economic challenges (E. Yeampierre, personal communication, February 17, 2023). The GRID plan has already secured important public (i.e. NYC EDC) and private sector (i.e. Equinor) investments to implement economic revitalization programs tied to the port and job training tied to the offshore wind industry (Nguyen & Leichenko, 2022). Public and private investments coupled with community-based plans can produce multiple benefits for climate adaptation goals.

Climate resilience investments can also bring new industries to environmental justice communities, with the potential to address legacy pollution while creating new economic opportunities (Shi, 2021). In NYC, the **NYC-EJA** and **UPROSE** are part of a coalition advocating for the city to replace nearby peaker plants with renewable energy battery storage facilities. NYC-EJA has also been in discussion with El Puente regarding peaker plant retirement strategies in their neighborhood and Brooklyn Community Board 1 (R. Dinnawai & D. Castillo, personal communication, June 14, 2023). This could create jobs, but a community-led strategy is necessary to ensure that residents are able to benefit from the new industry and do not lose waterfront access in the process (Bautista, Hanhardt, et al., 2015). Internationally, the **European Union**'s "Clean Energy for All Europeans" package promotes renewable energy communities and citizen energy communities in part to address energy poverty and inequity (Directive (EU) 2018/2001 of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources, 2018; Directive (EU) 2019/944 of the European Parliament and of the Council on Common Rules for the Internal Market for Electricity, 2019). Within this enabling policy environment, cities and local institutions can advance decentralized energy models, helping to create not only local jobs but also new income sources for residents. The cities of Rome and Paris are both experimenting with programs to support solar communities and eco-districts (Government of the City of Rome, 2022). The city of London created a Community Energy fund to facilitate access to funding for creating renewable energy communities in vulnerable neighborhoods (Mayor of London & London Assembly, 2023).

The United States has experimented with community solar, which has shown some of this potential but also raised questions around channeling benefits and opportunities to marginalized communities. The **Institute for Local Self-Reliance's Community Power Map** (2016) illustrates how much community solar efforts depend on a robust state and local policy enabling environment.

NYC has some promising investments in solar that have produced economic, environmental, and public health benefits for vulnerable communities. For example, **UPROSE** partnered with the MTA to secure a 685-kilowatt cooperatively-owned solar project with 200 residents, and WeAct trained and hired 100 residents in the installation of 415 KW of solar in public housing (E. Yeampierre, personal communication, February 17, 2023).

5.1.2 Designing adaptation strategies to maximize co-benefits and address multiple challenges within a community

Beyond economic development, adaptation planning has the potential to benefit communities more broadly. By intentionally harnessing planning processes and investments to advance what communities want and need climate adaptation can contribute to more livable places in a holistic way (Rudge, 2020). Adaptation strategies should address multiple challenges within a community, such as public health promotion, community infrastructure (e.g., parks and public spaces), and affordable housing.

In **Edgemere, Queens**, the City's 2017 Resilient Edgemere Community Plan (RECP) (City of New York Department of Housing Preservation and Development, 2017) aimed to leverage disaster recovery and other funding to make improvements to the neighborhood. The Plan incorporated a number of strategies for developing and managing new affordable housing, commercial/residential mixed-use, and open space in the neighborhood (City of New York Department of Housing Preservation and Development, 2017). For example, the Plan incorporates a Community Land Trust (CLT) model for over 100 vacant lots owned by the City to support different land uses with the goal to "work with local organizations to develop a model for community ownership to facilitate long-term affordability and resilient land stewardship" (Change Capital Fund, 2023; City of New York Department of Housing Preservation and Development, 2021).

Public health is often a primary co-benefit of climate adaptation. For example, **WE ACT** has created a 2022 Extreme Heat Policy Agenda to address extreme heat and its associated health risks (S. Jessel, personal communication, August 23, 2022).Whether addressing rising temperatures or any other climate risk, resilience policies are also public health policies.

In addition, many green development projects can take on community uses, such as **PUSH Buffalo** converting vacant lots into community gardens and developing abandoned buildings into affordable housing and commercial spaces (Hart & Magavern, 2017). This work generates a wide range of benefits, such as vacancy reduction, home insulation, and improved food access, among others.

Moreover, the benefits may be essential to placemaking and place-keeping, even when they are not measurable; for example, **El Puente** envisions using green infrastructure to create public spaces that can help root communities in the face of displacement pressures (R. Dinnawai & D. Castillo, personal communication, September 23, 2022). They apply four key principles in the review of green investments: (1) fosters community congregation, (2) reflective of community culture, (3) establishes a sense of connection to a place and its people (i.e. history), and (4) cultivates collective care in the maintenance of green spaces (R. Dinnawai & D. Castillo, personal communication, September 23, 2022).

5.2 Community-Driven Planning Processes

5.2.1 Understanding the local context and history and the role of land-use patterns

Understanding context and history is important not only to serve the community more effectively but also to make adaptation plans more successful in the face of intersecting housing and climate displacement risks. Without this background, planning processes risk perpetuating past harms and missing critical information. As Shokry et. al. (Shokry et al., 2020) explain, community-driven adaptation approaches "can be responsive in real time to social-ecological processes and ensure that benefits belong to vulnerable residents."

In **Edgemere, Queens**, the City's Resilient Edgemere Community Plan recognized the significant role of past racism and disinvestment in creating the conditions for social vulnerability, which sea-level rise now compounds. Similarly, **El Puente** has advocated for the closure of certain ramps on the Brooklyn-Queens Expressway (BQE) for adaptation initiatives, directly connecting the history of racist infrastructure development with resilience today (R. Dinnawai & D. Castillo, personal communication, September 23, 2022).

However, history does not just help explain current challenges and conditions; it also points to community assets and strengths. For example, the **New York City Environmental Justice Alliance (NYC-EJA)** continues to advocate for the equitable preservation of "working waterfronts" in environmental justice communities (some of these working waterfront parcels are referred to in NYC as "Significant Maritime Industrial Areas" (or SMIAs)). While NYC-EJA has successfully championed better environmental and climate protections for SMIAs since the 1990s, they have also understood the critical need to retain "working" (or industrial) waterfronts for their significant potential as clean renewable energy hubs and other sustainable infrastructure investment options, climate adaptation opportunities and the presence of local economic development bases for adjacent underemployed Black and Brown local communities (Bautista et al., 2014). For example, while the majority of these SMIAs fall within floodplains, maintaining SMIA zoning while imbuing resiliency measures in these areas is key to protecting against climate risks like flooding while providing an economic base for local residents that helps also prevent future housing displacement. A good example of this approach is **UPROSE**'s Green Resilient Industrial District (GRID) Plan (UPROSE, 2023), which preserves the industrial nature of the waterfront--understanding the importance of this manufacturing history in shaping the future of green manufacturing–and how Sunset Park residents will be a part of it.

Consideration of both past and future land use zoning and development patterns will be critical for ensuring new developments don't further exacerbate inequalities as well as climate and displacement risks. Waterfront developments in places like Harlem, Sunset Park, Edgemere, and other EJ communities were identified as important sites for equitable climate adaptation and planning processes that consider the effects on housing as well as climate protections. For example, the Hazard Mitigation Zone, a zoning tool used by the City to restrict land parcels from future development, was implemented in the north side of **Edgemere** and coupled with the development of Community Land Trust (CLT) as a way to address affordable housing concerns (Change Capital Fund, 2023). But there are floodprone waterfronts throughout the city that are actively being developed for market-rate housing that can exacerbate displacement and flooding risks.

5.2.2 Going beyond community engagement: community-led processes

Community members (including but not limited to residents) should have a direct, meaningful say in the decisions that affect them—from the start and on an ongoing basis in climate adaptation.

In **Edgemere**, community engagement was a part of creating the Resilient Edgemere Community Plan (City of New York Department of Housing Preservation and Development, 2017). However, residents continued to voice concerns about the voluntary buyout program that the Plan recommends (Kensinger, 2017). In this case, the community developed its own vision for a just resiliency plan reflected in the report entitled "Community Visioning for Vacant Land Following Managed Retreat in Edgemere, Queens, N.Y." (See RISE, (Seip, 2022)).

Fortunately, alternatives to traditional engagement models are available, such as the community planning congresses that directly shaped Buffalo's Green Development Zone. By centering community members' voices, **PUSH Buffalo** was better able to identify development and environmental priorities that could respond to immediate challenges, increasing buy-in and making the Zone more successful (Hart & Magavern, 2017) even when this type of community-driven planning was not possible during the COVID-19 pandemic.

UPROSE adapted their climate justice organizing, experimenting with learning circles and social media to re-engage residents in efforts to strengthen social cohesion (E. Yeampierre, personal communication, February 17, 2023). This approach focuses on survival strategies, ancestral knowledge and community priorities such as renewable energy, clean water, food sovereignty, and wellness (E. Yeampierre, personal communication, February 17, 2023). No matter which engagement tools are used, the uptake of adaptation solutions depends on community buy-in, which starts with community-led decision-making (Rudge, 2020, 2021).

5.3 Collaborative Development of Goals, Programs, and Policies

5.3.1 Developing a shared vision with buy-in from government leaders and leveraged investments

A shared vision helps community members, local groups, partners, and city governments efficiently work toward the shared climate adaptation goals. This buy-in also facilitates the flow of funding from governments to communities, and of essential information from communities to policymakers (Baptista, 2024).

Several of the New York environmental justice groups profiled are part of coalitions with local and state policy agendas. By working collectively, these groups can build political will for climate solutions that invest in the most impacted communities. Their work has contributed to legislation such as the statewide Climate Leadership and Communities Protection Act (New York State Climate Leadership and Community Protection Act, 2019).

One of the most powerful strategies that many EJ organizations employ for equitable climate adaptation is coupling policy advocacy with the implementation of climate adaptation measures and targeted investments in the most vulnerable communities. For example, groups like **NYC-EJA** and **WE ACT** supported the adoption of Local Law 97 and focused on investments in job training and economic opportunities for vulnerable residents to help upgrade buildings as part of the implementation of this important climate mitigation policy (E. Bautista, personal communication, November 10, 2022; S. Jessel, personal communication, August 23, 2022).

As a membership network, **NYC-EJA** helps to foster this cohesion by connecting environmental justice grassroots organizations in developing innovative environmental and climate solutions (New York City Environmental Justice Alliance website (New York City Environmental Justice Alliance, 2023). This was particularly critical when NYC-EJA created their New York City Climate Justice Agenda, an annual analysis of NYC climate policies and initiatives, accompanied by grassroots solutions designed to reduce racial disparities and climate vulnerabilities. For partnerships and coalitions to effectively work together, communicating clear and aligned priorities can then inform higher-level agenda-setting for government agencies and legislation.

PUSH Buffalo also leads policy advocacy, which has provided the insights necessary for New York State to create needed policies and programs: PUSH's Green Development Zone principles have been codified in New York State's Sustainable Neighborhoods Program; their planning conference helped lead to Green Jobs - Green New York (GJGNY); and, their campaigns have helped the state to develop new funding sources. All of these initiatives benefit cities beyond Buffalo as well, amplifying PUSH's impact via the state government (Hart & Magavern, 2017; Push Buffalo, 2019).

5.3.2 Developing concrete anti-displacement measures that consider housing and economic conditions

Resilience investments have the potential to intensify existing displacement pressures and create new ones. Several anti-displacement tools are available to both governments and local groups.

One strategy is to create community land trusts (CLTs) that can provide a source of affordable housing for residents facing climate displacement. **Edgemere** is implementing a CLT as part of the Resilience Edgemere Community Plan (City of New York Department of Housing Preservation and Development, 2017) and **PUSH Buffalo** landbanks properties they are not yet able to develop through the Buffalo Neighborhood Stabilization Corporation (A. Kim, 2021). Zoning policy is another impactful lever. For example, **UPROSE** has advocated for maintaining Sunset Park's industrial zoning because rezoning the area risks displacing current residents, as has happened in other NYC neighborhoods (E. Yeampierre, personal communication, February 17, 2023).

WE ACT is also working on addressing cost-of-living pressures, such as campaigning to lower utility rates, make energy efficiency measures more accessible, and advocating for publicly owned and generated power. By reducing energy costs, residents are less likely to be displaced because of utility debt or the increased expenses associated with climate change, like air conditioning (S. Jessel, personal communication, August 23, 2022).

Table 5: *Community-Based Equitable Climate-Related Projects and Plans* is based on a review of online content for each of the five non-profit organizations listed in the table. Additional information was collected from the NYC based organizations, using semi-structured interviews with representatives from the following organizations: WeAct for Environmental Justice, UpRose, El Puente for Peace and Justice, and the New York City Environmental Justice Alliance.

Table 5: Community-Based Equitable Climate-Related Projects and Plans

EJ Organization & Representatives	Equitable Climate-Related Projects & Plans
El Puente *South Williamsburg, Brooklyn*	■ Our Air / Nuestro Aire 5-point action platform ■ Organize a Community Resiliency & Public Health Emergency Taskforce ■ Mitigate impacts of BQE infrastructure on local community ■ Improve greenspaces for local residents like LaGuardia Park ■ Opportunities for green jobs and training programs ■ Participating in NY Renews, Last Mile Coalition, Climate Works for All, Forest for All New York City, NYC-CAPS (Communities Activating Open Spaces), and No NBK Pipeline Coalition
NYC-EJA Citywide membership	■ NYC Climate Justice Agenda 2020 ■ Grassroots Action for Green Infrastructure Equity (GAGE) ■ South Bronx Community Resiliency Agenda with The Point CDC

<table>
<tr><th>EJ Organization & Representatives</th><th>Equitable Climate-Related Projects & Plans</th></tr>
<tr><td></td><td>
■ Members of PEAK Coalition, NY Renews, Renewable Rikers, Waterfront Justice Project, and Climate Works for All
■ An Equitable Recovery: Creating 100,000 Climate Jobs for Frontline Communities of Color Report 2020
■ PEAK agreement (2020) with New York Power Authority (NYPA) to study the replacement of existing peaker plants with battery storage, leading to subsequent NYPA RFP to begin the replacement process (2022)
■ Helped pass Local Law 84 and LL85 related to extreme heat (July 2020)
</td></tr>
<tr><td>UPROSE
Sunset Park, Brooklyn</td><td>
■ Green Resilient Industrial District Plan (GRID, 2019)
■ NYC EDC partnership for community investments related to Offshore Wind Assembly & Maintenance facility
■ Local Law 97 job training for building retrofits
■ Community Learning Circles
■ Climate & Community Health Vulnerability Assessment survey
■ G.R.A.S.P app on how to prepare for extreme weather
■ Climate Justice Youth Summit and Climate Justice Center
</td></tr>
<tr><td>WE ACT
Northern Manhattan</td><td>
■ Extreme Heat Policy Agenda (2022)
■ Too Hot to Handle: The Reality of Extreme Heat in New York & How to Prepare Frontline Communities webinar
■ 2021 Cooling Center Report
■ Helped pass Gas Free NYC law, New York State’s All-Electric Building Act (S.6843A/A.8431), the Build Public Renewables Act, and Cumulative Impacts Law (S.8830/A.2103C)
■ Solar workers cooperative
■ Advocacy/support for distribution of 74,000 air conditioning units citywide, with 22,000 of those units distributed to NYCHA residents during COVID relief
■ Climate Ready Uptown Plan (CRUP) pamphlet
■ Climate Justice Working Group
</td></tr>
<tr><td>PUSH Buffalo
Buffalo, NY</td><td>
■ Community planning congresses shaped Buffalo’s Green Development Zone (PPG, 2017)
■ Green Development Zone principles codified in New York State’s Sustainable Neighborhoods Program
■ Community-based renewable energy projects
■ Green Development Zone hires local from PUSH’s workforce development initiatives
■ Buffalo Neighborhood Stabilization Corporation landbank manages vacant properties to prevent displacement
</td></tr>
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6 Conclusion and Opportunities for Future Research

6.1 Conclusion

The City's climate-related equity work since 2019 has become more explicitly focused on redressing environmental injustice and racial disparities. This includes the adoption of various laws and policies, internal institutional reforms, and incorporation of equity into risk assessments and resilience planning. There is, however, limited understanding of climate change impacts and adaptation needs at the community or neighborhood level and limited systematic data exists on city-sponsored adaptation projects and resilience investments. Going forward, the City's climate-related equity work would benefit from more comprehensive data on disaggregated climate risks at the local level and tracking of city-sponsored climate adaptation projects and resilience investments across communities. Climate adaptation and resilience planning should also consider the ways that climate change challenges that NYC faces are inextricably linked to the bioregion's early history, and how climate risks for the most socially vulnerable populations are linked to both past and present land use decisions and their underlying inequities. Understanding the impacts of this history is vital for formulating just and effective policies and strategies to mitigate and adapt to climate change.

Additionally, there are ongoing community-led climate adaptation and resilience initiatives that provide examples of how NYC can more equitably and justly incorporate local needs and solutions into climate adaptation strategies. These community-led efforts also reflect the desire for intersectional climate responses to multiple environmental and social vulnerabilities such as the need for affordable, safe housing, green jobs, and neighborhood stability. Without the creation and implementation of climate policies and practices that promote racially equitable procedures and outcomes, the City will risk perpetuating inequities in new forms. For example, climate displacement is an important dimension of social vulnerability to climate change and should be measured by the City. The City's ability to measure the risks of climate displacement at an appropriate scale, such as at the neighborhood level, could help determine whether and how new climate-resilient infrastructure or infrastructure investments might risk displacement. Without anti-displacement strategies in place, resilience-promoting investments can have inequitable outcomes. These strategies most often require prioritizing community-driven climate resilience approaches that mitigate the risk of displacement.

6.2 Opportunities for Future Research and Knowledge Gaps

There are existing gaps in the state of knowledge related to the key themes covered in this chapter that are important to note for future research, broadly, as well as for consideration by the next NPCC panel. First, there is a dearth of comprehensive data related to the City's climate-related equity work that would benefit from tracking. This tracking could include equity metrics that help elucidate the relationship between vulnerability indicators and investments over time. There is also a need for more granular, neighborhood-level assessments of climate change impacts and adaptation needs along with the tracking of the performance of climate adaptation projects and investments. This type of systematic data on city-sponsored climate adaptation projects and other related climate investments, as well as more comprehensive tracking of progress on climate adaptation and disaggregated climate risk data, will help improve equity outcomes across multiple dimensions (i.e. contextual, distributive, procedural).

Climate gentrification is a dynamic process that varies across contexts and hazards. There are myriad measures and indices of climate gentrification that emphasize different driving forces and use a variety of data sources. The empirical research related to climate gentrification processes is nascent and evolving. As new methods and data sources are developed, there will necessarily be refinements in our approaches and understanding of these complex systems. These methods will also benefit from more longitudinal and evaluative research that can better characterize, on a more granular level, climate gentrification processes in varying contexts. While this chapter puts forth the Climate, Displacement, and Socio-Vulnerability (CDSV) score for multiple climate hazards (coastal and fluvial flooding, heatwaves, hurricanes, and winter weather) in NYC, this approach may also be taken up in the next NPCC report to explore additional hazards, different socio-vulnerability data, and the use of machine learning tools to better capture potential linkages between climate, displacement and socio-vulnerability indicators. It will also be important to consider how at-risk communities and the City can access these tools and apply them to help prepare for and mitigate the impacts of climate gentrification processes. Finally, longitudinal, qualitative assessments of community-based, justice-centered, climate resiliency planning and implementation can be used to inform NYC's ongoing climate adaptation practices and investments. In particular, leading environmental and climate justice organizations in NYC can offer important insights and best practices for future progress.

7 Traceable Accounts

Key Message 1	**The City's climate-related equity work since 2019 has become more explicitly focused on redressing environmental injustice and racial disparities. Over the past five years, the City has embarked on four interrelated sets of actions to foster and advance equity in its approach to climate adaptation: (1) adoption of multiple laws and programs to address equity issues related to climate change impacts; (2) internal institutional reforms in the provision of city services; (3) development of indicators and metrics and digital, interactive, and mapping platforms that are publicly accessible to track and monitor city agencies' progress; and, (4) incorporating equity into ongoing climate risk assessments and in sustainability and resilience planning.**
Description of Evidence	These findings are supported by a multifaceted assessment of the City's progress on climate-related equity work. (1) Over the past decade, the City has adopted multiple laws and subsequent programmatic initiatives designed to incorporate environmental justice and equity into citywide planning and decision-making processes. For instance, LLs 60 and 64 from 2017(Local Law 60, 2017; Local Law 64, 2017) established the EJAB and EJ IWG which are responsible for the EJNYC report, EJNYC Web-based Portal and Mapping Tool and the EJNYC plan; LL 78 of 2021 (Local Law 78, 2021, p. 78) resulted in the creation of the Equitable Development Data Explorer and a Displacement Risk Map along with a requirement of Racial Equity Report for certain land use actions; and LL 122 of 2021 (Local Law 122, 2021, p. 122) resulted in the creation of the AdaptNYC program, a citywide climate adaptation plan, and the Climate Strong Communities program. (2) The City has increased efforts to advance racial equity and social justice within city agencies. It joined the Government Alliance for Racial Equity (GARE) network and employed GARE's Racial Equity Assessment tools to guide the development of racial equity policy and foster internal changes (Government Alliance on Race and Equity, 2023). Through Executive Order 45 (2019), the City created the EquityNYC program, designed to assess equity outcomes in the provision of city services and equity practices across city agencies (Executive Order 45, 2019). Integration of racial equity is observed in operational and planning efforts in other city agencies. Examples include the Department of Health and Mental Hygiene's Race to Justice Action Kit, NYC Commission of Human Rights' Anti-Black Racism Report, and the Department of City Planning's Comprehensive Waterfront Plan (City of New York Commission on Human Rights, 2019; City of New York Department of City Planning, 2021b; City of New York Department of Health and Mental Hygiene, 2023). (3) The City has multiple initiatives to identify indicators and metrics to track progress on equity and develop digital and interactive mapping platforms to foster transparency, and accountability. NYC Opportunity is leading the effort to identify and evaluate indicators and metrics on social and racial equity with initiatives include the social and equity indicators, poverty measures, and workforce metrics; these can be visualized on publicly accessible online platforms (City of New York Mayor's Office for Economic Opportunity, 2023b; *Poverty Measure - NYC Opportunity*, n.d.; *Social Indicators Report - NYC Opportunity*, n.d.). With goals to communicate progress and promote community- and neighborhood-level planning, other city agencies have also developed mapping tools for visualizing data on population, land use and zoning, and environmental risks and vulnerability. Data sources for many of these tools are available for download on the NYC Open Data website (City of New York, 2022). In addition, more citywide policy and planning documents (e.g., NYC Hazard Mitigation Plan, NYC Comprehensive Waterfront Plan, AdaptNYC program) are made available online in digital and interactive formats designed to be changed and updated over time, functioning as "living" documents rather than static ones (City of New York Department of City Planning, 2021b; City of New York Mayor's Office of Climate & Environmental Justice, 2022a; *Plan for Hazards - Hazard Mitigation - NYCEM*, n.d.). (4) The City continues to incorporate equity into ongoing climate risk assessments and sustainability and resilience planning. MOCEJ is currently sponsoring the Climate Vulnerability, Impact, and Adaptation Analysis (VIA) study to develop a comprehensive assessment of future potential climatic conditions and associated impacts in NYC (McPhearson et al., 2024). The VIA research has the potential to advance equity by providing key information and tracking tools on most at-risk populations and can be used to inform the development of forward-looking adaptation strategies that prioritize vulnerable populations and EJ areas. Environmental justice and health equity are core components of the City's latest sustainability

	and resilience vision, PlaNYC: Getting Sustainability Done (City of New York Office of the Mayor, 2023b). The plan contains multiple initiatives designed to increase resiliency and access to green and climate investments for vulnerable groups. Examples include the Climate Strong Communities program, FloodHelpNY and HomeFix programs, electrification and efficiency upgrades for NYCHA housing, and workforce development and training for green and circular economy sectors (City of New York Office of the Mayor, 2023b).
New Information and Remaining Uncertainties	While there is strong evidence that NYC has made progress in terms of integrating environmental justice and racial equity into its climate work, there are remaining uncertainties about the outcomes of climate-related equity efforts. Considering that many of these initiatives have been recently proposed or are only now underway, it remains difficult to determine whether locally relevant adaptation needs (as well as other quality-of-life needs) are being addressed. Other uncertainties are about the effectiveness of climate investments in addressing the root causes of environmental and social inequities and building adaptive capacity in underserved and marginalized communities. The data used to assess the City's progress was largely based on a review of City-initiated reporting documents and a sampling of expert interviews. There is limited peer-reviewed literature and no systemic review of the treatment of equity across NYC agencies. Thus, the evidence is limited by the number of respondents interviewed and the author's expert review of existing primary source documents from the City's public records.
Assessment of Confidence based on the Evidence	Given the evidence base, there is high confidence that NYC's climate-related equity work has advanced efforts to address environmental injustice and racial disparities.
Key Message 2	**The City's climate-related equity work would benefit from more comprehensive data on disaggregated climate risks at the local level and tracking of city-sponsored climate adaptation projects and resilience investments. There are limited understanding of climate change impacts and adaptation needs at the community or neighborhood level and limited systematic data exists on city-sponsored adaptation projects and resilience investments. More disaggregated climate risk data and systematic tracking of city-sponsored climate investments are needed.**
Description of Evidence	These findings are supported by the author's expert review and assessment of the City's efforts to characterize climate risks and adaptation needs at the community and neighborhood levels and to communicate progress on climate adaptation and resilience projects. While there are 59 community districts and numerous neighborhoods in New York, current evidence suggests that the City has only a few city-sponsored place-based or community-based adaptation plans. Examples include the Resilient Neighborhoods Studies, the Lower Coastal Manhattan Coastal Resilience Project, the Cool Neighborhoods NYC program, and the Resilience Edgemere Community Plan (City of New York Department of Housing Preservation and Development, 2017; City of New York Mayor's Office of Resiliency, 2017; *Lower Manhattan Coastal Resiliency (LMCR)*, n.d.; *Resilient Neighborhoods*, n.d.). While City has spent 73 percent of the $15 billion of federal appropriated rebuilding and recovery grants (as of June 2022), evidence suggests that current efforts to track and communicate climate adaptation projects and resilience investments do not provide a complete picture of the City's spending progress and the status of completed and planned projects (Yeung & Levers, 2022). For example, the Sandy Funding Tracker lacks detailed information about the status or anticipated completion dates of federally funded adaptation and resilience projects and City's capital contribution to these projects (City of New York Office of Emergency Management, 2023b). On the other hand, while the NYC Mitigation Actions Map conveys the status and location of the City's capital investments in hazard mitigation projects, without comprehensive community-based adaptation plans and strategies for each of the 59 community districts and/or neighborhoods, it remains difficult to determine whether local adaptation needs are identified and/or addressed (*CRA Dashboard – NYC Hazard Mitigation*, n.d.).
New Information and Remaining Uncertainties	With regard to characterizing climate risks and adaptation needs for communities and neighborhoods, the City has recently developed multiple initiatives designed to address this issue including the AdaptNYC program, the Climate Strong Communities program, and the Climate Vulnerability, Impact, and Adaptation Analysis (VIA) study (City of New York Mayor's Office of Climate & Environmental Justice, 2022a, 2022b; McPhearson et al., 2024). Uncertainties are related to engagement and coordination with local stakeholders, integration of local knowledge, and how climate interventions and investments reflect local

	planning goals, visions, and desires. There is currently little or no independent peer-reviewed literature assessing this topic comprehensively across the City. With regard to the systematic tracking of the City's adaptation projects and resilience investments, the New York City Office of the Comptroller has recommended that the City develop a Capital Project Tracker which provides detailed information about neighborhood-level projects (Yeung & Levers, 2022). The City, in response, implemented the NYC Capital Projects Dashboard in 2023 (City of New York Mayor's Office of Operations, 2024). Furthermore, the City is currently implementing an initiative called climate budgeting, which can potentially enable transparent tracking of capital funding for sustainability and resiliency initiatives pursued by city agencies (City of New York Office of the Mayor, 2023b). Given that the City is releasing its first Climate Budget in April 2024, it remains to be seen how exactly this process will evolve. Lastly, the City is counting on new federal and state funding streams to implement current unfunded planned and proposed projects (City of New York Office of the Mayor, 2023b). There are uncertainties regarding whether the City will be able to acquire sufficient state and federal funding necessary to complete these projects as well as how it plans to allocate and track the spending of the funds.
Assessment of Confidence based on the Evidence	Given the evidence base, and author's expert review of the City's reporting to date, there is high confidence that the City's climate-related equity work would benefit from more comprehensive data on disaggregated climate risks and adaptation needs at the local level and from systematic tracking of city-sponsored climate adaptation projects and resilience investments.
Key Message 3	**Some of the city's most vulnerable communities have evolved their approaches to combat a variety of environmental, climate, and social stressors. The organizations profiled in NPCC3's equity section report that they are implementing dynamic approaches to address the various risks they face while providing multiple benefits to their communities. These benefits include expanding access to solar energy and providing upgrades for cooling residences experiencing high heat and air pollution exposure.**
Description of Evidence	Three of the four organizations profiled in the equity chapter of the last NPCC3 report (Foster et al., 2019) were interviewed for updates to their climate adaptation initiatives. The author relied on public documentation online for the organization not interviewed. These organizations are located in areas mapped as most socially vulnerable to climate risks, as indicated by the SOVI index and similar indices. We followed up with these same organizations to determine their progress and evolution in addressing the multiple and intersecting climate, social, and economic stressors they face. Evidence was obtained directly from semi-structured interviews with implementing organizations and documentation, such as reports, retrieved from organizational websites.
New Information and Remaining Uncertainties	The assessment of progress to date and implementation was based on primary data sourced from semi-structured interviews with organizations and a review of publicly accessible reports. There is no peer-reviewed literature that has assessed this implementation process. Also, one organization was not reached directly, thus the full extent of their climate adaptation work may not be fully reflected in this report.
Assessment of Confidence based on the Evidence	There is a High confidence level that the reported updates and approaches to climate adaptation by NYC based environmental justice organizations have produced multiple benefits for respective environmental justice communities based on the author's review of primary source data and organizational reports.
Key Message 4	**The climate change challenges that NYC faces are inextricably linked to the bioregion's early history, including slavery and land dispossession. Understanding the impacts of this history is vital for formulating effective policies and strategies to mitigate and adapt to climate change. An appreciation of the historical legacy of climate impacts on the region, and on certain communities, also necessitates a commitment to reparations and restorative justice. By recognizing Indigenous knowledge, seeking restorative justice, and reconceptualizing our relationship to land, the City can forge a future that respects the environment, promotes social justice, and ensures the well-being of all communities.**
Description of Evidence	Cronon (Cronon, 2003) firmly established the relationship between colonial impacts on the ecology of New England and opened the examination of colonialism and environmental history. Wolfe (Wolfe, 2006) initiated the working historical theory of "settler colonialism" and Kauanui (Kauanui, 2016) discusses the ramifying impacts of this framework for interdisciplinary and Indigenous scholarship. Lipman (Lipman,

	2016) (2016) like Cronon examines the ways in which Coast Algonquian communities tended the "saltwater" estuaries that also became a colonial contact zone in the Long Island sound region. The Public History Project (PHP) is researching the interlinkage between Dutch and English trade and settler colonists engaged in dispossession, enslavement, massive extraction, and Atlantic World trade. This short historical section derives from this PHP research project. Perhaps most significant for the NPCC, the IPCC has regularly cited Indigenous Knowledge and Traditional Ecological and Environmental Knowledge as important knowledge that need to be enlisted in addressing climate crisis.
New Information and Remaining Uncertainties	The study of landscape ecology, Indigenous studies, enslavement studies, extractivism, and trade is a growing field of study and archives building. The evidence of each of these study areas has been well established, but the intersections of once-siloed areas of specialization are currently being explored by scholars in a variety of academic fields, including anti- and decolonial studies, Indigenous Studies, and African American/diasporic studies.
Assessment of Confidence based on the Evidence	Given the evidence from the historical record, peer-reviewed literature across multiple disciplines (i.e. decolonial studies, indigenous studies, anthropology, history, etc.) and the expert review of the author, there is high confidence that a systemic understanding of the history of NYC's development dating from pre-colonial records to the present, are relevant to the understanding of climate injustices.
Key Message 5	**Climate risks for the most socially vulnerable populations are linked to both past and present land use decisions and patterns and their underlying inequities. Although the relationships between historical land use and climate risk are complex and context-dependent, they often have similar underlying mechanisms such as past discriminatory land use and siting decisions, redlining and disinvestment, and lower land costs in hazard-prone areas. Many of these land use issues—past and present—reinforce one another and create future risks and vulnerabilities. Without intentional, anti-racist work toward climate mitigation, adaptation, and resilience, NYC will risk perpetuating these inequities in new forms.**
Description of Evidence	These findings are based on a growing body of literature that connects past and present land use to climate risks and social vulnerability today, with studies having the greatest focus on redlining (Hoffman et al., 2020; Katz, 2021; Wilson, 2020). Other evidence comes from research on hazardous and industrial land use (Maantay, 2002; Marlow et al., 2022; Mizutani, 2018), housing and investment decisions (Buchanan et al., 2020; Lee & Jung, 2014), aspects of geography—such as elevation and waterfronts (Collins et al., 2018; Keenan et al., 2018; Villareal, 2013) — and transportation planning and infrastructure (Faber, 2015; Hoffman et al., 2020). Academic studies also provide evidence on how land use issues contribute to future vulnerabilities, such as through disparities in buyouts (Elliott et al., 2020; Mach et al., 2019; Shi et al., 2022) and the inequitable distribution of investments in resilience and adaptation (Gould & Lewis, 2018; Hummel et al., 2021; Shokry et al., 2020). Research grounded in specific cities and communities, as well as news reports, demonstrate how local contexts and histories can moderate these general patterns (Campo-Flores & Kusisto, 2019; Lee & Jung, 2014; Peacock et al., 2014).
New Information and Remaining Uncertainties	There are relatively few studies that connect historical land use to climate risk in NYC specifically. Although studies from other locations suggest patterns that may appear in New York, contextual similarities and differences remain an important factor in determining how to interpret this evidence.
Assessment of Confidence based on the Evidence	Given the evidence base, there is high confidence that historical and present land use contributes to climate risk for socially vulnerable groups, particularly through the legacy of redlining. There is also high confidence that land use and adaptation decisions today will continue to affect this landscape.

Key Message 6	**Climate displacement is an important dimension of social vulnerability to climate change and should be measured by the City. The City's ability to measure the risks of climate displacement at an appropriate scale, such as at the neighborhood level, could help determine whether and how new climate-resilient infrastructure or infrastructure investments might risk displacement and identify ways to mitigate that risk. A combined climate displacement and social vulnerability (CDSV) score is proposed to integrate socio-economic, climate risk, and evictions and housing data to better measure the risks of climate displacement at the census-tract level.**
Description of Evidence	There is a developing literature on climate displacement or gentrification that has identified different “pathways” by which climate risks and impacts can operate to impact geographies and property markets (Keenan et al., 2018). The literature identifies three types of climate displacement or gentrification: the superior investment pathway, the cost-burden pathway, and the resilience investment pathway. Increasingly, studies assess the resilience investment pathway (K. Best & Jouzi, 2022) and further complicate the other pathways by recognizing that climate displacement is a complicated and dynamic process (Black et al., 2013). There are now a number of case studies documenting these dynamics in cities such as Miami (Keenan et al., 2018; Li & Grant, 2022), New Orleans (Aune et al., 2020), Seattle (de Koning & Filatova, 2020; Rice et al., 2019), and Philadelphia (Shokry et al., 2022). Moreover, a number of researchers have created climate displacement and gentrification indices based on a mix of demographics, physical characteristics, climate risk and other factors (Aune et al., 2020; K. B. Best et al., 2023; Melix et al., 2023; Tedesco et al., 2022). Although the literature has demonstrated that there is context-specific climate displacement (out-migration of households) that is attributable to various social, environmental, and land use patterns, it is not clear whether gentrification (in-migration of high-income households) is a separate or intertwined phenomenon (S. K. Kim & Park, 2023). Existing research is illuminating but more research is required to understand larger-scale patterns of migration and the exact relationship between climate change and gentrification. Moreover, there has been no study of climate displacement or gentrification in NYC.
New Information and Remaining Uncertainties	NYC There are several metrics that are being or have been developed to account for socio-vulnerability and climate hazards. Nevertheless, only a few studies focus on displacement and, very importantly, on the compounding effects of the hazards. In this regard, the CDSV score for NYC referenced here (Tedesco et al., 2024) provides an opportunity and specific metric the City to assess the combined effects of climate, socio-vulnerability, and displacement and identify areas where early intervention might be necessary. Adopting or adapting the CDSV score referenced here is promising based on the reported results. However, limitations and uncertainties remain in the methodology. For example, the CDSV for NYC adopts a linear combination of the scores from the multiple climate hazards, which implicitly doesn’t account for non-linear effects (e.g., feedbacks among hazards) and doesn’t resolve potential double-counting issues. Moreover, information on the margins of error (MOE) is not always available and should be accounted for in the future as part of the assessment of the outputs.
Assessment of Confidence based on the Evidence	Given the evidence base, there is very high confidence that climate displacement exists in a range of U.S. cities as a result of the interaction between climate risks, social vulnerability, and land-use patterns and dynamics. There is high confidence that climate is one driver of displacement risk, and that migration is responsive to climate risk. There is also high confidence that the CDSV score referenced here can be adopted or adapted by the City to better understand the compounding effects of specific climate hazards, social vulnerability, and displacement.

Key Message 7	**Without anti-displacement strategies in place, resilience-promoting investments can have inequitable outcomes. These strategies require several key approaches: (1) incorporating contextual equity and understanding the history of places down to the neighborhood level; (2) taking a holistic approach to reducing racialized vulnerability to climate shocks, including inseparable issues like housing and transit access; and, (3) recognizing that the cost burdens of climate adaptation (e.g., higher energy costs, insurance premiums, relocation) affect people differently—particularly when considered in light of homeownership and wealth gaps—and can result in increased displacement risks.**
Description of Evidence	Researchers have found significant links between climate risks, adaptation investments, housing, socio-economic inequalities, and residential migration and displacement (Rice et al., 2020; Shokry et al., 2020, 2022). Taken as a whole, the studies conducted on climate displacement and gentrification are now able to identify with more specificity how climate impacts and adaptative measures may contribute to changes in community characteristics and potential displacement of vulnerable residents in specific geographies (K. Best & Jouzi, 2022). These studies suggest that adaptative measures and resilience-promoting investments should account for the relationships identified in those studies to reduce the risk of displacing the most vulnerable and marginalized communities.
New Information and Remaining Uncertainties	The relationships between displacement and resilience-promoting investments, energy and other cost burdens, are still being investigated. There are an increasing number of studies investigating these relationships in specific places and geographies. No such study has been conducted in or for NYC.
Assessment of Confidence based on the Evidence	There is very high confidence that resilience-promoting investments can increase the risk of displacement in socially and economically vulnerable and marginalized communities. There is high confidence that providing affordable housing and reducing the costs burdens of climate adaptation can benefit these communities.

Key Message 8	**Key to achieving equitable climate adaptation is to prioritize community-driven climate resilience approaches. As an example of successful approaches, community-based organizations featured in NPCC3 have implemented climate adaptation initiatives that were attentive to the intersecting nature of climate risks and other health vulnerabilities, including the COVID-19 pandemic. These initiatives include climate mitigation strategies and provide multiple benefits including equitable access to renewable energy, affordable and efficient housing, and economic development strategies that promote equitable green, adaptation economies.**
Description of Evidence	There is growing and significant literature on community-driven climate resilience planning that finds the results of that planning are perceived to be, or are, fairer and more procedurally just than top-down, government or private sector led initiatives (Binder & Greer, 2016; Shokry et al., 2020). The findings of these studies were echoed in our interviews conducted with climate resiliency experts, city officials, and community-based organizations via semi-structured interviews as well as online website content review. In addition, previous case studies of NYC communities also document how community-driven climate planning seeks to address the multiple and intersecting risks that the most vulnerable and at-risk communities experience (Foster et al., 2019). There is also evidence in the peer reviewed literature that features the work of some of these NYC based environmental justice organizations as innovative and reflective of intersectional, climate justice approaches, including: Sze & Yeampierre (Sze & Yeampierre, 2017), Bautista, Osorio & Dwyer (Bautista, Osorio, et al., 2015), Nguyen & Leichenko (Nguyen & Leichenko, 2022), Rudge (Rudge, 2020, 2021), Bautista, Hanhardt, Osorio, & Dwyer (Bautista, Hanhardt, et al., 2015), Shi (Shi, 2021), and Baptista, Matsuoka, & Raphael (Baptista, 2024).
New Information and Remaining Uncertainties	There is a diversity of innovative approaches to equitable and just climate adaptation and resiliency planning and practices. No one approach is broadly applicable to every NYC community. However, each organization described new approaches to addressing intersecting climate, environmental, health, displacement, and other risks even while many of the impacts of their initiatives are still in the implementation or planning phases. There are uncertainties about how some of these initiatives will be implemented and whether additional lessons will be learned from long-term adaptation strategies. Longitudinal, qualitative research is needed to more fully understand these approaches and their applicability across contexts.

Assessment of Confidence based on the Evidence	There is very high confidence that the community-driven approaches to resilience and adaptation planning reflected in the efforts of the four NYC based environmental justice organizations interviewed are perceived to be more just and contribute to procedural equity overall. There is high confidence that some of these approaches have successfully been put into practice and are viewed as leading strategies as evidenced by both primary source reporting and the peer-reviewed literature.
Key Message 9	**Best practices from around NYC and the world highlight the importance of integrated, affirmatively anti-racist, equitable, and just approaches to tackling climate risks. The three broad categories of best practices identified for more equitable and racially just climate adaptation approaches are: (1) integrative approaches to climate resilience that seek out opportunities to advance just transitions and adaptive economies; (2) community-centered planning processes that make adaptation plans more successful in the face of intersecting housing and climate displacement risks; and, (3) collaborative development of goals, programs, policies by leveraging relationships between communities, civic organizations, and state and local government offices and programs.**
Description of Evidence	The ways that different communities, including local governments, respond to climate change and how they incorporate contextual and procedural equity is a rapidly growing field of research. Much of this research revolves around case studies. This workgroup reviewed the literature but sought to identify adaptation and mitigation practices in communities facing the multiple and intersecting risks identified by some of the most vulnerable NYC communities (Foster et al., 2019). We conducted semi-structured interviews with representatives from local environmental and climate justice identified community-based groups. We examined local case studies representing the City's efforts to engage in planning that reflected integrative and community-centered planning processes. We also identified practices outside of New York that were community-driven and addressed the multiple and intersecting risks facing these communities.
New Information and Remaining Uncertainties	There are uncertainties regarding best practices for incorporating justice into a city's adaptation and mitigation policies, plans, and actions. These uncertainties exist because of the need to adapt practices successfully employed in one place to another context. As such, just approaches should seek to understand and incorporate local knowledge and context. The uncertainties that exist are therefore uncertainties with regard to the application of specific practices in specific contexts.
Assessment of Confidence based on the Evidence	There is a High confidence level that the featured best practices reflect the importance of just climate adaptation approaches to address climate risks. This assessment is based on the author's expert review of a broad cross section of peer-reviewed literature on just climate adaptation approaches that are relevant for NYC's context.

8 Sustained Assessment

Climate justice requires careful attention to the intersecting impacts of climate change, social vulnerability, legacy pollution, as well as housing, energy, and health burdens. Sustained assessments of equitable and racially just climate adaptation strategies should include mechanisms for deepening community engagement to gather more granular data about climate risks that are emerging or exacerbated over time. Increased community partnerships can also help track the implementation of climate adaptation strategies and report on their potential to address multiple, intersecting forms of climate risks. Many community-based environmental justice organizations have experience with emergency response and adaptation needs and risks. They may also have community-based plans and initiatives for equitable climate adaptation that can be leveraged with City agencies to produce multiple benefits (Maantay & Maroko, 2009; Marlow et al., 2022; Mizutani, 2018).

Sustained assessments can also build on the robust set of existing indicators and interactive data platforms for environmental justice (i.e. NYC EJ Web Portal), climate change (i.e. NYC Environmental and Health Data Portal, NYC Climate Dashboard), and housing displacement (i.e. Equitable Development Data Explorer) available in NYC. There is an opportunity to build on the CDV scoring approach developed in this assessment to track climate displacement over time in NYC. The use of multiple vulnerability indicators and mapping tools can help elucidate areas of overlapping climate risk where specific measures may be needed. The use of combined indicators of social vulnerability, housing displacement risk, and diverse climate risks requires updated, grounded data that can be reviewed by communities as well.

Future assessments can consider ways to collect and monitor the distributive, procedural, and context-related equity dimensions of climate-related investments. For example, future efforts are needed to compile a comprehensive set of climate adaptation investments across NYC, from multiple agencies and funding sources. There is also a need to monitor and evaluate the distribution and impacts of the various types of climate adaptation investments over time using an equity framework. There is an opportunity to leverage and build on NYC's Environmental Justice Web Portal and Environmental Justice Plan, to incorporate climate displacement indicators and climate adaptation investment tracking systems. These ongoing, publicly available data sources can include community-sourced climate risk data, adaptation projects, and emerging needs over time (See Mayor's Office of Climate and Environmental Justice).

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Abstract:

This chapter of the New York City Panel on Climate Change 4 (NPCC4) report provides a comprehensive description of the different types of flood hazards (pluvial, fluvial, coastal, groundwater, and compound) facing New York City (NYC) and provides climatological context that can be utilized, along with climate change projections, to support flood risk management (FRM). Previous NPCC reports documented coastal flood hazards and presented trends in historical and future precipitation and sea level but did not comprehensively assess all the city's flood hazards. Previous NPCC reports also discussed the implications of floods on infrastructure and the city's residents but did not review the impacts of flooding on the city's natural and nature-based systems (NNBS). This -- the NPCC's first report focused exclusively on flooding – describes and profiles historical examples of each type of flood and summarizes previous and ongoing research regarding exposure, vulnerability, and risk management, including with NNBS and non-structural measures.

Keywords:

Flooding, Climate Change, Flood Hazards, Flood Risk Management, Natural and Nature-Based Systems, NPCC4

Recommended citation:

Rosenzweig, B., Montalto, F., Orton, P., Kaatz, J., Maher, N., Kleyman, J., Chen, Z., Sanderson, E., Adhikari, N., McPhearson, T., Herros-Cantis, P. (2024). Climate Change and New York City's Flood Risk – Interim Report. https://climaeassessment.nyc

Table of Contents

1 Chapter Summary

The purpose of this chapter is to provide a comprehensive description of the different types of flood hazards (pluvial, fluvial, coastal, groundwater, and compound) facing NYC and to provide climatological context that can be utilized, along with climate change projections, to support flood risk management (FRM). Previous NPCC reports documented coastal flood hazards and presented trends in historical and future precipitation and sea level but did not comprehensively assess all the city's flood hazards. Previous NPCC reports also discussed the implications of floods on infrastructure and the city's residents but did not review the impacts of flooding on the city's NNBS. This -- the NPCC's first report focused exclusively on flooding – describes and profiles historical examples of each type of flood and summarizes previous and ongoing research regarding exposure, vulnerability, and risk management, including with NNBS and non-structural measures.

Key Messages

Key Message 1: *NYC faces risks from four types of flood hazards: pluvial, fluvial, coastal, and groundwater, each with a unique geography of exposure that will expand in different ways in the future due to climate change. Identifying these four types as separate, but related, hazards is an important step in studying how they impact NYC, what FRM tools are available to address them, and where future research is needed. Climate adaptation planning must consider all four of these types of flood hazard and their potential impacts across a range of magnitudes, including very extreme events.*

Key Message 2: *Discussions about flooding often focus on risks within the Special Flood Hazard Areas (SFHA) mapped by the United States Federal Emergency Management Agency (FEMA). However, the FEMA SFHA maps present fluvial and coastal flood hazards only. The recently released NYC Stormwater Flood Maps represent the city's first attempt to map pluvial and some compound flood hazards, with risks spread out over a much larger fraction of NYC. In the coming year, the USGS and NYCDEP will be embarking on a study to investigate and model groundwater flooding in Queens and Staten Island. In this chapter, we present a preliminary assessment of pluvial* *and groundwater flood hazard exposure areas that can be utilized to support FRM. Additional research is necessary to develop hazard maps that represent a broader range of flooding hazards and their increase in magnitude in response to anthropogenic climate change.*

Key Message 3: *Much of NYC is exposed to pluvial flooding, which occurs when the intensity of precipitation exceeds the infiltration capacity of the soil and the hydraulic capacity of the sewer system. These conditions often occur during cloudbursts, short-duration periods of intense rainfall that can be embedded within large storm systems or occur as individual, hard-to-forecast thunderstorms. Intense rainfall has already been observed to have become more frequent in New York City since the mid-20th century and is projected to further intensify and occur more frequently with unmitigated climate change. Despite the increasing risk, pluvial flood hazards remain poorly understood. The NYC Floodnet project is beginning to collect observations of flooding when it occurs, but more monitoring of rainfall, in-sewer flows, and flooding, along with Hydrologic and Hydraulic (H&H) modeling of pluvial flooding processes and impacts is needed.*

Key Message 4: *In NYC, fluvial flood risks are spatially localized to areas of the Bronx and Staten Island where surface stream channels remain. In the remainder of the city, historical surface streams were filled and replaced, with their flow routed to the sewer system. As a result, fluvial flood hazard has largely been replaced by pluvial flood hazard in most of the city. Both fluvial and pluvial flood hazards will increase due to climate-change driven intensification of precipitation and elevation of sea level. While traditional floodplain management can be an effective strategy in reducing exposure to fluvial floods, a broader, watershed-scale approach that retains, details, and redirects stormwater is needed to jointly manage pluvial and fluvial flood risks.*

Key Message 5: *Current and future coastal flood risks are caused by high storm tides, rising sea levels, and historical development on landfill over tidal marshes and nearshore areas. In Jamaica Bay, tides and storm surges have also been significantly elevated by historical dredging and landfilling, worsening chronic and extreme flooding. For example, on December 23rd, 2022, a major flood event around Jamaica Bay was caused, in part, by dredging that has led to amplified storm tides which were nearly a foot higher there than elsewhere in the harbor. Further improvement of our understanding of future coastal flood hazard is possible through downscaling of climate model data and modeling of multiple compounding flood drivers.*

Key Message 6: *Many NYC neighborhoods have very shallow groundwater tables and already experience groundwater flooding. These areas include parts of the city that were developed when groundwater levels were substantially lower due to historical pumping of groundwater for municipal water supply. Groundwater flood risk has the potential to be particularly significant in NYC because of the prevalence of subterranean infrastructure. Groundwater flood hazards have not yet been assessed citywide, but preliminary efforts are underway. Sea level rise may cause groundwater levels to rise, resulting in inflow and infiltration of groundwater into sewer pipes and subterranean spaces and inundation of topographically vulnerable locations from below. Improved characterization of spatially heterogenous aquifer hydraulic properties and sustained monitoring of ground water levels will be necessary to develop projections for future groundwater flooding.*

Key Message 7: *Climate change is increasing the frequency of extreme precipitation events and elevating sea levels, increasing the likelihood of compounding either one of these flood drivers by the other. In addition, tropical and post-tropical cyclones (TCs) have caused severe storm surges and extreme rainfall to occur simultaneously. While assessment is limited by the small number of historical TC events, the limited evidence suggests that TCs can cause low-probability, dangerous compound flooding. Given the importance of TCs and limited historical data, a deeper understanding of compound flood hazard likely requires detailed modeling and downscaling to simulate such storms under the present and future climate.*

Key Message 8: *NYC's NNBS provide many valuable ecosystem services, including critical water regulation services that can play a role in FRM. However, many of these systems are themselves vulnerable to different flood hazards, especially along the coast. Research into how different types of NNBS are impacted by flood/storm surge events, hydroperiod changes, rising water tables and salinization is needed to better evaluate future changes in ecosystem services. Opportunities for designing NNBS to mitigate the impacts of various flood hazards need to be further explored.*

Key Message 9: *Comprehensive FRM plans must be designed to address the full range of flood hazards faced by individual communities. Planning must begin with participatory decision-making processes that establish* *neighborhood-specific levels of acceptable future flood risk. To reduce risks from current levels, FRM tailored to each community will include combinations of structural and non-structural approaches, including NNBS, that are implemented in ways that reduce social vulnerability and are also synergistic with community histories, needs, and goals.*

2 Introduction

2.1 Chapter Scope and Context

Located along the Atlantic coast with a year-round humid climate (Cui et al., 2021), NYC is subject to multiple types of flooding hazards (Figure 1). Even without climate change and independent of the significant anthropogenic morphological changes that have been made to the local geography, floods occur in this region due to extreme precipitation, coastal storm surges and high tides, high groundwater tables, and their co-occurrence (Figure 2). Over four centuries of urbanization, the city's land surface, streams, wetlands, underwater habitats, coasts and soils have all been radically modified (Montalto & Steenhuis, 2004; P. M. Orton, Sanderson, et al., 2020; Sanderson & Brown, 2007; Walsh & LaFleur, 1995). In addition, global climate change has elevated regional sea level, increasing the likelihood of coastal flooding (Braneon et al., 2024) and making it more difficult for sewers, rivers and streams to drain to the sea. In the absence of significant and rapid reductions in greenhouse gas emissions, sea levels will continue to rise and extreme precipitation events are projected to become more frequent, more intense, and possibly also larger in areal extent (Braneon et al., 2024; Fowler, Ali, Allan, Ban, Barbero, Berg, Blenkinsop, Cabi, Chan, Dale, et al., 2021). Together these phenomena carry significant implications for future flood severity, frequency, and the resources needed to manage flood risks.

Previous NPCC reports discussed some types of flooding, along with historical and projected changes in their occurrence due to climate change. For example, Gornitz et al, (2019) provided projections for future sea level rise, while Patrick et al., (2019) and P. Orton et al., (2015) mapped static and dynamic coastal flood risks, respectively. Orton et al.(2019a) updated the projections of storm-driven coastal flood risk considering monthly high tides and storm surge due to a broadened set of sea level rise projections and extreme wind. González et al., (2019) analyzed the climatology of heavy precipitation in NYC, including observed heavy rainfall days and trends in subdaily precipitation events at different durations, and their meteorological drivers, evaluated fluvial flooding in regional streams, and assessed the use of 311 to report street flooding. Zimmerman et al., (2019) described some of the potential impacts of flooding on critical infrastructure systems. While this body of knowledge is extensive, none of the prior NPCC reports comprehensively reviewed and/or mapped historical and future trends in all types of NYC flood hazards.

This chapter broadens the prior NPCC-led discussion of climate change impacts on NYC flood risks. We review the current science on how climate change will impact different types of flood hazards and their associated risks on people and natural ecosystems. We also present an introduction to the key dimensions of flood risk management (FRM) including the use of structural and non-structural strategies and NNBS. The relationship of flooding to health is described in Matte et al.(2024), while the relationship to equity is covered in Foster et al., (2024). Future changes in population and transitions that may impact flood management are discussed in Balk et al., (2024).

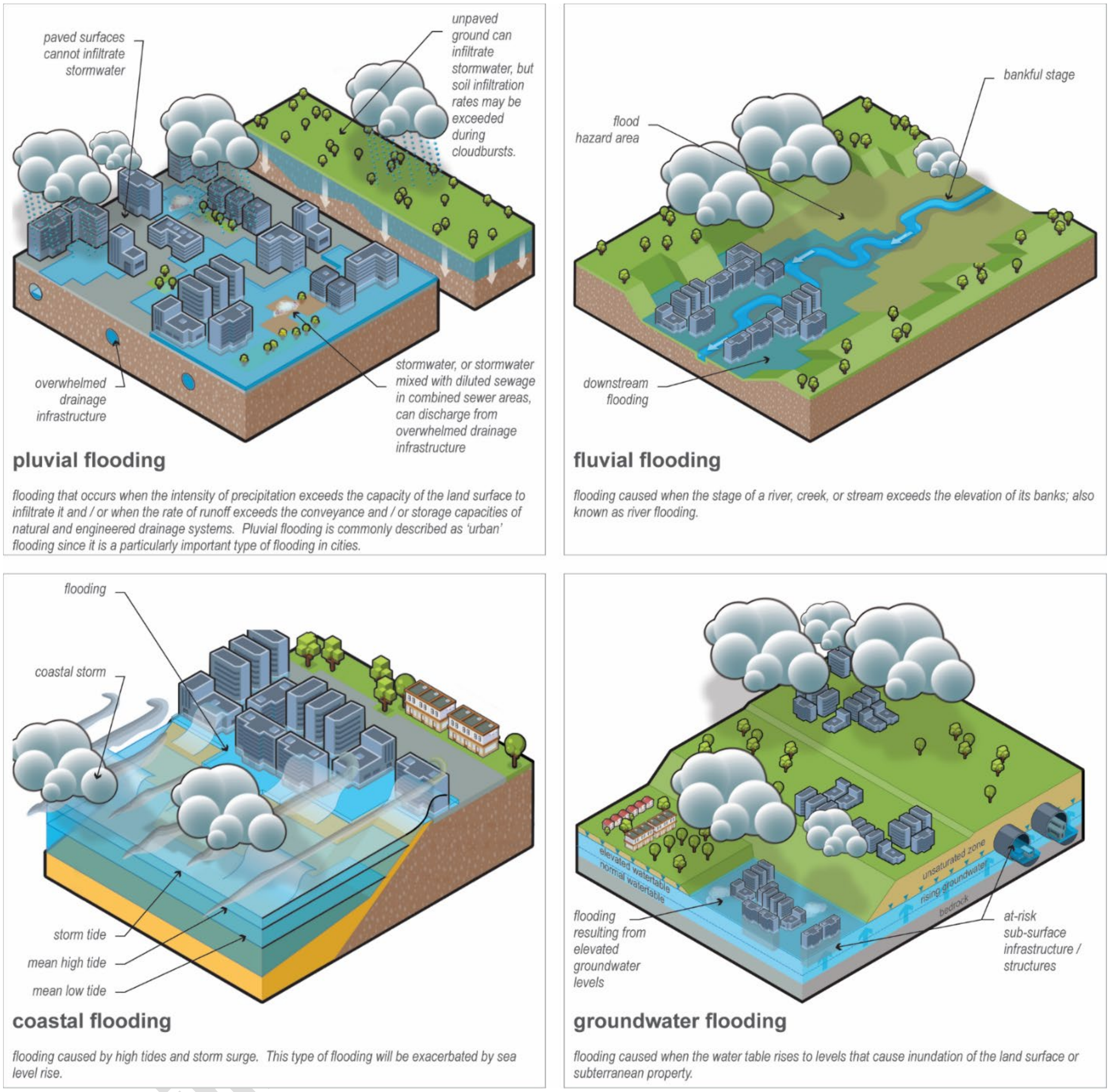

Figure 1: The four types of floods that impact New York City (pluvial, fluvial, coastal, and groundwater). The impacts of these four flood types can be compounded when they occur in combination resulting in Compound Flooding (Section 8). Figures by the authors, adapted from UK Research and Innovation (UKRI) and the Natural Environment Research Council (NERC) / Ben Gilliland under Creative Commons License CC BY-NC 4.0.

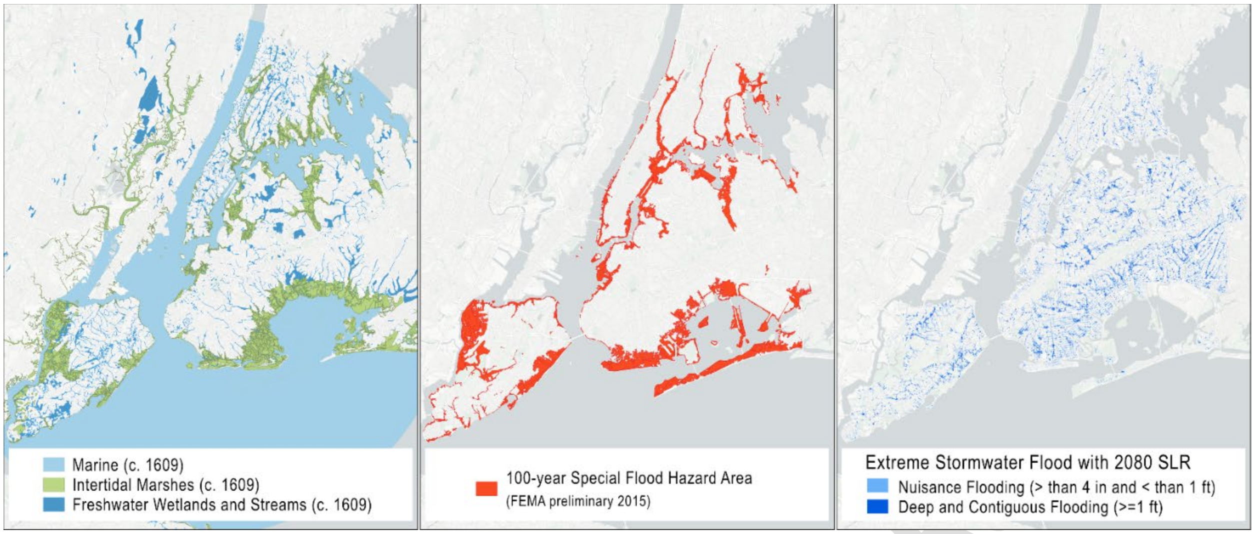

Figure 2: Historic streams and wetlands across the city (left), the FEMA 100-year Special Flood Hazard Area (center), and pluvial flooding resulting from ~3.5-inches of rain per hour with 58-inches of sea level rise (right). Areas where inland streams and coastal wetlands were landfilled for urban development tend now to be topographically low-elevation areas that are exposed to flooding. Areas landfilled to dispose of municipal waste and dredged sediment are now anomalously higher-elevation areas, even when located along the coast. The map of historic streams and wetlands was provided by Eric Sanderson and Lucinda Royte, New York Botanical Garden.

2.2 Chapter Organization

The chapter is organized as follows:

- Flood Risk
- Types of flooding (including a hazard characterization, a historic example, assessment of exposure and vulnerability, discussion of how climate change is projected to affect this hazard, and identification of persistent knowledge gaps)
    - Pluvial flooding
    - Fluvial flooding
    - Coastal flooding
    - Groundwater flooding
    - Compound flooding (various combinations of the above)
- Flood Risk Management
- Opportunities and Future Research

3 Flood Risk

3.1 Flood Risk

In undeveloped landscapes, flooding is a natural hydrologic process that plays an important role in the fate and transport of nutrients and sediment, geomorphological evolution, and the function of ecosystems (Benito & Hudson, 2010; Junk et al., 1989; McClain et al., 2003). In heavily developed landscapes like NYC, flooding can have adverse consequences for both human and ecological systems. Floods occur because of dynamic interactions between human, natural, and atmospheric processes. Policies that determine how natural and engineered landscapes are managed; specify specific protocols for the planning, design, and management of infrastructure; and/or influence certain types of human behavior can all significantly influence the occurrence of flooding and associated risks (Rainey et al., 2021).

A key climate change impact, flood risk is determined by four factors (Crichton, 1999; IPCC, 2023a).

1. The magnitude and frequency of flooding **hazards**,
2. The **exposure** of people, real property, natural ecosystems, and critical infrastructure to inundation when flooding occurs,
3. A variety of social, ecological, technological and infrastructure factors (Kim et al., 2022) that contribute to **vulnerability** to flooding, and
4. The **responses** that have been taken to mitigate flooding (e.g. **adaptation/transformation responses**), as well as any tradeoffs and/or unintended consequences of those responses or any other actions taken to address other societal needs that make flooding worse, commonly referred to as **maladaptation.**

Flooding creates risks when vulnerable people or ecosystems are exposed to flood hazards. Within cities, flood impacts can occur anywhere, e.g. within coastal and riverine floodplains but also at interior locations due to small-scale differences in topography, drainage system constraints, and building design (National Academies of Sciences, Engineering, and Medicine, 2019). Flood risks can also arise as unintended consequences of actions taken to address flooding or any other societal challenge (e.g. the construction of housing in flood hazard areas). Flood risk management (FRM) includes plans, actions, strategies, or policies taken to reduce the likelihood and/or magnitude of adverse potential consequences based on assessed or perceived risk (IPCC, 2023a). FRM can be accomplished by a variety of adaptation measures that may be implemented individually or in combination, by public and/or private entities from the Federal government down to individual landowners (IPCC, 2023b; Peck et al., 2022). Effective FRM requires equitable collaboration that is both vertical (e.g. across different governance levels) and horizontal (e.g. among various actors at any given level of governance), and must consider flooding's physical, social, and informational dimensions (National Academies of Sciences, Engineering, and Medicine, 2019).

3.2 Flood Hazard

Each of the four principal types of flooding that impacts NYC (pluvial, fluvial, coastal, and groundwater) are triggered by a wide range of associated hazards. For example, coastal flooding can occur due to infrequently occurring, but powerful storm surges that cause deep inundation over one or two tidal cycles; frequently occurring but moderate 'sunny day' high water that occurs during the highest astronomic tides each month; as well as by future sea level rise that will result in regular inundation of the lowest-lying areas of the city. Flood hazards can be amplified when they occur concurrently. This can include compound flooding (when coastal and rain-driven flooding occurs within the same event) or when multiple hazards with the same driver occur (such as the co-occurrence of pluvial and groundwater flooding, or pluvial and fluvial flooding, all of which are driven by precipitation).

The magnitude of a flood hazard at any given location is primarily characterized by the maximum depth of water inundation (Scawthorn et al., 2006). However, other factors may also strongly contribute to the magnitude of hazard during a flood event (Hossain & Meng, 2020; Wing et al., 2020). These include:

- **Fast-flowing water:** The force associated with flowing water can generate life-threatening conditions, even when floodwaters are only a few inches deep. The force of flowing water can cause pedestrians to be knocked down (Martínez-Gomariz et al., 2016; Musolino et al., 2020), and vehicles to be floated (Martínez-Gomariz et al., 2018), and can generate hydrodynamic forces that can destroy solid walls and dislodge buildings (FEMA, 2019). Fast flowing floodwaters can erode large volumes of soil and sand, undermining vegetation, bridge piers, sea walls and foundations. The transport and deposition of suspended sand and sediment, along with vehicles and other debris, can contribute to additional flood damages.
- **Waves:** Hydrodynamic forces caused by wave breaking, runup and slam can cause severe structural damage to buildings and other infrastructure located along the coast (FEMA, 2019; Hatzikyriakou & Lin, 2017).
- **Flooding rise time:** The time between the peak of a rain event that causes (pluvial and/or fluvial) flooding and the time of peak inundation (Gourley et al., 2013). Virtually all pluvial floods, and many fluvial floods in NYC are 'flash' floods, defined by the US National Weather Service (NWS) as events that have a rise time of less than 6 hours (Gourley et al., 2016). Fluvial floods along the Bronx River may have longer rise time due to the size of its watershed.

- **Inundation duration:** Describes the length of time over which an area remains inundated. Along with direct increases in the length of time of disrupted transportation, transport and utilities service, porous building materials exposed to floodwaters for longer durations have a greater likelihood of mold growth and corrosion (Marvi, 2020).

- **Water chemistry:** Floodwaters can transport dissolved and suspended contaminants, including potentially toxic chemicals or pathogens. The risk of waterborne infectious disease from exposure to floodwaters that have passed through combined and separate sewers is much greater than that associated with surface runoff (de Man et al., 2014; M.-C. Ten Veldhuis et al., 2010). Corrosion from saline coastal and groundwater inundation can cause additional damage to infrastructure and utilities (Abdelhafez et al., 2022; Tansel & Zhang, 2022) and can impact the health of urban trees and other vegetation that is not salt tolerant (Hallett et al., 2018a; Sacatelli et al., 2023; Woods et al., 2020).

- **Live electric current:** Submerged power lines or other inundated electrical systems can create areas of electrified floodwaters or conditions that allow people to otherwise contact live electric current. Jonkman and Vriling (2008) estimated that 3% of global flooding deaths were caused by electrocution, as occurred in College Point, Queens in 2004 (See Table 2 below).

As a rule, the magnitude of a potentially hazardous weather event is inversely related to its annual probability of occurrence (Marshak & Rauber, 2022). As a result, the magnitude of floods and the weather events that drive them are often described by their return period (Equation 1), or the inverse of the probability that an event will occur in any given year:

$$R = \frac{1}{P}$$

Equation 1: Return Period – where R = The Return Period (years), also known as the Annual Recurrence Interval (ARI); P = Probability of occurrence in any given year (# occurrences / # years analyzed), also known as the Annual Exceedance Probability (AEP)

While the return period provides a convenient way to describe the probability of occurrence of a particular hazard, it can be easily misunderstood for several reasons. First, it does not provide information on the timing of actual events. For example, a 100-year precipitation event does not necessarily occur once every 100 years. Rather, this event has a 1% chance of occurrence every year on average and, statistically, can happen more than once in the same year or not happen for many hundreds of years. Second, precipitation events with the same return period can imply very different precipitation accumulations, (typically measured in inches), and intensities (typically measured in inches/hour). For example, in NYC a 100- year, 24-hour precipitation event implies the accumulation of almost three times the amount of precipitation as would be associated with a 100-year, 1-hour event. However, the 1-hour event is more than 8 times as intense. Third, climate change is altering both the mean and extreme values of climate variables like precipitation accumulations and sea level (Braneon et al., 2024), creating uncertainty in the estimation of the frequency with which a particular event occurs.

For all the reasons discussed above, event return periods derived from retrospective analyses of historical climate data may be outdated and inadequate for use in designing FRM strategies. The return periods associated with certain flood hazards are expected to decrease with climate change through the 21st Century, as the climate system accelerates. The NYC Climate Vulnerability, Impact, and Adaptation Analysis (VIA) will soon be releasing updated and forecasted future return periods for NYC precipitation. As such research evolves, effective communication between practitioners, scientists, and the public is necessary to avoid misinterpretation and misuse of return period terminology in FRM planning (Water Environment Federation, 2023).

Despite their shortcomings, return periods are commonly associated with flood hazards, and they are used throughout this chapter. The reader is advised to treat these return periods with caution, and as a rule, to use the physical characteristics of the event (e.g. its duration, intensity, frequency, spatial extent, etc.) as a more precise descriptor of the flooding driver.

3.3 Flood Exposure

Exposure describes "the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage" (IPCC, 2012). For any specific flood hazard, exposure is a descriptor of what areas were affected by the hazard and who and what is in the affected area.

Due to NYC's density, critical infrastructure and thousands of people can be exposed to flooding, even when inundation is only limited to several city blocks.

Potential exposure to different flood hazards is typically evaluated using flood hazard maps. Flood hazard maps present the area over which a specific flood hazard has a defined probability of occurring. The most well-known flood hazard maps are the SFHA developed by FEMA, which are widely used to support city flood management. The SFHA identifies geographic areas that have a 1% chance of coastal and fluvial flooding each year (100-year return period) with an inundation depth greater than 1 foot. Additional mapped hazard areas provided by FEMA include areas within the SFHA that also experience waves of at least 3 feet in height above the base flood water level, and areas associated with the 0.2% (500-year storm surge or fluvial flood).

The term 'floodplain' is commonly used to describe FEMA's SFHA, but only a small fraction of NYC's flood hazard areas are classically defined floodplains- e.g. relatively flat alluvial landforms adjacent to rivers that are formed by processes associated with periodic flooding of the river (Benito & Hudson, 2010; Wolman & Leopold, 1970). This distinction has important implications for understanding flooding processes, risk, and potential opportunities to enhance the resilience of areas of the city exposed to flooding. To avoid confusion, in this chapter we use the more physically representative term 'SFHA' to refer to coastal and riverine flood hazard areas identified by FEMA.

When mapping flood risks, it is also important to be mindful of 'what is being exposed to what' (Carpenter et al., 2001). Flood hazard maps only represent areal exposure to a specific flood hazard – for example, areas exceeding a specific depth of inundation associated with an event with a specific return period. Areas outside of this zone may still be highly exposed to flooding from a higher magnitude (e.g. higher return period) event or from other types of flood hazards. Within any flood hazard area there is often likely to be a spectrum of exposure – with different locations exposed to different water depths and/or different combinations of flood hazards.

Table 1. Flood Hazard Maps used for exposure assessment in this chapter. It is important to note that each layer is associated with different probabilities of annual occurrence. ***Maps of Present-Day Hazard Areas***

Hazard	Return Interval	Type of Flooding	Methods	Source
Pluvial flooding (inundation depth greater than 4") from 2 inches of rain in one hour, falling uniformly across the city.	Approximately 10-year (10% probability each year)	Pluvial	InfoWorks ICM 1D-2D Hydrologic and Hydraulic (H&H) Hydrologic Modeling	Stormwater Resiliency Study (City of New York Mayor's Office of Resiliency, 2021)
Uncompounded (not co-occurring) storm surge and fluvial flooding (inundation depth greater than 1 foot); Base flood water depth is provided for most of the flood hazard area.	100-year (1% probability each year)	Coastal and Fluvial	HEC-RAS Modeling of identified water bodies	FEMA NYC Flood Insurance Study (FEMA, 2007, 2013)
Tidal Mean Monthly High Water (MMHW); Base Flood Depth associated with these tides varies across the hazard area.	0.08-year (1250% probability each year) in the 2020s	Coastal	3-D dynamic simulations of tides using the SECOM model with the NYHOPS operational setup	NPCC3 (P. Orton et al., 2019a)
Shallow Groundwater Areas: Areas where the depth to water table is estimated to be less than 10 feet below the land surface	n/a	Groundwater	Estimated based on pre-2013 water table observations and the topography of the land surface	(Monti et al., 2013a)

Maps Representing Potential Future Flood Hazard Due to Climate Change				
Pluvial flooding from ~3.5 inches of rain in one hour falling uniformly across the city, along with 58" of sea level rise; Inundation depth greater than 4" is delineated.	2080s 90th percentile sea level rise	Pluvial	InfoWorks ICM 1D-2D Hydraulic and Hydrologic Modeling	Stormwater Resiliency Study (City of New York Mayor's Office of Resiliency, 2021)
Tidal Mean Monthly High Water (MMHW with 58" of sea level rise); Base Flood Depth associated with these tides varies across the hazard area.	2080s 90th percentile sea level rise	Coastal	3-D dynamic simulations of tides using the SECOM model with the NYHOPS operational setup	NPCC3 (P. Orton et al., 2019a)

The dense, highly built-up environment of NYC presents unique challenges for providing direct counts of exposed populations. The smallest spatial unit at which population density data is available is the census block, which in NYC can represent several thousand residents (Manson et al., 2021). But flood hazard areas are often discontinuous and small relative to the size of census blocks, with boundaries that do not spatially coincide with them. In addition, at any given location in NYC, populations are often distributed vertically, with relevance for the evaluation of flood exposure. While residents on higher floors may be exposed to significant indirect impacts from flooding (such as loss of utilities or isolation), their exposure is very different from populations in ground-level or subgrade residences that may be exposed directly to deep inundation. Dasymetric mapping techniques can be used to apportion census block populations to flood hazard areas. However, these techniques have not historically been used to represent the vertical distribution of populations. Three dimensional dasymetric mapping of urban populations have only been introduced recently (Maroko et al., 2019; Pérez-Morales et al., 2022) and, to date, this approach has not been applied in NYC.

Throughout this chapter, maps depicting exposure of NYC's buildings to the flood hazard areas listed in Table 1 are presented. Because the Flood Insurance Studies (FEMA, 2007, 2013) used to delineate FEMA's SFHA in NYC do not consider pluvial or groundwater flooding, nor the impact of climate change on future flood exposure, this chapter utilizes the additional hazard layers listed in **Error! Reference source not found.**. Current and future pluvial flood hazard maps were developed by the City of New York. The US Geological Survey identified areas with shallow groundwater tables that are subject to future groundwater flooding. NPCC researchers developed maps of coastal hazards based on Mean Monthly High Water (MMHW) (P. Orton et al., 2019a). Spatial data on buildings and subgrade spaces were obtained from the publicly available New York City Building Footprints and *MapPLUTO* cadastral datasets (City of New York Department of City Planning, 2022; NYC OTI, 2023).

3.4 Flood Vulnerability

The term 'vulnerability' is used broadly in a variety of fields, including natural hazards management and everyday language. In this chapter, we define vulnerability as 'the propensity or predisposition' (IPCC, 2022, 2023a) of an individual, community, or natural system to be adversely affected by a flood, referring specifically to their 'capacity to anticipate, cope with, resist, and recover from the adverse effects of physical events' (IPCC, 2012). Flooding can cause many direct adverse effects in exposed communities, including loss of life (Table 2), injuries, and damage to property and utilities from inundation. It can also cause a variety of indirect adverse effects, including the disruption of transit and transportation, extended loss of electricity, heat, and other utility service, health impacts from mold or pathogen exposure, and stress, and can contribute to the involuntary displacement of individuals and communities (Ahern et al., 2005; Sampson et al., 2019; J. A. E. Ten Veldhuis, 2011; J. A. E. Ten Veldhuis & Clemens, 2010). Flooding can also disrupt, damage, or destroy NNBS, reducing their innate ability to provide urban ecosystems services, including those needed to buffer the impacts of climate extremes.

3.4.1 Vulnerability of human communities

Past floods have incurred significant known economic costs, but the true total costs borne by vulnerable NYC residents remain unquantified. In NYC, Post-Tropical Cyclone Sandy (2012) was estimated to have caused over $19 billion dollars of damage to NYC including lost economic activity, with much of this damage attributed to storm surge flooding (City of New York Office of the Mayor, 2013). In 2021, a cloudburst associated with the remnants of

Hurricane Ida ('Ida-Remnants Cloudburst) triggered an estimate $900 million (FMEA IA-$158M, SBA -$123M, NFIP-$28M, NYS-ONA-$1.5M, and CDBG-DR-$310M) in known damages *(Personal Communication, NYC Office of Emergency Management (July 13, 2023*). However, it is unlikely that such estimates include the total costs incurred by NYC residents. Nationally, existing flood data have been found inadequate in representing the magnitude of urban flooding impacts (National Academies of Sciences, Engineering, and Medicine, 2019). While typical flood damage estimates are based on flood insurance claims or financial assistance provided by FEMA or other federal agencies following a flooding disaster, most NYC residents, including many who live in areas highly exposed to flooding, do not have flood insurance. Additionally, the FEMA Individual Assistance Program may only cover a fraction of actual property damage costs and is only available during floods that are officially declared disasters by the President. Many impactful pluvial floods are highly localized and not declared disasters by FEMA (Lo, 2024), suggesting that the true total costs of flooding to residents of NYC could be substantially higher than published estimates.)

Table 2: Flooding events that caused 52 direct deaths in NYC since 1987. Additional fatalities from vehicle accidents associated with storm conditions are not included in this table.

Date	Type of Flooding	Description	Source
8/12/1993	Pluvial	An infant drowned in her basement when it flooded from heavy rains in Flushing, Queens.	(Lo, 2024)
8/11/2004	Pluvial	"Flash flooding of roads occurred at College Point, Queens. Two occupants of a vehicle were electrocuted by a fallen power line when they apparently stepped out of their vehicle into several feet of water."	(Lo, 2024)
10/29/2012	Coastal	36 fatalities were directly attributed to storm surge and high surf *(Staten Island: 23; Queens: 6; Brooklyn: 5; Manhattan: 2)*	NCEI Storm Events Database Episode 70044 (NCEI, 2023)
9/1/2021	Pluvial	10 drowning deaths in subgrade apartments and residential offices in Queens. 1 drowning death in a subgrade apartment in Brooklyn. 1 drowning death outdoors after falling into a body of water during the storm (The body of a pedestrian was found floating in the Gowanus Canal the day after the storm.) 1 direct fatality from asphyxiation resulting from a car fire that was caused by flooding of a vehicle	(Lo, 2024; Yuan et al., 2024)

A combination of infrastructure and socioeconomic factors contribute to flood vulnerability (Zahran et al., 2008).To help to evaluate the vulnerability of NYC residents to flooding, a team of academic researchers, working in collaboration with experts from the NYC Interagency Climate Adaptation Task Force (ICAT), developed The New York City Flood Susceptibility to Harm and Recovery Index (FSHRI) (Figure 3) as part of the NYC Vulnerability, Impacts, and Adaptation (VIA) study. The FSHRI is an index of socioeconomic vulnerability (susceptibility to harm and capacity to cope and recover from flooding) based on social demographic indicators (Table 3) provided through the American Community Survey (ACS) at the census tract level. These indicators were selected based on empirical evidence in the social science literature on socio-economic parameters that are correlated with measures of flood outcomes (Madajewicz, 2020; Madajewicz & Coirolo, 2016; Rufat et al., 2015; Zahran et al., 2008). The outcomes considered in the empirical analyses include depth of water for exposure; loss of life or injury; amount of damage to a home, loss of employment, and/or loss of access to food or health care for susceptibility to damage; and cost of recovery and length of various aspects of recovery for capacity to recover. The FSHRI is part of a larger effort to develop NYC's first Flood Vulnerability Index (FVI), which includes the FSHRI together with scenarios of exposure to different types of flooding. The FVIs are available on the NYC Mayor's Office Environmental Justice Mapping tool (EJNYC Mapping Tool, n.d.).

Table 3: Indicators used in the Preliminary NYC FSHRI

1. Black, Indigenous, People of Color (% that identify as any racial category besides 'White' and/or ethnically Hispanic/Latino)
2. Income (Per capita)
3. Disability (% with a disability)
4. Language isolation (% speaking English less than "well")
5. Children (% below 5 years old)
6. Elderly (% Above 60 years old)
7. Elderly population living alone (% living alone above 65 years old)
8. Healthcare access (% without health insurance)
9. Household income (% households making less than $75,000)
10. Home ownership (% households that are owner occupied)
11. Cost burdened households (% households spending 30% or more in their living costs)
12. Rent burdened households (% households spending 30% or more in their rental costs)

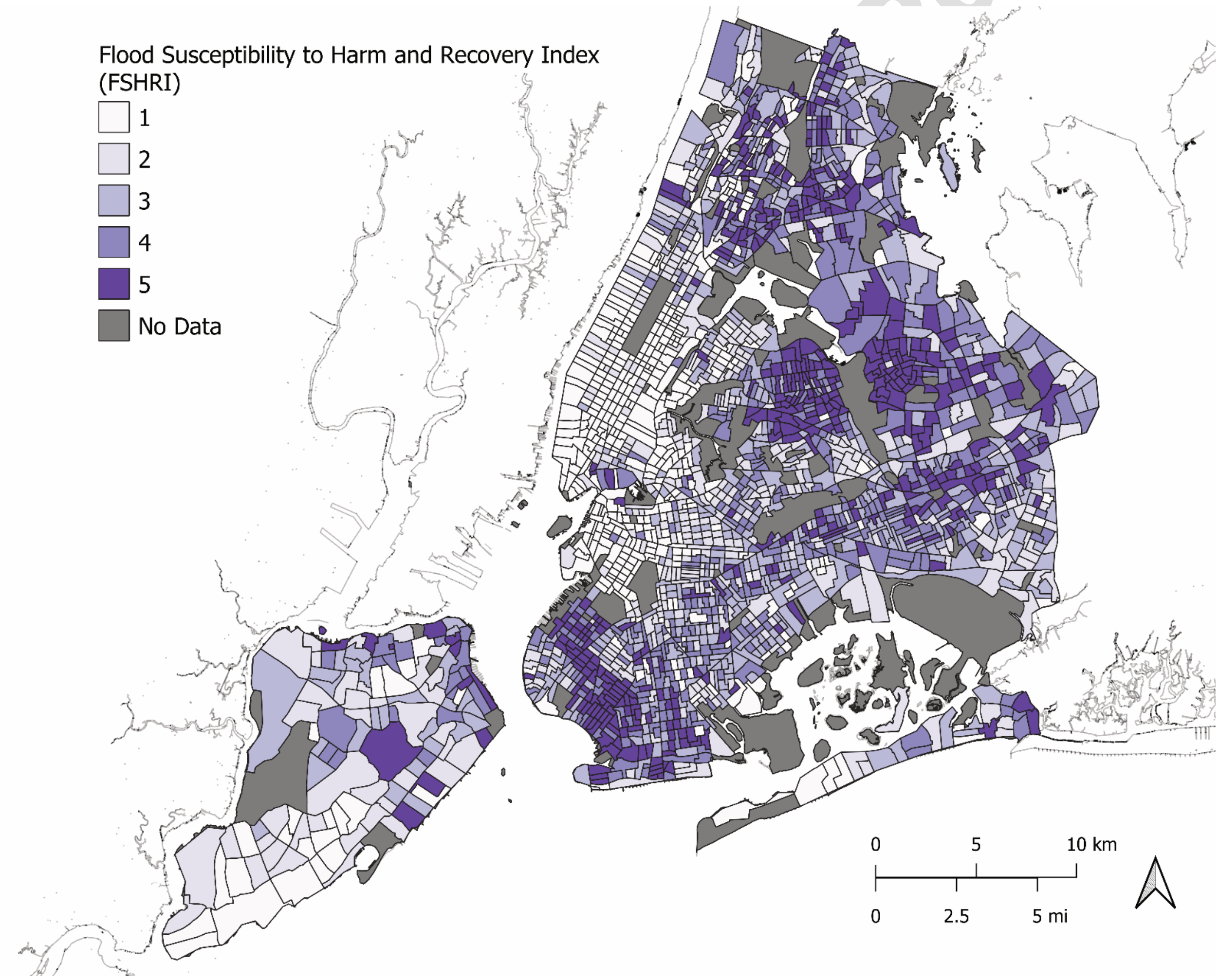

Figure 3: The Flood Susceptibility to Harm and Recovery Index (FSHRI), by census tract across NYC. Areas with higher socioeconomic vulnerability, as indicated by the FVI, may face more adverse effects if exposed to different types of flooding. The FSHRI does not consider exposure to any particular type of flooding. The NYC Flood Vulnerability Index, which includes the FSHRI and exposure to different types of flooding is available on the NYC Mayor's Office Environmental Justice Mapping tool. Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

Many features of the built environment contribute to, or reduce, vulnerability to flooding. For example, compared to traditional structures, buildings that have 'wet floodproofing' (measures that allow water to safely enter the enclosed areas of a house) or 'dry floodproofing' (measures that make a structure watertight below the level that needs protection) may be much less vulnerable even if they are highly exposed (NYC Planning, 2020). The placement and design of critical utilities, such as electrical, mechanical, and HVAC systems, can also be a key determinant of vulnerability. However, building-scale data on floodproofing and the elevation of critical utilities is not currently available. For this report we evaluate the exposure of two building typologies associated with both physical and socioeconomic buildings: 1-2 unit residential buildings with subgrade spaces (basements or cellars) and New York City Housing Authority (NYCHA) buildings. Residents of 1-2 unit residential buildings and residents of buildings with subgrade basements or cellars are more likely to experience costly and life-threatening flood damages than are residents of large multifamily buildings and buildings without inhabited subgrade space (City of New York Office of the Deputy Mayor for Administration, 2021; FEMA, 2019). For example, during the Ida-Remnants Cloudburst in 2021 (see Section 4.2), Small (1-2 family) residential buildings were disproportionately impacted, comprising 75% of the damaged buildings, while only representing 52% of buildings citywide (NYC OMB, 2023). Based on NFIP claims for Post Tropical Cyclone Sandy 2012, small residential buildings were also more likely to experience structural damage, particularly if built prior to modern flood resistant construction standards (NYC Planning, 2020). The presence of basements in older buildings can, themselves, contribute to structural damage during floods (FEMA, 2023a). In addition, basement apartments often provide a secondary source of income for small-residence property owners, who are often small landlords that live on-site. Basement apartments in these types of buildings disproportionately serve very low-income households, recent immigrants, and other socioeconomically vulnerable households that lack access to affordable options in the general housing market (NYC OMB, 2023).

Over 400,000 New Yorkers live in NYCHA residences, which can include many multi-generational communities with internal support structures and kinship networks that can help to reduce vulnerability to flood hazards, especially when compared with communities that lack such social cohesion (Beck, 2019; Bixler et al., 2021; Keene & Geronimus, 2011; Usamah et al., 2014). At the same time, NYCHA residents often face distinct socioeconomic and infrastructure vulnerabilities – they are disproportionately elderly, disabled, and low-income, and from groups that are victims of racism and ethnic marginalization (Hernández et al., 2018). Also, while substantial progress has been made in floodproofing and structurally reinforcing NYCHA buildings located in the FEMA SFHA since Post-Tropical Storm Sandy in 2012 (New York City Housing Authority, 2021) and pilot cloudburst management strategies are planned for some NYCHA developments (City of New York Office of Management and Budget, 2023; New York City Housing Authority, 2021), most NYCHA buildings outside the SFHA remain vulnerable to flooding. These vulnerability factors are exacerbated by a legacy of multidecadal deferred maintenance in many NYCHA properties (La Mort, 2018).

3.4.2 Vulnerability of natural and nature-based systems

NYC's NNBS provide a wide range of regulating, provisioning, supporting, and cultural ecosystem services, to which many NYC residents attach significant value (Miller & Montalto, 2019). These include water regulating services that can help reduce the impacts of different types of floods, as described in detail in the recently published International Guidelines for Natural and Nature-based Features for Flood Risk Management (Bridges et al., 2021). But NNBS are also vulnerable to climate change since shifts in temperature, flood frequency, sediment and salt loading can all impact their function and ability to provide ecosystem services.

For example, sea level rise and storm surges will raise coastal groundwater tables and cause saltwater to enter coastal aquifers (Nordio et al., 2023). Changes to soil salinity can trigger complex changes to vegetation composition, ultimately favoring salt-tolerant species (Woods et al., 2020). Though salt adversely affects trees at all stages of growth and development, responses vary significantly by species (Dmuchowski et al., 2022; Middleton, 2016; W. Wang et al., 2019). Exposed to salt water, some tree species may have difficulty germinating by seed (Kirwan et al., 2007; Woods et al., 2020), while others may stop producing new leaves, senesce prematurely, fail to recruit new individuals, or die (Munns & Tester, 2008). Analyzing street trees in Post Tropical Cyclone Sandy's inundation zone three years after the storm, Hallet et al. (2018b) found that red maple (*Acer rubrum*) was negatively impacted by saltwater flooding but was able to recover over time. London plane trees (*Platanus x acerifolia*), by contrast, showed high mortality and no signs of recovery.

Tidal wetlands are particularly sensitive to changes in both mean sea level and tidal range. Tidal wetlands require regular cycles of surface flooding and exposure, as well as deeper and longer duration episodic flooding that typically occurs during spring tides and storm surges. Some storm events can supply a pulse of sediment that enables wetlands to keep pace with sea level rise and weather future storm events (Carey et al., 2017; Castagno et al., 2018; Orson et al., 1998; Yeates et al., 2020). In contrast, other large storms can produce high velocities and can deepen channels and tidal flats, propagating waves further into tidal creeks, causing scouring and long-term erosion, even during subsequent calm conditions (Hauser et al., 2015; Leonardi et al., 2018).

The frequency of wetland inundation, also called its hydroperiod, is determined jointly by sea level and wetland elevation. Wetlands with hydroperiods that are extended due to sea level rise may undergo significant changes in structure and function (Fagherazzi et al., 2020; Montalto et al., 2006) that hinder their ability to provide ecosystem services such as water quality improvement, and wave attenuation, and can eventually lead to their loss (Valiela et al., 2023). In undeveloped landscapes, wetlands experiencing sea level rise migrate in a landward direction. However, in many parts of NYC, landward migration of tidal wetlands is impossible given the presence of engineered coastal infrastructure (e.g. highways, bulkheads, buildings, etc.) highlighting the importance of protecting existing and potential pathways (Calvin et al., 2018; Montalto & Steenhuis, 2004).

Tidal wetlands can also be sensitive to a reduction in hydroperiod, for example if a tide gate, barrier or other hydraulic restriction prevents high tide flooding (Montalto & Steenhuis, 2004). Less frequent flooding often results in a reduction in sediment delivery to the wetland surface. Wetlands that are sediment starved need active management and restoration to persist in place. Jamaica Bay marshes, for example, are sediment poor (Chant et al., 2021; Peteet et al., 2018) and extremely high nutrient loading impacts their structural integrity and ability to grow vertically (Deegan et al., 2012; B. R. Rosenzweig, Groffman, et al., 2018; Watson et al., 2014; Wigand et al., 2014). Courtney et al (2023) found that over a recent 20-year period, high tides propagated further into the groundwater aquifer of a brackish Hudson River tidal wetland even though the marsh surface elevation was increasing at a rate that matched sea level rise. This phenomenon was attributed to high tides increasing faster than mean sea level. Such impacts are significant given the importance of NYC wetlands in sustaining biodiversity and many critical and endangered species. Without active management, such wetlands undergo significant ecological changes (Morris et al., 2020) as outlined in detail in the City's Wetland Management Framework (Swadek et al., 2021).

Outside NYC and along the Eastern Atlantic coast, sea level rise has also been linked to a reduction in the distributional area of lichens (Allen & Lendemer, 2016), a modification of the position of the marsh–forest interface (Kirwan et al., 2007), reductions in carbon sequestration, above- and below-ground carbon storage potential (Meixler et al., 2023), and long term reductions in the radial growth of a coastal pine forest years after coastal inundation (Fernandes et al., 2018). More research is needed to determine the vulnerability of other NNBS to various flood hazards in NYC.

3.5 Responses

Flood risks are heavily influenced by the responses that are taken to reduce perceived flood hazards. If these responses result in successful adaptation or transformation, they can reduce flood risks. Responses that inadvertently increase risk or vulnerability to a hazard are referred to as maladaptive. In the flooding context, actions that transfer flood risks from one place to another, reduce flood preparedness, stimulate development in flood hazard areas, cause gentrification, or increase the vulnerability of NNBS can all be considered maladaptive. A thorough exploration of responses that increase and decrease flood risks is provided in Section 9 of this chapter.

4 Pluvial Flooding

4.1 Pluvial Flood Hazard Characterization

Pluvial flooding occurs when the intensity of precipitation and resulting stormwater runoff exceeds the capacity of the land surface to infiltrate it, and/or when the rate of excess precipitation exceeds the stormwater conveyance capacities of natural and engineered drainage systems, resulting in surface ponding (B. R. Rosenzweig, McPhillips, et al., 2018). This process dominates the hydrologic cycle of most densely developed cities, which typically have a high percentage of buildings, pavements and other impervious surfaces that inhibit stormwater infiltration. As a result, pluvial flooding is often referred to as 'urban' flooding (Agonafir et al., 2023).

Although impervious surfaces are the primary contributor to pluvial flooding, this mechanism can also occur over pervious surfaces. When the intensity of short duration precipitation events, (commonly referred to as cloudbursts [1], exceeds the infiltration capacity of pervious surfaces, the excess precipitation will accumulate and flow over the surface. This phenomenon is more likely when pervious surfaces are already saturated, and/or are covered with snow or ice (Andradóttir et al., 2021; Moghadas et al., 2018). Alizadehtazi et al. (2016) found that the infiltration capacity of urban park soils, tree pits without tree guards, porous pavers, and certain bioretention facilities were frequently below the intensity of the intensity of the 5 yr, 6 minute design storm used to design many components of the city's stormwater drainage systems, underscoring the potential of these pervious surfaces to produce runoff.

To reduce pluvial flooding, the city's separate and combined sewer systems were designed to intercept and convey 'excess precipitation' rapidly away from buildings and roads (Tarr, 2001). However, engineered drainage systems have a finite capacity, which is another key contributor to pluvial flood hazard. Three limitations of the sewer system that can contribute include: 1) the spacing and hydraulic capacity of different types of inlets, 2) hydraulic bottlenecks within the piped collection system, and 3) hydrologic overload. Each of these limitations is described in greater detail below.

- Inlet conditions: If stormwater is presented to sewer inlets at rates that exceed inlet hydraulic capacities, the excess runoff will bypass (even if the sewer pipes themselves are not full), causing pluvial flooding further down gradient. In general, grated inlets have higher hydraulic capacities than curb cuts, and curbcuts have greater hydraulic capacity if they are built with higher apron slopes and longer openings. Bypass can be exacerbated by adverse street slopes and/or if snow, leaves, litter, or other debris clogs stormwater inlets, reducing their interception capacities (Agonafir, Lakhankar, et al., 2022; Agonafir, Pabon, et al., 2022; Shevade et al., 2020; Shevade & Montalto, 2021). Bypass of inlets can also be triggered if there are blockages just downstream of the inlet, inhibiting free flow through them. The lack of an inlet can also trigger pluvial flooding if runoff accumulates in undrained topographic depressions.

- Hydraulic bottlenecks: Pluvial flooding can occur if the conveyance capacity of a particular segment of the engineered drainage system (e.g. a catch basin hood, a segment of pipe, a pump, etc.) is unable to convey stormwater through the system at the rate at which it is approaching that feature. Under these conditions, stormwater will back up within the pipes and can ultimately reach the surface through manholes and catch basins (known as a 'surcharge') and/or backup into low-lying buildings, subgrade spaces, and other topographically vulnerable areas.

- Hydrologic overload: During extreme precipitation events, some sewer pipes can become filled with water. Under these conditions, any additional rainfall, even at low intensities, will accumulate on the surface. The city's combined sewer system, which serves about 60% of the city and conveys both stormwater and wastewater in the same pipe network, was also designed with relief points to reduce the chances of surcharge or backup events. Known as CSOs, these features of the combined sewer system release untreated combined sewage into the city's surface water bodies, creating significant human and ecological health risks which could increase as climate change causes precipitation to increase.

Cloudbursts are a particularly important driver of pluvial flooding (B. Rosenzweig et al., 2019). Recent research by the VIA team (McPhearson et al., 2024) suggests that many historical pluvial flood episodes were triggered by short-duration (less than 6-hour) high intensity precipitation events. Cloudbursts may occur as highly localized, individual convective (thunderstorm) cells, or they can be embedded within larger storm systems, including tropical and post-tropical storms, large frontal systems, and Nor'Easters. The intense rain associated with any particular cloudburst is usually limited to small areas of the city, but intense rain can also be widespread if thunderstorms are organized into mesoscale storm systems (Smith et al., 2023).

The US National Weather Service provides Excessive Rainfall Outlook (ERO) forecasts, which can identify the large-scale weather and hydrological conditions associated with cloudbursts and flash flooding up to 5 days in advance (Burke et al., 2023). These regional forecasts are further enhanced for NYC based on event-specific mesoscale meteorological conditions, but current science is not able to provide forecasts of the exact location, areal extent, intensity, and timing of cloudbursts (L. Speight & Krupska, 2021). Advance warning of imminent potential flooding remains limited to radar-based observations of approaching extreme rainfall and in-situ observations of flooding that has already begun, with a nationwide average lead time of 61-68 minutes (Martinaitis et al., 2023). These forecasting challenges make emergency preparations and risk management for pluvial flooding particularly challenging.

4.2 Historical Example: Ida-Remnants Cloudburst Pluvial Flooding

New York City experienced widespread, severe pluvial flooding during a cloudburst on September 1, 2021 ('Ida-Remnants Cloudburst'). Flooding from this event caused 12 drowning fatalities in NYC, which included 11 deaths in subgrade residences and offices. A 13th direct fatality resulted from asphyxiation when the victim's flooded car caught fire. Figure 4 depicts flood related service requests during the event, along with the location of the residential drowning fatalities. As shown, many of these locations were far outside the most recently developed (Preliminary) SFHA (FEMA, 2013). Flooding from this event was also associated with extensive damage to property and critical infrastructure, displacement due to loss of living quarters, and major disruptions to transit and transportation networks (City of New York Office of Management and Budget, 2023; City of New York Office of the Deputy Mayor for Administration, 2021).

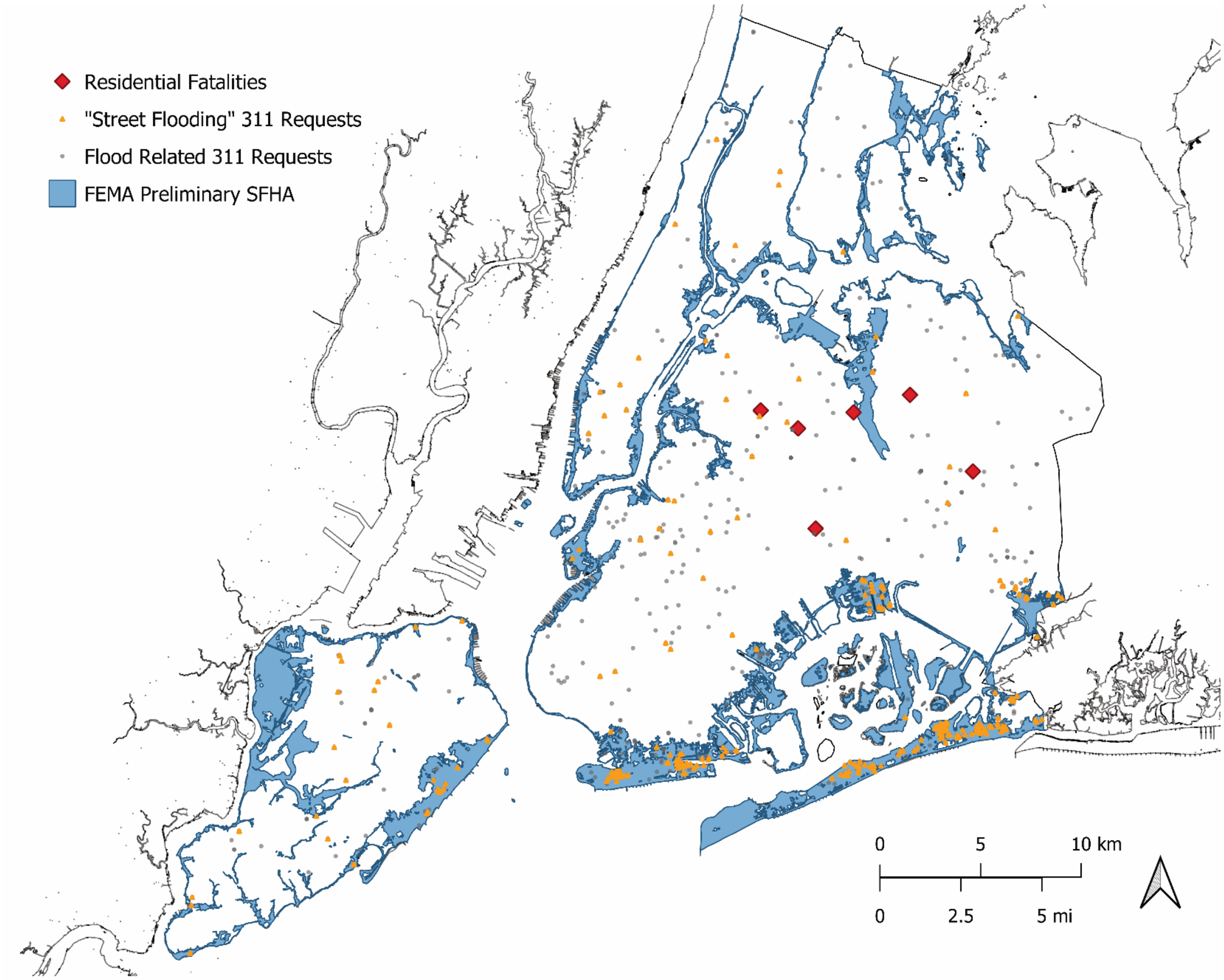

Figure 4: Fatalities in subgrade residences/offices, street flooding and flood-related 311 service requests in NYC during the Ida-Remnants Cloudburst (9/1/2023 - 9/2/2023). Along with 'Street Flooding', flood-related service requests include: Sewer Backup', 'Highway Flooding', 'Manhole Overflow', 'Possible Water Main Break', 'Catch Basin Clogged/Flooding', and 'Excessive Water in Basement. Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

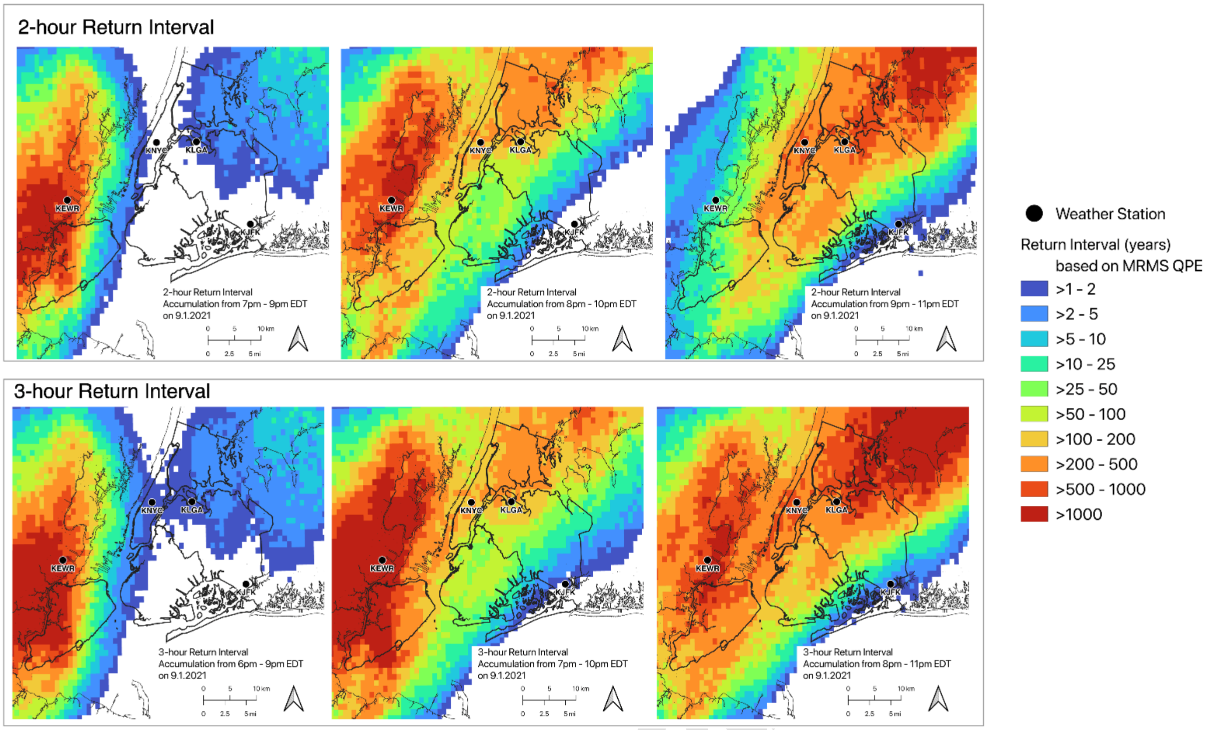

Figure 5: 2- and 3-hour return intervals across the city (during Ida) based on National Center for Environmental Prediction (NCEP) Multi-Resolution, Multi-Sensor (MRMS) Hourly Zip Files, 2021 Quantitative Precipitation Estimates (QPE) (Iowa Environmental Mesonet, 2023). Return intervals presented in these maps are based on NOAA Atlas 14 Intensity-Duration-Frequency (IDF) curves for the Central Park (KNYC) Weather Station. Extremely intense rain progressed from west to east across the city between 6pm and 11pm. Time series of precipitation at the area Automated Surface Observing System (ASOS) weather stations (KEWR: Newark Liberty International Airport; KNYC: Central Park Weather Station; KLGA: LaGuardia Airport; KJFK: John F. Kennedy International Airport) are provided in Figure 6. Graphic by BR Rosenzweig.

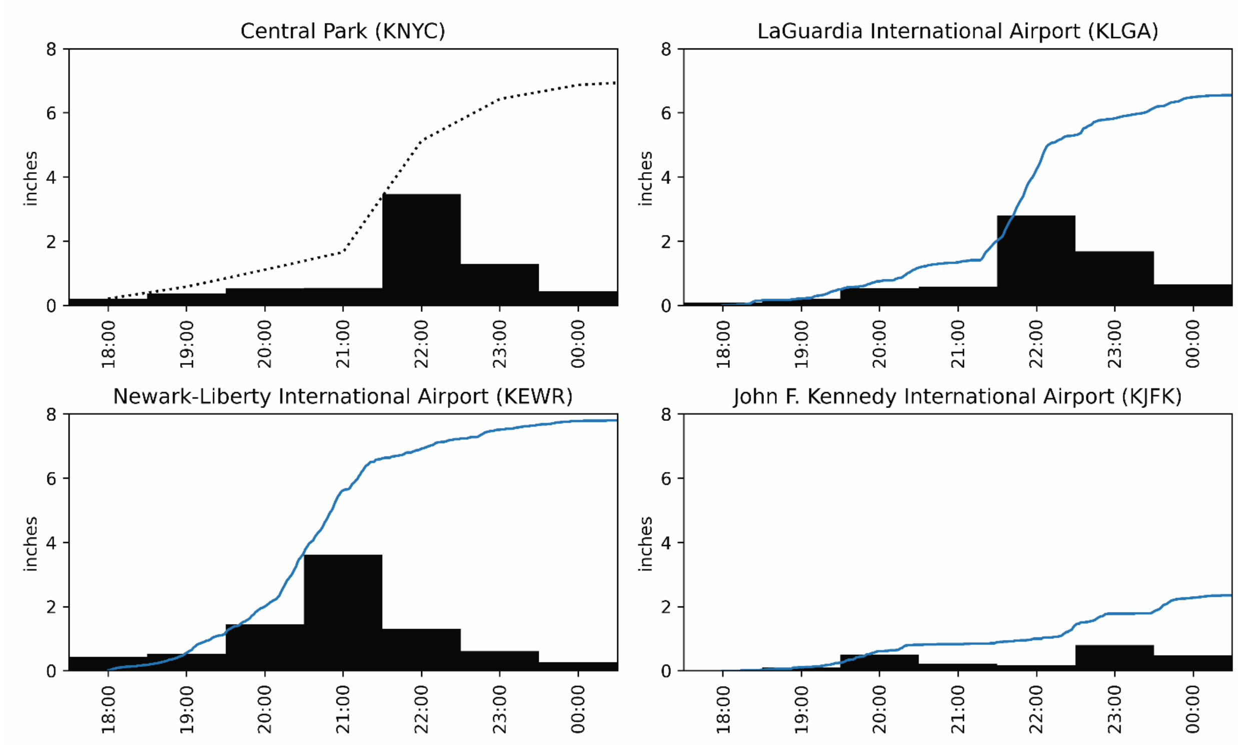

Figure 6: Hourly (black bars) and cumulative precipitation during the Ida-Remnants Cloudburst on September 1, 2021 (EDT) Cumulative precipitation was determined using 1-minute ASOS observations (blue lines). 1-minute data was not transmitted from the Central Park Station during this event. Cumulative precipitation was calculated based on hourly measurements (black dotted line) for that station. One minute data allows for evaluation of extreme accumulations that do not correspond with hourly measurement intervals. For example, 3.76 inches of rain fell in the 60-minute period between 21:18 and 22:18 at LaGuardia Airport. Graphic by BR Rosenzweig.

The extremely intense rainfall associated with this event resulted from three coinciding meteorological factors (Smith et al., 2023):

- The remnants of Hurricane Ida, which passed southwest of the city as a post-tropical surface low-pressure system, bringing deep tropical moisture. Precipitable water values peaked at 2.1-2.2 inches over the NYC metropolitan area during this event.
- A large, long-wave trough to the north of the city, which allowed a deep baroclinic wave to develop along the frontal boundary of the warm air mass associated with the approaching remnant low. This wave created instability and deep convection.
- A powerful, near-zonal jet streak at 250mb, centered over southeastern Canada. This placed NYC in the right rear entrance quadrant of the jet streak and beneath the area of high upper-level divergence. This upper-level divergence induced large-scale lift over the region, enhancing persistent, deep convection.

The Ida-remnants cloudburst was remarkable not only for its extreme rainfall intensity, but also for the large area of the city impacted by it. Most of the city received precipitation quantities that exceeded the 100-year 2 and 3-hour storm accumulations (Figure 5 and Figure 6). There was a sharp gradient in rainfall from west to east across the city, with far eastern parts of the city such as southeast Queens and the Rockaways receiving only moderate rainfall.

While there are multiple mechanisms through which climate change can increase the intensity of cloudburst events in NYC, these processes remain poorly represented in global-scale numerical models used to develop climate projections (Fowler, Wasko, et al., 2021). At present, there is insufficient information to determine if, or to what extent, climate change contributed to the intensity, duration, or areal extent of the Ida-remnants cloudburst. Attribution studies focused on this, and similar events, are needed to determine the role that climate change may have had in setting it up and whether more events of similar intensity and spatial extent will occur in NYC in the future.

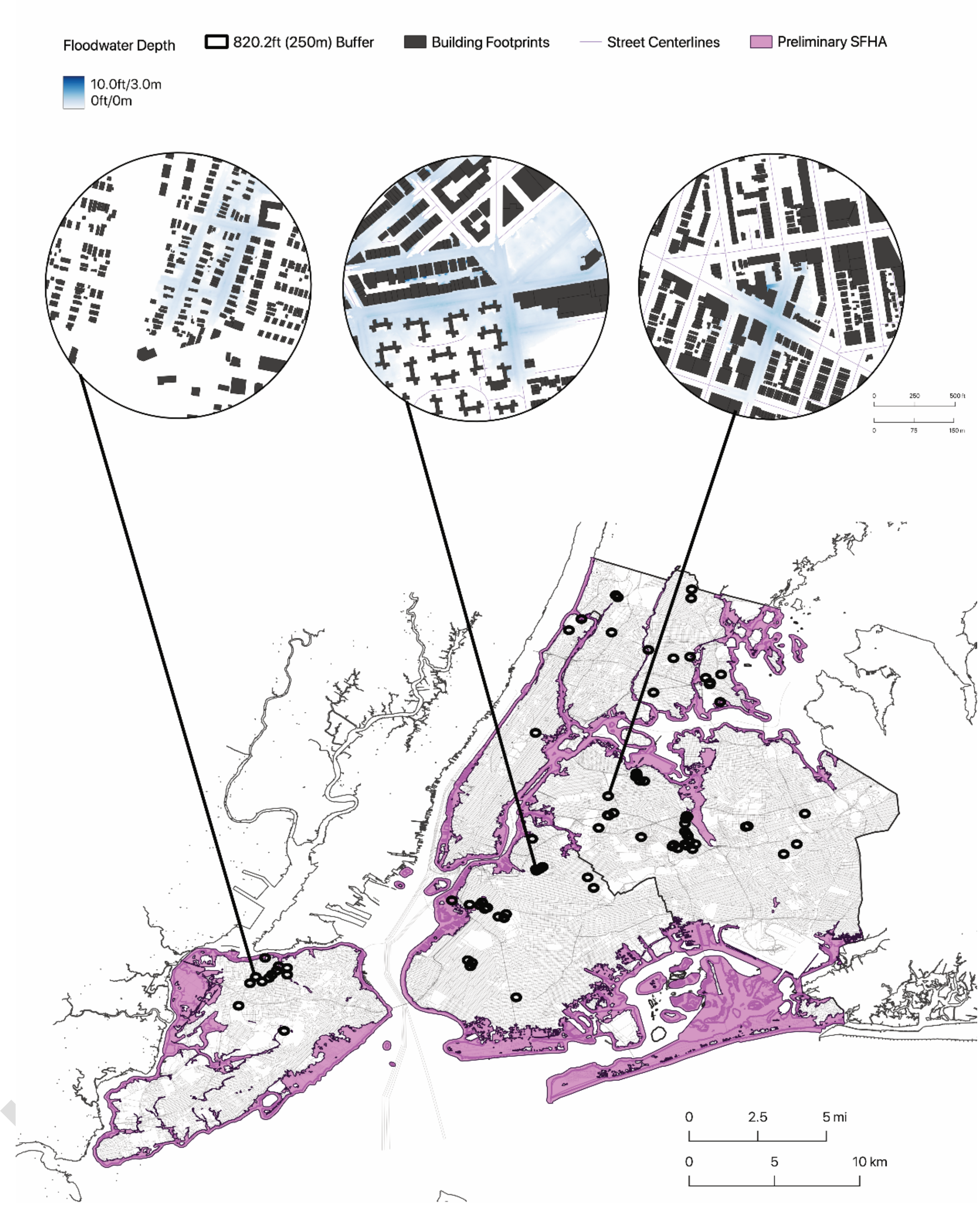

Figure 7: 83 high water marks (HWM) such as seed lines, mud, and debris were surveyed by the US Geological Survey in the weeks following the Ida-Remnants Cloudburst.((Finkelstein et al., 2023) Using these observations, land surface inundation was estimated within an 820.2 ft (250m) buffer of each observed HWMs. During the Ida cloudburst, deep inundation from pluvial flooding occurred in areas that were far from the water bodies used as the basis of FEMA SFHA modeling Flooding from this event was not limited to areas where HWMs were obtained, and also occurred in areas of the city that were not surveyed or where HWMs could not be identified. Several inundated areas are highlighted here and all HWM data from this survey can be viewed at: https://stn.wim.usgs.gov/fev/#2021Ida. Map by BR Rosenzweig.

4.3 Exposure and Vulnerability to Pluvial Flooding

4.3.1 Pluvial flood hazard mapping

In 2018, the NYC City Council passed Local Law 172 (Local Law 172, 2018), which required city agencies to develop maps to identify areas of the city that will be most exposed to flooding due to climate change. Because the FEMA's SFHA maps do not include pluvial flood hazard areas, NYCDEP contracted with an academic and consultant team on a Stormwater Resiliency Study (City of New York Mayor's Office of Resiliency, 2021), which became the first effort to map pluvial flood hazards in NYC.

Since pluvial flooding is caused by hydrologic processes that create runoff (e.g. precipitation excess) volumes that can exceed the limited hydraulic capacity of various components of the surface (e.g. channels, gutters, inlets) and subsurface (e.g. pipes, pumps, weirs) collection systems, mapping pluvial flood hazards requires the use of numerical models that can represent these complex and coupled processes at high spatial and temporal resolution (B. R. Rosenzweig et al., 2021). The Stormwater Resiliency Study involved the development of 13 Hydraulic and Hydrologic (H&H) models using Innovyze's InfoWorks ICM software (AutoDesk, 2023), each representing a major sewershed that drains into one of NYC's wastewater treatment plants. As detailed in the Stormwater Resiliency Plan (City of New York Mayor's Office of Resiliency, 2021), these models utilized a 1D-2D modeling approach. This coupled form of modeling is a recent advance and requires significant computing power and detailed topographic information. Some areas of the city, including large (>100,000 ft^2) parks, large (>250,000 ft^2) non-residential and non-commercial private lots, and any lots that intersect railway infrastructure were excluded from the resulting pluvial flood hazard maps due to a lack of information regarding their drainage system design (City of New York Mayor's Office of Resiliency, 2021).

The Stormwater Resiliency Study models were used to simulate flooding associated with the following three scenarios:

- **Moderate Stormwater Flood without Sea Level Rise:** ~2 inches of rainfall falling uniformly across the city in one hour.
- **Moderate Stormwater Flood with 2050's Sea Level Rise:** ~2 inches of rainfall falling uniformly across the city in one hour, co-occurring with coastal water levels elevated by 30 inches.
- **Extreme Stormwater Flood with 2080's Sea Level Rise:** ~3.5 inches of rainfall, falling uniformly across the city in one hour, co-occurring with coastal water levels elevated by 58 inches.

Each of these scenarios was simulated individually, as a singular event, without consideration of antecedent moisture conditions. Buildings were represented as obstructions. We utilize two of these three scenarios (Moderate Stormwater Flood without SLR and Extreme Stormwater Flood with 2080s SLR) in this report (Table 1).

To evaluate present day pluvial flood exposure, we use the Moderate Scenario with no Sea Level Rise. This is the only pluvial flood hazard layer that evaluates pluvial flooding associated with present-day mean high tide (Mean Higher High Water; MHHW) levels. This scenario identifies areas that are the most highly exposed to pluvial flooding – i.e., those that would experience inundation greater than 4 inches even from a relatively modest rain event of approximately 2 inches in one hour. Because this precipitation event is roughly associated with a 10-year return period, exposure cannot be directly compared to that of the FEMA SFHA, which is associated with 100-year (1% AEP) flooding. This scenario also represents less rainfall than occurred during the Ida remnants cloudburst which, in most of the city was a much more extreme event than this Moderate scenario, was spatially varying, and occurred for different durations in different portions of the city. Further, this hazard layer is a synthetic event and does not capture any operational or environmental conditions, such as catch basins being clogged due to leaves, ice, and/or debris.

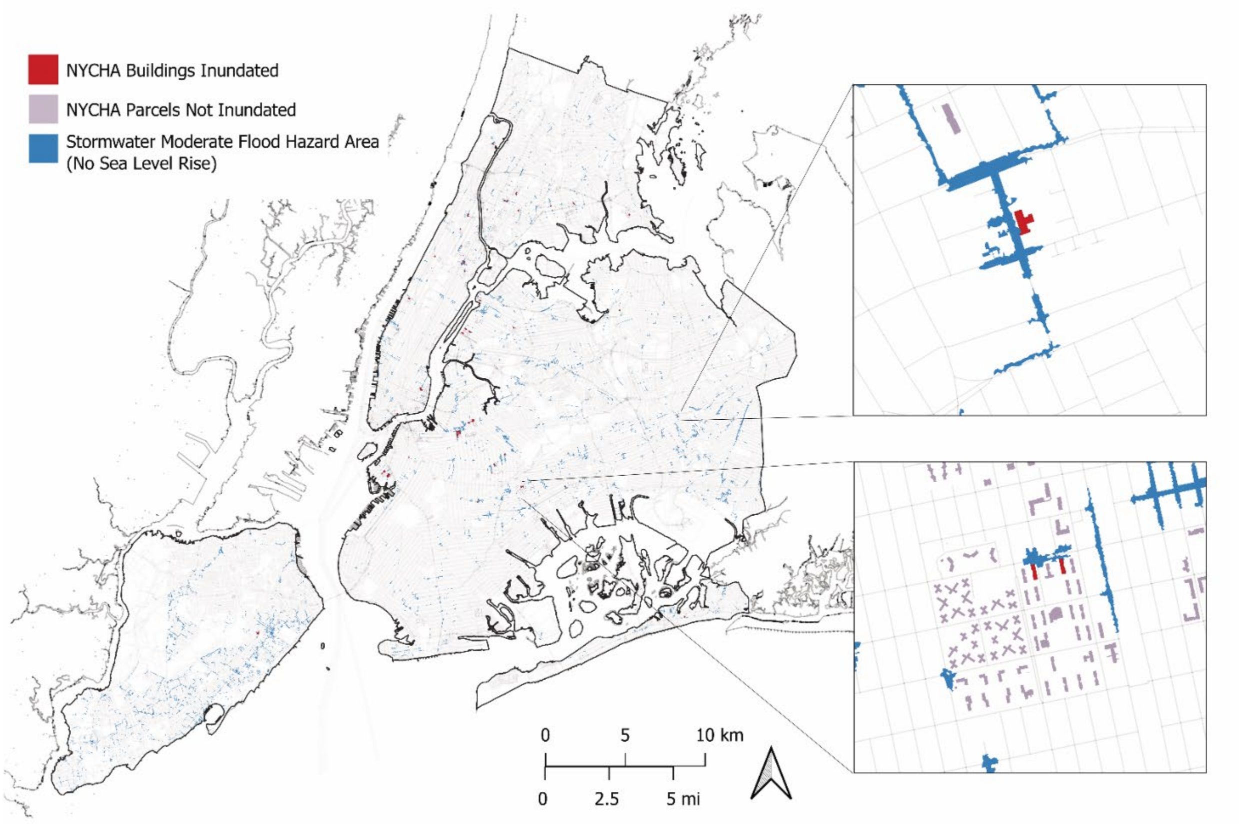

Figure 8: NYCHA developments with buildings that would be exposed to pluvial flooding from a moderately intense (~2 inches in one hour) rain event. NYCHA buildings represent less than 1% of the total buildings inundated under this scenario. Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

To estimate the number of buildings exposed to the Moderate pluvial flood scenario, we identified all buildings located within a 1 ft buffer of the simulated pluvial flood hazard area. Under this Moderate scenario 30,690 buildings would be exposed to stormwater inundation depths of greater than 4 inches. Of these exposed buildings, 16.7% (5,113) are single-story buildings and 41.7% (12,796) of the exposed buildings have basements, cellars, or subgrade spaces. Of the exposed buildings, 30.7% (9,413) are 1-2 residential unit buildings with subgrade spaces, and 0.36% (112) of the exposed buildings are part of NYCHA developments (Figure 8). In the interpretation of these results, it is important to note that the Stormwater Resiliency modeling assumes that ~2 inches of rain fall uniformly over the entire city. Such a scenario is unlikely to occur during an actual rain event.

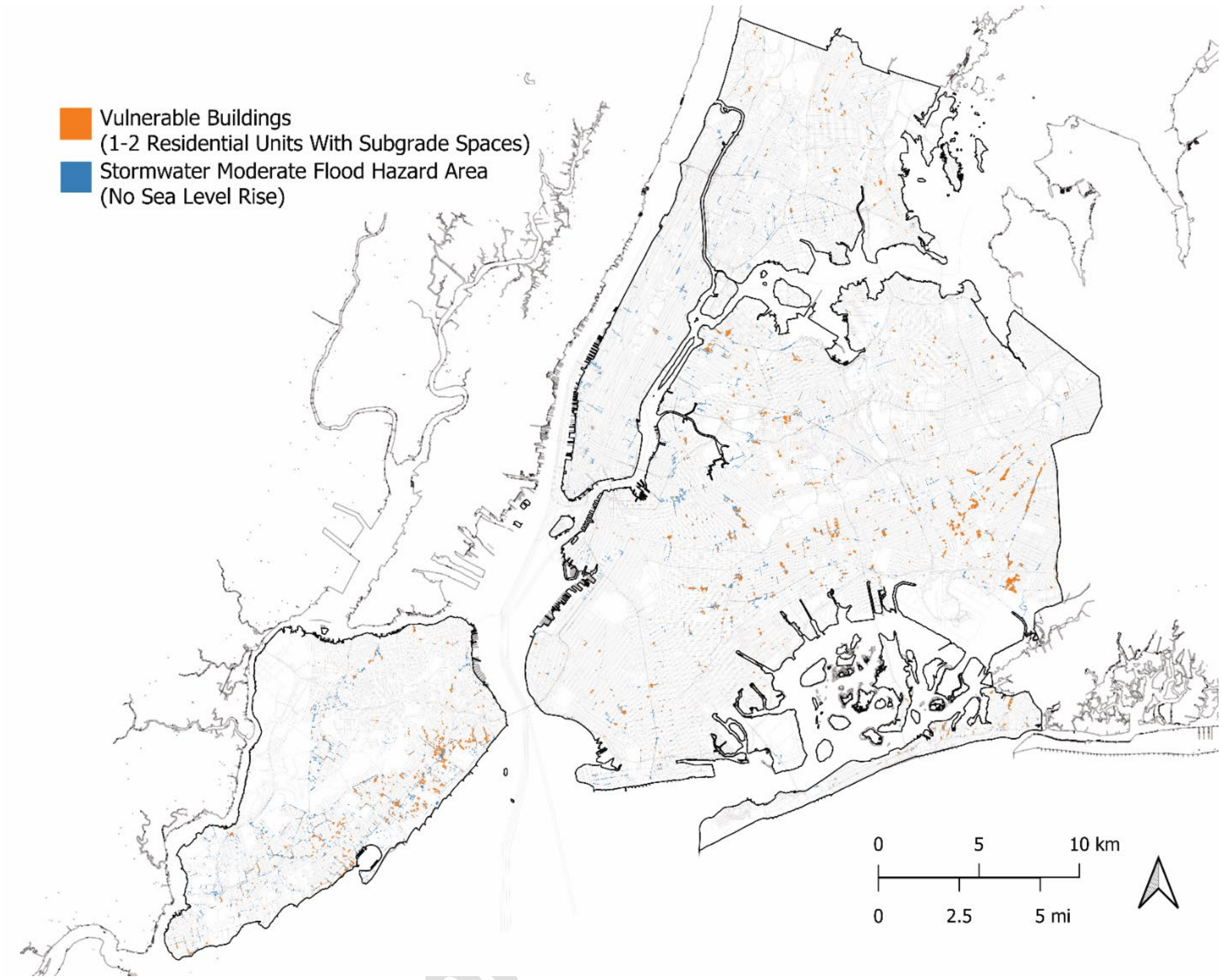

Figure 9: 1-2 family residential buildings with basements that would be exposed to pluvial flooding from a moderately intense (~2 inches in one hour) rain event. Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

4.4 Climate Change and Future Pluvial Flooding

Pluvial flooding is already a significant hazard for NYC, and it will be exacerbated by human-caused climate change throughout the 21st century, especially if global efforts to reduce greenhouse gas emissions are delayed. Climate change is expected to increase the probability of extremely intense, short-duration precipitation (Fowler, Lenderink, et al., 2021; Westra et al., 2014). Table 4 presents projected changes in the 10 yr (10% AEP) and 100 yr (1% AEP) precipitation accumulation falling in 1 hour. The relatively moderate (10 yr) cloudbursts that already cause pluvial flooding in some inland areas of the city (Figure 9) are projected to become 19 – 24% more intense. Greater potential increases are projected for more extreme (100 yr) storms, with 1-hour accumulations increasing by 20%, even if global emissions of heat trapping gases are reduced by mid-century, and by 30% under scenarios of unmitigated climate change. There is greater scientific uncertainty associated with these short-duration precipitation projections, compared with projections of future daily rainfall extremes (Fowler, Ali, Allan, Ban, Barbero, Berg, Blenkinsop, Cabi, Chan, & Dale, 2021). This consistent uncertainty presents a significant challenge for the design of stormwater infrastructure for pluvial flood resilience (L. M. Cook et al., 2020).

Table 4: 60-minute rainfall accumulation in inches at selected AEPs (return intervals). Contemporary precipitation values are from NOAA Atlas 14 at the Central Park Weather Station. Future precipitation projections are based on the mean citywide delta change factors derived from on an ensemble of climate models using the LOCA2 downscaling method for SSP245 (mid-century greenhouse emissions reduction) and SSP585 (unmitigated climate change). Values in parentheses represent the 10th and 90th percentile values at Central Park, and their projections based on the citywide mean change factor.

	2 Yr (50% AEP)	10 Yr (10% AEP)	50 Yr (2% AEP)	100 Yr (1% AEP)
Contemporary: NOAA Atlas 14	**1.28** *(1.04-1.58)*	**1.89** *(1.52-2.36)*	**2.57** *(1.93-3.41)*	**2.87** *(2.08-3.95)*
SSP245 (2050s-2090s)	**1.56** *(1.27-1.93)*	**2.43** *(1.95-3.02)*	**3.19** *(2.39-4.23)*	**3.62** *(2.62-4.98)*
SSP585 (2050s-2090s)	**1.64** *(1.33-2.02)*	**2.55** *(2.05-3.19)*	**3.34** *(2.51-4.43)*	**3.73** *(2.7-5.14)*

Along with projected increases in rainfall rates at any given location, recent studies have identified mechanisms that can result in increases in the areal extent over which intense rain falls with global warming (Y. Chen et al., 2021; Fowler, Lenderink, et al., 2021; Pendergrass, 2020). Most cloudbursts are highly localized and result in flooding only in small areas of the city at once, though these localized impacts can be severe and associated with life-threatening conditions in affected communities (B. R. Rosenzweig, McPhillips, et al., 2018). However, two of the most impactful historic pluvial flood events at the city-scale – the Ida Remnants Cloudburst and a cloudburst on August 8, 2007 that caused the unplanned shutdown of much of the subway system – were associated with organized systems of thunderstorms that resulted in extreme rainfall rates falling over widespread areas of the city (MTA, 2007; Smith et al., 2023). A potential increase in the size and organization of future cloudbursts would have significant implications for the citywide impacts of pluvial flood events (Peleg et al., 2022), but scientific understanding of this topic remains in the earliest stages.

Pluvial flooding may also be exacerbated in areas where groundwater tables rise in response to sea level rise (Section 7.4). In these areas, the ability for storm sewers to convey stormwater may be reduced by increased infiltration of groundwater into sewers (Liu et al., 2018; B. R. Rosenzweig, McPhillips, et al., 2018), leading to hydrologic overload (see above). Stormwater green infrastructure that utilizes infiltration may also be less effective as rising water tables reduce the volume of available unsaturated subsurface (K. Zhang & Chui, 2019).

Figure 10 presents the area that would be inundated greater than 4 inches under the Stormwater Resiliency Study Extreme Scenario. In this scenario, 206,859 of currently existing buildings would be exposed to pluvial flooding. For comparison, 88,700 buildings were in the area inundated by Post-Tropical Cyclone Sandy of 2012 (City of New York Office of the Mayor, 2013). However, as discussed previously, it is important to note that the Stormwater Resiliency modeling assumes that rainfall is uniform across the entire city, meaning this figure represents the ceiling of exposed buildings for a rainfall of this magnitude. A total of 32,918 (16%) of the buildings exposed in such a scenario are single-story buildings and nearly half (93,528; 45.6%) of these exposed buildings have subgrade spaces. The overwhelming majority (70,970) of the exposed buildings with subgrade spaces are 1-2 residential unit buildings (Figure 9). 897 (0.43%) of the exposed buildings are part of NYCHA developments, which are highlighted in Figure 10.

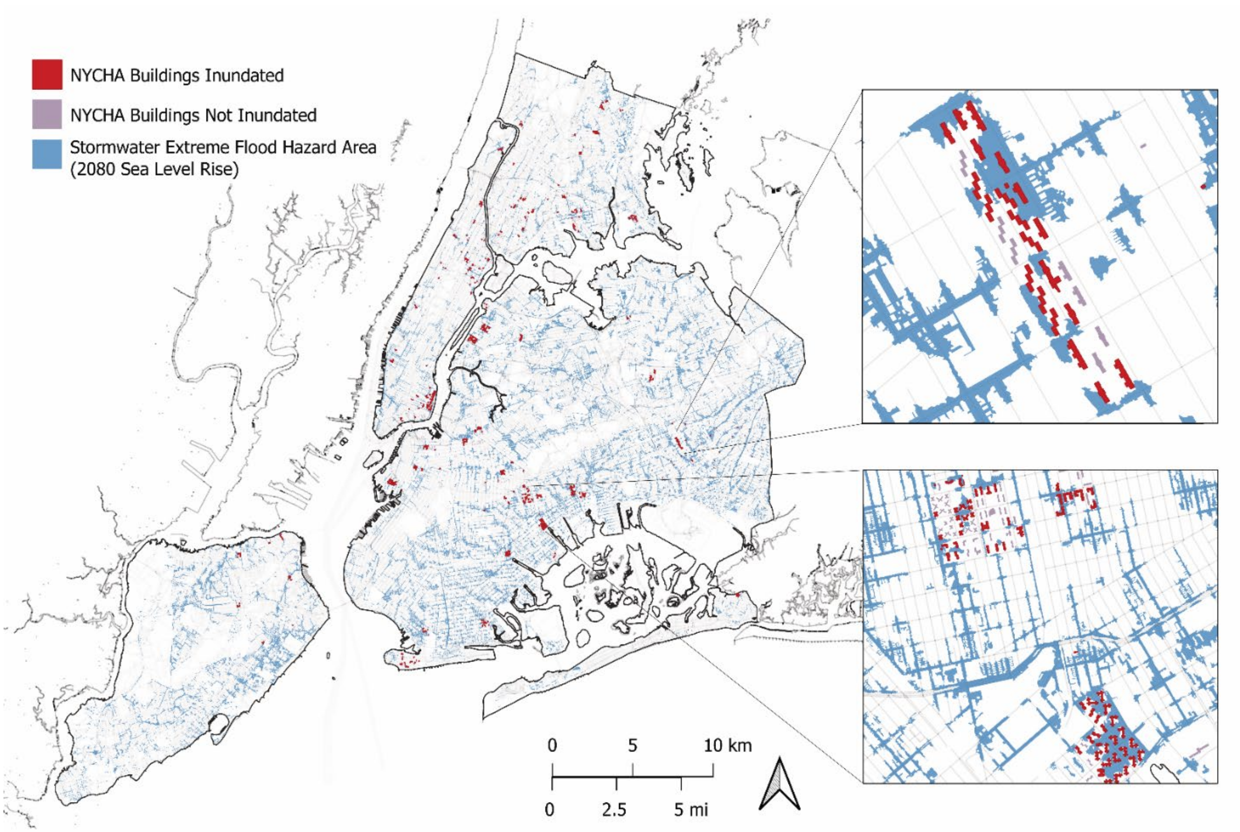

Figure 10: NYCHA developments that would be exposed to pluvial flooding during an extreme rain event (~3.5 inches per hour) with 58 inches of sea level rise, as modeled for the Stormwater Resiliency Plan (City of New York Mayor's Office of Resiliency, 2021). The inundated NYCHA buildings represent less than 1% of the total buildings inundated under this scenario, but nearly a third (30.1%) of NYCHA affordable public housing buildings. Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

4.5 Persistent Knowledge Gaps: Pluvial Flooding

Along with remaining scientific uncertainty on future short-duration precipitation, there remain critical knowledge gaps that limit our understanding of how future precipitation intensification with climate change will impact flood risk:

Monitoring of the hydrologic and hydraulic response and impacts of cloudbursts: There is currently very limited direct observational data on the hydrologic and hydraulic response to cloudbursts. Following the Ida-Remnants Cloudburst, the US Geological Survey mapped inundation depths by surveying high-water marks in several severely impacted communities in New York City (Figure 7), but observational data on flooding in response to extreme rain remain very limited. The collection of direct, in-situ monitoring of street flooding is being piloted through the NYC FloodNet project (Silverman et al., 2022) (discussed in Section 10, but a sustained monitoring network of flooding depths, in-sewer water depths and flow rates, and in-situ rainfall rates is needed to understand the hydrologic and hydraulic response to extreme rain in NYC. There may also be opportunities to develop methods to assimilate existing monitoring data that is collected for other purposes, such as traffic cameras.

Hazard Mapping: The pluvial flood hazard maps developed through the Stormwater Resiliency Study (City of New York Mayor's Office of Resiliency, 2021) provide novel and critical information to support flood risk assessment. However, currently available maps only represent a very small selection of potential precipitation scenarios, and these maps are only able to identify areas where inundation exceeds depth thresholds (4 inches or 1 foot) at some point during the flood event. Additional hazard maps that represent a broader range of plausible cloudburst scenarios and provide information on flood rise time, fast-flowing water, exposure to toxic chemicals and pathogens, and inundation duration are needed to support emergency response and flood management planning, and climate adaptation. The development of these additional hazard layers remains limited by the computational resources needed for this type of modeling and the limited availability of observational data on flooding in NYC, also described further in Section 10.

Pluvial Flood Vulnerability: As described in Section 3.4.1, the true costs of pluvial flooding to NYC residents remain poorly characterized. Additional work is needed to improve understanding of who is impacted by pluvial floods, in which ways, and incurring what tangible and intangible costs.

5 Fluvial Flooding

5.1 Fluvial Flood Hazard Characterization

Fluvial flood risks (also referred to as riverine flood risks) are caused when the stage of a river, creek, or stream exceeds the elevation of its banks. NYC's inland areas were historically drained by a dense network of streams, nearly all of which were filled, with their flow redirected to subterranean stormwater sewers by the mid-20th century (Figure 1). Remaining freshwater stream channels include the Bronx River, Valley Stream (which flows along the eastern edge of the city and is the head of Jamaica Bay), and small inland creeks in Staten Island. These streams provide critical freshwater habitat within the city but can cause flooding when their water levels rise above bankfull stage (e.g. the water level in a creek or stream at which flooding of the banks begins to occur) during both cloudbursts and longer duration rain events. Fluvial flood risks within the city are mapped in the Special Flood Hazard Area (100-year floodplain) maps provided by FEMA, along with coastal flood hazards (FEMA, 2007, 2013).

Fluvial flooding can be monitored directly using stream gauges, which provide in-situ measurements of stream water levels. Bankfull water levels are associated with inundation of the adjacent floodplain and can cause minimal societal impacts (if the floodplain is undeveloped) to moderate/major impacts if buildings, infrastructure, or other assets are located there. NPCC3 presented an assessment of fluvial flooding in regional streams outside the border of NYC with long-term gauge record. Additional research is needed to characterize fluvial flood risks within the city, especially in areas of the Bronx, Queens, and Staten Island.

5.2 Historical Example: Ida-Remnants Cloudburst Fluvial Flooding

At the time of writing, the only active stream gauge located within NYC is along the Bronx River at New York Botanical Garden, which provides observations from 2007– present.(USGS, 2016a) Over this period, 24 minor floods, 7 moderate flood events, and 7 major floods (Table 5) were observed through 2022 at this site (Figure 11). In addition, a flood on July 19, 2022 damaged the stream gauge such that the peak flood stage could not be recorded.

Table 5: Historic major flood events (stage above 4ft) observed at the Bronx River Stream Gauge at NY Botanical Garden (2007-2023): SOURCE: USGS Bronx River Stream Gauge (2024)

Rank	Dates	Peak Stage	Description
1	4/16/2007	6.05 ft (03:00 EDT on April 16, 2007)	Heavy rains from a Nor'Easter (A storm total rainfall of 8.41 inches was observed at Central Park (Storm Events Database Episode 5088 (NCEI, 2007))
2	9/1-2/2021	5.59 ft. (8:45am EDT on September 2, 2021)	Cloudburst associated with the remnants of Hurricane Ida (Described in Section 4.2)
3	8/27-28/2011	5.18 ft (8:15pm EDT on August 28, 2011)	Tropical Storm Irene (Described in Section 8.2)
4	3/11/2011	4.34 ft (12:15pm EDT on March 11, 2011)	Fronts associated with a slow-moving low-pressure system west of the city brought heavy rain (FXUS61 KOKX 110400 AFDOKX (NWS, 2011))
5	4/16/2018	4.24 ft (5:00pm EDT on April 16, 2018)	Heavy rainfall from a slow-moving warm front. Most rain occurred within a 3-4 hour period (Storm Events Database Episode 125008 (NCEI, 2018a))
6	9/25/2018	4.16 ft. (9:30pm EDT on September 25, 2018)	Heavy rainfall preceding a slow-moving warm front (Storm Events Database Episode 131100 (NCEI, 2018b))
7	4/17/2011	4.06 ft (5:45am EDT on April 17, 2011)	A cold front associated with a low-pressure system brought heavy rain (FXUS61 KOKX 170000 AFDOKX (NWS, 2011))

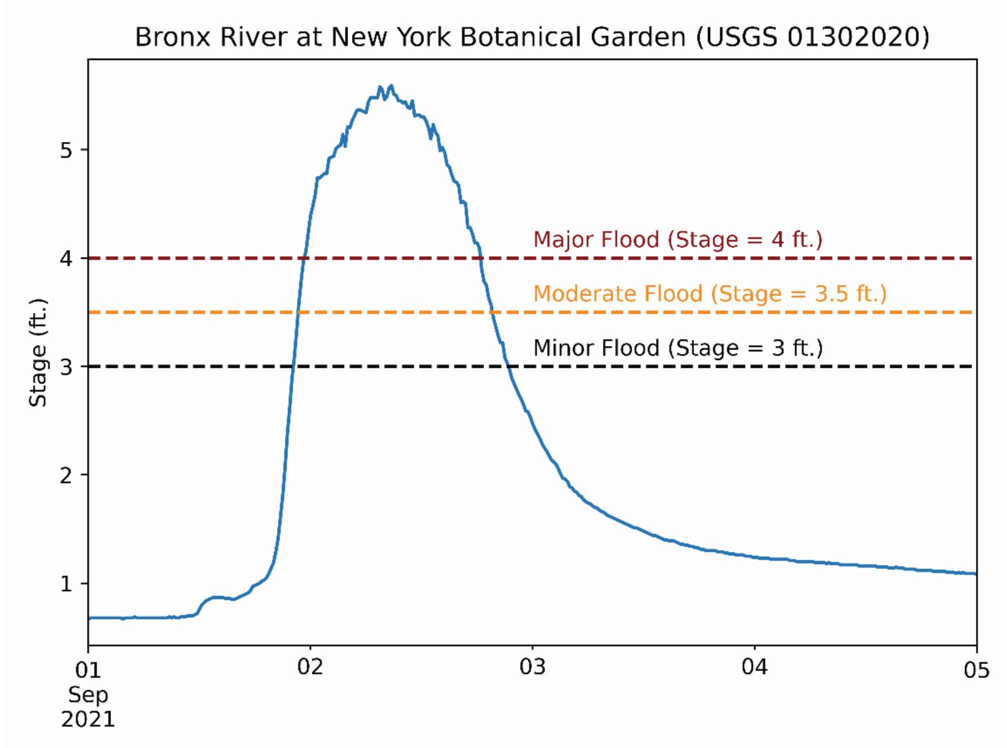

Figure 11: Stream stage in the Bronx River during the Ida-remnants cloudburst. The river remained above major flood stage for over 18 hours (from 11:30pm EDT on 9/1/2021 through 6:15pm EDT on 9/2/2021) SOURCE: Bronx River at NY Botanical Garden Stream Gauge (2024). Graphic by B.R. Rosenzweig

5.3 Fluvial Flooding Exposure and Vulnerability

5.3.1 Buildings and critical infrastructure exposed to fluvial flooding

Exposure to fluvial flooding was evaluated utilizing areas delineated in the FEMA SFHA that are adjacent to remaining inland water bodies. The FEMA SFHA excludes areas that would be flooded with depths less than 1 foot (0.3m), even though such shallow flooding could result in inundation of ground-floor and subgrade spaces. Based on this available hazard data, only 388 buildings are in areas that have a 1% AEP (100-year return interval) of flooding from inland streams and rivers (Figure 12). Of these buildings, 32.4% (126) are single-story buildings and 28.6% (111) of the total exposed buildings have identified subgrade spaces, which is somewhat lower than the percentage of buildings with subgrade spaces across the city. A total of 25.5% of the exposed buildings are 1-2 unit residential units with subgrade spaces. No NYCHA buildings are located in this inland fluvial hazard area.

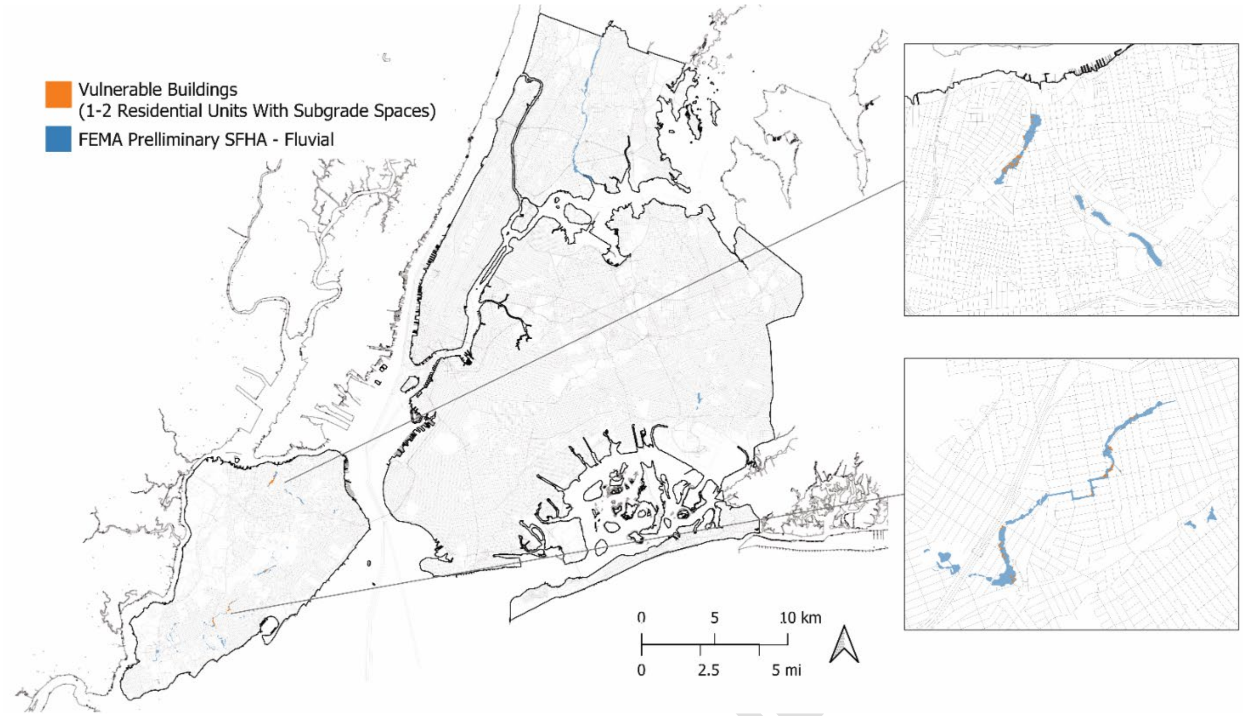

Figure 12: 1-2 family residential buildings with basements in areas of the city that would be exposed to fluvial flooding during a storm with a 100-year return interval (1% annual probability). As a result of the historic filling of most of NYC's natural streams, exposure to fluvial flooding has largely been replaced by exposure to pluvial flooding and is now limited compared to other types of flooding. However, areas adjacent to the Bronx River and small surface streams in Staten Island remain exposed. Source: Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

5.4 Climate Change and Future Fluvial Flooding

As with pluvial flooding (Section 4.4), the projected amplification of precipitation with climate change will increase the frequency and magnitude of fluvial floods in the future. Fluvial flooding will also be exacerbated by sea level rise since NYC's rivers and streams are tidal and drain to the harbor. Rising seas will impede this drainage and may increase groundwater levels and, in turn, stream baseflow, resulting in an increased frequency of stages that exceed flood thresholds (Habel et al., 2020; Moftakhari et al., 2017). FEMA Flood Insurance Studies do not consider changing precipitation patterns or groundwater levels with climate change and do not represent the increased fluvial flood hazard that will result from unmitigated climate change.

5.5 Persistent Knowledge Gaps: Fluvial Flooding

Our understanding of NYC's fluvial flood risk and potential future changes is limited by the same gaps in short-duration precipitation data discussed for pluvial flooding (Section 4.5). In addition, most of the residences exposed to fluvial flooding are in the flood hazard area of streams in Staten Island that are currently ungauged. The reactivation or installation of stream gauges along these high-exposure streams would support enhanced characterization of fluvial flood risk and the development of optimized strategies for fluvial flood resilience. As discussed in the section on pluvial flooding, an estimate of the annual cost of damages due to fluvial flooding on NYC residents is currently not available. However, since the chances of residents of floodplains having FEMA flood insurance are higher, estimates based on FEMA claims may be better estimates than for other flood hazard types.

6 Coastal Flooding

6.1 Coastal Flood Hazard Characterization

With 520 miles of shoreline (City of New York Department of City Planning, 2021), NYC is exposed to severe coastal flooding resulting from high tides and storm surge, as demonstrated during Post Tropical Cyclone Sandy in 2012. Severe coastal floods are caused by two types of storms, predominantly tropical cyclones in warm seasons (June through October) and extratropical cyclones in cooler seasons (November through May)(Colle et al., 2010; P. M.

Orton et al., 2016). Major factors influencing the occurrence of severe coastal floods include the timing of the wind- and pressure-driven storm surge relative to high tide (Kemp & Horton, 2013), and amplification of storm surges due to winds that blow into the concave coastline of the New York Bight (Gurumurthy et al., 2019). Chronic high-tide flooding is also a problem for some NYC neighborhoods, due to sea level rise, dredging, and landfilling of wetlands (Pareja-Roman et al., 2023). Present-day coastal flooding for monthly high tides were mapped for NYC by NPCC3 and include some localized areas around Jamaica Bay. (P. Orton et al., 2019a) Coastal extreme floods are mapped in the Special Flood Hazard Area maps provided by FEMA, which represent coastal or fluvial flood hazards only (FEMA, 2007, 2013).

6.2 Historical Example: Coastal Flooding on December 23, 2022

Extreme historical events such as Sandy and the 1821 Category 3 hurricane that struck NYC, with storm tides of 11.1 and 9.8 ft (relative to the year's mean sea level) at the Battery, respectively, have been a focus of widespread research in recent years (Brandon et al., 2014; P. M. Orton et al., 2016; Strauss et al., 2021). However, National Weather Service (NWS) designated "major floods" (**Error! Reference source not found.**) from less extreme storms have a factor of 10-20 higher annual probability of occurrence than these two historical extreme events today and even higher in future decades. See water-level return period curves in Orton et al. (P. M. Orton et al., 2016). Below, we highlight a recent major flood to raise awareness of these far more common but nevertheless dangerous and damaging events.

In December 2022, a powerful, inland extratropical cyclone located over the Great Lakes Region caused winter storm impacts across the Midwest and northeastern United States. Although the storm was located hundreds of miles west of NYC, it generated powerful southeasterly winds that generated a storm surge along the coast. Early on the morning of December 23rd, a moderate 3-foot storm surge peaked simultaneously with one of the year's highest tides to cause substantial flooding around NYC. Water levels across most of the city exceeded the moderate flood threshold of the NWS (see Figure 13), with those at the Battery peaking at 5.9 feet NAVD88, which is an approximately 3-year return period event. Water levels in Jamaica Bay (Figure 14), however, exceeded NWS major flood thresholds there and peaked at 6.7 feet above NAVD88 (Inwood, USGS gauge; Figure 13) (USGS, 2016b) which is an 8-year return period water level (P. M. Orton, Sanderson, et al., 2020) and the second highest in the bay's 20-year data record, behind (but ~3.9 feet below) Post-Tropical Cyclone Sandy. The likely cause of Jamaica Bay's high peak water levels relative to those elsewhere around NYC was local tide amplification which has raised perigean-spring ("king") high tides by about 0.7 feet, due to a combination of historical dredging and urban development of wetlands surrounding the bay (Pareja-Roman et al., 2023). Flood depths in some areas surrounding Jamaica Bay were observed by FloodNet sensors to be about 3 feet, whereas only shallow nuisance flooding was observed in the harbor areas (typically well below 1 ft). The relative sea level rise around NYC of ~1.3 feet since 1900 was also clearly a contributor to these water elevations and flood depths.

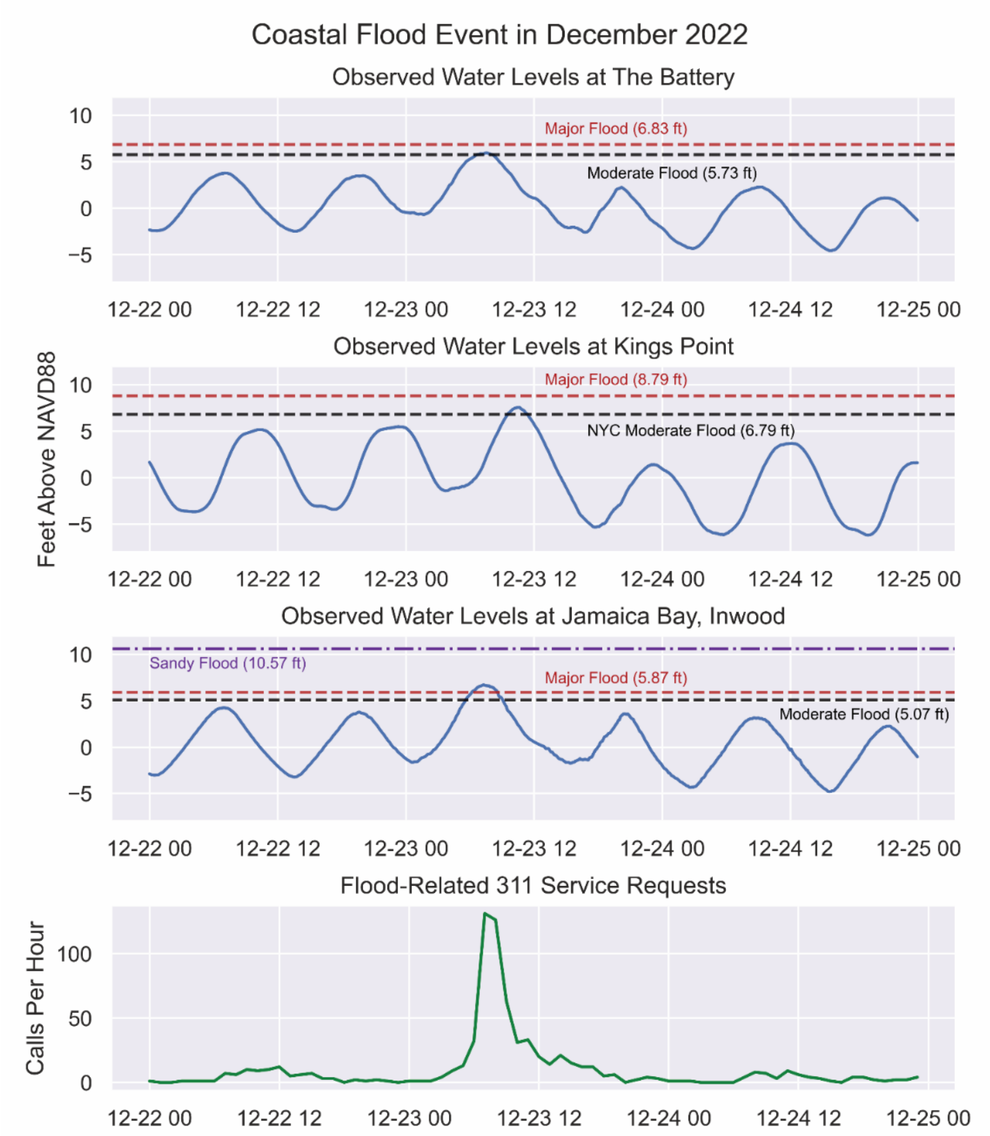

Figure 13: Observed water levels and 311 service requests related to flooding (bottom panel) around NYC from December 22-24, 2022. Tide gauge locations are provided in Figure 14. National Weather Service flood thresholds and Post Tropical Cyclone Sandy are shown as horizontal lines for comparison. Figure by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

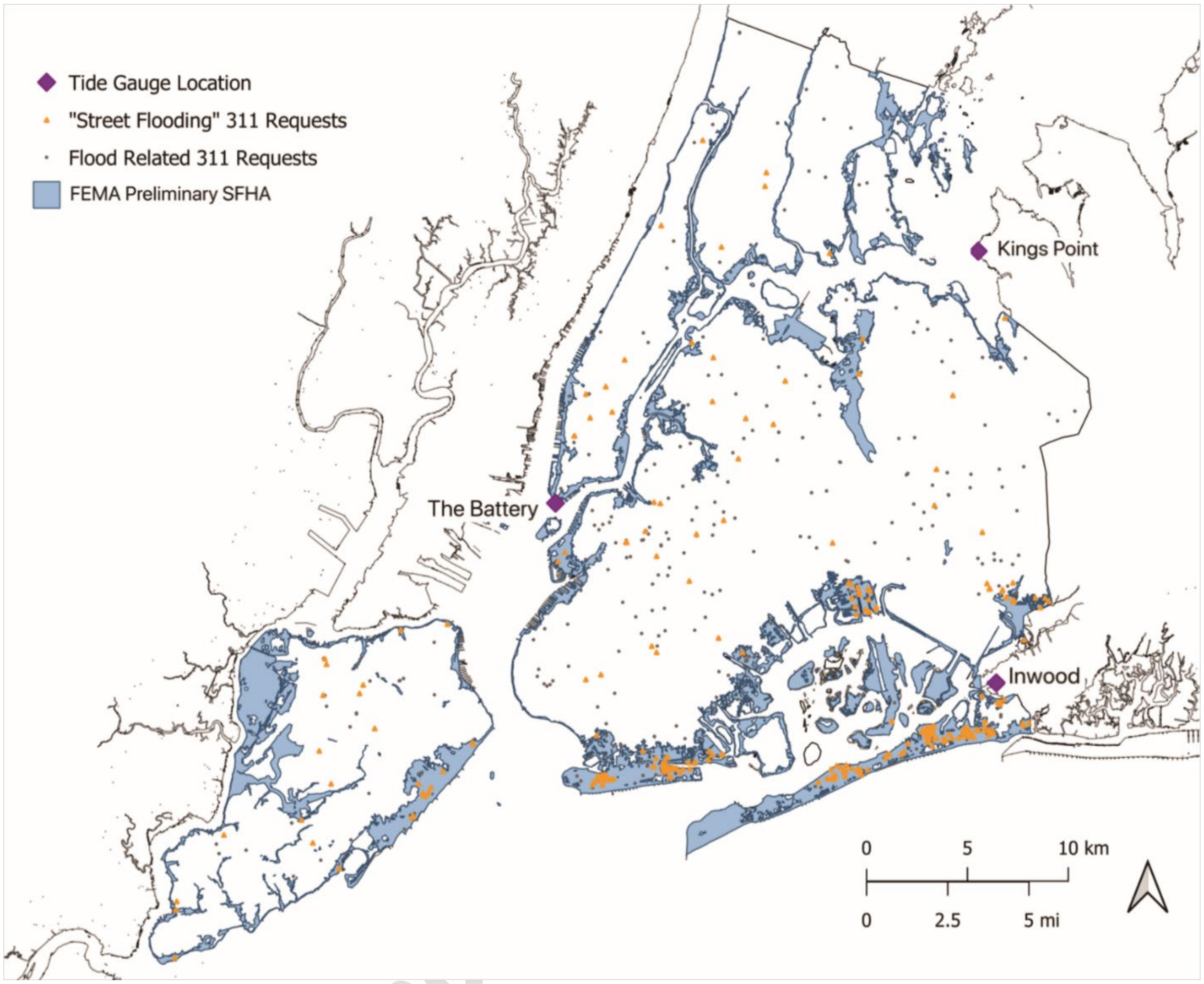

Figure 14: Street flooding and flood-related 311 service requests in NYC on December 23, 2022. Along with 'Street Flooding', flood-related service requests include: Sewer Backup', 'Highway Flooding', 'Manhole Overflow', 'Possible Water Main Break', 'Catch Basin Clogged/Flooding', and 'Excessive Water in Basement. During this event, street flooding requests are concentrated in coastal areas, particularly along Jamaica Bay. Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

6.3 Coastal Flooding Exposure and Vulnerability

Based on FEMA's last completed Flood Insurance Study (FIS) (FEMA, 2013) 67,255 buildings are located in coastal areas that have a 100 yr return interval (1% AEP) of flooding in the contemporary climate. About 30% (20,197) of these buildings are single-story buildings and 33.1% (22,242) of the total exposed buildings have identified subgrade spaces. Of the exposed buildings, 27.0% (18,176) are 1-2 unit residential units with subgrade spaces. Figure 15 and Figure 16 illustrate the extent of this exposure to NYC's vulnerable populations by highlighting the NYCHA developments and 1-2 residential unit buildings with subgrade spaces in coastal areas threatened by inundation during a 100-year storm-surge event. Along with storm surge, coastal flooding can occur as a result of high-tide ('sunny day') flooding, which will increase with sea level rise. Figure 17 highlights vulnerable 1-2 unit residential buildings that are exposed to present-day flooding when tide levels reach the Mean Monthly High Water (MMHW) level. No NYCHA buildings are in this current hazard area. For comparison, Figures 18 and 19 present NYCHA buildings and 1-2 unit residential buildings with basements that will be exposed to approximately monthly (MMHW) tidal flooding with 58 inches (1.47m) of sea level rise (NPCC 2080 Scenario) in the absence of adaptive flood risk management efforts.

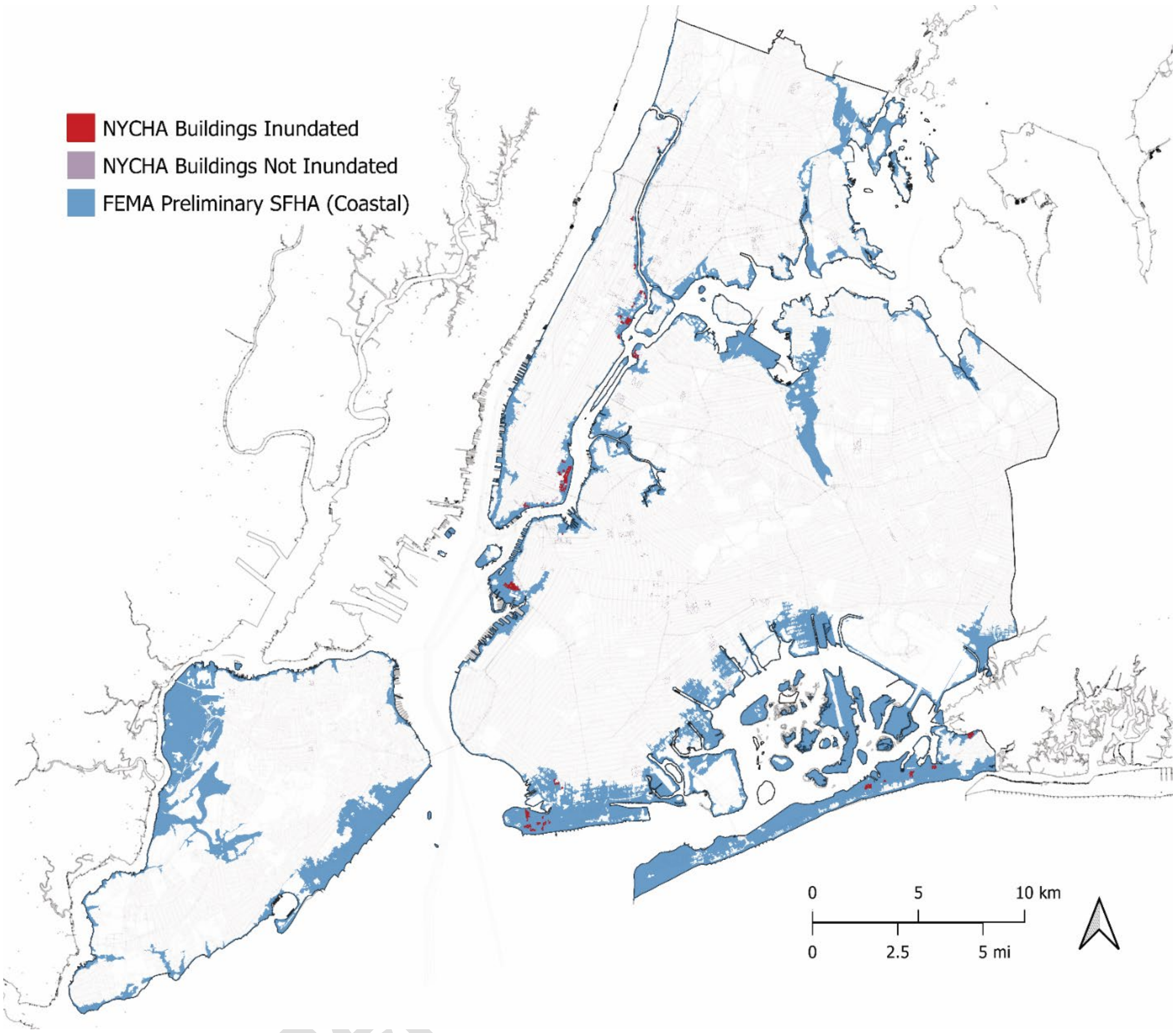

Figure 15: New York City Housing Authority (NYCHA) buildings in coastal areas exposed to 100-year (1% annual probability) storm surge flooding. Source: Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

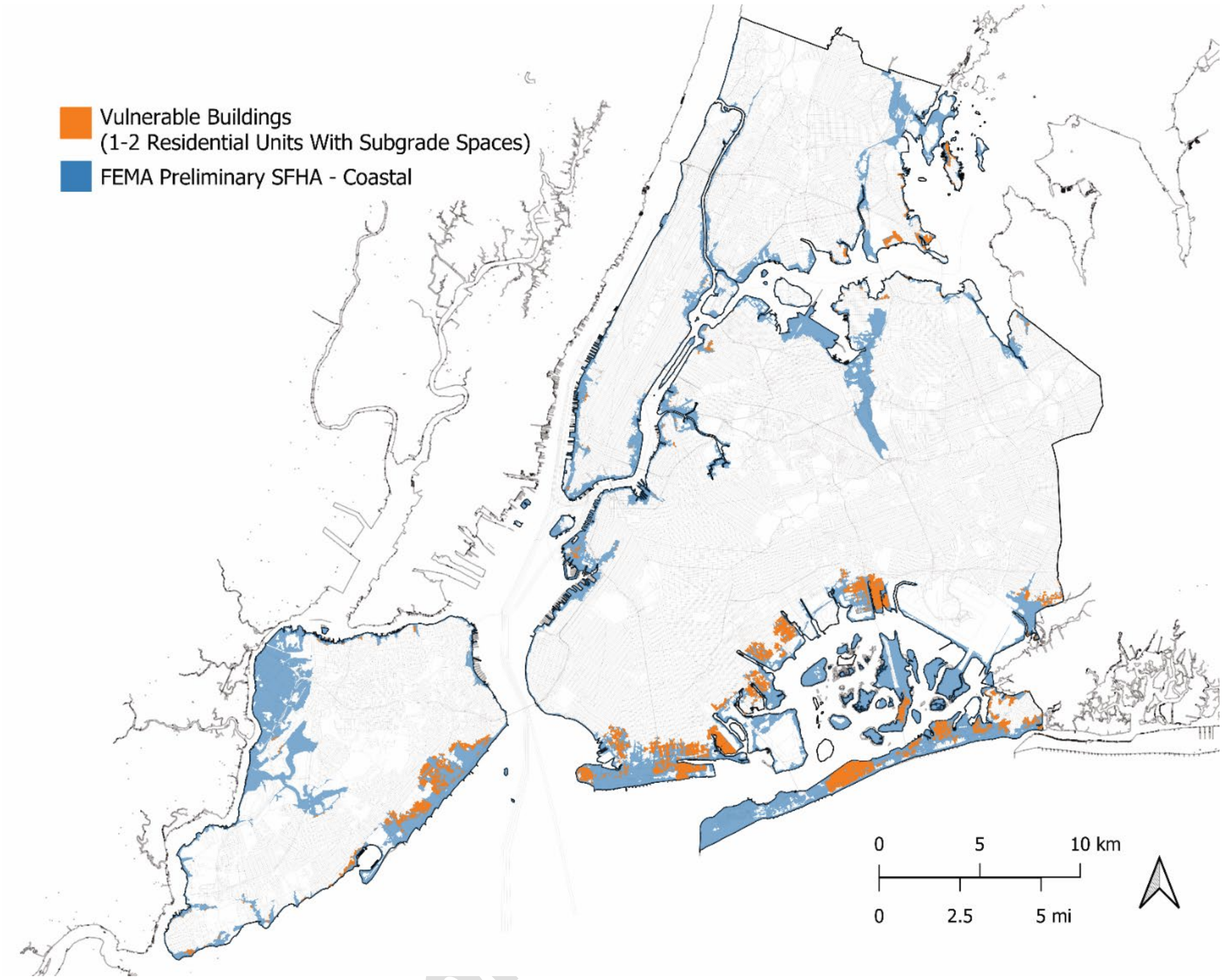

Figure 16: 1-2 residential unit buildings with basements located in the Preliminary FEMA Special Flood Hazard Area adjacent to the coast. Source: Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

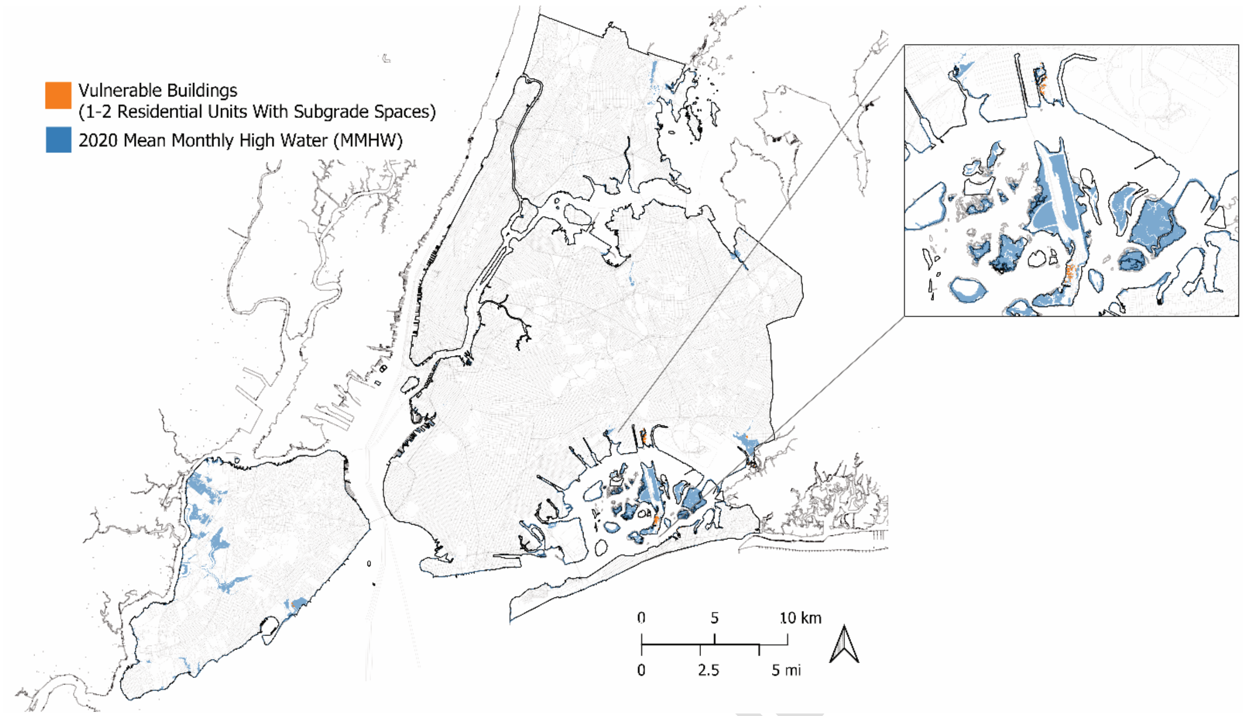

Figure 17: The Flood Vulnerability Index (FVI) 1-2 residential unit buildings with subgrade spaces in coastal areas exposed to present-day flooding from tide levels at the Mean Monthly High Water (MMHW). Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

6.4 Climate Change and Future Coastal Flooding

It is well-established that SLR will continue to increase the frequency and magnitude of NYC coastal floods (P. Orton et al., 2019a), but the potential role of changing storms is an area of high uncertainty and active research (Braneon et al., 2024). Present day and future coastal flood risks with sea level rise have been extensively described in previous NPCC reports. Patrick et al. (Patrick et al., 2019) and Orton et al. (P. Orton et al., 2019a) applied static and dynamic flood modeling to map coastal flood hazards, respectively. Orton et al. (P. Orton et al., 2019a) also updated the projections of future coastal flood risk considering monthly high tides and extreme storm surges across a broadened set of sea level rise projections. While there is consensus that atmospheric warming will likely intensify tropical cyclones in the future, cyclogenesis, storm frequency, and storm tracks are also likely to shift. As a result, there is considerable uncertainty and spatial variability in projections of future changes to storm surge and it remains an active research area that has not yet been incorporated into NPCC flood maps.

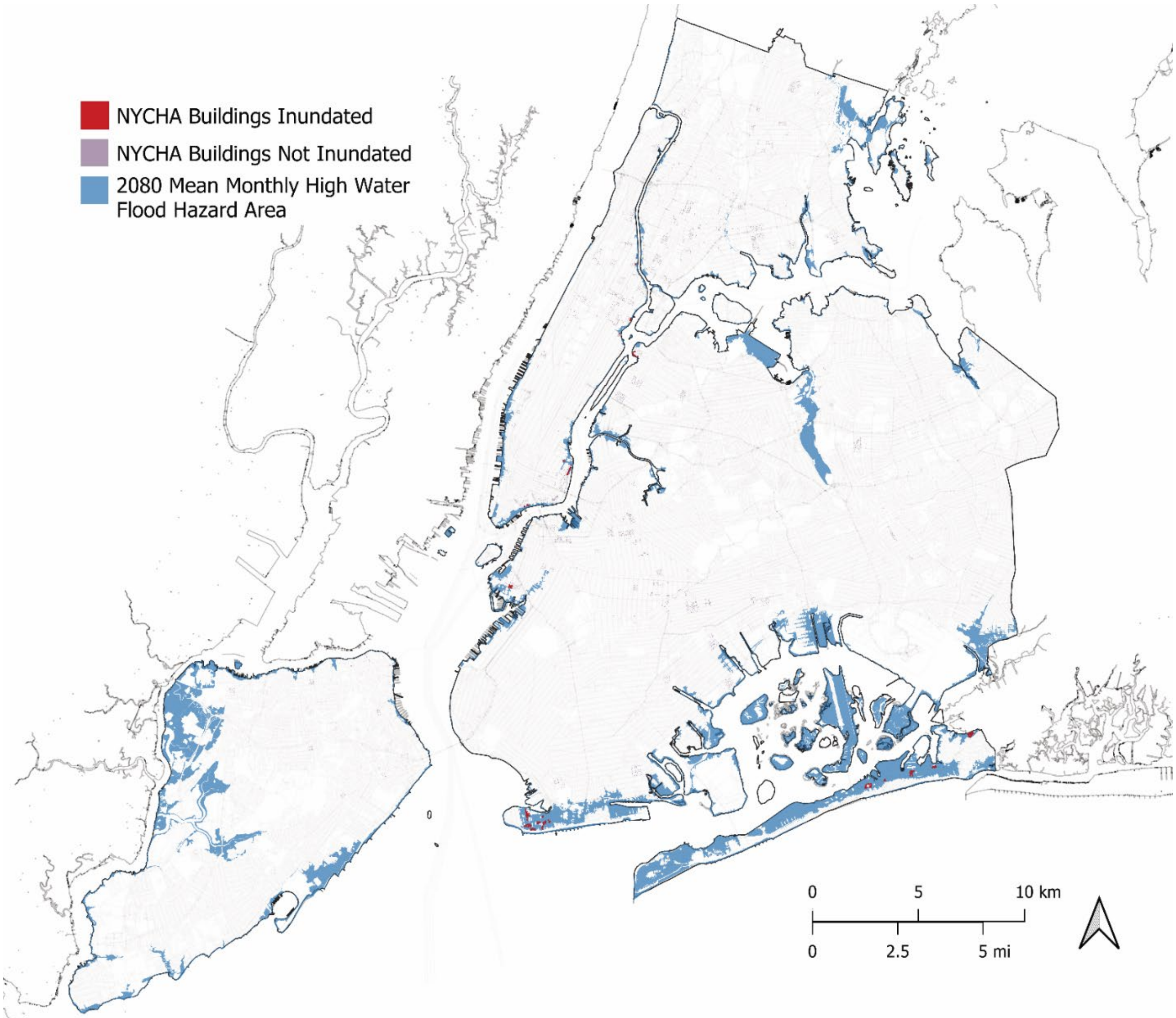

Figure 18: New York City Housing Authority (NYCHA) buildings in coastal areas that are projected to be exposed to flooding from the Mean Monthly High Water (MMHW) with 58 inches (1.47m) of sea level rise (NPCC3 2080 Scenario). Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

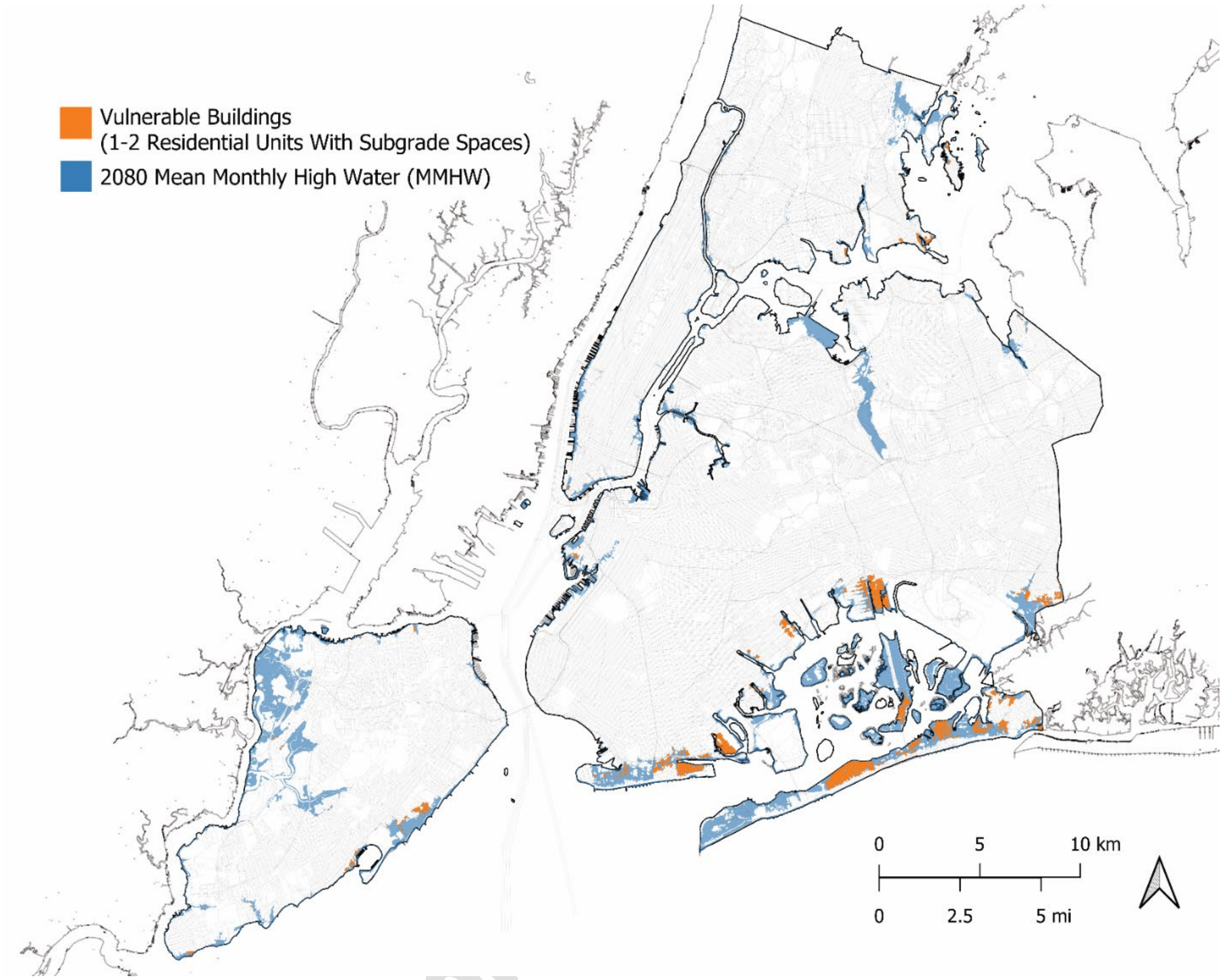

Figure 19: 1-2 residential unit buildings with subgrade spaces in coastal areas that are projected to be exposed to flooding from the Mean Monthly High Water (MMHW) with 58 inches (1.47m) of sea level rise (NPCC3 2080 Scenario). Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

6.5 Persistent Knowledge gaps

There continues to be a need for deeper research into coastal storms, storm surges and climate change impacts in the NYC region. There remain persistent cross-study differences in estimates of present-day storm tide hazards (Cialone et al., 2015; Nadal-Caraballo et al., 2015; P. M. Orton et al., 2016), as well as future changes to hurricane-driven storm surge. Hybrid storms like Sandy are poorly understood, as are the influences of climate change on such storms. These have all previously been noted as key uncertainties (P. Orton et al., 2019a).

Secondary or periodic maxima in non-tidal anomalies after a storm surge event have been referred to under the general term of "resurgences" or "edge waves" (Munk et al., 1956) but are relatively poorly understood. What is known is that these resurgences cause extremely rapid drawdowns of water levels on the tail end of a storm surge event, then a resurgence of as much as 3.5 feet in water levels that can cause flooding about 7-8 hours later if it coincides with high tide (Ayyad et al., 2022; Munk et al., 1956). A broader concern is that a storm could cause an initial surge followed by a surprising resurgence into highly populated neighborhoods. Research is needed to assess the associated risk from such events, including flood modeling of extreme historical and potential future cases of resurgence.

Post Tropical Cyclone Sandy's flooding predominantly affected New York Harbor (southern and western areas of NYC), and the coincidence of peak storm surge with low tide spared areas of South Bronx and Northern Queens from more severe flooding (P. M. Orton, Conticello, et al., 2020). Extreme storm surges and flooding can affect these areas of NYC when hurricanes cross Long Island, causing extreme east winds and storm surges funneling down

Long Island Sound and into the East River, the relatively narrow but potentially important connection between Long Island Sound and New York Harbor. For example, the 1938 "Long Island Express" Hurricane set the historical record for water level in the upper East River (at Willets and Kings Points). Hurricane and extratropical cyclone coastal flood prediction models run by NOAA (National Oceanic and Atmospheric Administration (NOAA), 2023) have poor resolution in the East River. The hydrodynamic model applied in the last FEMA study and now again in a current study showed its worst performance and widespread low-biased water levels for this storm event in the East River (FEMA, 2013). Potential deficiencies in modeling the East River may be undermining our understanding of coastal flood risk, as well as forecasting and emergency management, and should be further investigated.

In the post-Sandy period, many adaptation policies and strategies have been put into operation. Studies to evaluate these strategies are ongoing, and the city has incorporated lessons learned from their experiences with Sandy in guidance for future coastal FRM projects (City of New York Mayor's Office of Climate Resiliency, 2021). But more research is needed to fully document lessons learned ten years after Sandy, listing benefits and limits of coastal flood adaptation strategies that were adopted in response to that event.

7 Groundwater Flooding

7.1 Groundwater Flood Hazard Characterization

Groundwater flooding occurs when the elevation of the water table – a surface that can be used to represent the level at which the subsurface is saturated with water – is higher than that of the land surface or subterranean infrastructure, resulting in the inflow and/or infiltration of groundwater into these spaces (Habel et al., 2020; Macdonald et al., 2012). Groundwater flooding can occur in the absence of human activities, during very wet seasons or years when recharge rates greatly exceed evapotranspiration, resulting in a rise in the water table that inundates areas that are typically dry. But groundwater flooding has also become a globally-significant issue for cities that transition from the use of groundwater supply to other sources (Coda et al., 2019; Foster, 2020). As the water table rebounds from the lowered level induced by historical groundwater pumping, land areas that had previously been dry could more frequently become wet or waterlogged.

The elevation of the water table is determined by the interaction of weather and climate, human water management activities, local topography, and subsurface hydrogeology. The subsurface structure of NYC is complex and varies across the city (NYC MOS, 2015). NYC is underlain by inclined crystalline basement rock that dips from northwest to southeast. Following this incline, the bedrock outcrops in parts of the Bronx and northern Manhattan, with generally thin overlying unconsolidated deposits in much of the Bronx, Manhattan, Staten Island, and northwest Queens. Much of the remainder of Queens and Brooklyn are underlain by sand and gravel glacial deposits that increase in thickness with the sloped bedrock from nearly zero in northwest Queens to over 1,100 feet at the southeast edge of the city (Soren, 1971).These aquifers were historically pumped extensively for municipal supply, with pumping in the easternmost parts of the city continuing through the 1990s (Buxton & Shernoff, 1999). This pumping, over a period of many decades, contributed to a decrease in groundwater flow to streams and the coastal and inland wetlands left that remained in the urban area.

In addition, many of the city's tidal creeks and coastal wetlands were extensively landfilled from the 18th through the 20th centuries (Sanderson & Brown, 2007; Soren, 1971). Today, many of the city's coastal communities are underlain by urban fill materials, which are highly variable in thickness and composition across the city (Walsh, 1991; Walsh & LaFleur, 1995) In many of these areas, the hydrographic legacy of the historic stream corridors remains, and these areas are underlain by very shallow groundwater. The hydraulic properties of historic landfill materials also remain poorly characterized, with implications for the ability to predict groundwater levels and flow using numerical groundwater models.

Areas underlain by shallow water tables (the surface representing the approximate depth to saturation with groundwater) may experience groundwater flooding during atypically wet seasons when the water table rises above the elevation of subterranean infrastructure or the land surface. Extensive areas of Brooklyn and Queens have an estimated depth to groundwater less than 10 feet (See Figure 20 in Monti et al. (Monti et al., 2013b)). Groundwater levels in other parts of NYC are very poorly characterized due to the more complex fractured bedrock geology and the lack of historic groundwater utilization and monitoring in these parts of the city.

Groundwater flooding is an issue of particular concern in areas of the city that were developed during times when groundwater levels were artificially lowered through municipal groundwater pumping. This includes several neighborhoods in eastern Brooklyn and southern Queens that were developed in the mid- to late 20th centuries, when the surficial, Upper Glacial Aquifer was extensively pumped by the Flatbush, Woodhaven and Jamaica Franchise Areas of the New York Municipal Water Supply Company (Buxton & Shernoff, 1999). Many buildings and other infrastructure in these areas were constructed by builders that were unaware that the water table was depressed by intensive pumping, or who assumed that pumping would continue indefinitely. When municipal pumping was discontinued due to saltwater intrusion and other water quality concerns, the water table rebounded, rising above the level of subterranean infrastructure such as basements and subway tunnels that had been constructed when groundwater levels were depressed through pumping (Soren, 1976). Many of these communities now require continuous groundwater pumping of basements and tunnels to prevent inundation and may face enhanced risk of groundwater flooding during wet seasons.

7.2 Historical Example: Groundwater Flooding in Lindenwood

The Lindenwood section of East New York (located at the border of Brooklyn and Queens) is one of several communities across the city that is particularly exposed to groundwater flooding due to its development, topography and location near the coast of Jamaica Bay (Figure 20). Like many Jamaica Bay coastal communities, the depth to the water table underlying much of the Lindenwood area was estimated to be less than 10 feet in 2013 (Monti et al., 2013b). Some areas of this community are located on landfilled historic riparian wetlands of Spring Creek and are particularly low in elevation.

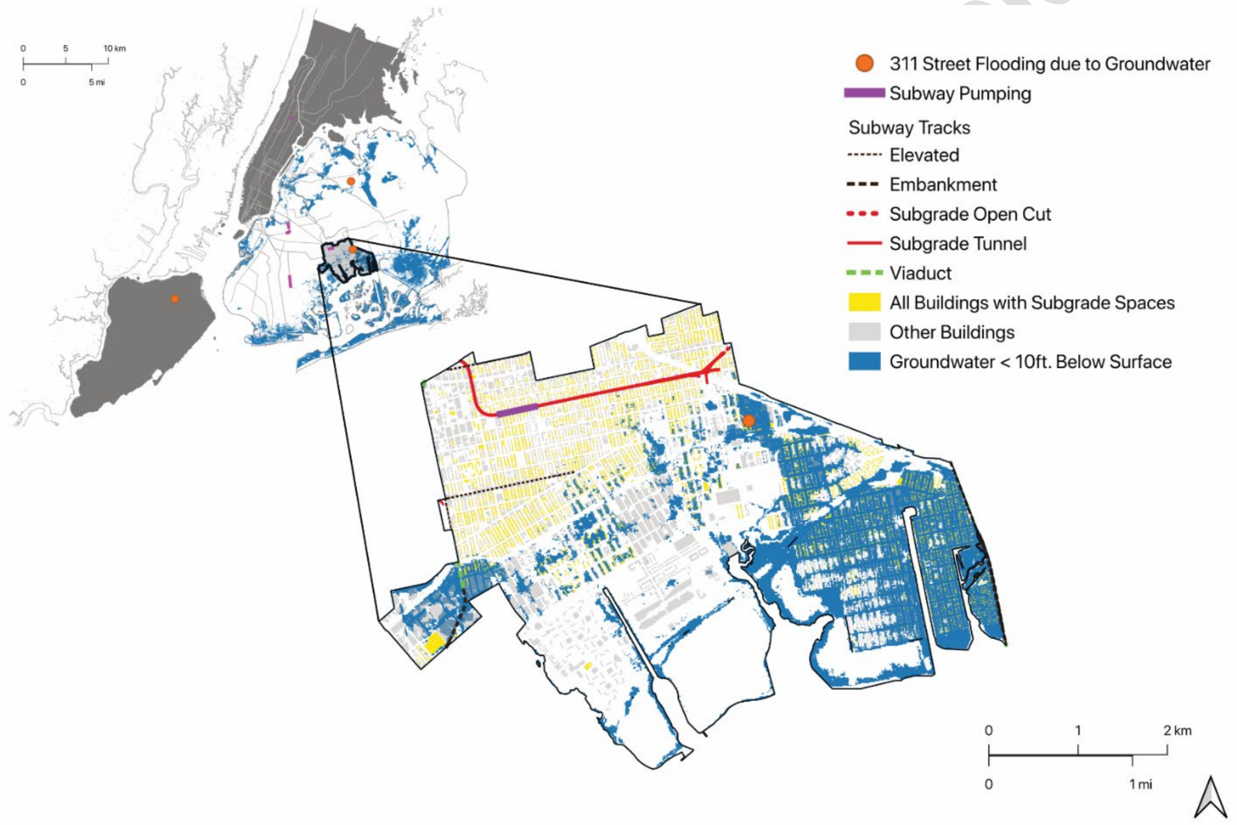

Figure 20: Shallow groundwater and subgrade infrastructure in East New York--Lindenwood. Subgrade subway tracks in this area already require pumping due to shallow groundwater. In 2010, the New York City Department of Environmental Protection reported groundwater flooding in response to a street flooding service request in this area. Map by BR Rosenzweig

Groundwater flooding has been a documented issue in East New York - Lindenwood since the 1970s, following the cessation of municipal pumping in the adjacent Woodhaven Franchise Area (Soren, 1976). This includes basement flooding and damage to building foundations due to the elevated water tables. In addition, a 311 service request for street flooding in this area was attributed to a groundwater flooding condition (Unique Key # 16370230 on 4/3/2010 (NYC 311, 2010).

7.3 Groundwater Flooding Exposure and Vulnerability

7.3.1 Buildings and critical Infrastructure exposed to groundwater flooding

No groundwater flood hazard maps are currently available for the city. As an alternative, for this assessment, we use areas where the depth to the water table has been mapped as shallow as a proxy for areas that may be exposed to groundwater flooding in the future. The USGS conducts an annual synoptic survey of groundwater levels observed in monitoring wells on Long Island each April and May. This surveyed data of the water table elevation is used to develop a map of 'Depth to Water' - the distance from the land surface to the water table. When observational data were available, this survey included groundwater levels in the NYC boroughs of Brooklyn and Queens, which are located on Long Island. At present, April-May 2013 is the most recent period for which groundwater monitoring data is available for these two boroughs, although the USGS and NYCDEP are planning to reestablish groundwater monitoring in these two boroughs and across the city for future assessment of groundwater hazard.

The 2013 Depth to Water layer was used to identify areas of Brooklyn and Queens where the depth to the water table was less than 10 feet below the land surface – this threshold was determined based on the accuracy of the Depth to Water layer Como et al. (2018). In these two boroughs 83,800 buildings are located in areas where the depth to the water table is less than 10 feet. Of these buildings, 33,996 (40.6%) have subgrade spaces and of these buildings, 28,411 (33.9% of the total exposed) are 1-2 residential unit buildings.

Figure 21 and Figure 22 illustrate the extent of shallow groundwater in NYC's boroughs of Brooklyn and Queens, and locations of vulnerable buildings (NYCHA developments and 1-2 story residential buildings with subgrade spaces).

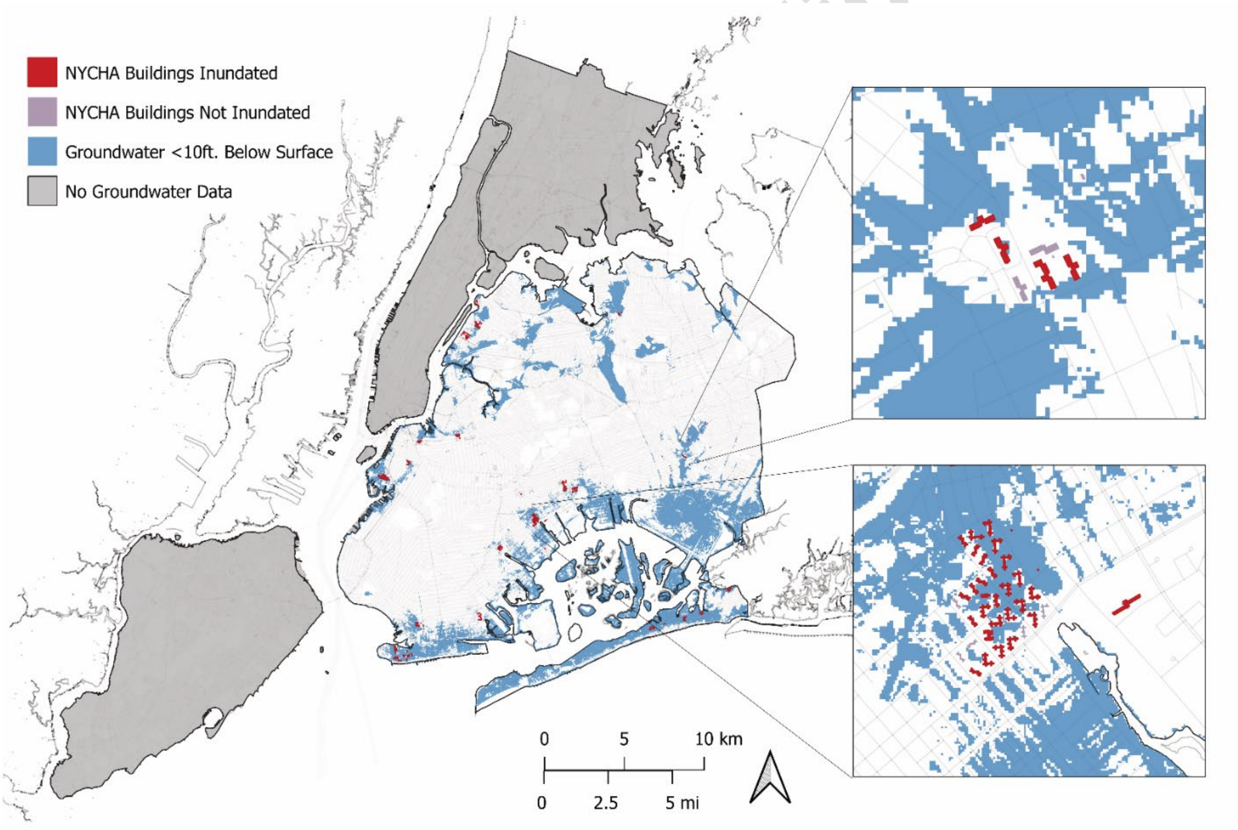

Figure 21: NYCHA buildings located in areas underlain by shallow (< 10 foot) groundwater. Depth-to-water data are currently only available for the NYC boroughs of Brooklyn and Queens. Source: Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

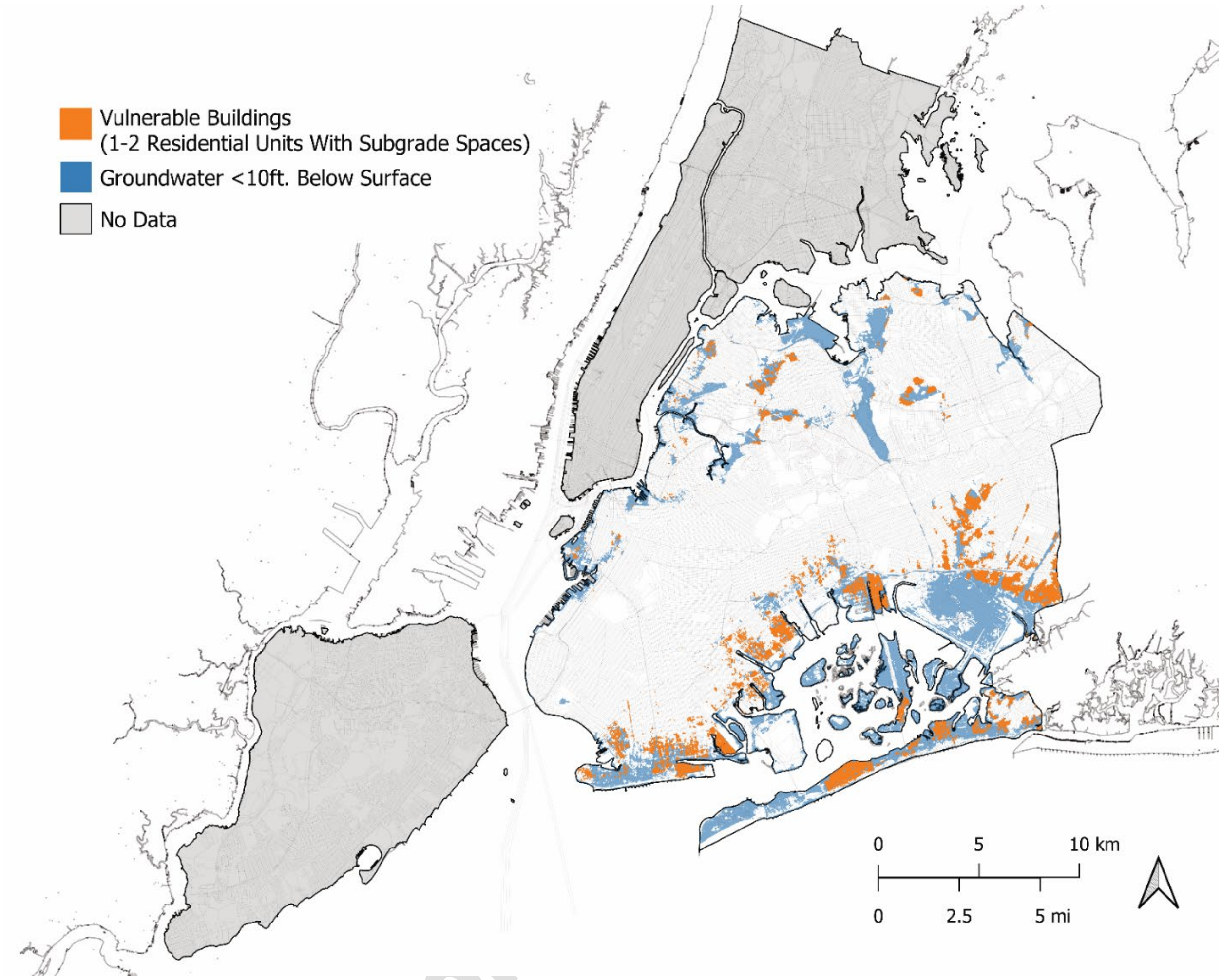

Figure 22: 1-2 residential unit buildings with subgrade spaces located in areas underlain by shallow (<10 feet) groundwater. Source: Map by NPCC4 Fellow Fiona Dubay, Sarah Lawrence College.

7.4 Climate Change and Future Groundwater Flooding

Climate change can potentially exacerbate existing groundwater flood hazards through two mechanisms: First, the projected increases in annual precipitation with climate change (Braneon et al., 2024) may result in a net increase in recharge to the city's surficial aquifers, elevating the water table. However, when the water table is near the land surface, the impact of increased precipitation may be partially mitigated by concomitant increases in evapotranspiration with warmer temperatures (Smerdon, 2017). Predicting climate change impacts on groundwater recharge will be particularly challenging in NYC, where leakage to and from sewers significantly contributes to the subsurface water balance (Buxton & Shernoff, 1999; Buxton & Smolensky, 1999).

The second mechanism results from the impacts of sea level rise on groundwater elevation and flow (Figure 23). At the coast, seawater and groundwater function as a system, coupled through the flow of fresh groundwater towards the sea and the intrusion of dense, saline seawater into coastal aquifers. Close to the shore and assuming uniform soil properties, the water table will stabilize to an elevation that is just above the increased local mean sea level at steady-state (S. W. Chang et al., 2011; Strack, 1976), resulting in emergence at the surface and inundation of areas with shallower water tables - even if they were otherwise protected from direct coastal inundation by floodwalls or dunes at the shore (Habel et al., 2020; Rotzoll & Fletcher, 2013). In relatively flat, humid areas such as NYC, this water table rise will be limited by surface drainage once the water table emerges at the lowest-elevation areas, a process described as 'topography-limitation' (Michael et al., 2013). For example, in a numerical modeling study, Befus et al. (2020) found that surface drainage at topographic low areas significantly limited the areal extent of water table rise in response to rising sea levels across the state of California. However, in NYC, this topography-limitation effect could actually lead to concentrated groundwater flooding in populated, low-elevation areas of the city where groundwater drains at the surface – even if changes in the depth-to-water in other parts of the city is stabilized through this process. Communities developed in the legacy valleys of filled streams would be particularly exposed to risk through this mechanism. In addition, once the water table rise is stabilized by groundwater emergence at the surface, the groundwater freshwater-saline interface will begin advancing inland (S. W. Chang et al., 2011; Werner & Simmons, 2009), a process known as saltwater intrusion that would exacerbate corrosion damage of subterranean infrastructure located below the water table and harm to inland NNBS that are not adapted for saltwater as described previously (Tansel & Zhang, 2022). Courtney et al. (Courtney et al., 2023) found evidence that tidal fluctuations are propagating further into a Hudson River tidal wetland today more so than they were 20 years ago.

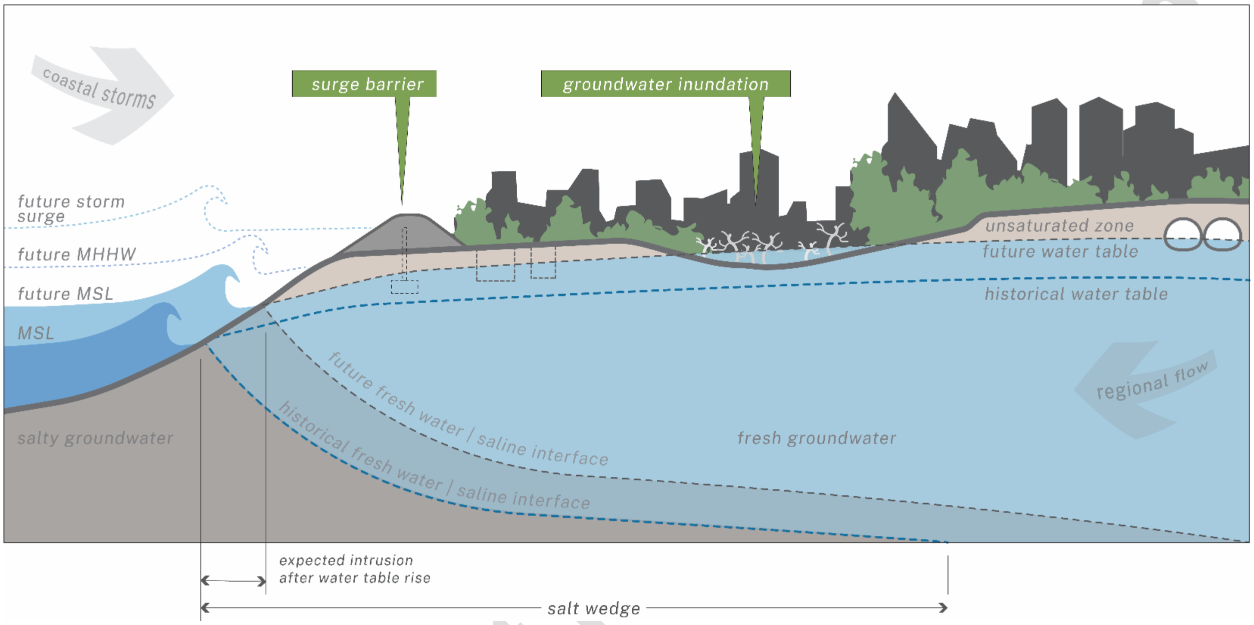

Figure 23: Sea level rise and surficial groundwater at an idealized shoreline. Figure by the authors.

7.5 Persistent Knowledge Gaps: Groundwater Flooding

The idealized case of a uniform groundwater aquifer at steady state that we described above provides a useful first assessment of the potential magnitude of water table rise due to sea level rise, and this assessment has been utilized in previous studies of climate change and urban groundwater flooding (Rotzoll & Fletcher, 2013; Sukop et al., 2018). However, actual groundwater conditions and the response to sea level rise in NYC will be determined by our local aquifer and infrastructure conditions (Bonneau et al., 2017; Sharp et al., 2003). As such, care should be taken in drawing conclusions from studies completed for different locales and spatial scales. In NYC, groundwater conditions are not idealized in that water table elevations will be influenced by sewers (Liu et al., 2018; Su et al., 2019, 2022) and site-scale groundwater pumping for dewatering, which may mitigate the amount of water table change due to sea level rise but exacerbate saltwater intrusion. Furthermore, changes to historic shorelines and low-lying areas that were filled as the NYC area was developed will also influence groundwater response to sea level rise and groundwater recharge (Mancini et al., 2020). Nonetheless, these initial, available studies are useful in identifying *potential* risks and considerations for evaluating NYC's groundwater flooding hazards.

In addition, the steady-state assumption does not allow for the assessment of the timing of the groundwater response to sea level rise. Numerical models that can simulate the transient water table response in heterogenous aquifer systems can provide enhanced understanding of groundwater flood hazard under different scenarios of sea level rise (Habel et al., 2019), but the predictive skill of these models is highly dependent on the availability of data on spatially distributed aquifer properties, the location and depth of sewers and subterranean groundwater drainage systems, and on observations of groundwater levels for model calibration and validation (Bosserelle et al., 2022).

Understanding sea level rise impacts on the shallow groundwater system in NYC in light of anthropogenic influences (e.g. urban drainage systems) is the subject of an upcoming U.S. Geological Survey study (USGS, *Personal Communication, March 8, 2024*). The USGS has signed an agreement with NYCDEP to reestablish, operate, and maintain a hydrologic-monitoring network program in NYC designed to focus on groundwater-flooding assessment, resiliency efforts, and hazards mitigation.

As the groundwater monitoring wells are reactivated, the USGS-NYCDEP study will focus on the following elements:

- Conducting applied research to aid in the efficient and economical implementation of groundwater flooding abatement systems.
- Developing a groundwater map for Staten Island to inform current and future design of Bluebelt stormwater management corridors.
- Investigating and modeling the effects of sea level rise and saltwater intrusion upon the groundwater system and Bluebelts in Queens and Staten Island.
- Investigating and modeling potential ground subsidence resulting from a lowered groundwater table.

Additional research is needed to improve understanding of how sea level rise could increase groundwater flood hazards and associated impacts on the city's infrastructure systems on a site-by-site basis. A higher water table could increase the need for pumping to the inundation of subways, tunnels, utility vaults and other subterranean infrastructure by infiltrating groundwater. Increased pumping will require increased electricity demands. In addition, if the pumped water is discharged directly into nearby waterways. This could also result in increased loading of nutrients or other groundwater contaminants to these water bodies. For example, Benotti et al. (2007) estimated that contemporary subway dewatering contributes to nitrogen loading in NYC's Jamaica Bay.

Rising water tables could also reduce the conveyance capacity of sanitary and stormwater drainage systems and limit exfiltration of stormwater from the base of green stormwater infrastructure facilities (Liu et al., 2018; K. Zhang & Chui, 2019), potentially exacerbating pluvial flooding (Section 4.1). At higher elevations, groundwater can also infiltrate into septic systems (Habel et al., 2020) and reduce the service life of pavements (Knott et al., 2017, 2018). Limited information is available regarding the impact of rising groundwater levels on shoreline flood protection infrastructure such as sea walls and levees, and specifically the potential for groundwater flooding inland of these systems that could reduce their overall effectiveness (Habel et al., 2020; Rotzoll & Fletcher, 2013).

8 Compound Flooding

8.1 Compound Flooding Hazard Characterization

The impacts of NYC's four flood hazards (coastal, fluvial, pluvial, groundwater) can be compounded when they occur in combination. For example, a tropical cyclone that brings both heavy rain and storm surge could result in coastal, fluvial, and pluvial flooding. An intense rainstorm that occurs in the spring or during a very wet season when groundwater tables are elevated could result in both groundwater and pluvial flooding (Corada-Fernández et al., 2017). Future climate change and sea level rise could aggravate the effects of compound floods by increasing their frequency (Lai et al., 2021) or altering the co-occurrence of flood drivers (Ward et al., 2018). An initial analysis of historical observations found that the likelihood of joint occurrence of extreme rainfall and storm surge within a given storm system (defined as a three-day window) has increased over the past century, possibly due to climate change (Wahl et al., 2015).

Federal risk assessment and forecasting have, however, rarely incorporated multiple flood hazards into flood modeling due to the limited capabilities of existing models and lack of statistical assessments of compounding factors (P. Orton et al., 2012). Compounding of floodwater sources has not been incorporated into flood hazard mapping from FEMA (e.g. flood insurance rate maps) or NOAA (e.g. SLOSH Maps) (NOAA National Hurricane Center, 2023; Zachry et al., 2015). This deficiency is gradually being addressed, with new models being developed and methods applied to better assess compounding. For example, the USGS New York Water Science Center is assessing compound flood risk from the combined effects of sea level rise on storm surge, tidal and groundwater flooding, and stormwater (United States Geological Survey, 2021). This research project is exploring and mapping vulnerability to individual and co-occurring flood drivers across the project study area, which includes NYC. The study also includes developing a coupled model framework that links coastal, groundwater and stormwater models to better understand the dynamics connecting surface stormwater, coastal ocean, and groundwater.

The most widespread compound flood hazard for NYC is likely compound hazard from rain and storm surge, given that coastal and pluvial flooding commonly co-occur during coastal storms. Analyses of historical data under the

Climate VIA project have quantified the baseline present-day hazard from co-occurrence of these two drivers (Z. Chen et al., in Preparation). The research focused on simultaneous and near-simultaneous rain and storm surge through analysis of hourly historical data because NYC is located on several small, heavily urbanized watersheds, where the time of concentration is short, and rain and surge must be nearly simultaneous to cause compounding. This is an improvement upon prior assessments that analyzed daily rain totals and looked at three-day windows for assessing co-occurrences (Lai et al., 2021; Wahl et al., 2015). The new analyses included ranked correlations of rain and surge and joint return period analyses. Storm types were separated into tropical cyclones, extratropical cyclones and "neither" events (e.g. localized convective thunderstorms) using historical storm track datasets.

The results of this new research reveal non-zero correlations between rain and storm surge, suggesting that there is a higher probability of one variable being extreme when the other is extreme. When all storm types are merged together, rain and surge have a low, but non-zero rank correlation. However, for TC data alone, their correlation can be high. In addition, when one of the two flood drivers is extreme (the "primary" driver), the magnitude of the secondary flood driver during TCs is much higher than for other storm types. Even though they occur less frequently than extratropical cyclones or other storm events, rain and surge during the most extreme cases (the upper tail region of the probability distribution) are more correlated for TCs than for all events combined (a combined assessment). Assessing extreme (50- and 100-year) joint rain-surge events from TCs gives a worse rain and surge hazard than assessing all events combined. As a result, TCs require separate hazard assessments to avoid underestimation of extreme compound flood hazards (Z. Chen et al., in Preparation).

The timing of the joint flood drivers is also important to their potential compounding. For TCs alone, there are moderate negative correlations between peak rain intensity and the lag to peak surge, indicating that the most intense TC rain and surge events (e.g.,100-year) have the most potential for simultaneous extreme flood drivers and thus, compounding. Prior studies have only focused on New York Harbor (the Battery) but a paired assessment of Kings Point tide gauge data addresses compound flood hazard for South Bronx and Northern Queens. It showed this area has qualitatively similar compound rain-surge compound hazard characteristics. However, we found the peak surge at Kings Point tends to have 2-6 hours of lag time behind the peak rain rate during TCs (due to slow surge propagation along Long Island Sound). This could reduce the risk of pluvial-coastal compound flood hazard but raises the risk of fluvial-coastal compound flood in nearby Bronx River.

8.2 Historical Example: Tropical Storm Irene

Tropical Storm Irene 2011 hit NYC with a large storm surge (4.2 feet at the Battery), high coastal water levels, and simultaneous heavy rainfall. The compounding by rain and river streamflow increased peak water levels only very slightly (2%) in New York Harbor (P. Orton et al., 2012). No street flood sensor observations or flood modeling existed for NYC during that storm, but the combination of "moderate" to "major" NWS coastal flood levels along shorelines of NYC and heavy rainfall (as much as 3.3 cm in 1 hour; 14.4cm in 12 hours) may have caused compound flooding. This lack of quantitative evidence has motivated efforts to deploy hundreds of real-time flood sensors on streets (City of New York et al., 2024; Silverman et al., 2022) and to develop hydrologic and hydraulic models of the city (City of New York Mayor's Office of Resiliency, 2021), both of which can be used to quantify compound flooding and better understand the potential efficacy of mitigation strategies.

8.3 Compound Flooding Exposure and Vulnerability

While very little detailed quantification of on-the-ground compound flooding has been possible until recently, areas believed to experience compound flooding are typically in coastal flood zones, and include locations like East New York, The Rockaways, and Gowanus. In-situ observation efforts like FloodNet, are poised to greatly expand the data available to quantify the City's flooding.

8.4 Climate Change and Future Compound Flooding

Given the relatively new science of compound flooding, relatively little research has looked at quantifying future trends. However, rising sea levels alone are likely to cause worsened compounding of pluvial flooding in coastal floodplains, and any intensification of rainfall extremes could similarly compound coastal floods. Recent work by Gori et al. (2022) showed that extreme rain and surge correlations could rise by up to 25% by 2100 due to climate change, and both SLR and storm climatology changes are important to the rainfall-surge joint hazard at the NY/NJ area. The recent Stormwater Resiliency Study (City of New York Mayor's Office of Resiliency, 2021) assessed future rain intensity change and SLR impacts on pluvial flooding. Research prior to that study used global climate model results for changes to extreme rainfall and used simplified conservative (high-end flooding) modeling approaches by assuming it is always during the high tide for all the extreme rainfall scenarios (Ghanbari et al., Submitted).

8.5 Persistent Knowledge Gaps: Compound Flooding

Completed recent research (City of New York Mayor's Office of Resiliency, 2021) has mainly focused on pluvial flooding and sea level rise, but more comprehensive research on all flood hazard types, including groundwater and Bronx River-fluvial compound flooding is needed. Moreover, rain-surge compounding is also increased by tides, and thus quantification of the joint rain-surge-tide probabilities is important for determining the compound flooding. While most research to date has focused on less-frequent, extreme compound events, more research on the chronic flooding that will result from more-frequently occurring high tides and the infiltration of groundwater into storm sewers is needed.

A critical next step will be compound flood modeling and analyses of street flood observations alongside the results of statistical assessments like those summarized above, to translate these data into an understanding of actual on-the-ground impacts; two drivers can co-occur, but their combined flood depth is often less than their sum.

Further use of 311 flood-related service requests and NYC FloodNet Street Flooding observations (Silverman et al., 2022) can greatly aid these research endeavors. The impact of climate change on compound flooding is another area of future research. The improved understanding of past and present-day compound flood hazards presented above helps identify the factors needed to study future changes in compound flooding. For example, tropical and post-tropical cyclones are an important area of study for the most extreme compounding events, and the climatological changes to these storms are an important area for future research.

9 Flood Risk Management (FRM)

9.1 Context for Flood Risk Management (FRM)

As discussed throughout this chapter, NYC's ecology and development history play an important role in contextualizing the geography of the city's contemporary flood risks. Many of today's flood hazard areas were historically natural streams and wetlands (Figure 1) that flooded regularly. But the risks associated with pre-urbanization flooding in these areas were low since the ecological communities found there were well-adapted to these conditions, and the human population exposed to these floods was relatively low. Contextually, this pre-urbanization level of flood risk can be viewed as an ***unavoidable*** floor (Figure 24, left), below which risk cannot be reduced. It is worth noting that even if the NYC metropolitan area had never urbanized, flood hazards – and in turn, flood risk - would have continued to increase through the 20th century, due to the effects of global climate change on sea level and precipitation patterns (as represented by the yellow box on the first column).

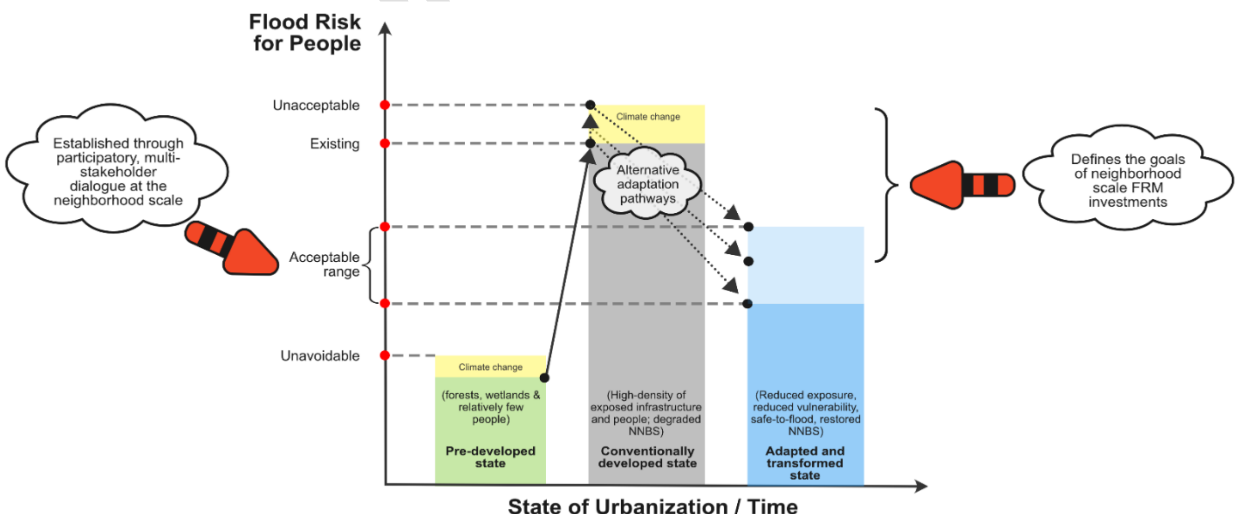

Figure 24: Evolution of flood risks for people as a function of urbanization, climate change, and adaptation pathways. The yellow boxes represent increases in flood risk due to climate change. The heights of the green, grey, and blue bars represent NYC flood risks in pre-developed, conventionally developed, and adapted/transformed states, respectively. The solid arrow represents the increase in flood risk due to historical urbanization. The dotted arrows represent alternative adaptation pathways as could emerge participatory, multi-stakeholder decision making processes use to plan FRM Source: (Figure credit: FA Montalto)

As the city urbanized, streams were filled and natural areas were replaced with impervious surfaces, the potentially exposed population grew into the millions and flood risks for people greatly increased (Figure 24, middle). More people and infrastructure systems were exposed to each flood, without the natural buffering provided by the historical ecological systems. As in cities across the country (National Academies of Sciences, Engineering, and Medicine, 2019; Wasley et al., 2023), the impacts of flooding came to be experienced differently across different populations. As evidenced by the severity of flood impacts documented throughout this chapter, this ***existing*** level of flood risk is already high and climate change (e.g. yellow box, middle column) will raise it further. Given the extensive work by NPCC and other researchers to quantify the potential effects of climate change on the city, and the growing attention being given to flood risk management, the current level of flood risk ought to represent a ceiling, above which future flood risks are not allowed to rise.

To orient adaptation investments made in the city, there is a need for open, public, inclusive, multi-stakeholder deliberation about the range of future flood risks that are ***acceptable*** to NYC residents. This deliberation is a necessary precursor to adaptation decisions which are inherently political and driven by values – both expressed and unexpressed - about what to preserve, what to change, and what to allow to evolve in an un-managed fashion (Mach & Siders, 2021). Adaptation decisions will have long-term, legacy implications and will create path dependencies that cut off future options available to reduce flood risks (Haasnoot et al., 2021), especially in the neighborhoods directly impacted by them. At this important phase in the city's dynamic development, community members need to work with governmental decision-makers, scientists, and others to decide what level of future flood risks they are willing to accept in their communities, and which of many adaptation pathways (e.g. unique combination of FRM approaches) will be pursued to achieve those goals. An overview of the FRM options that are available is provided in the next section.

9.2 Scope of Flood Risk Management (FRM)

Flood risk management (FRM) is an evolving term used to describe a variety of structural and non-structural approaches – or responses - (Figure 25) that seek to decrease the human and ecological impacts of floods. As defined here, following UNDRR (2023) and (Wasley et al., 2023), structural measures include some form of physical infrastructure, or the application of engineering, including nature-based engineering, to reduce flood risks. Non-structural measures use knowledge, practice, agreements, laws, policies, capacity building, financing, and public awareness raising and educational campaigns to accomplish the same goals. FRM seeks to minimize the impacts of climate change through mitigation (Sharifi, 2021); reduction in inundation exposure through gray- and nature-based approaches (Depietri & McPhearson, 2017; L. E. McPhillips et al., 2021; P. M. Orton et al., 2015); and a reduction in vulnerability factors (Kim et al., 2019; Rufat et al., 2015). FRM can be planned by government agencies with a responsibility for water or flood management but can also be initiated by flood-exposed stakeholders themselves. When FRM actions have the unintended consequence of increasing flood risk, they can lead to maladaptation (see Section 3.5).

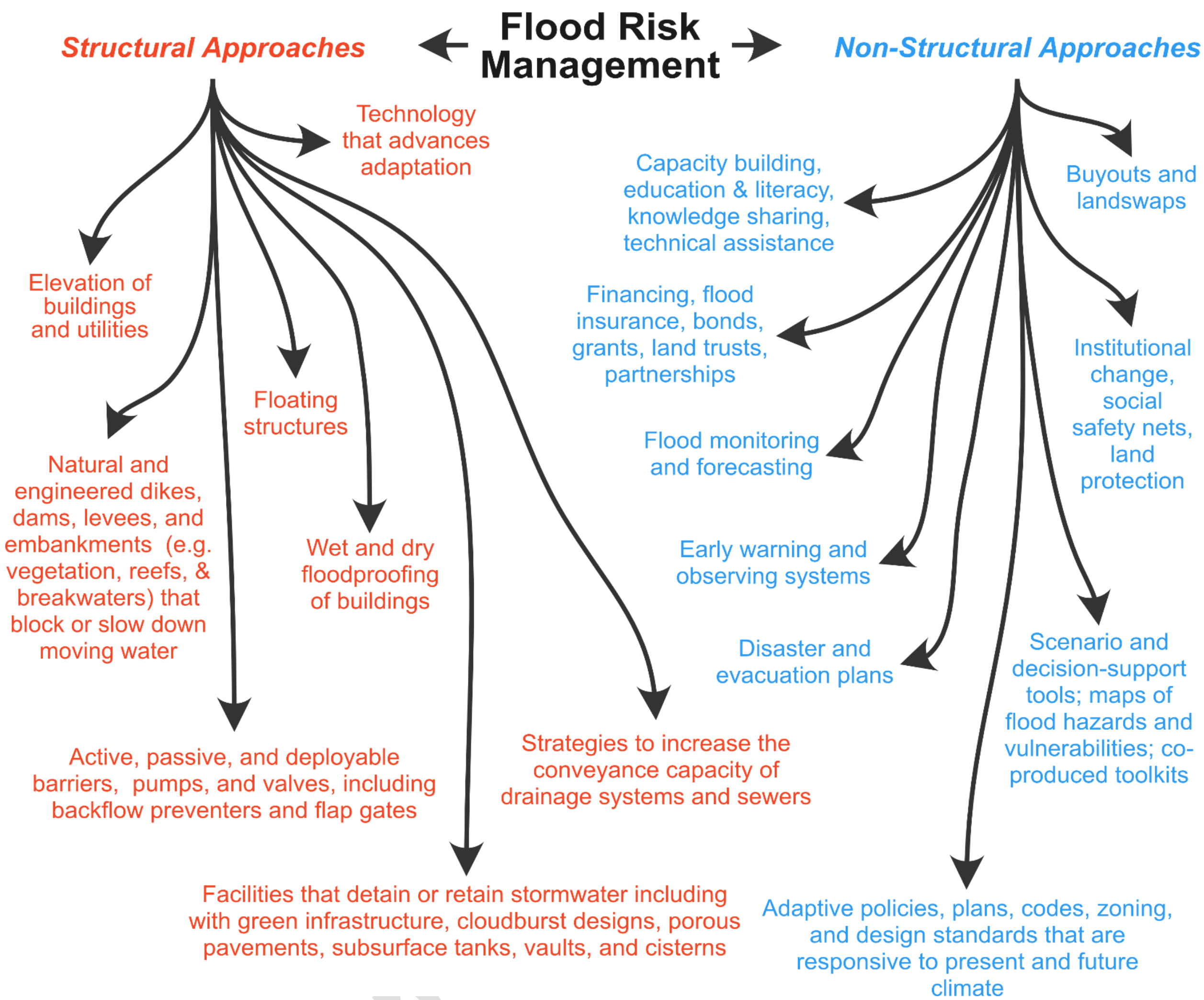

Figure 25: Structural and Non-Structural approaches for addressing the human and ecological impacts of floods. Some portions of this figure were adapted from Wasley et al. (Wasley et al., 2023) Graphic by FA Montalto.

Decisions regarding FRM are complex because they involve selecting which combination of responses should be implemented, at what spatial and temporal scales, to manage which types of floods, with what intended impact, and through what kinds of partnerships and collaborations. Over the past two decades, the principles guiding FRM have evolved rapidly. There has been a shift from responses that sought principally to control floods, to responses that made it easier to live with them, to most recently learning and change processes that sought to fundamentally transform communities to reduce risk in the long-term (Rözer et al., 2022; L. Wang et al., 2022). Prior to this century, FRM responses were predominantly reactive, structural, and undertaken after a flood occurred. Today, increasingly – though perhaps not fast or widely enough - FRM is viewed as a critical component of a multifaceted, pro-active strategy that seeks to reduce the vulnerability and increase the livability of flood prone communities before, during, and after flooding events, in the context of climate change and ongoing urbanization (Abdel-Mooty et al., 2022; Cea & Costabile, 2022).

Martin-Breen and Anderies (Martin-Breen & Anderies, 2011) introduced a taxonomy that can be used to define different classes of FRM adaptation responses. This schema differentiates between *Resistance*-based responses that seek to "bounce back" to pre-flood 'normal' conditions (e.g. the Resistance Approach)(Abdulkareem & Elkadi, 2018; Liao, 2012), and *Resilience*-based responses that involve either an incremental adaptation to a new post-flood 'normal' state (e.g. the Adaptive Approach), or a fundamental transformation of the social and ecological conditions that determine flood risk (e.g. the Transformative Approach) (Martin-Breen & Anderies, 2011). The Resistance approach to FRM fundamentally seeks to preserve the status quo in the exposed community by 'fighting with water' in different ways to keep it away from where it can have negative impacts. It is typically applied at larger spatial scales, for example by building a levee, seawall, or flood gate dyke (McClymont et al., 2020). If it exacerbates flooding elsewhere, it can lead to maladaptation. The two Resilience approaches involve decentralized actions inside communities but at different scales and for different purposes as broken down below:

- Because it recognizes the need for exposed communities to 'live with water', the **Adaptive approach** may incentivize property retrofits (e.g. various forms of floodproofing, and/or elevation of buildings or utilities) or other measures that prepare that community for a specific future condition.

- Recognizing the same need, the **Transformation approach** does not adopt any fixed end point (e.g. either a historical or future normal condition) as the goal for FRM. Rather, it accepts that climate change (and other social and ecological processes) is creating a dynamic, evolving context in which continuous societal change and transformation will be needed, for example determining where and how people live, and where and how natural systems are integrated into developed landscapes. Like the Adaptive resilience approach, these changes can be decentralized and small-scale. But like the Resistance approach, these changes could also drastically modify how entire communities look and feel. All three approaches can be implemented through various combinations of structural and non-structural measures, but with significantly different end goals governing how they are applied.

9.3 Pros, Cons, and Caveats of Different FRM strategies

It is crucial that decision-makers, community members, and others be cognizant of the challenges and tradeoffs associated with different FRM responses as they collaborate to design comprehensive FRM strategies for specific districts, neighborhoods, or properties in NYC. An overview of these factors is provided below.

9.3.1 Resistance responses

Resistance responses can be among the fastest and easiest ways to provide immediate protection to existing communities, though recent reviews (Cea & Costabile, 2022; McClymont et al., 2020), point to several potential unintended consequences (e.g. maladaptation) specifically of the engineered components of this approach:

- Resistance strategies frequently prioritize flood control over the need to conserve, restore, and/or create natural systems, undervaluing the natural water regulating services that NNBS provide. Historical investments in engineered flood control measures nationwide often came at the expense of NNBS, increasing natural systems vulnerability (McClymont et al., 2020), and reducing their ability to provide ecosystem services. In urban contexts, a general lack of understanding about how to integrate natural systems into the built environment resulted in a significant loss in the ability of natural systems to buffer the impacts of floods. Resistance strategies can cost-effectively reduce flood frequency and associated impacts and can also be designed to protect vulnerable NNBS. However, these same responses can also result in negative ecological impacts. These negative impacts could include changes in sedimentary systems, water column stratification, animal migration and habitat connectivity (P. Orton et al., 2023). Tognin et al (2021) documented how operation of the Venice storm surge barrier can reduce episodic sediment supply to tidal wetlands, compromising their ability to provide ecosystem services. Barriers can provide a temporary solution to sea level rise but set up difficult long-term choices between natural system function and human welfare. Already, many existing surge barriers are being closed with increasing frequency due to sea level rise, reflecting the potential for their overuse (P. Orton et al., 2023).

- Some Resistance strategies can cause maladaptation by transferring flood hazards from one location to another. For example, sea walls and levees like those under consideration by the US Army Corps of Engineers as part of the NY & NJ Harbor and Tributaries Focus Area Feasibility Study (NYNJHATS) can, under some conditions, increase water levels and induce flooding both upstream and downstream of them (Hummel et al., 2021).
- Once built, Resistance designs can be difficult to retrofit and adapt. This obduracy (Chester et al., 2019) can result in their eventual failure and obsolescence as the climate and other conditions continue to change around them.
- Resistance strategies can cause a false sense of security ("the levee effect") among residents in the protected community who believe that the risk of flooding has been eliminated. If this perception results in less flood preparedness, cancelled insurance policies, or if it leads to more development in these communities, it can increase risk in the long-term (National Research Council, 2013), even if it initially drops, and especially if future sea level rise turns out to be greater than the rates assumed by the levee designers (Han et al., 2020).
- When such systems fail, the consequences can be worse than would arise without protection, since other flood preparation measures may not be in place (F. Zhang et al., 2020).
- By controlling floods, Resistance strategies reduce the capacity of communities for episodic adaptation and learning, compounding vulnerability over time.
- By reducing personal experiences of flooding, public understanding of floods and motivation for planning and implementation of FRM can become limited to public messaging and general information, increasing latent risks.

9.3.2 Resilience responses

By adapting and/or transforming communities, Resilience responses reduce flood vulnerability. However, as synthesized by (McClymont et al., 2020; Rözer et al., 2022), Resilience responses also present several key challenges:

- As broached in the Futures and Transitions Chapter, Resilience Strategies that require individual actions (e.g. elevating utilities, downloading an app) require that local stakeholders have access to information and resources about flooding. Local stakeholders also need agency in FRM decision-making, and the ability to self-organize if they are to have the capacity to implement these measures.
- By prioritizing decentralized local measures, Resilience strategies can have the unintended consequence of shifting flood management responsibility from government to flood vulnerable groups who may not have the knowledge or resources to design, implement, and maintain FRM in the long term.
- These strategies can be logistically, socially, and institutionally complex to implement since they must modify a large fraction of the flood vulnerable area to meaningfully reduce overall risks and require collaboration among multiple stakeholders.
- The Transformative approach can also imply significant demographic, socioeconomic, and cultural changes, with potential implications for environmental and climate justice – both positive and negative – that must be considered.

9.3.3 Natural and Nature-based Systems (NNBS) responses

To address the historical, anthropogenic dimensions of flood hazards, many FRM plans include NNBS. Under the right conditions, NNBS can provide flood protection and mitigation in both short-term and long-term FRM plans (Bridges et al., 2021; L. McPhillips et al., 2023). However, in their current highly modified configuration, NYC's NNBS would need to be significantly enhanced and expanded if they are to address the most significant flood hazards facing the city.

Some of the flood reducing ecosystem services of NNBS include:

- Storm surge attenuation: High elevation and continuous salt marshes can reduce storm surges by 1.7-25 cm/km, especially when the marsh has a high elevation and is continuous (Leonardi et al., 2018; Wamsley et al., 2010).
- Wave attenuation and reduction in erosion: Even salt marshes that are too small to mitigate storm surges can be an effective means of attenuating storm-driven wind waves, reduce wave related flooding, and reduce erosion (Marsooli et al., 2017). Depending on the density and condition of marsh vegetation, these systems can attenuate waves with up to 95% reduction in wave energy occurring over just 100 meters of marsh with 50% vegetation cover, and this same attenuation over even shorter distances with denser vegetation (Castagno et al., 2022).
- Mitigation of fluvial flows: Stream restoration and stream daylighting can help spread out and dissipate fluvial floodwaters (Swadek et al., 2021).
- Mitigation of soil crust formation: Terrestrial vegetation canopies can play a key role in protecting urban soils from the impact of raindrops, which could otherwise break up soil particles and create a surface crust that, in turn, reduces infiltration and increases runoff (Alizadehtazi et al., 2020).
- Stormwater management: In addition to NYCDEP's standard ROW GI, urban parks (Feldman et al., 2019), vegetated urban yards (Mason & Montalto, 2015), and Stormwater Capture Greenstreets (Catalano De Sousa et al., 2016) can also be used to attenuate urban runoff, and can contribute to reducing the severity of flooding during extreme rain events when designed with low hydraulic loading ratios (e.g. the ratio of the tributary catchment area to the GI facility area) and/or as part of a comprehensive, watershed-level approach. Green roofs (Abualfaraj et al., 2018) and various kinds of permeable urban surfaces (both vegetated and unvegetated) will not yield runoff during moderate rain events that occur in NYC (Alizadehtazi et al., 2016).
- Mitigation of coastal flooding: A novel NNBS approach of shallowing estuary bathymetry has been shown to be particularly effective for reducing coastal flooding around Jamaica Bay (Marsooli et al., 2017; P. M. Orton et al., 2015; Stevens Institute of Technology et al., 2015). While it is well-established that historical dredging, landfill and wetland loss in the Bay are a major factor in current tidal and extreme event flooding (P. M. Orton, Sanderson, et al., 2020; Pareja-Roman et al., 2023; Stevens Institute of Technology et al., 2015), only limited research has been conducted into the potential for this type of NNBS to be used solely or in combination with hard infrastructure or non-structural approaches for mitigating flooding for mitigating Jamaica Bay flooding.

The flood protection value of NNBS is, however, highly dependent on local conditions, design (Wong et al., 2020), and the scale (e.g. land area) over which these systems can be implemented. The following factors limit the ability of existing NNBS to provide FRM services in NYC.

- **Limited remaining wetland extent:** The large area of salt marsh that would be required to effectively reduce coastal flooding does not exist in NYC due to its natural deep harbor and 20th century development with landfill on marshes (P. M. Orton et al., 2015).
- **Siting and design of engineered NNBS:** Stormwater management practices designed for water quality improvement or CSO management are typically intended to capture only the first 1-2 inches of rainfall over their tributary drainage area (TDA) because that 'design storm' (Markolf et al., 2021) generates a volume of stormwater (e.g. the 'water quality volume') that is greater than the volume of runoff produced by 80-90% of all annual rain events. That volume of runoff is also believed to contain the 'first flush' of pollutants that, if captured, provide significant reductions in pollutant loads. GI and other stormwater management practices that are sized to capture more than the water quality volume are often considered overdesigned and prohibitively expensive (L. M. Cook et al., 2020). GI and other stormwater management practices designed for water quality improvement may thus be too small to mitigate pluvial flooding associated with larger events. For example, Figure 27 compares the NYCDEP design storm depths associated with site and house connections in combined sewer districts to the total accumulation of precipitation during some recent extreme precipitation events. The ability of GI and other stormwater management practices to intercept street runoff can be compromised by inlet clogging, and is inversely correlated to the peak rate and volume of TDA runoff (Catalano De Sousa et al., 2016; Shevade et al., 2020), which are both expected to increase with climate change. GI and other stormwater management practices would need to be made bigger or significantly upscaled to provide FRM as a co-benefit. In its Citywide Cloudburst Program, NYCDEP is piloting a variety of strategies for managing larger quantities of stormwater using curbside porous pavements and stormwater

retention sites located both inside and outside of the right-of-way (City of New York Department of Environmental Protection, 2023), but planning and design these projects are still in the early stages.

- **Green gentrification:** Some concern over the potential for NNBS to lead to gentrification has also been expressed. Various forms of NNBS which, in the right configurations, can detain stormwater, reduce waves, and otherwise help to reduce some kinds of flood risks can also increase property values and housing prices, ultimately resulting in the displacement of working-class residents and racialized groups and cultures ("the greenspace paradox") (Anguelovski et al., 2022). Parks have been positively associated with gentrification processes in mid-sized cities across North America and Western Europe (Triguero-Mas et al., 2022). In NYC, research into this maladaptive role of green spaces is limited. Li (2023) found that the Million Trees initiative raised housing values and attracted more white, educated, and young households, but did not lead to significant gentrification. By contrast, Black and Richards (2020) found that The High Line increased housing values closest to it by 35.3%, exacerbating ongoing gentrification forces in the Chelsea section of Manhattan.

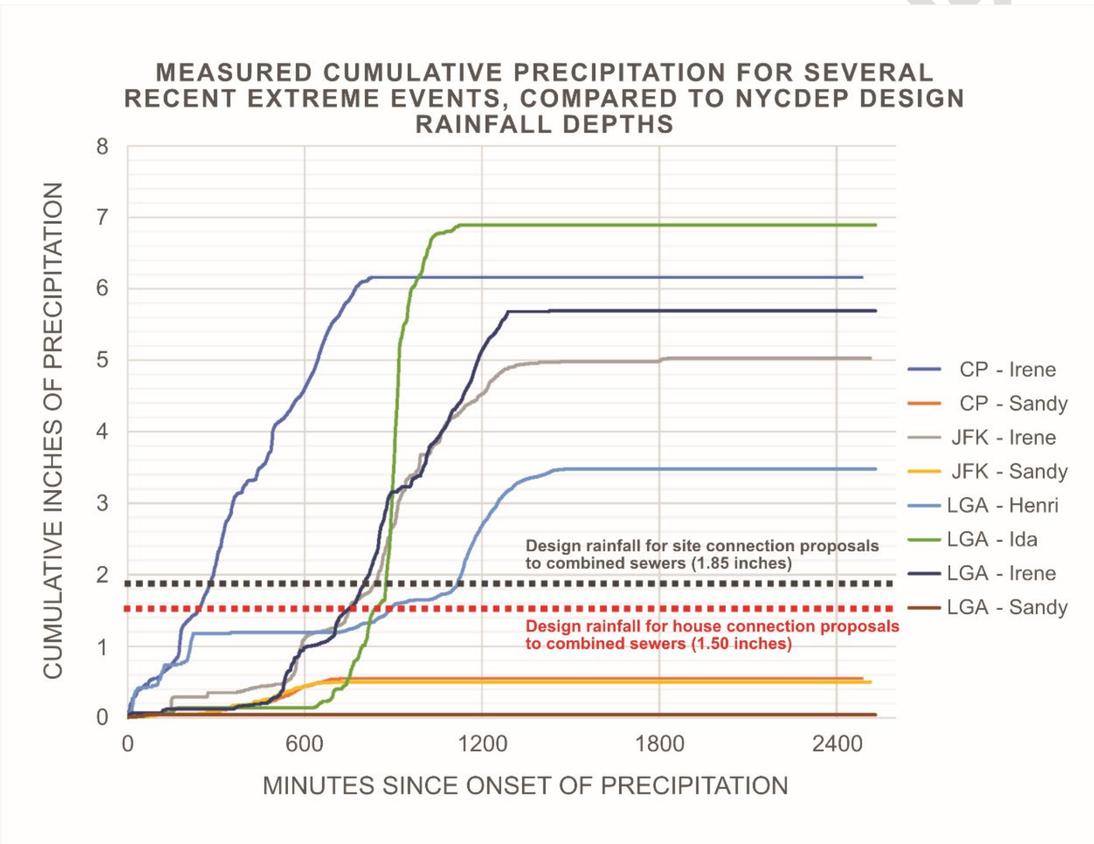

Figure 26: Precipitation accumulations of recent extreme events and NYCDEP design storm depths. CP, JFK, and LGA refer to one minute precipitation data obtained from the gauges at Central Park, John F. Kennedy Airport, and LaGuardia Airport, respectively. The horizontal dotted black and red lines refer to the design rainfall depths used to design stormwater management practices for sites and houses, respectively, when they are connected to combined sewers. House connections apply to 1, 2, or 3 family dwellings less than 20,000 square feet in total site area that connect to a sewer that fronts the house. Site connections refer to all other connections to combined sewers (Figure credit: FA Montalto)

9.3.4 Non-structural responses

Non-structural responses can include managed retreat and flood forecasting and early-warning systems, along with policy measures to support recovery when floods occur.

Managed Retreat

Though it is often framed as a single response, managed retreat can be implemented gradually and strategically as part of a multidecadal sequence of actions that may include many of the approaches shown in Figure 25, accompanied by iterative community engagement, vulnerability assessments, planning, and equitable compensation for those who are eventually resettled (Haasnoot et al., 2021). Managed retreat projects that have been implemented across the globe have involved mandatory relocation, along with projects that are community-supported or community-led (Ajibade et al., 2022).

Strategies used to operationalize managed retreat include voluntary buyouts, restrictions on post-flood rebuilding, setbacks of future development from flood hazard areas, conservation easements, and downzoning. Buyouts are a common non-structural approach to flood prevention in the United States. In a buyout, property-owners are offered compensation for the value of their homes if they relocate (Dundon & Abkowitz, 2021; Mach et al., 2019). A buyout requires the government's willingness to buy a property, and the property owner's decision to voluntarily move- a decision that may be precipitated by a flood. Buyouts may be helpful for homeowners, but do not resolve the hardship that flooding poses on renters.

Following Post-Tropical Cyclone Sandy, property owners in severely impacted NYC communities were offered buyouts through the NYC Build It Back and state-level New York Rising Buyout and Acquisition programs (Binder & Greer, 2016; Koslov et al., 2021). Homeowners in central Queens requested buyouts again after the Ida-Remnants Cloudburst (Maldonado, 2021). Through PlaNYC, the City is currently working to develop a "blue-sky" program that will work with households interested in moving away from high-risk areas, by providing housing/financial counseling services to facilitate moving and to minimize long-term displacement from NYC, and then through robust public engagement, converting these properties to sustainable/resilient end uses. Buyouts are discussed more fully in NPCC4: Advancing Climate Justice in Climate Adaptation Strategies for New York City (Foster et al., 2024).

Another approach, land swaps, involves owners of flood prone low-lying properties swapping title with the owner of less flood prone and typically vacant properties within the same community, typically a government agency. Such programs may be spearheaded by residents or led by governmental agencies or non-governmental organizations in sustained partnership with community members. However, even when programs are voluntary, residents can feel compelled to participate, especially if they lack other means of remaining safely in exposed locations (Yarina et al., 2019).

In NYC's Edgemere neighborhood, pilot land swaps – some of the first to be implemented for FRM anywhere in the country - were used to allow property-owners whose homes had been damaged by the storm to exchange their property titles for city-owned property with newly constructed homes in the neighborhood that were not located in the FEMA SFHA. As part of these efforts, a community-led visioning exercise so that community members could determine how to best utilize the undeveloped flood prone properties in a sustainable way that also serves longstanding community needs was conducted (Seip, 2022). The original storm-damaged homes were demolished and converted into city-owned conserved natural lands. But, ultimately, only three land swaps were successfully completed through this program (Spidalieri et al., 2020).

Application of such strategies can prevent exposure to flood hazards when sea level rise and other climate-related changes render other forms of FRM ineffectual. But they can also be fraught with a variety of challenges. (Baja, 2021; New et al., 2023; Yarina et al., 2019) Objectors to managed retreat often express concerns about a lack of transparency and community participation in decisions regarding when and where governments make this option available, a lack of fairness and equity specifically as pertains to community impact in historically marginalized communities, and concerns about the fate of ecological resources (Mach & Siders, 2021). Given that all of NYC is subject to some kind of flood risk, uniform application of managed retreat would imply abandoning large portions of NYC permanently. Advocates suggest that if global climate change continues at its current rate, retreat from low lying coastal area "is an inevitable adaptation action," better planned in advance (Haasnoot et al., 2021). But FRM decisions related to flood exposure, it is important to consider potential inequities. While the wealthy may deliberately accept flood risks, housing options are often more limited for other groups. Decisions regarding where to discourage development and where to protect it are intrinsically related to class, race, and ethnicity (H.-S. Chang et al., 2021; Hendricks & Van Zandt, 2021; Kruczkiewicz et al., 2021) and thus directly related to issues of equity.

Flood forecasting and warning systems

Flood forecasting and warning systems are also examples of non-structural strategies for FRM. They can provide the advanced lead time needed for evacuations, the deployment of active floodproofing barriers, and other emergency planning needed to reduce exposure and vulnerability to flooding when a hazard is imminent. Flood forecasting and warning systems require accurate forecasts of the extreme meteorological events that can cause flooding, numerical models to develop predictions of the extent and magnitude of the resulting flood hazard, and the dissemination of warnings in a manner that is accurate, timely, and can support taking protective actions to reduce flood exposure and vulnerability (Sadiq et al., 2023). To be useful for risk management, forecasts and warnings must be understood by stakeholders and connected to decision processes. As a result, these systems are reliant on both robust social science, along with accurate physical forecasts (Uccellini & Ten Hoeve, 2019).

Key developments in remote-sensing and in-situ observation technologies, data assimilation, and numerical weather forecast modeling have enabled advances in the forecasting of many types of weather systems. For example, National Hurricane Center forecast errors for Atlantic Basin tropical storms and hurricanes have fallen rapidly in recent decades, and contemporary 72-hour predictions of hurricane tracks are more accurate than 24-hour forecasts were 40 years ago (Alley et al., 2019). There have also been recent improvements in NHC hurricane intensity forecasts (Cangialosi et al., 2020). Accurate forecasting of cloudbursts at the longer lead times needed to support emergency preparations remain limited, however.

For the New York City Metropolitan Region, the NWS Weather Forecast Offices release official consensus coastal flood forecasts and warnings when a storm threatens. The Stevens Institute of Technology Flood Advisory System (SFAS) utilizes ensemble meteorological forecasts and numerical hydrologic and hydrodynamic modeling to provides accurate predictions of coastal total water levels (Ayyad et al., 2022; Georgas et al., 2016). These time-dependent predictions include 5th, 50th and 95th percentile water levels out 4.5 days into the future and are available online where users can also sign up for coastal flood warnings and alerts (Stevens Institute of Technology, 2024). These data are also shared with NWS, who combine them with NOAA model data for their official forecasts.

Operational warning systems for urban pluvial flooding remain in development. Recent advances in convection-permitting numerical weather models and ensemble forecasting make real-time pluvial flood warning systems technologically feasible for the first time. (Schubert et al., 2022) developed a flash flood warning system forced by Quantitative Precipitation Forecasts. This system was able to forecast High Water Marks (HWMs) with a Mean Absolute Error of 2.2ft (0.69m) and to predict flooding distress calls and FEMA damage claims with hit rates of 90% and 73%, demonstrating the potential to operationally forecast urban pluvial flooding, but also the need for continued research and development. Significant investments in both operational H&H model development and computational resources will be needed to increase prediction lead times even to several hours and to reduce the spatial resolution of predictions to less than ~4 mi^2 ($10km^2$) (L. J. Speight et al., 2021). Once a flood forecast has been generated, public alert and warning systems provide information to populations at risk of imminent flood hazards, with the goal of "maximizing the probability that people take protective actions and minimize the delay in taking those actions" (National Academies of Sciences & Medicine, 2018). Alerts and warnings can be issued by various entities, such as local, state, and federal governments, schools, and media stations. These entities can utilize multiple methods to send alerts and warnings to the public, including tv/radio broadcast, phone and email technologies and short message service (SMS). In addition, social media has emerged as a necessary component for public alert and messaging in the last decade (Guillot et al., 2020). For example, in NYC, NotifyNYC is an opt-in emergency public communications program available in multiple languages (Notify NYC, 2024). Participants can register to receive alerts about different types of flood-related and other emergencies, through multiple methods of communication such as basement-specific preparedness messaging before expected rain events.

9.3.5 The need for an integrated response

As recognized in NPCC4: Advancing Climate Justice in Climate Adaptation Strategies for New York City (Foster et al., 2024), the significant linkages that exist between climate risks, adaptation investments, and socioeconomic inequality means there is no singular approach to equitable flood resilience that is broadly applicable in NYC. Instead, diverse, multiple, and overlapping approaches must be developed with local input crucial in selecting those most suitable to the unique context of each exposed community. Most flood resilience researchers, and various Mayor's Office of Climate and Environmental Justice (MOCEJ) policy documents, now advocate initiating the FRM planning process by considering a diverse, multifaceted, all-of-the-above approach that is gradually tailored to the characteristics, needs, and types of flooding facing each community.

9.4 FRM in NYC

Integrated FRM plans for many NYC neighborhoods could ultimately include some or all of the following components (Cea & Costabile, 2022; McClymont et al., 2020; Peck et al., 2022):

1. Non-structural flood-exposure reduction measures – flood exposure reduction measures, flood forecasting and early-warning systems, along with policy measures to support recovery when floods occur.

2. Engineered flood protection measures – including both grey and NNBS- designed to prevent flooding from occurring in targeted areas. These could include engineered dunes to protect against high tides and surges such as have been installed in the Rockaways, as well as features such as the sea walls, levees, and storm surge barriers under consideration as part of the NYNJHATS project. Decisions regarding which

communities receive engineered flood protection carry significant equity implications and should not be based solely on traditional benefit cost ratios that only monetize the value of protected real estate assets. The potential for unintended ecological or social consequences (e.g. maladaptation) should also be evaluated and mitigated.

3. Leveraged and expanded investments in water quality protection – As mentioned in several places in this report, significant investments are being made to improve NYC water quality using both grey and green stormwater management practices which, through enhancement and upscaling, could provide some flood mitigation. As described above, protocols used to site and design GI currently limit the value of this investment for FRM. For GI and other stormwater management practices to be useful in mitigating flooding, they need to be implemented across significantly increased areas than required for compliance with clean water regulations (Atkins, 2015; Regional Plan Association, 2022). An analysis conducted by the Regional Plan Association (2022) asserts that GI application rates in a section of Central Queens would need to be 40x greater than current levels to fully eliminate flood accumulations of 12 inches or more caused by 3.5 inches of rain over an hour, and 60x more to fully eliminate flooding. To achieve such higher levels of GI application, creative new strategies for resolving a wide range of non-trivial surface (e.g. driveways) and subsurface (e.g. infrastructure, utilities, contaminated soils, bedrock, etc.) constraints would need to be devised. To date, these types of obstacles have been a major impediment to GI implementation across the city (NYC DEP, 2014, 2021). The current GI Program prioritizes watersheds that discharge to waterbodies that do not meet their current water use standards. However, as is clear from the City's Stormwater Resiliency maps, pluvial flood hazards are pervasive and GI facilities intended for FRM would need to be applied virtually city-wide. If higher GI application rates are accompanied by strategic modifications to GI design standards (for example, the use of more hydraulically efficient inlets, deeper surface depressions that are directly connected to subsurface vaults and stone reservoirs, etc.), these investments in water quality could be integrated into a community's unique FRM strategy. In communities with high water tables, soils with low permeability and/or excessively high percentages of fine particles, and/or shallow bedrock, these practices would also likely need to be lined and connected via underdrains to local catchbasins (B. Rosenzweig & Fekete, 2018; K. Zhang & Chui, 2019). To overcome the perception that these enhanced GI facilities are overdesigned, and to justify the additional costs associated with their construction and maintenance, the hybrid role intended for this new generation of GI facilities (i.e. water quality improvement and FRM) would need to be recognized formally and encoded in new interagency agreements. Unique and unprecedented cost-sharing strategies would also need to be devised, since these practices would provide a level of service beyond that needed for Clean Water Act regulatory compliance.

4. Make the City Safe to Flood through an Expanded Cloudburst Program –. In January of 2023, NYC Mayor Adams announced $390 million in funding for Cloudburst Resiliency Projects that will include innovative plans to detain, retain, and store stormwater in four flood-prone communities in Corona and Kissena Park, Queens; Parkchester, Bronx; and East New York, Brooklyn (City of New York Department of Environmental Protection, 2023). This program relies heavily on porous pavements, offline storage, and slightly modified applications of existing GI designs. The City could decide to expand this program to include a wide range of innovative features, such as the Cloudburst Roads, Retention Roads, Retention Spaces, and Green Roads currently being implemented in the City of Copenhagen, Denmark (Figure 27). The cloudburst infrastructure being implemented in Copenhagen are a form of Resilience FRM and designed to utilize streets and other surface features to manage stormwater associated with the very extreme rain events (1% AEP/100-year return interval) associated with pluvial flooding (City of Copenhagen, 2012).

5. Structural flood vulnerability mitigation measures – Designs and retrofits such as wet and dry floodproofing that reduce the magnitude of the disturbance relative to a threshold, decreasing the consequences of flooding in the exposed area. Examples include structural measures such as blowout panels to allow for safer egress from basements during floods (FEMA, 2023b). These could also include building codes that require elevating utilities, installing pumps, reinforced basement walls and other similar measures, as implemented recently in Venice, Italy (Editorial Team, 2019).

6. Non-structural flood vulnerability mitigation measures – flood monitoring and forecasting, early warning systems, evacuation and disaster management plans help communities to better understand and prepare for flooding. As an example, the city's expanding network of FloodNet sensors are now being used to record high tides, storm surges, and runoff during extreme precipitation events so that this information can be used to plan FRM and emergency response (Mydlarz et al., 2024).

7. Flood recovery measures – measures that help to recover and return to normal efficiently after a flood event, for example emphasizing reconstruction, rebuilding, compensation, or insurance.

8. Transformational strategies– strategies that help a community to learn, adapt, and gradually change to a suite of dynamic conditions that determine flood hazard and exposure, while simultaneously addressing multiple local needs and challenges

9. Global Knowledge Transfer: Globally, a variety of comprehensive strategies have been developed to manage flood risk, and many opportunities for co-learning between NYC and other regions are possible. As one example, the European Floods Directive (EFD) (Council of the European Union, 2007) was established to reduce the negative consequences of flooding on human health, economic activities, the environment, and the cultural heritage of the European Union (EU). This directive requires EU member states to conduct risk assessments to identify Areas of Potential Significant Flood Risk (APSFR); followed by mapping of the potential consequences of floods of different types and magnitudes; and finally, development of FRM plans including specific measures implemented according to the unique hazard and risk characteristics of each APSFR.

10. Leveraging of federal resources: Nationally, FEMA's recently launched Building Resilient Infrastructure and Communities (BRIC) grant program (Federal Emergency Management Agency (FEMA), 2023) incentivizes pre-disaster capacity building, as well as design and management of infrastructure projects, including projects incorporating NNBS, that reduce flood risk. Executive Order 14030 reinstates the Federal Flood Risk Management Standard that requires agencies to prepare for and protect federally funded buildings and projects from flood risks (Federal Emergency Management Agency (FEMA), 2022). The Bipartisan Infrastructure Law included $50 billion to help communities protect against multiple hazards including floods.

Some of these FRM components are already built into local FRM plans and policies. The Lower Manhattan Coastal Resilience and the East Side Coastal Resiliency Projects both aim to reduce coastal flood risks in individual neighborhoods of Manhattan. The City of New York's Climate Resilience Design Guidelines (2022a) provide guidance on how to reduce the impacts of extreme precipitation, sea level rise, and heat on capital projects (e.g., infrastructure, landscapes, and buildings). These guidelines focus on reducing stormwater inputs to the city's sewer system and selecting appropriate design flood elevations for Capital projects located in current and future coastal floodplains. In its Neighborhood Coastal Flood Protection Project Planning Guidance, the City of New York (2021) provided guidance for initial concept planning, feasibility and design stages of neighborhood scale coastal flood protection projects that are equitable, resilient, and well designed. This guidance underscores the importance of shaping these projects to address unique neighborhood characteristics, maximize community benefits and improve the public realm. In its long-term vision for Increasing Stormwater Resilience in the Face of Climate Change, NYCDEP (New York City Department of Environmental Protection, 2021) describes a multi-faceted approach which will involve some upscaling its implementation of rain gardens, stormwater medians, onsite detention projects, green roofs, Bluebelts, and cloudburst projects to augment drainage capacity while providing valuable community co-benefits. The Vision also includes interim measures that will improve communication between residents and the City, better maintain existing drainage infrastructure, and better predict where flooding occurs now and in the future. It is noteworthy, however, that these measures do not explicitly address the need to manage higher volumes and intensities of stormwater (e.g. contemporary 100-year or greater rain events), protect the coast, reduce groundwater flooding, or build resilience to compound-hazards.

To date, no community-initiated FRM plans have been developed in NYC. However, while none of the case studies reviewed in the Equity Chapter mention the development of any community-scale FRM plans, other community-scale resiliency planning efforts that emphasize anti-displacement, and a just energy transition are underway, as profiled on the Regional Plan Association's recently launched NYC Climate Resilience Plan Mapper (Regional Plan Association, 2023). PlaNYC and Mayor Adams' Climate Strong Communities program will leverage resources to build climate resilience in communities that did not receive Post-Sandy relief funds (City of New York Mayor's Office of Climate & Environmental Justice, 2022b; City of New York Office of the Mayor, 2023). Examples of individual properties that have developed site-scale FRM plans can also be found throughout the city.

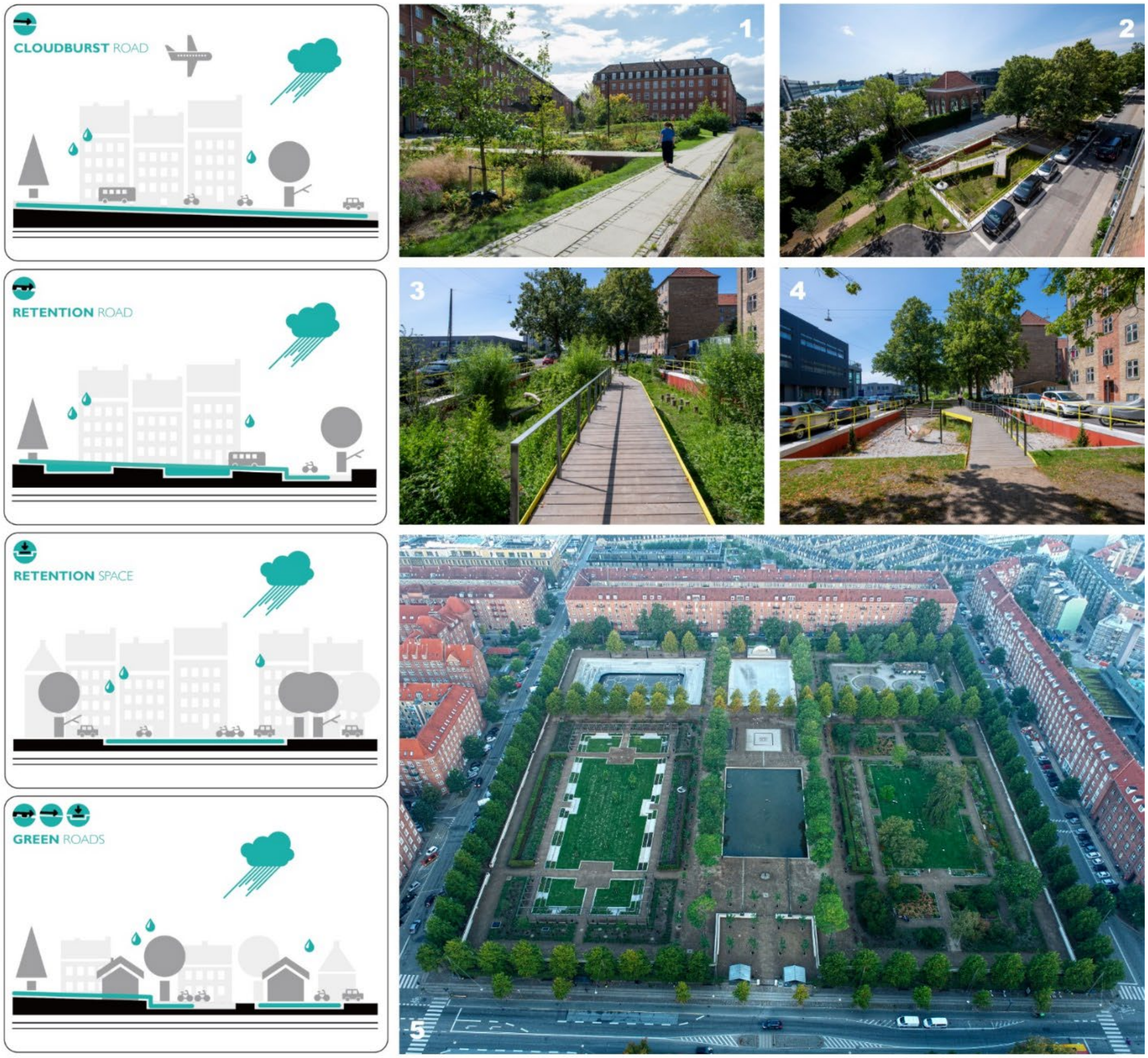

Figure 27: Cloudburst roads (starting upper left) are designed to convey runoff generated during extreme events on the surface to places where that can flood safely. Elevated curbs, recontoured street cross sections, and slightly depressed intersections are used to direct the flood waters. Retention roads (second down, left) are designed to retain and detain flood waters in subgrade cisterns, vaults, and curbside planters integrated into the right-of-way. This approach is similar to NYCDEP's current Cloudburst standards. Retention spaces (third down, left) retain and store floodwater in multifunctional urban spaces such as depressed parking areas, squares, gardens, and recreational fields. Examples from Copenhagen, Denmark: Tåsinge Plads (1), Scandiagade (2-4), and Enghavepark (5). Finally, Green roads (bottom, left) are designed to remove and retain water on smaller roads and alleys. Photos 1-4 courtesy of Troels Heien, Photo 5 courtesy of Anders Pedersen. Diagrams courtesy of the City of Copenhagen.

10 Opportunities for Future Research

Though recent City guidelines and vision documents are important and impactful, much more applied research is needed to reduce flood risks and build flood resilience in NYC. Several key opportunities for future research are summarized below:

10.1 Continue to monitor, model, and map all flood hazards, and their interactions, across NYC

Through a collaboration between the city and academic partners known as FloodNet, the City will be deploying a total of 500 ultrasonic surface flood depth sensors around the City by mid-2027 (City of New York et al., 2024). These sensors will be helpful in flood response, namely by quantifying the real-time depth and duration of different types of flooding. These sensors can also be helpful in calibrating and validating hydrologic and hydraulic models to historic flood events captured by the sensors, improving model confidence for use in simulating current and future flood hazards. Ideally, the FloodNet sensors will be accompanied by other data acquisition initiatives as described below:

- More precipitation gauges that record precipitation accumulations at subhourly temporal resolution.
    - More spatially explicit, sub-hourly precipitation data are needed to better map spatial variability in extreme precipitation and to drive real-time simulation of pluvial flood hazards. To support FRM, these observations must be accessible to the research and engineering consulting communities, and the data must be quality controlled. The integration of precipitation observations with community science programs could enhance community understanding of extreme precipitation, climate change, flooding, and FRM, ultimately leading to social transformation.
- More water level and flow gauges throughout the harbor and in local rivers, creeks, and sewers.
    - If planned along with the precipitation gauges and co-located near the FloodNet sensors (applicable for in-sewer gauges), this water level and flow data would improve the accuracy of hydrologic, hydraulic, and hydrodynamic modeling, improving our ability to simulate sewer flows, coastal and fluvial flood risks, and estuarine water quality, supporting flood preparation and ecological transformation. It could also help to design flood-risk prevention and flood protection measures in coastal or fluvial floodplains. Stevens Institute has maintained 12 water level gauges in the harbor region for the Port Authority since 2015. Data can be visualized online alongside forecasts (http;//stevens.edu/SFAS) but aren't available for download.
    - If these gauges were maintained by governmental agencies like NOAA and USGS, working in close collaboration with NYCDEP, community scientists, fishers, and community-based organizations, they could also help advance social transformation.
- More groundwater monitoring wells instrumented with water level loggers and salinity/conductivity probes.
    - Positioned near the coasts and in topographic depressions, these data could help to improve our understanding of groundwater levels and groundwater flow directions, as well as quantify the extent saltwater intrusion into coastal artesian aquifers. In this way the data would help to design groundwater Flood-Risk prevention and Flood Protection measures.
- Digitize the geotechnical test results conducted by City as part of its Green Infrastructure Program.
    - The City has invested millions of dollars in geotechnical testing to support its evolving Green Infrastructure program. This data includes depth stratified soil texture analysis, and critical information regarding depth to groundwater and depth to bedrock. If this data were digitized, georeferenced, and made open source, it could be helpful in improving groundwater modeling throughout the city.
    - Along with the additional groundwater depth data described above, this geotechnical information could also help to identify subsurface infrastructure and subgrade spaces vulnerable to groundwater flooding, promoting Flood Preparation, and could also help to design appropriate Flood Protection measures.

The proposed new data sets could help to improve the City's ability to model pluvial, fluvial, coastal, and groundwater flood hazards. Key to this initiative is a commitment to perpetual data collection at consistent locations, facilitating retrospective analysis of historical trends and helping ensure that the most extreme flooding events are captured for model calibration. Sustained procurement of high-quality and high spatial and temporal resolution data will build a strong flood-related data repository, ensuring the City can leverage the most recent and future advancements in data-intensive technology (e.g. digital twins and AI).

It is also recommended that the City continue to integrate and develop high resolution models that can be used to simulate coastal hydrodynamics, sewer, surface, and groundwater flows in the same modeling platform. For water quality improvement purposes, NYCDEP uses an ensemble of 1D hydrologic and hydraulic models to simulate separate and combined sewer flows through its major trunk sewers. Development of the recently released Stormwater Resiliency Maps required enhancing portions of these 1D models with higher resolution representation of various elements of the drainage system. The Stormwater Resiliency Study also coupled the 1D model to a 2D model representation of the surface, enabling "rain-on-grid" simulation of pluvial flood patterns. In partnership with NYCDEP, the USGS is developing a transient numerical model of water table response to sea level rise in Queens and Staten Island. The accuracy of these early attempts at model integration could be improved by creating higher resolution data such as digital elevation models, land use cover maps, and other digital representations of the built environment. Integrated modeling can provide more detailed and site-specific results but will require significantly higher computing power. Use of cloud-based computing technology would reduce computation time and facilitate assessment of long-term historical data (requires a substantial simulation period) and near real-time warning systems (requires near-instantaneous model results to issue warnings). Cloud computing may also improve modeling of interacting, compound flood risks across integrated modeling platforms.

Recent statistical and probabilistic assessments of rain and storm surge (See Section 8.1) (Z. Chen et al., in Preparation) demonstrate that co-occurrence of these flood drivers can occur during extreme storm events. However, an important next step will be to simulate these scenarios in flood models such as those described above. Given the availability of one or more such flood models, it is recommended that an assessment of actual compound flood risk is initiated.

10.2 Continue to develop flood vulnerability indices like the FSHRI, which can be used to support the equitable allocation of resources for flood risk management in priority neighborhoods

As described throughout this chapter, NYC is subject to different flood hazards, each with a unique geography of exposure. Flood hazard geographies are expected to expand in the future as the climate changes. When integrated with or overlayed on top of flood hazard maps, the recently developed Flood Susceptibility to Harm and Recovery Index is an important first step in identifying neighborhoods and populations with greatest need for resources to support FRM. The maps published in this chapter represent an initial attempt to map social vulnerability in areas exposed to flooding where specific hazards have been mapped. Future work could identify socially vulnerable neighborhoods that are exposed to a broader range of types and magnitudes of flooding, including compound flood hazards which have not yet been comprehensively modeled. Additional research could also examine vertical differences in flood vulnerability focusing on residents of multistory buildings. Although many types of flooding have historically been analyzed separately, there are many advantages to holistically analyzing all types of floods within the same modeling domain, including coastal, pluvial, fluvial, and groundwater hazards.

Along with socioeconomic factors, infrastructure and the built environment features are important contributors to flood vulnerability that should be evaluated in future flood vulnerability assessment. In this report, we provide an assessment of exposed buildings with known infrastructure vulnerabilities to flooding that could be mapped using available geospatial data. These included 1-2 unit residential buildings with basements and other subgrade spaces. However, other datasets that would support a more comprehensive assessment of infrastructure vulnerability are currently unavailable. Examples include:

- Citywide data on the elevation of critical building utilities (e.g. boilers, electrical systems)
- Citywide data on with/without wet- and dry-floodproofing features

Efforts to develop these data would provide a valuable opportunity to enhance flood vulnerability assessment research.

10.3 Grant decision-making power and resources to non-governmental stakeholders to develop community-driven FRM plans at the neighborhood and/or landscape scale

In NPCC3 Foster et al (2019) reported that representatives of the city's most socially vulnerable communities desire a deeper engagement in climate planning via collaborative co-productive planning processes. However, in the United States, formal responsibility for FRM is distributed across various levels of government from the Federal government to the states, down to the City, and it can be institutionally complex for governmental stakeholders to relinquish meaningful decision-making roles to non-governmental flooding stakeholders. That said, many strategies for meaningful engagement of community stakeholders in climate decisions have been implemented in different places.

To scale-up adaptation efforts and build capacity among multiple stakeholder groups, the Urban Climate Change Research Network has hosted Urban Design Climate Workshops in Paris, Naples, Durban, and NYC (Urban Climate Change Research Network (UCCRN), 2023). In a study of alternative strategies for implementing green infrastructure in the Bronx, Wong and Montalto (2020) demonstrate how incorporation of surveyed community preferences in GI siting decisions can bring about greater long term economic and social impact from the City's GI program. In the recent NYC Climate Adaptation Scenarios workshop series (Balk et al., 2024; E. Cook et al., 2022), participants co-imagined scenarios through which NYC residents, provided adequate information and infrastructure, become resilient to extreme precipitation as they self-organize into community land trusts that manage locally generated stormwater in innovative ways.

Multi-stakeholder participation in FRM poses some challenges, such as the possibility of differences of perception and/or conflicts among different stakeholder groups, including both governmental and non-governmental entities, each of whom have different perceptions, knowledge, values, and needs; and the possibility that ideas that emerge from a deliberative process might be logistically complex to implement. Co-development of FRM plans requires investment of adequate time and resources (Almoradie et al., 2015; Maskrey et al., 2022). A broad array of stakeholders should be engaged early in the FRM planning process (Ceccato et al., 2011; Sahin & Mohamed, 2013), with open communication allowing stakeholders to express differing views and opinions, and collaborative technology such as remote conferencing tools and online collaboration platforms used throughout the process (Almoradie et al., 2015). Regular meetings, training sessions, and awareness-raising campaigns can be organized to co-develop goals, concepts, and decision-making frameworks, build capacity, reduce conflicts, and promote mutual understanding (Ceccato et al., 2011; Estoque et al., 2022; Maskrey et al., 2022; Pagano et al., 2019).

Such methods can be used to engage flooding stakeholders in key decisions regarding equity in FRM, including:

- How are community stakeholders engaged in decisions around flood prevention and protection?
- How will prevention and protection measures change access to, and cultural relevance of, flood hazard areas?
- How does flood prevention influence destination communities and receiving locations?
- Do community stakeholders have the means and capacities to maintain flood-risk reduction measures over time?
- How does prioritization of protection vary across communities?
- Which groups are most likely to experience losses or disruptions as a result of a particular kind of flood?
- How can resources be allocated to minimize transboundary risks? What additional resources are necessary to protect neighboring communities?

10.4 Develop incentives, policies, and enable comprehensive transformations of the city emphasizing long-term flood resilience, sustainability, and equity, highlighting the role of NNBS

- Flood risk prevention, protection, mitigation, and preparedness measures can help to reduce near term flood vulnerability. Due to its role in changing precipitation patterns and raising sea levels, climate change contributes to NYC's current and hazards and will further increase NYC's future flood hazards in the absence of rapidly-initiated global reductions of greenhouse gas emissions. However, as described throughout this report, flood risk is also determined by the extent to which the city's human population and its ecosystems are exposed and vulnerable to flood hazards. Exposure and vulnerability, in turn, are the result of land use, infrastructure, and social policies that dramatically transformed the ecology of NYC. Urgent, citywide transformation of these systems will be needed to manage future flood risks if global climate change is allowed to continue unabated. These transformations must include both ecological restoration and restorative social justice.

11 Traceable Accounts

Key Message 1	NYC faces risks from four types of flood hazards: pluvial, fluvial, coastal, and groundwater, each with a unique geography of exposure that will expand in different ways in the future due to climate change. Identifying these four types as separate, but related, hazards is an important step in studying how they impact NYC, what FRM tools are available to address them, and where future research is needed. Climate adaptation planning must consider all four of these types of flood hazard and their potential impacts across a range of magnitudes, including very extreme events.
Description of Evidence	The risks associated with coastal and fluvial flooding have been evaluated through Flood Insurance Studies by the Federal Emergency Management Agency (FEMA, 2007, 2013). Projections of sea level rise with climate change and its impacts on coastal flooding have also been evaluated in previous NPCC reports (González, Ortiz, Smith, Devineni, Colle, Booth, Ravindranath, Rivera, Horton, & Towey, 2019; P. Orton et al., 2019b). Projections of amplified precipitation due to climate are provided in Ortiz et al. (2024). In this assessment, we also conduct a review of the scientific literature, technical reports, and government agency databases on risks associated with pluvial and groundwater flooding.
New Information and Remaining Uncertainties	Significant uncertainties remain regarding the risks of associated flood hazard types that have not yet been mapped (e.g. fast-moving water, daytime and residential exposure of populations at the spatial scales relevant to flooding in New York City, and the tangible and intangible cost of flooding when it occurs. There are also high remaining uncertainties on how climate change will impact short-duration, intense rainfall events associated with pluvial and fluvial flooding. These uncertainties are discussed in Braneon et al (2024) and Ortiz et al (2024). In addition, observations of shallow groundwater levels in Brooklyn and Queens are available through 2012, but continuous observations along the coast are not available to allow for an analysis of trends with sea level rise. There is also very limited observational data available on aquifer properties and shallow groundwater levels in Manhattan, The Bronx, and Staten Island.
Assessment of Confidence based on the Evidence	Based on the available evidence and the authors' expert judgement, there is high confidence that pluvial and fluvial flooding will increase due to climate change if flood hazard mitigation efforts are not implemented. Given the trajectory and projections of sea level rise, it is virtually certain that coastal flooding will increase. Confidence on both the magnitude, spatial distribution, and timing of the groundwater table rise in response to sea level response – and resulting groundwater flooding in the absence of mitigation efforts – remains very low.
Key Message 2	Discussions about flooding often focus on risks within the Special Flood Hazard Areas (SFHA) mapped by the United States Federal Emergency Management Agency (FEMA). However, the FEMA SFHA maps present fluvial and coastal flood hazards only. The recently released NYC Stormwater Flood Maps represent the city's first attempt to map pluvial and some

	compound flood hazard with risks spread out over a much larger fraction of NYC. In this chapter, we present a preliminary assessment of pluvial and groundwater flood hazard exposure areas that can be utilized to support FRM. Additional research is necessary to develop hazard maps that represent a broader range of flooding hazards and their increase in magnitude in response to anthropogenic climate change.
Description of Evidence	The assessment of building exposure to flooding was conducted through overlay analysis of existing flood hazard (City of New York Mayor's Office of Resiliency, 2021; FEMA, 2013) and depth-to-water table (Monti, 2013) layers with geospatial datasets on the location of building footprints (NYC OTI, 2023), NYCHA Public Housing Development Map Data (NYC OTI, 2020), and a one-time data layer of Building Elevation and Subgrade Spaces in February, 2022 (NYC DCP, 2013). Analyses were conducted using Python 3 and QGIS 3.22 software.
New Information and Remaining Uncertainties	In this assessment we provide new information on the exposure of two types of buildings associated with increased vulnerability: New York City Housing Authority (NYCHA) residences and 1-2 family residential buildings with basements or other subgrade space. Uncertainties associated with each data layer used in the exposure assessment are described in their respective sources.
Assessment of Confidence based on the Evidence	Confidence is high in the overall trends exhibited by the H&H models used to map pluvial flooding exposure, showing that more intense rainfall will produce more flooding because the drainage system is not sized to convey the return period events that were simulated. Confidence is medium regarding the exact extents and depths of predicted flooding at the street/property-scale due to stated model resolution. The water table elevation map for Brooklyn and Queens used to map potential groundwater flooding exposure was developed through a synoptic survey of observational and supply wells across Long Island conducted by the USGS in 2012 (Monti et al., 2013b). Depth to water estimates were developed using this layer and a Digital Elevation Model created by NOAA and the USGS through the Disaster Relief Appropriations Act of 2013. The resulting Depth to Water Layer has a vertical accuracy of 10 feet (Como et al., 2018). While confidence in the overall spatial patterns provided by this layer is high, this layer may not represent finer-scale variation in the water table or changes that may have occurred since 2012. Groundwater data in Manhattan, The Bronx and Staten Island remains very limited, and no depth-to-water table layer is currently available for these boroughs.
Key Message 3	Much of NYC is exposed to pluvial flooding, which occurs when the intensity of precipitation exceeds the infiltration capacity of the soil and the hydraulic capacity of the sewer system. These conditions often occur during cloudbusts, short-duration periods of intense rainfall that can be embedded within large storm systems or occur as individual, hard-to-forecast thunderstorms. Intense rainfall has already been observed to have become more frequent in NYC since the mid-20th century and are projected to further intensify and occur more frequently with unmitigated climate change. Despite the increasing risk, pluvial flood hazards remain poorly understood. The NYC Floodnet project is beginning to collect observations of flooding when it occurs, but more monitoring of rainfall, in-sewer flows, and flooding, along with Hydrologic and Hydraulic (H&H) modeling of pluvial flooding processes and impacts are needed.
Description of Evidence	In this assessment we utilize the outputs of H&H modeling (City of New York Mayor's Office of Resiliency, 2021) to evaluate the areal extent of potential

	pluvial flooding in New York City during moderate and extreme rain events. 311 service requests were used to map the locations across the city where community members have been impacted by street flooding during intense rain events. Narrative data provided through the National Center for Environmental Information's (NCEI) Storm Events Database and *Storm Data* publication also provide insight on severe impacts of historical pluvial flooding across the city and their associated meteorological conditions. Future precipitation projections are based on the mean citywide delta change factors derived from on an ensemble of climate models using the LOCA2 downscaling method for SSP245 (mid-century greenhouse emissions reduction) and SSP585 (unmitigated climate change). These analyses are described in McPhearson et al. (2024).
New Information and Remaining Uncertainties	In this assessment, we provide a literature review on impactful pluvial flooding in NYC, and an exposure assessment of vulnerable buildings to pluvial flooding. While there are multiple mechanisms through which climate change can increase the intensity of cloudburst events in NYC, these processes remain poorly represented in global-scale numerical models used to develop climate projections. We also provide a detailed case study of a cloudburst associated with the remnants of Hurricane Ida in 2021, which resulted in 13 direct fatalities, severe disruptions, and extensive damage in many parts of the city. This case study includes a literature review, an assessment of rainfall rates and return intervals associated with this event, and mapping of 311 service requests of street flooding and other flood-associated complaints. Attribution studies focused on this, and similar events, are needed to determine the role that climate change may have had in setting it up and whether more events of similar intensity and spatial extent will occur in NYC in the future. Significant uncertainties remain in quantitative projections for extreme precipitation since the processes associated with short-duration intense precipitation events remain poorly represented in the global-scale numerical models used to develop climate projections (Fowler, Ali, Allan, Ban, Barbero, Berg, Blenkinsop, Cabi, Chan, Dale, et al., 2021). Significant uncertainties also remain regarding rainfall intensity and areal extent thresholds for pluvial flooding and with hazards associated with pluvial flooding such as fast-flowing water and exposure to pathogens.
Assessment of Confidence based on the Evidence	Based on the available evidence in the scientific literature and the authors' expert judgement, there is high confidence that short-duration, intense precipitation events will continue to increase in frequency and magnitude in the absence of rapid mitigation of global climate change. As a result, pluvial flooding will occur more frequently due to climate change if flood hazard mitigation efforts are not implemented. At the same time, there is only medium confidence in the quantitative projections of these increases, due to remaining uncertainties in the representation of short-duration precipitation processes in global climate models.
Key Message 4	In NYC, fluvial flood risks are spatially localized to areas of the Bronx and Staten Island where surface stream channels remain. In the remainder of the city, historical surface streams were filled and replaced, with their flow routed to the sewer system. As a result, fluvial flood hazard has largely been replaced by pluvial flood hazard in most of the city. Both fluvial and pluvial flood hazards will increase due to climate-change driven intensification of precipitation and elevation of sea level. While traditional floodplain management can be an effective strategy in reducing exposure to fluvial

	floods, a broader, watershed-scale approach that retains, details, and redirects stormwater is needed to jointly manage pluvial and fluvial flood risks.
Description of Evidence	The locations of remaining inland streams and rivers in New York City were assessed in the FEMA 2013 Flood Insurance Study (FEMA, 2013).
New Information and Remaining Uncertainties	There are high remaining uncertainties on how climate change will impact short-duration, intense rainfall events associated with pluvial and fluvial flooding. These uncertainties are discussed in Braneon et al (2024) and Ortiz et al (2024).
Assessment of Confidence based on the Evidence	Based on the available evidence and the authors' expert judgement, there is high confidence that fluvial flooding will increase along with pluvial flooding due to climate change if flood hazard mitigation efforts are not implemented.
Key Message 5	Current and future coastal flood risks are caused by high storm tides, rising sea levels, and historical development on landfill over tidal marshes and nearshore areas. In Jamaica Bay, tides and storm surges have also been significantly elevated by historical dredging and landfilling, worsening chronic and extreme flooding. On December 23rd, 2022, a major flood event around Jamaica Bay was caused, in part, by dredging that has led to amplified storm tides which were nearly a foot higher than elsewhere in the harbor. Further improvement of our understanding of future coastal flood hazard is possible through downscaling of climate model data and modeling of multiple compounding flood drivers.
Description of Evidence	Recent research has demonstrated that Jamaica Bay landscape changes have made tides larger and worsened storm tides, playing a similar role to past sea level rise in worsening flooding (P. M. Orton, Sanderson, et al., 2020; Pareja-Roman et al., 2023).
New Information and Remaining Uncertainties	Important remaining uncertainties for coastal flood hazard are baseline storm climatology and climate change effects on storms. Also, a case is made (Section 6.4) that coastal storm surge models used for risk assessment and forecasting may have inaccuracies due to the challenge of simulating flow through the narrow and sharply curving areas of East River.
Assessment of Confidence based on the Evidence	There is very high confidence that sea level rise will continue to worsen monthly and extreme coastal flooding, but large uncertainties remain in the exact amounts, as reflected in NPCC projections. Confidence is high that landscape change has worsened flooding for Jamaica Bay, given that the finding is based both on contrasting models and observations from the 1870s and modern era. Confidence is low in the effects of future storm changes on coastal flooding.
Key Message 6	Many NYC neighborhoods have very shallow groundwater tables and already experience groundwater flooding. These areas include parts of the city that were developed when groundwater levels were substantially lower due to historical pumping of groundwater for municipal water supply. Groundwater flood risk has the potential to be particularly significant in NYC because of the prevalence of subterranean infrastructure. Groundwater flood hazards have not yet been assessed citywide, but preliminary efforts are underway. Sea level rise may cause groundwater levels to rise, resulting in inflow and infiltration of groundwater into sewer pipes and subterranean spaces and inundation of topographically vulnerable locations from below. Improved characterization of spatially heterogenous aquifer hydraulic properties and sustained monitoring of ground water levels will be necessary to develop projections for future groundwater flooding.

Description of Evidence	Observations of shallow groundwater levels in Brooklyn and Queens are available through 2012, but continuous observations along the coast are not available to allow for an analysis of trends with sea level rise. There is also very limited observational data available on aquifer properties and shallow groundwater levels in Manhattan, The Bronx, and Staten Island so exposure assessment could not be conducted for these boroughs.
New Information and Remaining Uncertainties	There are remaining uncertainties about the rate of sea level rise and substantial remaining uncertainties associated with the hydrogeology of NYC's complex subsurface, both which will determine the transient response of the groundwater table to sea level rise. There are also remaining uncertainties associated with the rate and distribution of groundwater pumping to dewater subgrade spaces and tunnels and its potential impacts on the water table and receiving water quality.
Assessment of Confidence based on the Evidence	Confidence on both the magnitude, spatial distribution, and timing of the groundwater table rise in response to sea level response – and resulting groundwater flooding in the absence of mitigation efforts – remains very low.
Key Message 7	Climate change is increasing the frequency of extreme precipitation events and elevating sea levels, increasing the likelihood of compounding of either one of these flood drivers by the other. In addition, tropical and post-tropical cyclones (TCs) have caused severe storm surges and extreme rainfall to occur simultaneously. While assessment is limited by the small number of historical TC events, the limited evidence suggests that TCs can cause low-probability, dangerous compound flooding. Given the importance of TCs and limited historical data, a deeper understanding of compound flood hazard likely requires detailed modeling and downscaling to simulate such storms under the present and future climate.
Description of Evidence	Sea levels have risen 1.5 feet since 1860 and are accelerating, with projections of 25-65 inches by 2100 (~2 to ~5.5 feet; 80% confidence range (Braneon et al., 2024). Significant increases have been observed in the frequency of extreme (95th and 99th percentile) rain events and in the magnitude of all rain events in the New York City Metropolitan Area since the mid 20th century (Braneon et al., 2024). Further increases are projected through the 21st Century (Braneon et al., 2024)These separate changes alone can increase the potential for compound flooding.
New Information and Remaining Uncertainties	Analyses of historical data under the Climate VIA project (Section 8) have quantified the baseline present-day flood hazard from co-occurrence of rain and storm surge. The research focused on simultaneous and near-simultaneous rain and storm surge through analysis of hourly historical data because NYC is located on several small, heavily urbanized watersheds, where timescales of drainage are short, and rain and surge must be nearly simultaneous to cause compounding. The results reveal non-zero correlations between rain and storm surge and that there is a higher probability of one variable being extreme when the other is extreme. For all storm type data merged together, rain and surge have a low, but non-zero rank correlation. However, for TC data alone, their correlation can be high. In addition, when one of the two flood drivers is extreme (the "primary" driver), the magnitude of the secondary flood driver during TCs is much higher than for other storm types. More comprehensive research on all flood hazard types, including groundwater and Bronx River-fluvial compound flooding is needed. While most research to date has focused on less-frequent, extreme compound events, more research on the chronic flooding that will result from more-frequently occurring high tides and the infiltration of groundwater into storm drains sewers is needed for NYC. Also, a critical next step will be compound flood modeling and analyses of street flood observations alongside the results

	of statistical assessments like those summarized above, to translate these data into an understanding of actual on-the-ground impacts; two drivers can co-occur, but their combined flood depth is often less than their sum.
Assessment of Confidence based on the Evidence	The limited historical record of TCs affecting NYC limits our confidence in NYCs potential for joint occurrences of heavy or extreme rain and surge, which we understand with medium confidence. We have high confidence that there will be increased chronic compound flooding from rainfall and higher sea levels unless flood mitigation efforts are undertaken.
Key Message 8	NYC's NNBS provide many valuable ecosystem services, including critical water regulation services that can play a role in FRM. However, many of these systems are themselves vulnerable to different flood hazards, especially along the coast. Research into how different types of NNBS are impacted by flood/storm surge events, hydroperiod changes, rising water tables and salinization is needed to better evaluate future changes in ecosystem services. Opportunities for designing NNBS to mitigate the impacts of various flood hazards need to be further explored.
Description of Evidence	Intensive development of NYC has significantly reduced the area and functionality of its natural systems, replacing them with developed surfaces. Research into the impact of climate change on natural systems is underway in NYC and throughout the region but more work is needed to examine how specific changes are impacting specific systems and what can be done to mitigate negative impacts.
New Information and Remaining Uncertainties	More research is needed to understand how NNBS respond to climatic changes including changes in precipitation patterns, temperature, and tidal flood frequency.
Assessment of Confidence based on the Evidence	We have great confidence that climate change and historical development has negatively impacted natural systems.
Key Message 9	Comprehensive FRM plans must be designed to address the full range of flood hazards faced by individual communities. Planning must begin with participatory decision-making processes that establish neighborhood-specific levels of acceptable future flood risk. To reduce risks from current levels, FRM tailored to each community will include combinations of structural and non-structural approaches, including NNBS, that are implemented in ways that reduce social vulnerability and are also synergistic with community histories, needs, and goals.
Description of Evidence	A large body of research has been published recently on FRM locally, nationally, and internationally. This research includes peer-reviewed journal papers, grey literature, and practitioner reports focusing on the physical effectiveness of these responses and the logistical, governance, and socioeconomic factors that constrain their implementation.
New Information and Remaining Uncertainties	Much of the research on FRM is nascent. Very few long-term studies exist.
Assessment of Confidence based on the Evidence	We are very confident that successful FRM strategies will both respond to the unique set of local flood risks and be synergistic with community needs.

12 Sustained Assessment

NYC's flood risks vary across the four types of flooding presented herein and in the ways in which they may compound. Moreover, these risks require watershed-scale understanding of stormwater for pluvial and fluvial flood risks, improved characterization of, and monitoring of groundwater levels and potential for future groundwater flooding, and more holistic approaches to capture coastal flooding impacts alongside more comprehensive understanding of existing systemic adaptive capacities.

While NYC's NNBS provide many valuable ecosystem services, they too are at risk, especially along the coast, and so researching how different types of NNBS are impacted by flood/storm surge events, hydroperiod changes, rising water tables and salinization is needed to better evaluate ecosystem services. Given increasing opportunities to work with NNBS to reduce risks while improving NY's public realm, understanding how such systems might adapt given expected climate changes and how to build into such systems more adaptive capacity remains an ongoing area of research.

Beyond the technical analyses needed, sustained assessment offers New Yorkers the opportunity to deepen their understanding of NYC's flood risks while simultaneously improving individual and organizational capacities to address those risks. While technical experts continue risk assessments, broader collaborations between governmental, institutional, business, and community-based organizations could help NYers to better understand these risks and the implications to the households and economies of New York.

Future assessments could consider how recently launched activities, such as Rainproof NY or the Climate Knowledge Exchange Flood Series, improve community awareness of the ability to cope with, and the opportunities to adapt to, these risks. Moreover, these could be further leveraged to couple technical analyses and community preparedness in mutually supportive ways wherein community readiness becomes a recognized criterion, particularly for communities where planned investments in flood risk reduction measures are underway or are in planning.

Recognizing that sustained assessment sets the stage for ongoing dialogue within these communities and across various groups of stakeholders while also emphasizing shared growth, setting agenda specific to sustained assessment and NYC's flood risks could enable a whole of community approach, similar to the approaches well underway in Copenhagen and Amsterdam.

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This assessment was also supported by analyses by Nonso Elelleh (Sarah Lawrence College NPCC Fellow 2021), Ivy Steinberg-McElroy (Drexel University NPCC Fellow 2022), Lilliana LoGiudice (Sarah Lawrence College NPCC Fellow 2022), and Isaiah Aguilar (Sarah Lawrence College NPCC Fellow 2022)

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The authors also thank Ronald Busciolano and Kristina Masterson of the U.S. Geological Survey (USGS) - New York Water Science Center for their guidance on availability of USGS data, their participation in work group meetings, and their review of chapter sections related to USGS expertise during development of this chapter.

The assessment does not represent the policy position of any agencies whose staff are co-authors.

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Abstract:

This chapter of the New York City Panel on Climate Change 4 (NPCC4) report considers climate health risks, vulnerabilities, and resilience strategies in New York City's unique urban context. It updates evidence since the last health assessment in 2015 as part of NPCC2 and addresses climate health risks and vulnerabilities that have emerged as especially salient to NYC since 2015. Climate health risks from heat and flooding are emphasized. In addition, other climate-sensitive exposures harmful to human health are considered, including outdoor and indoor air pollution, including aero-allergens; insect vectors of human illness; waterborne infectious and chemical contaminants; and compounding of climate health risks with other public health emergencies, such as the COVID-19 pandemic. Evidence-informed strategies for reducing future climate risks to health are considered.

Keywords:

public health, climate change, exposure pathways, health outcomes, heat-related health outcomes, flood-related health outcomes, climate-sensitive exposures, NPCC4

Recommended Citation:

Matte, T. D., Lane, K., Tipaldo, J., Barnes, J., Knowlton, K., Torem, E., Anand, G., Yoon, L., Marcotullio, P. J., Balk, D., Constible, J., Elszasz, H., Ito, K., Jessel, S., Limaye, V. S., Parks, R. M., Rutigliano, M., Sorenson, C., & Yuan, A. (2024). NPCC4: Climate Change and New York City's Health Risk: Interim Report.
https://climateassessment.nyc

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1 Chapter Summary

This chapter considers climate health risks, vulnerabilities, and resilience strategies in New York City's unique urban context. It updates evidence since the last NPCC health assessment in 2015 as part of NPCC2 (Kinney et al., 2015) and addresses climate health risks and vulnerabilities that have emerged as especially salient to NYC since 2015. Climate health risks from heat and flooding are emphasized. In addition, other climate-sensitive exposures harmful to human health are considered: 1) outdoor and indoor air pollution, including aero-allergens, 2) insect vectors of human illness, 3) waterborne infectious and chemical contaminants, and 4) compounding of climate health risks with other public health emergencies, such as the COVID-19 pandemic. At the end of this chapter, evidence-informed strategies for reducing future climate risks to health are considered.

1.1 Key Messages

***Key Message 1**: Climate change-related health risks are a threat to all New Yorkers, but especially those most vulnerable because of age, poor health, racial and social inequities, and social isolation. Inequities in household and neighborhood physical environments also mediate vulnerability to climate-health impacts. Addressing key environmental and social drivers of vulnerability is an essential adaptation strategy. Many current NYC policies and strategies, (e.g., improving access to residential air conditioning, tree planting), aim to accomplish this. These efforts can be informed and evaluated using data on climate-health vulnerabilities, such as components of the heat vulnerability index (HVI) and a flooding vulnerability index (FVI) under development (VIA Interim Report).*

***Key Message 2**: Heat waves are, on average, the deadliest type of extreme weather in NYC and in much of the US. Even hot, but not extreme, summer weather causes serious illness, death, and other harms to wellbeing. Because of climate change, NYC will experience more dangerous hot weather. Most heat-related deaths are due to exacerbation of chronic health conditions, such as cardiovascular disease. Indoor exposures can be especially deadly for people without air conditioning who have one or more physical or mental health conditions, are energy insecure, or are older adults. Also vulnerable are those with jobs exposing them to unsafe temperatures. These risk factors can be consequences of structural racial, social, and economic inequities. Adaptive measures are needed that protect vulnerable populations from season-long heat-health risks, including from non-extreme but hot weather. Evidence-informed strategies include enhanced access to air conditioning, reducing energy insecurity, engaging community and health provider networks to reach vulnerable populations, and augmenting tree canopy cover.*

***Key Message 3**: Public health can be impacted before, during, and after flooding, which exposes New Yorkers to risks of drowning and other injuries, stressful evacuation, short- or long-term displacement from home, and exposures from clean up, repair, water contaminants, and mold from water damage. Climate projections for NYC anticipate an increase in extreme precipitation days and sea level rise contributing to more frequent flooding over wider areas. Socioeconomic disadvantage, racial inequities, pre-existing health conditions, and flood-vulnerable housing and infrastructure amplify health impacts of flooding. Adaptation strategies that modify these factors can reduce future flooding impacts on health.*

***Key Message 4**: Hotter weather can increase concentrations of harmful air pollutants, including fine particles and ground-level ozone, by increasing emissions of precursor pollutants and the formation of ozone on warm, sunny days. These pollutants are harmful to health for all New Yorkers, but especially for the very young and old, people with certain chronic health conditions, those without residential air conditioning, and those living where emissions from buildings and traffic are concentrated. Most of these vulnerability factors are more common among Black, Latino, and low-income households. Despite a warming climate, air quality has improved in New York City because of reduced local and regional emissions. Recent wildfire smoke plumes affecting much of the eastern US indicate the potential to reverse a trend of improving air quality. Efforts to further reduce emissions and exposures of vulnerable populations can prevent or mitigate climate-related air quality impacts.*

***Key Message 5**: Nationally, pollen monitoring data shows that climate change is causing an earlier, longer, and possibly more intense plant pollen production season, but this trend is less evident in the northeast. Within New York City, pollen from several common tree species, ragweed, and grasses contribute to seasonal allergic rhinitis and asthma exacerbations. The burden of asthma exacerbations from any cause is greatest in communities with less access to health care and more household asthma triggers leading to less well-managed asthma. Ambient pollen levels are influenced by local weather, allergenic plant density, and species composition. Air conditioning and filtration can reduce indoor pollen exposure. Attention to local tree cover density and species composition along with improved access to care, evidence-based asthma management, and patient education can reduce pollen exposure, vulnerability, and future allergic illness.*

***Key Message 6**: In the northeast, changes in climate, landcover, habitat, and host animal ranges continue to shift the spatial and seasonal distribution of mosquitos and ticks that are current or potential vectors of human illness. Within New York City, the spatial distribution of these vectors and potential for human infection and serious illness varies with differences in the built environment, natural habitat and host animal abundance, human behaviors, and population vulnerability. Seniors, those with chronic illnesses, and people who are homeless are more susceptible to complications from West Nile virus (WNV) infection. Lyme disease risk among New Yorkers is increased among those engaged in outdoor activities mostly outside the city, but also in Staten Island and a limited area in the Bronx. Vector-borne disease (VBD) risk is also increased by international travel to and immigration from disease-endemic areas. Disease surveillance, vector monitoring and control, and public and clinician awareness can reduce future risks in a changing climate.*

***Key Message 7**: Climate change may increase risk of exposure to water-borne pathogens in surface waters and wastewater in and around New York City and could threaten its drinking water sources and distribution system. Increased flooding can cause exposure to contaminants from household sewage backups and in surface waters from combined sewer overflows (CSOs). Rising temperatures facilitate the growth and spread of pathogens such as bacteria that cause gastrointestinal illness, Legionnaire's disease, and a range of illnesses from harmful algal blooms. Extreme weather and climate change impacts on New York City's source and distribution infrastructure could compromise water quality and quantity. Continued maintenance and adaptation of infrastructure along with coordinated surveillance of water quality, human, and animal health can help prevent adverse impacts on health.*

***Key Message 8**: Climate risks can be compounded when they disrupt lifeline infrastructure systems or overlap with non-climate public health emergencies. Examples include power outages during recent extreme heat events and the COVID-19 pandemic creating potential disease transmission risks in cooling centers and other publicly accessible indoor spaces. The health risks from compound hazards can be reduced through investing in lifeline and other critical infrastructure and building mechanical systems that are adapted to extreme weather, redundant, and flexible. Rapid, flexible, collaborative, multi-sectoral responses are needed to respond to pandemics and other unanticipated compound hazards.*

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2 Introduction

2.1 Chapter Scope: New York City's Human Habitat, Weather, and Health

A premise of this chapter is that "Cities are for people and therefore human health, wellbeing, safety, security, and opportunity should be central considerations in sustainable urban development (Capon, 2017)."

Protection from the direct harm of climate extremes is just one of many basic biophysical and psychosocial needs that New Yorkers share with all people (Capon, 2017). In a changing climate, New York City shares with all cities the imperative of continually adapting its social and physical infrastructures to provide healthy human habitat, especially for its most vulnerable people and communities. As a coastal, densely developed city, New York has both inherent challenges and advantages for protecting people from climate change health risks, while enabling sustainable, low-carbon living. These health risks and per capita carbon emissions vary considerably within the city and between the city and other parts of the region.

Variation in human vulnerability to climate risks and in contributions to carbon emissions are shaped by New York City's unique and varied built and natural environments, its racial and ethnic diversity, and the enduring legacy of racial and economic injustice and inequality shared with the region, state, and nation. Racial injustice, historical land disposition, and more contemporary land use policies and practices are among the social and economic forces that have shaped an inequitable distribution of access to healthy, climate-adapted human habitat. The topic of climate equity is addressed more fully and in-depth in *NPCC4: Advancing Climate Justice in Climate Adaptation Strategies for New York City* (Foster et al., 2024).

Climate-adapted human habitat includes but is not limited to shelter, especially housing, that protects people from unsafe temperatures and flooding, energy services that affordably and reliably meet essential needs, and outdoor environments with natural and built features that enable healthy activity and mobility while also reducing exposure to heat, flooding, and other climate-sensitive weather hazards. Thus, vulnerability and resilience to climate risks are mediated and modified by the social and population context, by characteristics of the physical environment, and by causal interactions among these factors and characteristics (See Figure 1). This framework is the organizing structure for this assessment of health risks, vulnerabilities, and adaptation/resilience strategies for New York City.

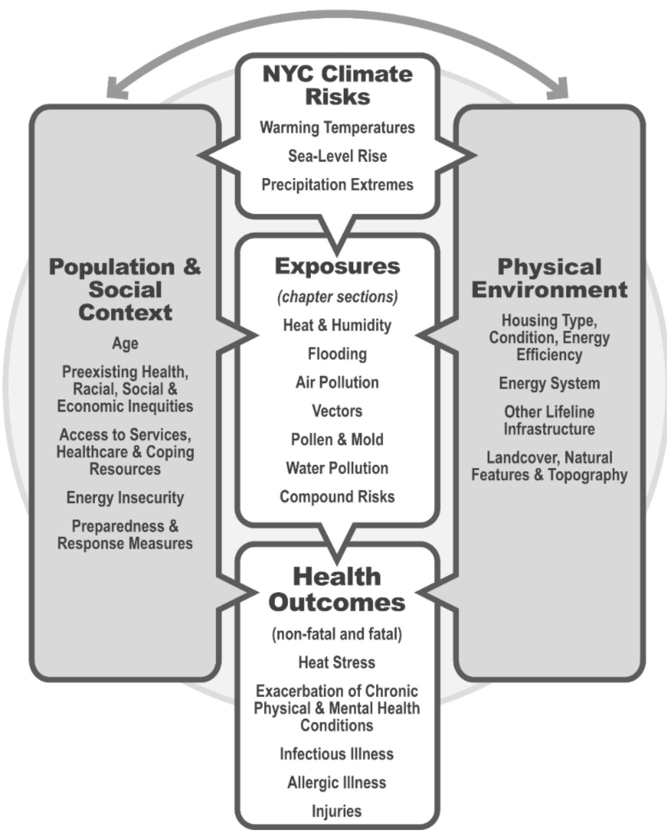


Figure 1: Urban Climate Change Health Impact Framework. Sections of this assessment correspond to exposures. Separate assessment reports cover the topics of racial, social, and economic inequities (Foster et al., 2024) and energy (insecurity, system, and housing energy efficiency) (Yoon et al., 2024). Framework adapted from Chapter 1, Figure 14.1 in Introduction: Climate change and human health. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment (Balbus et al., 2016).

2.2 Chapter Organization and Scope

This assessment will consider climate health risks, vulnerabilities, and resilience strategies in New York City's unique context. It will also provide an update on evidence since the last NPCC health assessment in 2015 as part of NPCC2 (Kinney et al., 2015) and address climate health risks and vulnerabilities that have emerged as especially salient to NYC since 2015.

Climate health risks from heat and flooding will again be emphasized, as these represent the largest present threats and because – absent continued adaptation – anticipated climate change (Braneon et al., 2024) will increase health risks from hotter summers, and the increasing frequency and severity of flooding. An assessment of life-safety and health risks from pluvial (cloudburst or extreme rain) flooding will complement a synthesis of coastal storm and flooding health impact evidence, including new studies since NPCC2.

In addition to the two climate risks that are the focus of this chapter — heat and flooding— other climate-sensitive exposures harmful to human health are considered: 1) outdoor and indoor air pollution, including aero-allergens, 2) insect vectors of human illness, 3) waterborne infectious and chemical contaminants. This assessment also considers compound health risks from co-occurrence of extreme weather events and of extreme weather with other public health emergencies, such as the COVID-19 pandemic. At the end of this chapter, evidence-informed strategies for reducing future climate risks to health are considered.

In addition to topics covered in this chapter, a large and growing body of evidence demonstrates how energy insecurity can amplify both overall climate impacts on health and their inequitable distribution among communities and populations, including in New York City. Energy insecurity's role in vulnerability to climate risks is noted in this chapter and addressed more fully in a separate chapter, *NPCC4: Climate Change, Energy, and Energy Insecurity in New York City*, (Yoon et al., 2024). That chapter also notes how protecting public health requires that local, state, and national energy transition policies and investments reduce energy insecurity and preserve and enhance reliability and resilience of NYC's energy system.

Other topics related to climate change and health that are amenable to adaptation at the local level will be addressed in other chapters of this NPCC4 assessment, including health impact assessment to estimate benefits of climate action, adaptive and maladaptive uses of air conditioning in NYC in *NPCC4: Concepts and Tools for Envisioning New York City's Futures* (Balk et al., 2024), and potential for health co-benefits of modifying the public right of way (streets and sidewalks); also in Balk et al., (2024).

Climate impacts on some domains relevant to the health of New Yorkers, such as agriculture, oceans, larger scale ecosystems, and global health, conflict, and international migration, require adaptations and responses primarily at the state and national levels. These domains are considered in other assessments, including the Fourth and upcoming Fifth National Climate Assessments (USGCRP, 2018, 2023), and the Sixth Intergovernmental Panel on Climate Change Impacts Adaptation and Vulnerability Report (Pörtner, H.O. et al., 2022). Finally, while this assessment does consider mental health impacts of, and vulnerabilities to, local climate risks and exposures, the topics of climate anxiety and other mental health effects of awareness about global climate and ecological change and how to best respond – areas of active and evolving research (Clayton, 2020; Crandon, Dey, et al., 2022; Kurth & Pihkala, 2022; Lawrance et al., 2022; Wortzel et al., 2022) – are beyond the scope of this assessment.

3 Climate-health exposures, impacts, and vulnerabilities in New York City

3.1 Heat: Extreme Heat Events and Higher Warm Season Temperatures

3.1.1 Current and projected future climate and local health risks

The NPCC3 noted that observed summer temperatures from 2010 to 2017 largely fell within the range of NPCC2 projections, continuing warming trends observed at Central Park since 1900 and somewhat steeper increases at LaGuardia and JFK airports. Using updated models, the NPCC3 projected that on average heat waves will be more numerous, intense, and longer in the coming decades (González et al., 2019). The NPCC4 climate projections update and refine these but are qualitatively similar in forecasting a future with warming temperatures, more hot days, and more frequent extreme heat events for New York City (see Braneon et al., 2024).

Climate and emissions projections generally align in pointing to anthropogenically driven climate change causing a continued increase in global warming. This is due in part to the inertia inherent in the global climate system and a significant "emissions gap" between commitments and actions (UNEP, 2018). Unavoidable, anticipated increases in multiple climate hazards, including hotter weather, are creating and will increase multiple risks to humans, health infrastructure, and ecosystems (Pörtner, H.O. et al., 2022). In addition, in New York and other large cities, heat exposure is amplified by the urban heat island (UHI) effect, (National Oceanic and Atmospheric Administration, 2023b) which is discussed in more detail later in this chapter and will be addressed more fully in *NPCC4: Tail Risk, Climate Drivers of Extreme Heat, and New Methods for Extreme Event Projections* (Ortiz et al., 2024).

3.1.2 Health impacts and pathways

Hot and humid weather is dangerous and can cause a range of serious health impacts (Figure 2). In a typical summer, heat-related deaths and illnesses are not highly visible because they often happen behind closed doors in homes and without much news coverage. This can make it hard for the public to recognize the dangers of heat. In recent years, however, news coverage of the devastating and historically unprecedented heat waves in India and Pakistan in 2015 and 2022, Canada and the US Pacific Northwest in 2021, and many extreme heat events globally has underscored the increasing dangers of heat and warming climate for the general public and some policymakers (Fears & Eger, 2022; Webber & Sanders, 2023).

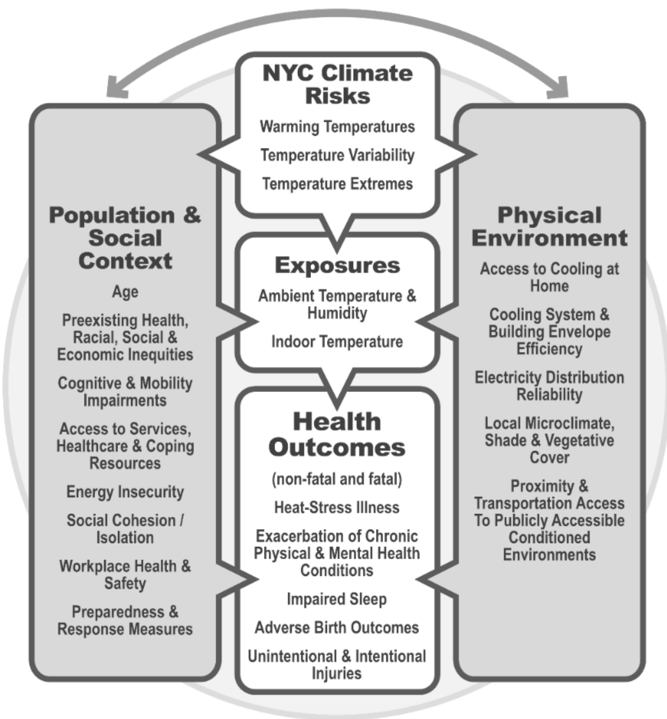


Figure 2: Heat Health Impact Pathways and Vulnerabilities. Framework adapted from Chapter 1, Figure 14.1 in Introduction: Climate change and human health. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment (Balbus et al., 2016).

Heat exposure can directly cause heat-related illnesses such as heat cramps, heat exhaustion, and heat stroke (life threatening high body temperature caused by heat exposure) (Mora et al., 2017; National Oceanic and Atmospheric Administration, 2023b). It can also exacerbate existing chronic conditions such as cardiovascular, pulmonary, or renal diseases as discussed further below. Both heat-related illnesses and heat-related exacerbations of chronic conditions can lead to emergency department visits, hospital admissions and, in the most severe cases, death.

Surveillance of deaths identified on death certificates as caused or accompanied by heat-related illnesses – often referred to as heat stroke deaths and hereafter referred to as heat-stress deaths – has the advantage of timeliness and can give insights into circumstances for individuals succumbing to heat. However, heat-stress deaths are likely under ascertained and underreported, and certainly underestimate the true mortality burden from hot weather (Weinberger et al., 2020). Most epidemiologic studies use a comprehensive approach of statistically estimating excess mortality from natural causes (i.e. chronic conditions), all causes, or broad causal categories (Petkova, Morita, et al., 2014). Consistent with this practice, the NYC Department of Health and Mental Hygiene (NYC Health Department) conducts surveillance for both heat-stress deaths and excess mortality from natural causes, referred to as heat-exacerbated deaths. In its 2023 report (City of New York Department of Health and Mental Hygiene, 2023b), the NYC Health Department estimates that hot weather, defined as days with a maximum temperature reaching 82°F or hotter, kills an estimated 352 New York City (NYC) residents each year, on average. This includes an annual average of 7 heat-stress deaths from 2012-2021. By contrast an annual average of 345 heat-exacerbated deaths occurred from 2016-2020; 115 of those deaths occurred during extreme heat events, defined by the National Weather

Service heat advisory threshold for NYC (National Weather Service, 2023): "at least two consecutive days with a maximum heat index (HI) of 95°F or higher or any day with a maximum HI of 100°F or higher".

National counts of heat-stress also greatly underestimate the lethality of hot weather. The annual average of 153 heat deaths in the US according to data compiled by the National Weather Service (National Oceanic and Atmospheric Administration, 2023c) and 702 heat-related deaths according to the US CDC (Centers for Disease Control and Prevention, 2023a) do not include heat-exacerbated deaths. A recent study using data from 297 counties representing 62% of the US population estimated that more than 5,500 deaths were attributable to heat (i.e. were heat-exacerbated deaths) annually from 1997-2006 (Weinberger et al., 2020).

In addition to mortality from exacerbation of chronic health conditions, higher-than-normal warm season temperatures are associated with an increased risk of deaths from external causes in the US. These include deaths from drowning and transport injuries, as well as homicides and suicides (Parks et al., 2020). Higher ambient temperature is associated with homicide and interpersonal violence in cities, including New York, especially during the warm season (R. Xu et al., 2020). Two studies have found that the risk of cocaine overdose deaths in NYC increased with ambient temperature, a relationship also seen in other jurisdictions (Auger et al., 2017; Bohnert et al., 2010; Marzuk et al., 1998).

Nationally, emergency department (ED) visits for all causes increase somewhat on extreme heat days. ED visits for heat-related illness increase much more during heat waves (S. Sun et al., 2021), and are a better indicator for assessing heat-health severity during an extreme heat event than increases in all-cause ED visits. Heat-associated mortality in NYC has been shown to correlate with heat-related illness ED visits by a roughly one-day lag (Mathes et al., 2017). For timely heat related health surveillance, NYC monitors EMS calls for heat and ED visits for heat-related illness using syndromic surveillance data (City of New York Department of Health and Mental Hygiene, 2022j).

A wide variety of chronic health conditions can be exacerbated by heat exposure. In NYC, hospital admissions for renal, cardiovascular, respiratory conditions and mental health conditions increase during hot weather (Fletcher et al., 2012; S. Lin et al., 2009). For this reason, and others discussed below, people with one or more of several chronic health conditions are more susceptible to heat-related illness (see Section 3.1.4.2). In addition, a recent review and meta-analysis of US studies found an increased risk of both pre-term birth and low birthweight associated with higher temperatures and extreme heat, especially during the third trimester; a smaller number of studies have found associations between high temperature and still birth (Bekkar et al., 2020).

Heat-related health problems can also have adverse financial repercussions for individuals, especially for those without health insurance or adequate insurance (Limaye et al., 2019; Y. Liu et al., 2019). Prior work documents some of the heat-mortality impacts that have occurred in NYC (City of New York Department of Health and Mental Hygiene, 2023k). When assessed by applying a Value of Statistical Life approach, these total at least $20.1 billion (in 2023 dollars), from heat-related excess mortality in 2016-2020, and heat stress deaths 2012-2021 (City of New York Department of Health and Mental Hygiene, 2023c; United States Environmental Protection Agency, 2014a). A wider range of societal cost estimates to NYC for care of climate-sensitive illnesses and premature loss of life are being developed for the city and will be reported separately in the Climate Vulnerability, Impact, and Adaptation Analysis (VIA) (McPhearson et al., 2024), a multi-disciplinary research effort, led by faculty at the New School in NYC, focused on future potential climate conditions and associated socio-economic impacts.

Hot weather can strain the power grid, resulting in power outages. While NYC already experiences substantial heat-related mortality each summer, in recent years the city has not had to contend with prolonged and unprecedented temperatures seen in other parts of the world, such as the weeks-long extreme heat that affected Pakistan and India in 2022 with temperatures in some cases exceeding 120°F (E&E News & Harvey, 2022). Such extended heat waves could be catastrophic in NYC if accompanied by a power outage. Lack of mechanical cooling for New Yorkers is a critical concern during a heat wave, especially because indoor temperatures can be higher than outdoor temperatures in the absence of air conditioning due to building thermal inertia (Vant-Hull et al., 2018). In 2003, in NYC, there was a 2-day power outage during hot but not extreme weather. Even so, there was a 122% increase among accidental deaths and a 25% increase among non-external cause deaths attributable to the outage, resulting in 90 excess deaths over the period (G. B. Anderson & Bell, 2012). A 2003 heat wave in Europe resulted in more than 70,000 deaths (Robine et al., 2008). Of those, about 15,000 occurred from August 1 to August 20 in France (Fouillet et al., 2006), where home air conditioning prevalence is also low. Record, extreme heat in the Pacific Northwest in 2021 over about a week resulted in more than 600 deaths directly attributed to the heat in British Columbia (White et al., 2023), many of them in Vancouver where only about a third of the population has home air conditioning (Henderson et al., 2022). Nearly all – 98% – of these deaths occurred in homes without cooling (British Columbia Coroners Service, 2021). In addition to loss of air conditioning, other threats during a heat event complicated by a power outage include lack of subway service, elevators and pumped potable and other water to upper floors of NYC's many high rises, and strain on emergency responders. Outages can also strain the healthcare system as more people require medical care when they lose home cooling, the ability to charge electrically powered medical devices, such as oxygen concentrators, and access to other essential services that require electricity. A heat wave accompanied by a major flooding event that damages energy infrastructure or impedes emergency responders could also be particularly deadly. The public health impacts of power outages are discussed further in Yoon et al., (2024)

The reliability of the energy grid is key to maintaining population health and supporting emergency response efforts (see NPCC4, Yoon et al., 2024). Building-level back up energy systems, for example solar panels with battery storage, or microgrids can help buildings maintain essential services during power outages.

Backup systems can also help the health care sector respond during hot weather with power outages. Nationally, hospitals certified by the U.S. Centers for Medicare & Medicaid Services are required to have generators capable of running air conditioning, but there is no similar explicit federal requirement for nursing homes (Patel et al., 2022). In New York State, nursing homes and long-term care facilities are required to maintain safe temperatures but are not required to have generators capable of running air conditioning (New York State, 2004).

Heat impacts may be felt in other areas, such as schools, that could eventually affect educational attainment, economic opportunity, lifetime income and health. Higher temperatures are associated with lower scores on high stakes academic exams in the US (Graff Zivin et al., 2018) and China (Graff Zivin et al., 2020). An analysis of NYC Regents high school exit exams found that higher temperatures on exam days were associated with substantially lower test scores (J. Park, 2017). Data on air conditioning was incomplete and only available at the school (not classroom) level but indicated that 38% of schools lacked air conditioning and that the temperature effect on test scores was larger in such schools. Cumulative hot days during the school year were also associated with a reduction in student performance. In 2017, NYC announced plans to air-condition all classrooms to provide a safe and comfortable learning environment for students (City of New York, 2017). NYC school buses are required to provide air conditioning on buses transporting children with special needs. There have been reports of dangerously hot conditions on school buses, however, including those transporting kids with special needs (Coleman, 2019; Edelmen & Bamberger, 2022).

Increasing temperatures may also impact food safety. Warm temperatures have been associated with more food safety violations for insufficient refrigeration equipment and cold food holding in the summer in NYC restaurant inspection data, indicating that even during current summer temperatures some restaurant infrastructure is strained (Dominianni et al., 2018).

3.1.3 Temperature, other heat-stress metrics, and health outcomes

Environmental heat stress is influenced by several factors, including air temperature, humidity, velocity, and radiant heat such as from sunlight or hot pavement. A variety of heat exposure metrics have been developed to consider both ways in which humans respond to heat stress and environmental conditions in different settings: indoors and outdoors, in sun and shade, and by populations that engage in physical activity during hot weather and those who are able to avoid strenuous activity.

In hot conditions, body heat is shed to maintain a safe body temperature. This happens in several ways, including evaporation of sweat, contact with cooler air and radiation of heat from skin warmed by increased blood flow (Hosokawa et al., 2019). Heat-related illness results when a person's ability to maintain a safe body temperature or stay hydrated is overwhelmed by environmental conditions. As noted earlier, heat exposure can also exacerbate chronic health conditions, such as through stress on compromised respiratory and cardiovascular systems, and dehydration that decreases kidney function (City of New York Department of Health and Mental Hygiene, 2022b). Physical activity generates more body heat and increases heat stress. People living or working in a locality can acclimatize, generally within a few weeks, to hotter weather to a certain extent, as their bodies become more able to shed heat, such as through sweating (National Institute for Occupational Safety and Health (NIOSH), 2020).

Heat-stress metrics commonly used include the air temperature, heat index (which includes humidity), Humidex, and the Wet Bulb Globe Temperature (WBGT) (Hosokawa et al., 2019). Humidity can impact sweat evaporation, a key cooling mechanism. The WBGT is based on temperature, humidity, sun angle, cloud cover, and wind speed. It was designed to assess heat stress risk in people who are outdoors in unshaded locations and to guide activity limitations and cooling breaks for populations such as workers, soldiers, and athletes (Budd, 2008; Hosokawa et al., 2019).

Temperature and the heat index have been widely shown to predict population risk of increased deaths and serious illness during hot weather in different countries, in US cities, and in NYC in particular (Curriero, 2002; Metzger et al., 2010a; Tobías et al., 2021). An NYC study showed that the maximum heat index predicted excess mortality as well or better than many other metrics and that the risk of heat associated death rose in a non-linear way (Metzger et al., 2010a), though this study did not include the WBGT, which is appropriate for use in outdoor occupational and athletic settings. Despite the influence of humidity on individual heat stress, a recent multi-country study suggests humidity measures may not improve prediction of mortality risk at the population level (Armstrong et al., 2019). This does not mean that humidity does not contribute to heat stress, however. Because temperature and heat index are highly correlated, population-level studies may be unable to disentangle the relative contributions of heat and humidity to associations with health impacts.

The relationship between unseasonably warm and extremely hot daily temperatures and health is both non-linear and cumulative (Gasparrini et al., 2015; Z. Xu et al., 2016). As temperatures rise, the risk of heat-related death begins to increase more steeply and grows with more consecutive days of hot weather. Taking the non-linear and cumulative effect of higher temperatures into account, there may be little if any additional "heat wave effect" on mortality risk (Hajat et al., 2006). It is nonetheless useful to set criteria for extreme heat events, calibrated to health risks in a particular locale, so that heat advisories can be issued to the public and heat emergency plans can be activated on days when the health risk from heat is highest. Even during periods of extreme heat, risk can vary; heat waves that are long and/or those with higher peak temperatures are particularly dangerous (G. B. Anderson & Bell, 2011; Hajat et al., 2006).

In NYC, heat-health advisory levels have been set according to analyses of the local relationship between heat and mortality. An NYC study found that when the heat index reaches 95°F or higher for two or more days, or 100°F or greater for any period, the risk of death from chronic conditions increases more steeply (Metzger et al., 2010a). On the basis of this study, the National Weather Service (NWS) and the NYC Office of Emergency Management in 2008 agreed to lower the threshold for issuing NWS heat advisories and activating NYC's heat emergency plan to these levels (Benmarhnia et al., 2019; Ito et al., 2018) (see Section 4).

While the hottest days of summer are the most dangerous to health, even moderately hot days can be harmful. About two-thirds of NYC's annual heat mortality are associated with moderately hot days when the temperature is between 82°F and 95°F (City of New York Department of Health and Mental Hygiene, 2022b). One reason why these moderately hot days have a greater cumulative impact is that they occur much more frequently than extreme heat days (Figure 3) (City of New York Department of Health and Mental Hygiene, 2022b). For example, from 2011-2020, more than 20% of late June through mid-August days reached 90°F or higher (City of New York Department of Health and Mental Hygiene, 2022b). While the proportion of days above 90°F is highest in July, hot days historically can happen in May through September. In NYC, from 2016-2020, heat-exacerbated deaths occurred most frequently in July (37%), followed by August (28%), June (18%), September (10%), and May (7%). Interventions to address the season-long risk on moderately hot days, as well as the heightened risk during extreme heat events, will protect public health (City of New York Department of Health and Mental Hygiene, 2023b). Ongoing health surveillance can help elucidate risks as the NYC warm season lengthens.

In an analysis of trends in heat-exacerbated mortality, the Health Department found that deaths declined substantially between 1971 and 2000 but leveled off after 2000 and began increasing in the past decade as NYC's climate has warmed and the increase in residential air conditioning plateaued (City of New York Department of Health and Mental Hygiene, 2023b). The increases in heat-exacerbated deaths are attributable to a corresponding increase in moderately hot, but not extreme heat days (Figure 3), indicating that heat adaptation measures such as residential cooling, need to be available to people during entire the warm season.

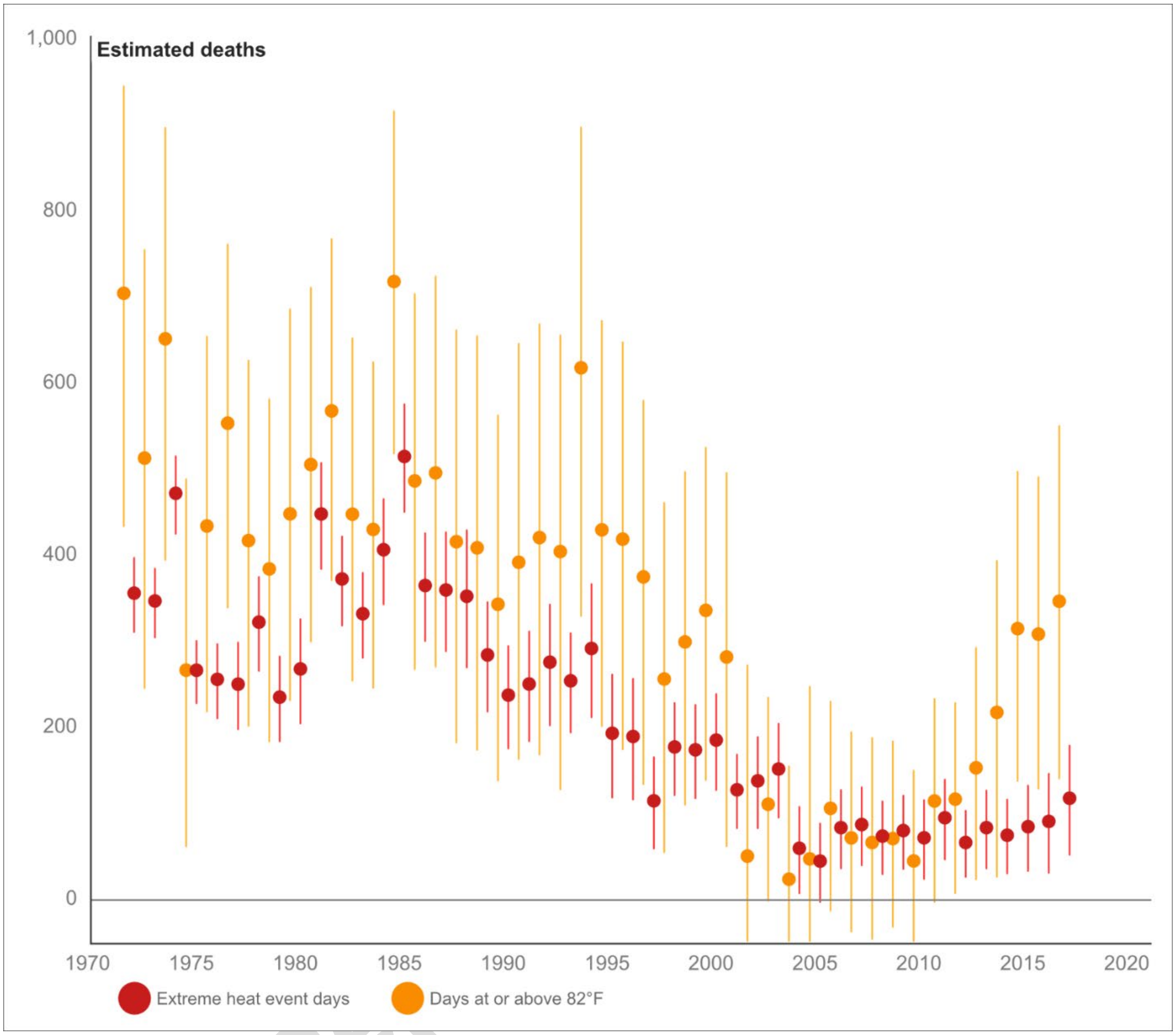


Figure 3: Annual average heat-exacerbated deaths for Extreme Heat Event (EHE) days, and days reaching a maximum temperature of 82°F or higher, including EHE days, in 5-year moving time windows, 1971-2020, New York City. EHE days were defined as at least 2 consecutive days with 95°F or higher daily maximum heat index (HI) or any day with a maximum HI of 100°F or higher. The EHE and Days at or above 82°F estimates come from separate regression models. Source: 2023 New York City Heat-Related Mortality Report.(City of New York Department of Health and Mental Hygiene, 2023b)

The relationship between temperature and mortality varies geographically (USGCRP, 2018) even to the building level. Research at the global scale suggests that the minimum mortality temperature (MMT) collected from 658 communities in 43 countries was between 14.2°C (58°F) and 31.1°C (88°F) decreasing by latitude (Tobías et al., 2021). Research at the national scale indicates that heat-mortality rates are higher in the northeast and midwest compared to the south (B. G. Anderson & Bell, 2009). Another study in 11 large US cities suggests that MMT for heat varies between 65.2°F (18.4°C) and 90.4°F (32.4°C) with higher temperatures at lower latitudes, (Curriero, 2002) reflecting in part less adapted physical environments (e.g. less air conditioning) in northern cities like NYC. Differences in building types and in the prevalence of indoor cooling account for some of the geographic variation (see Section 3.1.5). Less population acclimatization may also play a role, especially when temperatures rise faster than physiologic acclimatization in normally cooler locations and seasons (Guo et al., 2016), such as during an early spring heat wave.

3.1.4 Who is most vulnerable and why? Health, demographic, and social factors

3.1.4.1 Race and Income

Heat risks to health are greater for people with lower household incomes, and other limited financial resources, and higher energy cost burdens, which reduce their ability to avoid heat exposure. The energy cost of air conditioning, for example, must be weighed against other pressing priorities, such as purchasing food or medicine (Bhattacharya et al., 2003; Hernández, 2016). Racist and socially unjust policies have also created differences in economic opportunities, neighborhood environments, housing, energy access, and have led to overlapping health and environmental burdens (Bailey et al., 2017) among communities of color and low-income residents. Black New Yorkers in particular are more likely to be exposed to heat and, as a consequence, have higher rates of heat-health impacts – inequities that are caused by past and current racism (City of New York Department of Health and Mental Hygiene, 2023b; Foster et al., 2024).

The historical roots and current pathways linking structural racism and other unjust policies to present climate risk disparities are complex and the social context itself is also continually changing. The historic and future linkages of inequity to climate vulnerability are considered more fully in Foster et al.,(2024). Some of these pathways most relevant to heat-health risks are briefly considered here. For example, beginning in the 1930s, the practice of "redlining" at the federal level designated over 80% of the Black population in NYC at that time as living in "hazardous" mortgage risk zones. Climate researchers have shown that surface temperatures in formerly redlined areas across the country are on average 2.6°C (4.7°F) warmer than in non-redlined areas, due in part to less tree canopy and more impervious surface (Hoffman et al., 2020a). Redlining, zoning, and land-use planning and patterns over time, and how they interact to create and maintain climate inequities, are discussed in depth in Foster et al.,(2024).These factors, as well as displacement (i.e. gentrification), have shaped heat-health risk in the city. While some formerly redlined neighborhoods have relatively low heat vulnerability indices (Benz & Burney, 2021; City of New York Department of Health and Mental Hygiene, 2022g; Zipp, 2009), inequities in heat vulnerability persist. Neighborhoods that are home to more people living below the poverty line and Black residents tend to have less vegetative and tree cover and less access to air conditioning at home (City of New York Department of Health and Mental Hygiene, 2022b, 2022g; Madrigano et al., 2018). These pathways for increased heat exposure are some of the reasons why Black New Yorkers are disproportionately affected by heat-exacerbated mortality (Madrigano et al., 2015) and experience rates of heat stress mortality that are twice as high as White New Yorkers (City of New York Department of Health and Mental Hygiene, 2022k).

Racism and economic disadvantage create health vulnerabilities through multiple, interacting pathways including, but not limited to, access to affordable and healthy food, access to safe places for physical activity, and health care systems that do not provide care to all who need it. For example, there are large inequities in access to health insurance by race, income, and documentation status. People without health insurance are less likely to have access to primary care, receive preventative health screenings, and have fewer resources to manage chronic conditions (Fiscella & Sanders, 2016; Gaffney & McCormick, 2017; Karliner et al., 2010; Starfield et al., 2005; Timmins, 2002; Vernice et al., 2020). Sub-optimal management of health conditions because of these barriers may, in turn, predispose individuals to heat-related illness or exacerbation of their health conditions. Even when care is accessible, people of color may receive substandard treatment due to racial bias (Bailey et al., 2017).

Households experiencing energy insecurity are much less able to afford air conditioning purchases, maintenance and repair, efficiency upgrades, weatherization, or utility costs of using air conditioning during hot weather (See NPCC4, Yoon et al. (Yoon et al., 2024)). Hotter summers caused by climate change will raise these already high cooling energy cost burdens for low-income households (Ortiz et al., 2022) and will further strain the electric grid, which tends to be more prone to outages and brownouts in marginalized communities (Berkman et al., 2022; Marcotullio et al., 2023).

During the deadly 1995 Chicago heat wave, a comparison of the social conditions in two low-income neighborhoods found that the neighborhood with high levels of social connectedness and vibrant public spaces fared much better. By contrast the community with declining population levels, high levels of empty housing stock and abandoned buildings, reduced levels of business and other street activities, higher crime rates, socially isolated seniors, and neglected public spaces like parks and sidewalks, fared much worse. People living in this neighborhood, which was also home to more Black residents and comparatively more people living below the poverty line, may have felt discouraged from interacting with their surrounding community, making it harder to maintain social connections to call upon during times of emergency. Klinenberg (2001, 2015) posits Black Chicago residents were more likely to live in communities with high levels of disinvestment, and that is one reason why that population suffered higher death rates during the heat wave. There were also some neighborhoods in Chicago with more Black residents that stayed safe during the heat wave, but those areas were not experiencing population decline and other forms of neighborhood depletion.

3.1.4.2 Chronic and mental health conditions

Chronic physical health conditions, including diabetes, obesity, high blood pressure, respiratory conditions like chronic obstructive pulmonary disease (COPD), congestive heart failure, and kidney disease also increase vulnerability to and risk of illness and death from heat stress exposure (Cui & Sinoway, 2014; Ebi et al., 2021; S. Lin et al., 2009; Meade et al., 2020; Sasai et al., 2021). People with these conditions may be less able to maintain a safe body temperature or be more prone to dehydration because of their condition or medications they must take (Meade et al., 2020). People of color and people with lower incomes bear an inequitable burden of chronic conditions, as discussed above, and this is evident in NYC for diabetes and other chronic health conditions (Figure 4).

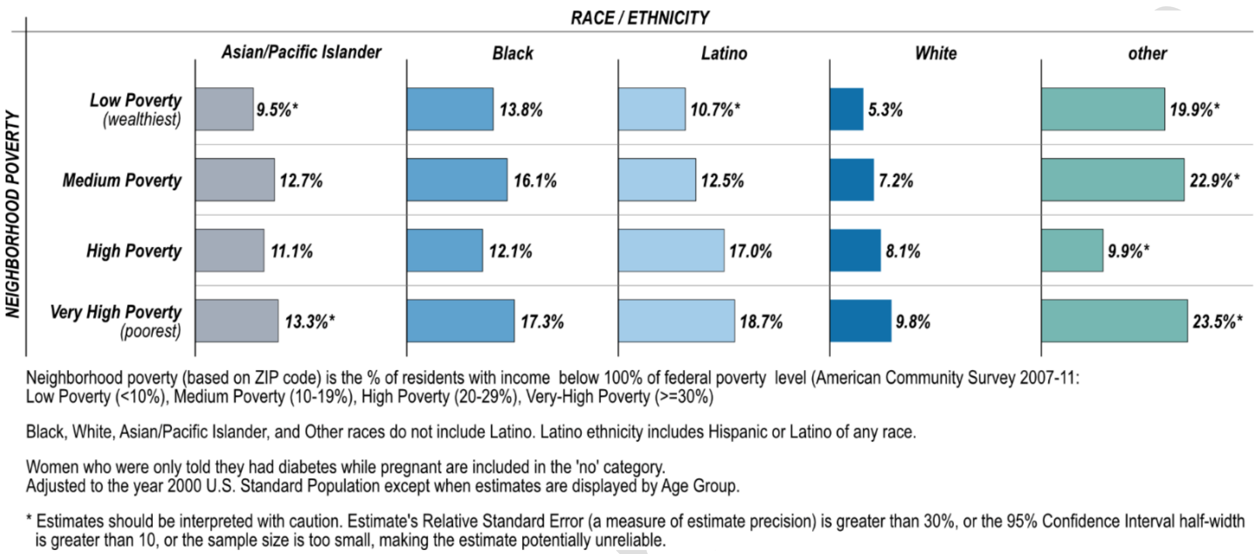


Figure 4. Prevalence of people who have ever been told they had diabetes by neighborhood poverty and race/ethnicity, 2017. Source: (City of New York Department of Health and Mental Hygiene, 2023i)

People with mental health and cognitive conditions are more vulnerable to heat-related illness and to exacerbation of their pre-existing conditions by heat exposure. In a national multi-city study of Medicare participants, those with chronic cardiovascular, respiratory, or neurologic conditions, including dementia, were associated with an increased risk of hospitalization during extremely hot weather (Zanobetti et al., 2013). Recent studies in NYC have shown an increase in ED visits for mental health and cognitive conditions (Yoo et al., 2021) associated with increases in daily outdoor ambient temperatures above 27°C (~81°F), including schizophrenia, mood disorders, anxiety, self-harm, substance use, Alzheimer's disease, and dementia (Yoo et al., 2021). Nationwide studies among US adults also demonstrate these relationships (Nori-Sarma et al., 2022; S. Sun et al., 2021). In addition, several studies have documented increases in suicide attempts associated with increases in temperature and/or humidity (Burke et al., 2018; Hu et al., 2020; Kim et al., 2019; Page et al., 2007; Parks et al., 2020).

There are multiple drivers of risk for people experiencing mental health conditions that likely play a role in increased susceptibility during hot weather. Mental health drivers include medication interference with body temperature regulation, coexisting physical health conditions, and reduced ability to recognize the heat risks and engage in self-care (Health Canada, 2011; R. Thompson et al., 2018). Heat can impact sleep quantity and quality, which may exacerbate mental health conditions (Minor et al., 2022). Limited evidence suggests that schizophrenia patients may be physiologically sensitive to environmental heat stress independent of medication (Bark, 1998). These factors, combined with social and environmental factors, such as social isolation, worse housing quality, or inability to pay for or run air conditioning, can compound risk. Men are more likely than women to be socially isolated through their 50s, in general, and at older ages, when they are never married or experienced relationship disruption (Umberson et al., 2022).

3.1.4.3 Age

Aging is associated with changes in physiology, adaptive capacity, and greater likelihood of social isolation that can increase risk to heat (Gamble et al., 2013). Thirst and thermoregulatory mechanisms, including evaporative heat loss, and adaptive behaviors may decline with age. Older adults are more likely to have chronic health conditions and take medications that predispose to heat-related illness (Gamble et al., 2013; Hooper et al., 2014; Larose et al., 2013;

Millyard et al., 2020). While NYC has a younger age structure than other parts of the state or country, it too is aging and in the coming decades will see sizable increases in the proportion of population over age 65 (City of New York Department of City Planning, 2013). Women are more likely to live longer than men, and by themselves in those older ages, increasing their chances of becoming socially isolated, which may increase risk for mortality associated with heat or other causes (Ausubel, 2020; Holt-Lunstad et al., 2015; Medina et al., 2020). Older adults are more vulnerable to a range of climate risks to health, as discussed further in

BOX 1. Importantly, age increases the likelihood of social isolation (Umberson et al., 2022) which itself increases the likely impact of climate-related stresses and may be associated with living alone. For example, most of the heat-related deaths in British Columbia, Canada in 2021, discussed more in section 3.1.2, occurred among older adults who lived alone and had multiple chronic conditions (British Columbia Coroners Service, 2021). Notably, 67% of the deaths were among adults over age 70 and 56% were of those who lived alone.

Heat creates health risks across the life course. Although children and adolescents do not suffer the highest burden of heat-related disease compared to other age groups in epidemiologic studies, they are sensitive to heat exposure. Infants and children (particularly young children) must rely on adult caregivers to help them stay safe, cool, and hydrated (Centers for Disease Control and Prevention, 2019; National Oceanic and Atmospheric Administration, 2023d). Children and adolescents may also spend more time outside during play and sports, and may take longer to acclimatize to warmer temperatures (Mangus & Canares, 2019; National Oceanic and Atmospheric Administration, 2023d). Few studies have been able to investigate to what extent children's physiological differences influence heat risk, however,(Health Canada, 2011; Mangus & Canares, 2019), and there are also few studies that assess heat impacts among children. In NYC, one study found that higher temperatures were associated with increased rates of ED visits for children aged 0-18, with the greatest risk for children 0-4. Increased rates of hospital admissions for children aged 0-4 and 13-18 were also associated with warmer temperatures. ED visit risks were elevated for heat-specific, general symptoms, and injury diagnostic codes (Niu et al., 2022). In addition, the prevalence of any mental illness and serious mental illness is higher among younger adults, compared to those aged 50 and older in the US, contributing to potential heat risk among this age group (National Institute of Mental Health (NIH), 2023).

BOX 1. Aging and climate vulnerability in New York City

About 15% the population of New York City is above age 65 and this proportion is expected to increase (United States Census Bureau, 2021). This is a lower proportion than state- or nation-wide (17.3% of the U.S. population is over age 65), but like elsewhere, the proportion of the city's population over age 65 is expected to increase substantially in coming decades (City of New York Department of City Planning, 2013; United States Census Bureau, 2021). Between 2010 and 2021 New York City's median age rose considerably, increasing from 35.6 up to 38.2 years and the proportion of NYC's population over age 65 is expected to increase by about 15% between 2020-2030 alone, and with disproportionately greater increases in the Bronx and Staten Island (City of New York Department of City Planning, 2013; NYC Department of City Planning, 2022). In big diverse cities like New York, older urban residents are more likely to come from historically disadvantaged or immigrant communities and have lower levels of education, income and insurance (Garcia et al., 2022; Gusmano et al., 2010).

As New York City's population ages and climate impacts unfold, the vulnerability of older adults to hazards such as temperature extremes (heat and cold), storms and flooding is a growing concern in part due to physical and neurological aspects of aging. Chronic conditions (e.g. dementia, diabetes, and kidney disease) and acute conditions (e.g. heart attacks, falls, and pedestrian accidents) are more common in older adults, with disparities in many conditions by race with higher rates among Black than white adults (Boersma et al., 2020; CDCMMWR, 2022; Younan et al., 2022). Aging may also bring a decreased ability to complete activities of daily living (ADLs) and yield changes in physiology, including mechanisms associated with thermoregulation (Hooper et al., 2014; Kenny et al., 2017; Millyard et al., 2020). Older adults, and those with chronic conditions, may be more likely to experience adverse health outcomes during periods of extreme cold and heat (Gamble et al., 2013; Lane et al., 2018; Millyard et al., 2020). Dehydration is also a concern in older adults (Hooper et al., 2014) and drugs taken for chronic conditions may contribute to dehydration risk (Puga et al., 2019). People with dementia may have a reduced capacity for adaptive behaviors in response to temperature or extreme weather events. Evacuation is a concern, especially for those with mobility or sensory impairments, and since when evacuating, medication may be lost or forgotten (Ochi et al., 2014).

Socioeconomic and demographic characteristics compound these vulnerabilities. These include living arrangements, kin networks, social networks, and housing characteristics as well as ideas and perceptions about risk and planning in old age. Though living alone, loneliness and social isolation are risk factors for mortality at all ages, these increase with age, with risk modified by gender and relationship history (Holt-Lunstad et al., 2015; Umberson et al., 2022). Nearly one out of three older adults living in NYC live alone and one out of three older adults live in a multigenerational household with differences by race and ethnicity (Greer et al., 2019). Older immigrants may be more likely to experience loneliness and social isolation (Zemba & Wilmoth, 2022). One-third of older adults in New York report that they have limited or no English proficiency (Greer et al., 2019). City dwellers live in a wider range of housing types from high-rise apartments to single-family homes, and a wider range of housing tenure arrangements (Molinsky & Forsyth, 2022), which place them at different vulnerabilities in the aging-health-climate interface. Approximately 6% of New Yorkers are New York City Housing Authority (NYCHA) residents (including public housing, PACT, and Section 8 housing), representing 11.2% of the rental housing stock of the city (New York City Housing Authority, 2023). Ten percent of older New

Yorkers do not have working air conditioning (and 21% of older public housing residents) and 13% use supplemental heating (28% of older public housing residents) (Greer et al., 2019). Energy insecurity highlights how poverty, housing, and aging interact to place more vulnerability on people at risk of morbidity and mortality in a warming climate (See NPCC4, Yoon et al. (Yoon et al., 2024)).

3.1.4.4 Pregnant people

Pregnant people are more susceptible to heat-related illness because of pregnancy-induced changes to thermoregulation, including increased weight gain, which may make it harder to release heat, and heat production by the developing fetus (S. Sun et al., 2019). Heat exposure may also lead to pre-term birth, reduced birth weight, and still birth (Bekkar et al., 2020), as noted in Section 3.1.2. Pregnant people who work outdoors, work in un-air-conditioned environments or lack access to home cooling are likely most at risk (Qu et al., 2021). A recent study in New York State found associations between extreme heat and increased ED visits for a number pregnancy complications, including threatened/spontaneous abortion, renal diseases, infectious diseases, diabetes, and hypertension, with effects strongest among Black and low-income residents (Qu et al., 2021).

3.1.4.5 People experiencing homelessness

People experiencing homelessness may be at a high risk for exposure to extreme heat, especially in urban areas due to increased heat exposure from the urban heat island effect. It is unclear how well heat alert messages reach unhoused populations and how they are perceived (Bezgrebelna et al., 2021). Unhoused populations have fewer financial resources, resulting in reduced ability to address health conditions that can contribute to heat susceptibility (Bezgrebelna et al., 2021). A limitation of heat-related illness and death data for this population is that denominators and standard, consistent definitions for people experiencing homelessness are not available to compute absolute rates or relative risks. In NYC, between 2000 and 2011, people experiencing homelessness accounted for an estimated 5%, 3%, and <1% of heat stress deaths and heat-related illness hospital admissions and ED visits, respectively (Wheeler et al., 2013). NYC's most recent annual report on deaths among people experiencing homelessness showed a more than threefold rise in deaths from fiscal years 2018 to 2022, with drug-related deaths increasing most rapidly (NYC Department of Health and Mental Hygiene, 2023). While this report does not examine excess mortality associated with hot weather in this population, it may have risen substantially given the increase in people experiencing homelessness in the city (Brand, 2022; Newman, 2023), and the lack of access to cooling among unsheltered homeless people. Other studies show an association between heat and natural cause and drug overdose deaths in NYC (Bohnert et al., 2010; City of New York Department of Health and Mental Hygiene, 2022b) and with injury deaths nationally (Parks et al., 2020). Exposure to cold temperatures, however, still presents a larger risk in NYC for people experiencing homelessness. Cold exposure was the second most common external cause of death (19 deaths, 4 % of the total) among New Yorkers experiencing homelessness in FY 2022 (NYC Department of Health and Mental Hygiene, 2023).

3.1.4.6 Incarcerated people

In NYC, incarcerated people are exposed to unhealthy hot and cold indoor conditions due to a lack of federal, state, and local protections against dangerous indoor temperatures (Correal, 2019; Donavan, 2021, 2022; Holt, 2015; The Intercept, 2022). Thermal conditions inside these facilities are also a racial justice issue - incarcerated people in NYC and across the US are disproportionately Black or Brown due to a long and ongoing legacy of racist criminal justice practices (Bailey et al., 2017). The US prison population is also aging and has high rates of mental and physical health conditions, putting individuals at increased risk during extreme weather conditions (Holt, 2015). A recent national study found that 3-day heat waves were associated with a 7.4% increase in total mortality in US state and private prisons, with the largest regional effects in the Northeast (Skarha et al., 2023).

3.1.4.7 Occupation

Journalistic investigations of 2010-2020 Occupational Safety and Health Administration (OSHA) records reported that over 380 workers across 37 states in the U.S. died from occupational heat exposure (Shipley et al., 2021). Risk varies by occupation. The construction industry, an important employer in NYC (Jain, 2021), ranks second nationally behind agriculture in the rate of heat-related death (Gubernot et al., 2015). Deaths directly attributed to occupational heat stress are relatively infrequent among NYC construction workers (Toprani et al., 2017), though heat stress may indirectly contribute to other more common fatal construction injuries, such as falls (Gubernot et al., 2014), which accounted for 58% of the 144 construction worker deaths in NYC from 2007-2014 (Toprani et al., 2017).

A meta-analysis of international studies of occupational injury due to heat exposure from 2004 to 2020 found that there was sufficient evidence for a 1% increased risk of occupational injury for every 1°C (1.8°F) temperature increase compared to a regional reference temperature and limited evidence of a 17% higher risk during heatwaves, with the highest occupational injury risk in humid subtropical climates like that of NYC (Fatima et al., 2021). Research suggests that people are comfortable and productive at stable temperatures between 20°C and 25°C (68°F and 77°F) (de Dear & Schiller Brager, 1998; Halawa & van Hoof, 2012). For every 1°C exceeding this range, between 25°C and 32°C (77°F and 89.6°F), work productivity decreases by 2% (Seppanen et al., 2006).

Outdoor workers and those who work in un-air-conditioned indoor spaces are at increased risk of heat exposure and illness during hot weather. Heat-related illness and death have been documented in mail and package delivery workers in the United States (Tannis, 2020). Recent media reports highlighted worker concerns about heat exposure and a lack of air conditioning in trucks and warehouses in the NYC area and across the country during the summer 2022 heatwave (Irizarry Aponte & Maldonado, 2022; Rosenberg, 2022). One source estimates that more than 2.2 million workers in New York State are in high-risk occupations for heat exposure (Constible, 2023). Professions at heightened risk of indoor heat exposure include kitchen, warehouse, and manufacturing workers (Lerardi & Pavilonis, 2020; OSHA, 2022). Workers exposed to high temperatures who wear personal protective equipment such as healthcare workers and firefighters may also be at increased risk of heat stress due to reduced ability shed excess body heat (Bose-O'Reilly et al., 2021; Coca et al., 2017; Davey et al., 2021; McLellan et al., 2013).

3.1.5 Influence of buildings and the built environment

3.1.5.1 Outdoor urban environment

NYC is experiencing higher summer temperatures because of climate change and the Urban Heat Island (UHI) effect. The UHI occurs when cities are hotter than surrounding suburban and rural areas – sometimes up to 15 to 20°F hotter.(National Oceanic and Atmospheric Administration, 2023a) The annual average magnitude of NYC's urban heat island (comparing Central Park to surrounding suburban and rural locations) has been rising gradually and has been observed to be between about 2.5 degrees centigrade (Gaffin et al., 2008). The UHI is caused by more dark paved surfaces that absorb heat, less vegetation and cooling from evaporation, more waste heat from buildings and vehicles, and less ventilation in urban canyons created by tall buildings (National Oceanic and Atmospheric Administration, 2023b). The increasing UHI may explain a third of the warming trend in NYC during last century (Gaffin et al., 2008). In NYC overnight minimum temperatures are increasing the most compared to mean and maximum daytime temperatures (City of New York Department of Health and Mental Hygiene, 2022b), as expected with UHI amplification. The physical processes influencing NYC's UHI are considered in more detail in Ortiz et al., (2024). The rest of this section addresses how the UHI and outdoor landcover influence vulnerability to heat exposure.

Higher overnight temperatures can impair sleep quality (Obradovich et al., 2017) and reduce the respite vulnerable people need to recover from heat exposure. In addition to the regional temperature gradient caused by the UHI, neighborhood environments within cities also cause variations in surface and ambient temperatures and modify the health risks of hot weather. The UHI can worsen human health risks and discomfort by locally increasing ambient temperatures during extreme heat episodes, increasing energy demand for cooling (which can lead to blackouts), and generating higher emissions of air pollutants from associated cooling energy production (United States Environmental Protection Agency, 2023d) and modify the health risks of hot weather. Greenery can decrease ambient and surface temperatures through shade and evapotranspiration. Local temperature reductions depend on the amount of space greened, however. For example, a study of overnight temperature and green space in NYC found that an association between local ambient temperature and vegetative cover was only observed where vegetative cover was 32% or greater in a 200m buffer zone around temperature monitoring sites (Johnson, Ross, et al., 2020). Forested natural areas within cities are significantly cooler than other locations, including landscaped areas under trees (Crown et al., 2023). Thus, NYCs several large urban forests in parks can provide a respite for those able to visit them because they live nearby, can reach those that are accessible by transit, or are able to drive or bike to them. Trees and other nature in locations closer to where most residences and human activity occurs in the city can provide health benefits. In addition to reducing air temperature and providing shade from radiant heat exposure, neighborhood greenspace, such as tree canopy, parks and forests, has been associated with better physical health, reduction in morbidity in some disease categories, lower levels of depression, and lower levels of stress and helps mitigate poor air quality (van Dillen et al., 2012; Yitshak-Sade et al., 2019). A greater proportion of tree and vegetative cover in a community has been associated with a reduced risk of heat-exacerbated deaths (Conlon et al., 2020; Reid et al., 2009). The intersection of the physical environment factors (i.e., lower levels of green space) with neighborhood racial composition and other social factors has been used to construct compound heat vulnerability indices, including one for NYC (Madrigano et al., 2015; Nayak et al., 2018) (Figure 5).

3.1.5.2 Indoor environments and health risks

The home is often a setting for dangerous heat exposure among vulnerable people. Those who die of heat stress in NYC are most often overcome by heat in dangerously hot homes (City of New York Department of Health and Mental Hygiene, 2022b). In addition, heat-exacerbated deaths occur more often at home than in hospitals or other institutions (Madrigano et al., 2015). Although place of exposure is not consistently recorded, exposure at home is also the most reported setting for NYC heat-related illness hospital admissions (Wheeler et al., 2013). Vulnerable

New Yorkers most often stay home during hot weather, even if they are unable to stay cool because of a lack of air conditioning (Lane et al., 2014).

In NYC homes without air conditioning, it can be up to 10°F hotter indoors than outdoors (Vant-Hull et al., 2018). Warm indoor conditions in homes without AC can persist for up to 3 days after the temperatures have cooled off outside following extreme heat (Vant-Hull et al., 2018) due to thermal inertia of the buildings and lack of cross ventilation. This may play a role in the delayed effects of up to 3 days documented in studies of NYC heat-exacerbated deaths (Matte et al., 2016; Metzger et al., 2010a). Elevated indoor temperatures also play a role in deaths and illnesses that occur when the outdoor temperature is moderately hot but not extreme. Higher indoor temperatures during the summer season can also interfere with sleep quantity and quality (Minor et al., 2022; Quinn & Shaman, 2017), which could exacerbate mental health conditions associated with hot weather (Lõhmus, 2018).

National studies have documented declines in excess mortality that occurred as residential air conditioning increased from 10% in 1960 to nearly 90% nationally by 2004 (Barreca et al., 2013). In NYC during the latter part of the 20th century, there was a substantial decline in excess mortality associated with higher temperature during the warm season (Petkova, Gasparrini, et al., 2014). Analyses of data from 1971 to 2020 showed that heat-exacerbated mortality in NYC decreased until 2000, and then plateaued until 2010. Heat-related mortality rates have begun to increase in the recent decade as NYC warm season temperatures have risen and residential air conditioning rates citywide have remained flat (City of New York Department of Health and Mental Hygiene, 2022b). While more than 90% of NYC Households now have air conditioning, the proportions without access vary more than four-fold across neighborhoods (City of New York Department of Health and Mental Hygiene, 2022g). People with lower incomes and Black New Yorkers are less likely to have access to home air conditioning (Madrigano et al., 2018). Racial disparities in central air conditioning prevalence across four other northern US cities explain some of the racial differences in heat-related mortality (O'Neill et al., 2005). Adaptive and maladaptive uses of mechanical cooling in New York City are addressed in NPCC4, Balk et al. (2024).

Increased heat directly impacts thermal conditions in indoor environments, particularly in the absence of air conditioning (Climate Central, 2021; National Oceanic and Atmospheric Administration, 2023b). In a study in NYC, apartments without AC on upper floors receiving direct sunlight with southern exposures were warmer (Vant-Hull et al., 2018). The facades of the building and building albedo affect the heat absorption in a building (Bulkeley et al., 2011; Latha et al., 2015), as does insulation. Some building types and materials require more energy to cool interiors and heat up more rapidly without air conditioning. For example, all-glass high rises and pre-2000 high-rise buildings tend to heat more rapidly during power outages (Porritt et al., 2012; White-Newsome et al., 2012).

3.1.5.3 Neighborhood-level vulnerability

Heat risk is not distributed uniformly across NYC neighborhoods. The city's Heat Vulnerability Index (Figure 5) is a composite measure of social and environmental factors used to identify neighborhoods that are at increased risk of heat-exacerbated mortality during hot weather (City of New York Department of Health and Mental Hygiene, 2022f, 2023f). Components are derived from an epidemiologic study of heat mortality in NYC (Madrigano et al., 2015) and has been validated to show that higher HVI levels are associated with greater heat-exacerbated excess mortality. Components include measures of surface temperature, green space, residential air conditioning prevalence, median income, and the percent of Black New Yorkers, the population most impacted by heat mortality in NYC due to persistent structural racism, described in section 3.1.4.1 above.

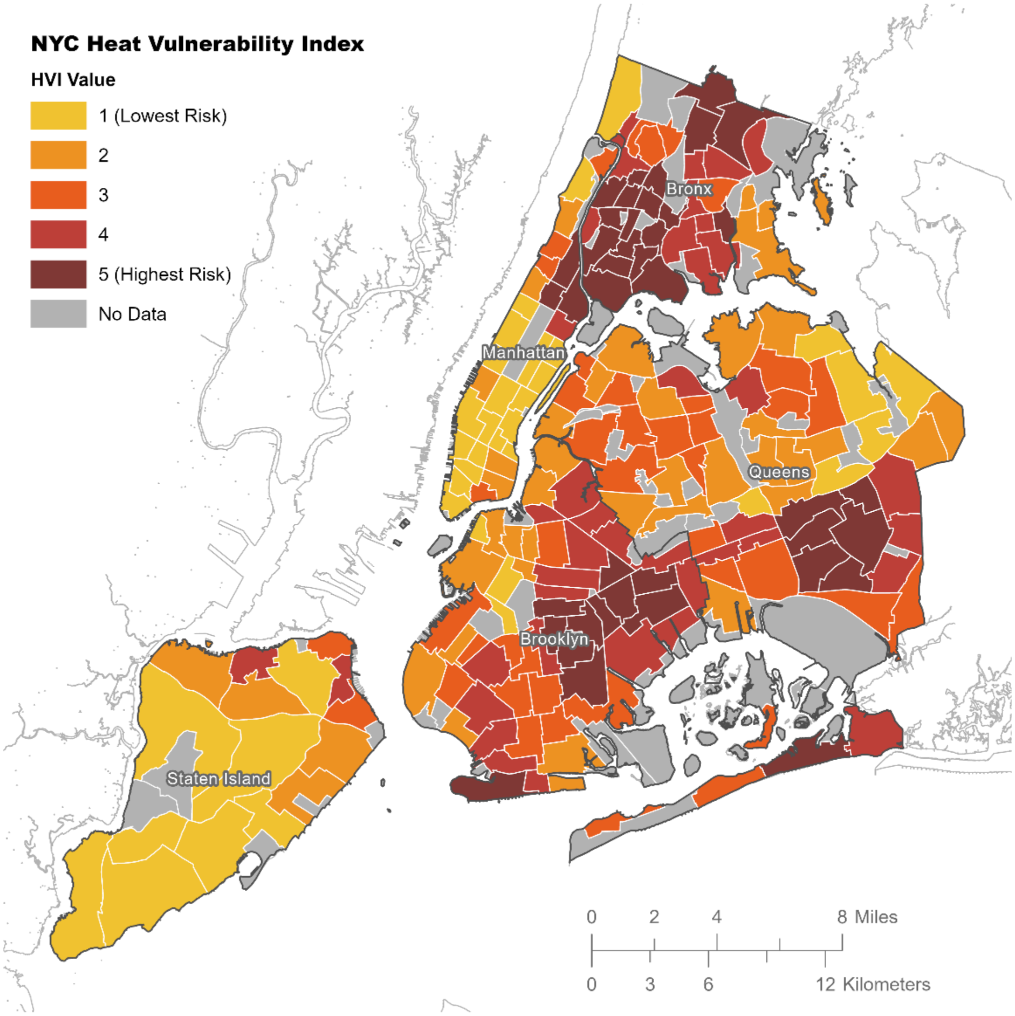


Figure 5: The Heat Vulnerability Index (HVI) for New York City identifies neighborhoods where the risk of death associated with extreme heat episodes is higher. It uses a statistical model based on surface temperature, green space, access to home air conditioning, a measure of home income, and racial-ethnic composition – all at the Neighborhood Tabulation Area (NTA) level. It was adapted and updated from an earlier epidemiologic study (Madrigano et al., 2015). Data Source: (City of New York Department of Health and Mental Hygiene, 2023f)

3.2 Flooding

3.2.1 Synopsis of NPCC2 health assessment

The NPCC2 2015 report was the last detailed assessment of public health risks of flooding in New York City (Kinney et al., 2015). Coastal storms and flooding were identified as principal climate-health hazards, along with extreme heat. Following the devastating impact of Post-Tropical Cyclone Sandy (also sometimes referred to as "Hurricane Sandy," "Superstorm Sandy," or "Sandy"), NPCC2 focused on health impacts of storm surge flooding as well as other coastal storm risks related to wind and evacuation. The Post-Tropical Cyclone Sandy experience showed how health vulnerabilities from floods are "magnified when critical infrastructure is compromised" and storm surge-related health risks are compounded by sea level rise and more intense storms.

Drawing on then-available studies of impacts of Sandy and other coastal storms, such as Hurricane Katrina, the NPCC2 identified seven causal pathways for health impacts from flooding: 1) direct impact phase injuries and deaths such as from immersion, moving debris, or electrocution, 2) evacuation risks, 3) secondary hazards from utility outages, 4) exposure to contaminants or mold from floodwater or water damage, 5) displacement and disruption of services and access to care, 6) stress, trauma, and other mental health impacts, and 7) cleanup and recovery health and safety risks. These same health impact pathways apply to all types of flooding, though their relative importance will vary by type. See Figure 6.

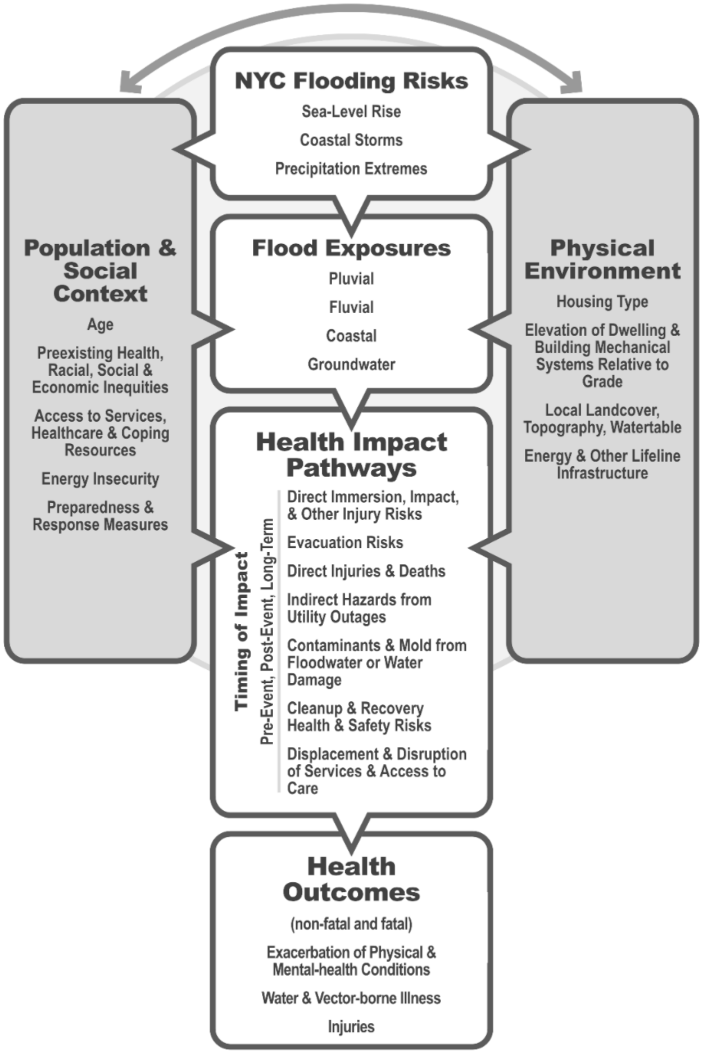


Figure 6: Flooding health impact pathways and vulnerabilities. Framework adapted from Chapter 1, Figure 14.1 in Introduction: Climate change and human health. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment (Balbus et al., 2016).

3.2.2 Recent and projected NYC flood risks

3.2.2.1 Pluvial and fluvial flooding and health

Despite predictions of increasing extreme precipitation events, the 2015 NPCC2 public health report stated, based on experience at that time, that in contrast to Post-Tropical Cyclone Sandy's deadly surge, extreme rain flash flooding was "not a major threat to life safety" in NYC. Hindsight has shown this to be incorrect. Cloudburst events that can cause pluvial (rainfall) flooding continue to grow in magnitude (Huang et al., 2017), and the NPCC3 noted increasing observed precipitation trends that tracked NPCC2 projections while recommending research and NYC-commissioned studies of heavy rainfall levels that could cause severe flooding in NYC (New York City Panel on Climate Change, 2019). Following those recommendations, the NYC Stormwater Resiliency Plan (SRP) and an associated study identified areas of inland flooding from heavy rain (City of New York Department of Environmental Protection, 2022a). NYC had long been under an EPA Clean Water Act mandate to reduce combined sewer overflows (CSOs) that occur during heavy precipitation. The SRP understandably focused on bolstering green and built infrastructure measures for CSO prevention as well as property protection – noting an 80% reduction in CSOs since the 1960s. Thus, efforts to understand and plan for extreme precipitation (pluvial) flooding in NYC came before the lethal risk of cloudburst events was made clear (City of New York Office of the Deputy Mayor for Administration, 2021). As recently as September 29, 2023, unexpected widespread flooding associated with a stalled Tropical Storm dropped over 8 inches of rainfall on JFK Airport, exposing the city's risk of inundation from even indirect storm hits. This emphasizes the benefits of addressing basement apartment vulnerability as part of the city's overall affordable housing efforts and expanding efforts to flood-harden subways beyond coastal surge areas. A detailed discussion of flooding relevant to NYC is presented in NPCC4, Rosenzweig et al. (Rosenzweig et al., 2024) and general flooding-related definitions and terms are included in this assessment's companion glossary. The topics of changes in the public right of way and the importance of acknowledging flood risks to drivers are also mentioned in NPCC4, Balk et al., (2024).

Events since 2015 and the climate and flooding assessments covered in NPCC4, Braneon et al., (2024) and NPCC4, Rosenzweig et al., (2024) have made it clear that life safety and other public health risks for New Yorkers are not limited to flooding from coastal storms. Pluvial (rain-related), fluvial (from rivers and streams), and groundwater flooding hazards also threaten NYC. However, FEMA's Special Flood Hazard Area maps are based only on fluvial and coastal surface water body flooding, and do not consider pluvial or groundwater flooding, both important in NYC (See NPCC4, Rosenzweig et al. (Rosenzweig et al., 2024), Key Message 2).

The potential for cloudburst events to cause deadly pluvial flooding was made clear by Tropical Storm Elsa, in July 2021, and the Ida Remnants Cloudburst (also sometimes referred to as "Hurricane Ida," or "Ida") in September 2021. Heavy rain from Elsa flooded NYC subways and streets, requiring rescue workers to intervene to assist people trapped in below grade dwellings and other low-lying areas that were inundated in that event. Ida's unprecedented 3 or more inches of rainfall in one hour in some neighborhoods warranted NYC's first flash flood emergency in the city's history. Storm sewers were quickly overwhelmed in parts of the city. The rapid onset, extensive flooding of roads and below-grade spaces of inland areas outside established flood plains caused numerous drowning deaths among residents trapped in basement apartments in NYC and in their cars in New Jersey (Rosenzweig et al., 2024, tbl. 2).

Fluvial flooding occurs when a river, creek, or stream stage exceeds the elevation of its banks. Streams across most]of NYC's inland areas have been filled over time, with most surface water flow now redirected to subsurface stormwater sewers. Only a few freshwater stream channels and small inland creeks remain in NYC (Rosenzweig et al., 2024). There are relatively limited areas in NYC with high fluvial flood vulnerability (Rosenzweig et al., 2024, fig. 12). Current understanding of fluvial flood risks and projected future changes are limited by the shortage of stream gauges in the city, but FEMA does include fluvial flood hazard, along with coastal flooding, in the modeling to develop its Special Flood Hazard Area maps.(City of New York Department of Environmental Protection, 2023a)

3.2.2.2 Coastal flooding and health

While future risks are difficult to quantify, coastal flooding is very likely to increase in frequency, extent, and height because of climate change and other factors covered in depth elsewhere in this assessment (see Braneon et al., 2024; Ortiz et al., 2024; Rosenzweig et al., 2024).

Sea level rise increases the range of coastal flooding and introduces lingering effects as areas of New York become increasingly uninhabitable due to chronic flooding, potentially decreasing the available housing stock and increasing the mental stress of unplanned as well as planned relocation. There are interactions between coastal sea level rise and groundwater flooding, and these complex saline-freshwater systems can be further affected by increases in annual precipitation, or subterranean drainage and sewer infrastructure (Rosenzweig et al., 2024). In addition to these interacting coastal flooding risks, recurrent tidal flooding is now a regular occurrence in low lying coastal areas such as Edgemere in Queens. Nationally, the National Oceanic and Atmospheric Administration (NOAA) identified a 200% increase in high tide flood days from 2000 through 2021 and projected average high tide flooding by 2050 to occur on 45-70 days per year (National Oceanic and Atmospheric Administration, 2022). Social and economic risks include loss of neighborhood functions such as shared beaches or piers that support community cohesion and recreation, and loss of housing, businesses, and associated revenues. Notably, flood insurance claims are paid for damages to communities impacted by recurrent overland tidal flooding that affects two or more acres, or two or more properties, but the National Flood Insurance Program (NFIP) doesn't cover flooding due to groundwater entering a basement, or for backups of sewer systems (Federal Emergency Management Agency, 2023a). These flood events can be insured against through purchase of a rider often referred to as a basement backup or sewer backup rider on homeowners' insurance policies.

Prior to coastal storm landfall, evacuation can disrupt health care, increase stress, and create other health risks, especially for the most vulnerable people, such as those dependent on dialysis or other types of frequent health services. While long-range weather forecasting improves awareness of incoming storms and increases the lead time available to prepare, resident preparedness does not necessarily increase, particularly for those with fewer resources or fewer alternatives (Rao et al., 2023). Immediate event-phase health effects include fatal injuries, especially from immersion (drowning) and blunt trauma (from flood debris). During the post-storm phase, health risks persist as residents deal with flooded properties and struggle with access to basic services such as power and transportation. Additional post-storm health risks can arise from exposures to insect disease vectors, water-borne pathogens in floodwaters and from sewage backups and overflows, construction-related hazards, as well as exposure to various hazardous materials and toxic chemicals. Long-term health effects can include chronic physical and mental stress from property and monetary loss, displacement from neighborhoods, social networks and services, and interruption of health care.

3.2.2.3 Groundwater and health

Rising groundwater threatens to flood structures in a number of areas in NYC, particularly in eastern Brooklyn and southern Queens (Rosenzweig et al., 2024), and especially below-grade spaces. Groundwater was pumped for drinking water in parts of southeastern Queens until 2007, but has not been used since then (City of New York Department of Environmental Protection, 2023a). Intrusion from rising or fluctuating underground water levels during especially wet seasons can cause flooding that damages sanitary infrastructure and mobilizes subsurface sources of waterborne pathogens or chemical contaminants. Groundwater flooding can also compromise building and underground infrastructure stability, and can threaten ecosystems (Semenza, 2020). While globally the greatest health-related threat from groundwater relates to arsenic contamination of drinking water systems, NYC's drinking water comes from upstate surface reservoirs, and as a result, arsenic is not detected in NYC drinking water (City of New York Department of Health and Mental Hygiene, 2023e).

3.2.2.4 Compound flooding

Climate change will likely increase risks and health impacts from all four types of flooding under consideration, and from their co-occurrence. Compound flooding (the co-occurrence of coastal, fluvial, pluvial, and/or groundwater) is not well understood due to limitations in modeling and less available research on household or individual health impacts of compound flooding as compared to singular types of flooding. A 2021 study compared various types of flooding to household outcomes, noting significant differences in financial, psychological and physical impacts and resulting coping and preparatory measures (Thieken et al., 2021). While the NYC VIA Team is currently analyzing compound flooding (Rosenzweig et al., 2024, sec. 8), compound flood-related health impacts are not part of the VIA analysis, leaving questions as to impacts of various combinations of flooding types to New Yorkers. Compound flooding impacts are also not included in current FEMA flood maps, which do not consider pluvial or groundwater flood risks.

3.2.3 Updated flooding-health epidemiology evidence

3.2.3.1 Flood event phases and health-relevant exposure pathways

There are multiple possible pathways that can result in flood-related adverse health impacts. The various phases of flooding events – pre-event, event phase, and post-event – are each associated with different pathways of potential disruptions and harms (Parks et al., 2021, 2022), depending in part on the cause of flooding and associated hazards, such as high winds. Because of this complexity, as with heat waves, the complete health toll from flooding cannot be fully ascertained by immediately-available reports of injuries or deaths. Recent excess mortality studies have revealed a much greater toll (Parks et al., 2023) and still more health impacts can be experienced months later by those relocated to far off communities. As with all climate-health risks, pre-existing factors increase vulnerability, including health, socio-demographic, and environmental factors. The following sections describe these overlapping flood phase-related pathways and pre-existing vulnerability factors.

3.2.3.2 Pre-event phase pathways

Emergency Preparation and Evacuation: Pre-event health risks relate to the extent to which New Yorkers have awareness of impending events and readiness to prepare themselves or have the ability and means to evacuate to a safe shelter. Emergency preparation could occur through multiple methods, including cell phone alerts, e-mail notifications, signage, and increasingly, clinical settings (Angelini, 2017; Madrigano et al., 2018; Patz et al., 2014; Trombley et al., 2017). Social media posts also have value, particularly when they permit two-way communication between authority and respondent and provide information on who evacuated or is in the process of doing so (Jaeger et al., 2008; Y. J. Liu & Fraustino, 2012; Wang & Zhuang, 2017). However, the decision to evacuate is a complex one, even under an evacuation order (S. Brown & Parton, 2014). While awareness of evacuation zones may positively correlate with evacuation behavior, exposure to prior alerts that over- or under-estimated the severity of a storm may also impact the decision to evacuate (Rao et al., 2023). The issue of language equity can exacerbate preparedness challenges faced by low English proficiency communities (Venkatraman, 2022).

Insurance and Housing: Many people living in flood prone areas remain uninsured from flood losses. After Post-Tropical Cyclone Sandy, it was estimated that infrastructure damages cost at least $19 billion (City of New York

Office of the Mayor, 2013). Just over half of the 1-4 family homes in the high-risk zone were insured when Sandy hit NYC (Dixon et al., 2013; Limaye et al., 2019). Moreover, even with recent changes to more risk-based pricing of insurance coverage under the National Flood Insurance Program (NFIP), some residents are unable to afford premiums (Dixon et al., 2013; Federal Emergency Management Agency (FEMA), 2022; Natural Resources Defense Council, 2023). Also, residents outside of FEMA designated floodplains may not recognize their flood risks and may not choose to insure for flooding. Most tools show coastal flooding risk but are not clear enough about the types of flooding not shown, leading to a false sense of security about flood risks (Pasternack, 2023). Even when risks are known, residents may have few choices given housing availability and affordability (Limaye et al., 2019; Madajewicz, 2020). Moreover, while NFIP is available to owners and renters, the risks they face may be different. Flood risk disclosure legislation and planned voluntary housing mobility programs may help alleviate this challenge (City of New York Office of the Mayor, 2023a; State of New York, 2021). In 2022, statewide legislation was enacted that requires landlords to disclose past flood damages and risks to renters (Scata, 2022)); in 2023, similar legislation was passed for home buyers. See NPCC4, Rosenzweig et al.,(2024) for more details on flood vulnerability.

3.2.3.3 Event phase pathways

Event phase pathways include direct exposure to fatal and non-fatal immersion, wind-blown debris, and electrocution from downed and submerged power lines. Emergency communications, system failure, access to care, and short-term displacement, and affordable housing shortages contribute to this pathway.

Direct injury risks: Paterson et al. (2018) note that drowning is the most immediate cause of death from flooding particularly among men who may have greater risk-taking behaviors. Among direct injury deaths in NYC due to Sandy, about 70% were drownings; among those who drowned at home, at least 30% (9 people) were found in basements or lived in basement apartments (Seil et al., 2016). Paterson et al.(Paterson et al., 2018) also identify expected acute events such as orthopedic injuries and lacerations, and unexpected ones such as burns from flammable liquids spreading on the surface of floodwaters. Chronic health conditions may also worsen with flooding due to noncompliance with medication from interruption to availability, challenges accessing care, and the physical workload of recovery. For example, mortality rates in those with cardiovascular disease and diabetes may increase. Paterson et al. (Paterson et al., 2018) also identify increases in acute events in those with chronic respiratory diseases due to disrupted maintenance therapy, loss of power to life-saving medical devices, reduced glycemic control, reduced physical activity, poorer nutrition and disrupted treatment leading to increased risks of ketoacidosis and death. Among older adults in nearby New Jersey, ED visits during Sandy increased for the injuries already mentioned as well as a range of other ailments (McQuade et al., 2018).

The majority of the Ida Remnants Cloudburst deaths in NYC resulted from drowning in basement apartments (City of New York Office of Management and Budget, 2023; City of New York Office of the Deputy Mayor for Administration, 2021; Yuan et al., 2024). These tragic deaths revealed the need to evaluate risk based on locations within buildings, with heightened risks to those on lower floors with greater exposure to floodwaters. This is further explored in Rosenzweig et al., (2024) and in the NYC *Flood Vulnerability Index* (FVI) developed in the NYC *Climate Vulnerability, Impact, and Adaptation Analysis* (VIA) (McPhearson et al., 2024). Additionally, the loss of life from Ida brought into sharp relief how NYC's climate vulnerability is increased by its scarcity of affordable housing, which has long caused households to live in illegal basement dwellings that don't meet building codes for safety (Regional Plan Association, 2022). While any lower level could be suddenly inundated by pluvial flooding, those that lack emergency exits or fail to meet other life safety measures increase occupant risks (Afridi & Morris, 2021; FEMA, 2023; Hornbach et al., 2022; Negret, 2021; Pratt Center for Community Development, 2008).

Emergency Communications: Surveys conducted by Yong (2017) and Kreslake (2019) provide insight into opportunities for improving emergency communication by surveying some of the most vulnerable populations on their risk perception and disaster preparedness. Black, Hispanic, and lower-income households placed a strong importance on receiving high-quality information and assistance from the government during a flood disaster as well as on policies to both reduce emissions and pollution and offer rebates and loans to add cooling roofs and other interventions (Kreslake, 2019). Importantly, given the diversity of NYC, providing information in multiple languages and via trusted community-based organizations, particularly for immigrant populations, is key. In Yong's survey, risk perceptions and "societal trust" were found to differ between Canadian-born and immigrant populations in Canada, affecting emergency preparedness positively and negatively, respectively (Yong, 2017).

Systems Failure: The Ida Remnants Cloudburst resulted in MTA and roadway flooding, impacting resident access to home or work. Interruptions to transportation systems in turn introduces challenges to those dependent on others to provide daily support, such as home health workers or home food and pharmacy delivery. In 2012, Sandy led to widespread and lengthy power outages. Health effects of power outages are discussed in NPCC4, Yoon et al. (2024).

Access to Care: Access to emergency care is limited during flood events. Some emergency responders may not be able to travel to emergency rooms or to access New Yorkers in need, for example, when flooded streets cannot be traversed by ambulances. People dependent on buses or subways to access care are similarly challenged. Pharmacies may not be open and healthcare facilities may be unable to serve patients with standing appointments for dialysis and other procedures or types of visits. Healthcare workers may be unable to get to their designated facilities, resulting in staffing shortages. Simultaneously, hospital admissions may increase, particularly for geriatric patients, as evidenced following Post-Tropical Cyclone Sandy (Gotanda et al., 2015; Tarbochia-Gast et al., 2022).

3.2.3.4 Post-event and recovery phase pathways and health impacts

Post-event and recovery phase pathways and health impacts include greater potential exposure to (a) water- and vector-borne illness, (b) aeroallergens as well as (c) other harmful exposures (d) adverse birth outcomes, I stress, fatigue, and mental health burdens due to flood-related destruction of homes and interruptions to workplaces (Alleyne et al., 2021; Bloom et al., 2016). NYC health risks from aeroallergens and water- or vector-borne illnesses are considered later in this chapter. After tropical cyclones, increased hospitalizations from respiratory diseases, infectious and parasitic diseases, and injuries have been observed, along with higher death rates from these as well as neuropsychiatric conditions (Parks et al., 2021, 2022). In addition, the flood recovery phase introduces (f) access to care challenges, (g) building repair risks, and (h) long-term displacement risks. A recent systematic assessment identified the need for "research on disability, chronic disease, relocation populations, and social interventions (NYC Department of Environmental Protection, 2022; Trombley et al., 2017). Workers involved in clean up and recovery are also at greater risk (A. Brown, 2022).

Water-Borne Illness: Increasing temperatures can contribute to the types of more intense rainfall-flooding events described earlier, with associated potential for contact with enteric pathogens (Semenza, 2020) in floodwater or surface water contamination from combined sewer overflows. Nationally, tropical cyclones are associated with an increased risk of several waterborne infectious diseases, lasting days to weeks (Lynch & Shaman, 2023). A fuller consideration of climate change related exposure to pathogens, other contaminants in water and human illness is in section 3.6.

Vector-Borne Illness: While vector-borne illnesses can increase alongside increased mosquito breeding areas following flood events, for some mosquito vector species, flooding can also wash away preferred habitat and breeding sites, helping to reduce vector populations. The relation of flooding to these illnesses is complex, geographically varied, and depends on vector species (see Vector-Borne Pathogens section 3.4 of this chapter). As New York experiences more flood events and as temperatures continue to rise, mosquito breeding is expected to increase and in turn generate increases in West Nile virus (City of New York Department of Health and Mental Hygiene, 2022l).

Other Harmful Exposures: Cleanup of flooded properties can expose residents and workers to mold from water damage (see section 3.4.2) and to hazardous materials including asbestos or toxic chemicals (Smalling et al., 2016) as well as increase risks of electrocution (Yari et al., 2020). Tree removal workers without training in flood cleanup are at greater risk of injury (Ochsner et al., 2018). Construction may pose hazards including exposure to sharp or heavy objects as well as dust. Moreover, when power outages require residents to use alternative power supplies, carbon monoxide poisoning increases (Schnall et al., 2017).

Birth Outcomes: A systematic review of research on flood impacts on pregnancy outcomes found increases in the prevalence of low birth weight and gestational hypertension, but no significant differences in preterm birth rates (Partash et al., 2022). Power outages associated with Sandy in eight NY state counties increased the number of ED visits for several pregnancy complications, especially among young, Black, Hispanic, and uninsured individuals (Xiao et al., 2021). A focused study of pregnancy outcomes following Hurricane Harvey in Texas showed significantly higher likelihood for adverse outcomes (Mendez-Figueroa et al., 2019). Another analysis of birth records in Texas showed coastal storms during pregnancy were associated with an increased risk of labor complications. The authors hypothesize, however, that associations with low birth weight and gestation found in other studies may be an artifact of the method used to define pregnancy interval (Currie & Rossin-Slater, 2013).

Stress, Fatigue, and Mental Health: Chronic flooding and the challenges of being in continuous recovery mode increase stress. Causes range from the stress of displacement (such as from flooded basement apartments to emergency or temporary housing), from the loss of property/assets, to increased financial burdens for recovery costs or wage losses, which in turn exacerbate mental health challenges for some, and introduce new challenges for others. Stressful conditions have been linked to increased cognitive risks (Zuelsdorff & Limaye, 2023). Increasing frequency of flood events fatigues already overworked health service providers and EMS teams. The loss of sense of home as a safe haven is an emerging area of pediatric research (Mort et al., 2018). Following Hurricane Harvey impacting Houston, mental health symptoms consistent with post-traumatic stress disorder (PTSD) were associated with those experiencing impacts to their properties, including displacement and exposure to contaminated floodwater (Li et al., 2021). A more recent analysis of crisis help-seeking in Louisiana before and after Hurricane Ida showed an increase in crisis texts as documented by crisis counseling services including "thoughts of suicide, stress/anxiety, and bereavement, in the four-week, three-month, and four-month post impact period (Wertis et al., 2023)."

Short- and Long-term Damage and Displacement Risks: Short- and long-term loss of housing such as those immediately homeless following Post-Tropical Cyclone Sandy and the Ida Remnants Cloudburst amplifies the ongoing shortage of affordable housing in NYC. With many affordable units being at or below grade, flooding frequently destroys the unit with recovery requiring full remediation before occupants return home. Short-term displacement also impacts the ability to access transit to jobs, resulting in less earnings, or loss of jobs due to absences. More broadly, children who were evacuated are susceptible to a range of mental health symptoms related to their unique relationship to place and time and the disruption of friend networks (Mort et al., 2018). How inequities shape displacement risk is considered more fully in NPCC4, Foster et al. (2024).

Those displaced may face extended recovery timeframes, furthering the financial burden. Damage to neighborhood health care facilities, schools, and other services can further threaten physical and mental health among people remaining in their homes and/or faced with displacement and contemplating relocation. Relocation may impact access to jobs, schools, or childcare or may require greater portions of income for better quality housing, such units on higher floors. Continuity of health care services can be compromised when people needing ongoing care must relocate or neighborhood facilities close. Following Post-Tropical Cyclone Sandy, increases in emergency department, inpatient, and outpatient mental health visits, especially for Medicaid patients, were redistributed to facilities outside the catchment area of two hospitals which closed because of storm damage (Hall et al., 2016). Emergency planning that includes pets and companion animals during disasters is important to limit occurrences of trauma among people forced to abandon their pets, or who refuse to evacuate rather than leave their animals (Chadwin, 2017).

Following Ida, the city identified the need for evacuation measures and communications to those living in basement and ground level apartments (City of New York Office of the Deputy Mayor for Administration, 2021). However, the city has few resources to support evacuations during cloudburst events (such as consistent neighborhood-based shelters prepared to mobilize in advance) (New York City Housing Authority, 2022). Given estimates of over 100,000 basement apartments across NYC (City of New York Housing Preservation and Development, 2022b, 2022a), the scale of need extends well beyond available resources. In 2022, the NYC Comptroller released a new report, *Bringing Basement Apartments into the Light*, which called for establishing a Basement Board to provide basic rights, responsibilities, and protections for basement apartment residents and owners. Moreover, the NYC Department of Environmental Protection (DEP) is attempting to better understand cloudburst flooding and its impacts in different boroughs, but does not have detailed basement apartment locations (Hornbach et al., 2022).

3.2.4 Pre-existing factors that impact flood vulnerability (health, socio-demographic, and physical environment factors)

A range of pre-existing factors can increase people's vulnerability to flood risks. Factors include health (for example, chronic physical and mental illnesses), socio-demographics (age, poverty, and race, among others), and physical environment (such as the type of residential dwelling structure). These factors can increase vulnerability across all or multiple flood event phases; and people are often affected by more than one pre-existing flood vulnerability.

3.2.4.1 Pre-existing factors that impact vulnerability - mental and physical health

Preexisting mental health conditions, including depression, PTSD, and substance dependence, have been identified as potentially increasing susceptibility to harm from flooding. Similarly, multiple indicators of chronic physical illness, such as cardiovascular disease, cancer, end-stage renal disease, and being immunocompromised may make people more sensitive to the consequences of flooding, such as prolonged power outage, water contamination, living in congregate shelters and displacement (Lane et al., 2013; Lempert & Kopp, 2013).

3.2.4.2 Pre-existing factors that impact vulnerability – socio-demographic and physical environment

Household Location: Household location is a significant determinant of flood exposure. Households with proximity to the coastal areas, to riverine areas, or to low-lying areas of NYC, have more direct exposure to floodwaters. One of NYC's biggest challenges is its sizable building stock of structures built prior to 1983 when Flood Insurance Rate Maps (FIRMs) were first enacted (City of New York, 2022). Older buildings are frequently challenging to retrofit to accommodate today's changing, climate change-fueled environmental conditions. However, there are few resources available to help residents understand these inherent risks (see Rosenzweig et al., 2024 for flood vulnerabilities in NYC). As noted earlier and discussed in detail in the Rosenzweig et al., (2024), FEMA Flood Insurance Maps do not currently identify places at risk of pluvial or groundwater flooding. Also, as recent cloudburst events and recent flooding from high groundwater have shown, additional areas throughout the boroughs have flood exposures. The Ida Remnants Cloudburst showed that location in a designated flood hazard area is not the only indicator of actual flooding risk: below-grade areas not yet mapped as such proved to be at heightened risk of flooding. Moreover, with long-term sea level rise, some households are in places that will be subject to permanent inundation, such as in Edgemere, Broad Channel, and Old Howard Beach, Queens. RISE Rockaway and The Nature Conservancy are currently working with residents of Edgemere to develop more community awareness of long-term sea level rise and a shared community vision for Edgemere's future (City of New York Department of Housing Preservation and Development, 2017; Seip, 2022). Particular flooding risks and vulnerabilities occur among mobile homes, which tend to be located in flood plains (Smith, 2022). While only one mobile home park is currently in NYC on Staten Island, mobile homes could come under consideration as a future strategy to expand affordable housing stock, making their over-representation in National Flood Insurance Policy claims more locally relevant (Porpora, 2021).

Socio-Demographic: Demographics also correlate with certain evacuation behaviors: older adults may be less likely to evacuate, while higher-income, white, and female populations may be more likely to evacuate (R. R. Thompson et al., 2017). Many public housing participants in a survey about evacuation behavior did not leave their residences for reasons related to health, responsibility for the care of another family member or neighbor, and distrust of government services and support (Hernández et al., 2018). Post-Tropical Cyclone Sandy revealed more about those populations who are more sensitive to the consequences of flooding, particularly for recent immigrants lacking documentation and dependent on landlords to restore their homes even as they personally lost their possessions. Similarly a disproportionate number of deaths from the Ida Remnants Cloudburst flooding occurred among recent immigrants (Lai & Fisher, 2021). People who are incarcerated, institutionalized or otherwise under government responsibility and living in congregate settings may face unique risks connected to restricted autonomy and movement, and associated vulnerability, especially if living in flood zones (A. Brown, 2022). A fuller assessment of how socio-demographic factors influence vulnerability to flooding is in NPCC4, Foster et al. (2024).

Allostatic Load: [Please refer to this assessment's companion glossary for a descriptive definition of "allostatic load" and other terms.] Multiple social vulnerabilities and chronic hardship among residents of public housing impacted by Sandy were characterized in a qualitative study as depleting the collective "resilience reserve", limiting the capacity of people to take protective measures before and after the storm impact (Guidi et al., 2021; Hernández et al., 2018). Following Post-Tropical Cyclone Sandy, the intersection of race, ethnicity, age, and economic disadvantage contributed to greater flooding exposure and post-storm persistent distress in marginalized communities (Faber, 2015).

Mobility-related Conditions: Following Post-Tropical Cyclone Sandy, people with mobility access needs, such as elderly or disabled people, were vulnerable to immediate flooding impacts, such as escaping flood waters, or longer term, such as isolation in high elevation apartments due to lasting flood-related elevator outages (Weichselbaum, 2012).

Physical Environment: Injury risks and health effects are mediated through infrastructure and building impacts, especially at home. Building typologies and household location amplify loss of life, physical harms, and chronic mental stress. Beyond the immediate health impacts stemming from compromised shelter, other conditions, such as energy insecurity, sustain exposures longer than the lifespan of the event. While energy insecurity is addressed in NPCC4, Yoon et al. (2024), the public realm, water supply, and transportation also warrant attention.

Building Typologies: The risk New Yorkers face during a flooding event, whether from storm surge like Post-Tropical Cyclone Sandy, or flash flooding, like the Ida Remnants Cloudburst, differs depending upon several factors, including the location and type of residence. Whether a resident lives in a high- or low-rise building, the risks of sheltering in place depend on the type of construction and its resilience. Multiple studies on building impact show that 1-2 story bungalows are much more likely to take the bulk of structural damage during storm and flooding events, while high-rise buildings are more structurally stable, but may lose lifeline utilities which can reduce access to life-saving medications, potable water, the ability to get and maintain food at safe temperatures, and increase exposure to heat/cold-related illness and stress (Casey-Lockyer et al., 2013; City of New York Office of the Mayor, 2013). For example, among NYC injury deaths from Post-Tropical Cyclone Sandy, drowning accounted for 70% of all deaths. In addition, 60% of NYC deaths occurred at home, and disproportionately in Staten Island where mostly low-rise, single family home neighborhoods were impacted by the storm surge (City of New York Office of the Mayor, 2013; Seil et al., 2016). Post-Sandy analysis of impacts to building stock recognized that buildings in shoreline areas receiving the brunt of the storm surge had more damage than those that did not have direct storm surge. However, building height, construction type, and age were also predictors of damage, with older and single-story light frame buildings suffering more severe damage (18% of all buildings damaged, yet 73% of structurally damaged or destroyed). High rise buildings in these same areas experienced less structural damage but lost function due to systems (mechanical and electrical) failure (City of New York Office of the Mayor, 2013, Chapter 1). Residents of both types of buildings are at risk and may be asked to evacuate or shelter-in-place, move to higher or lower ground, or a variety of other directives. A recent FEMA report series relates building characteristics, such as un-reinforced weak walls in older NYC buildings, to increased mortality risks from the Ida Remnants Cloudburst, and considers risks to life safety when cellars or basements are occupied (Federal Emergency Management Agency, 2023c).

Moreover, risk can change depending upon the type of material used in a dwelling's walls, roof, and structure. Citywide, a substantial proportion of low-rise (1-2 floors) buildings with wood frame construction were completely destroyed or rendered structurally unsound and uninhabitable by severe storm surge damage, while very few multi-story (7 or more floors) "non-combustible" steel and masonry structures sustained such damage (City of New York Office of the Mayor, 2013). On the other hand, many residents who sheltered in place or returned to mid- and high-rise residential buildings, including many public housing residents (Hernández et al., 2018), experienced other health impacts as building systems were disabled (City of New York Office of the Mayor, 2013; Lane et al., 2013). If mechanical, electrical, or plumbing (MEP) systems are damaged by flood water, elevators, power supply, heat, or water supply/toilets may be compromised. In turn exit routes may be unavailable, particularly for those who require assistance navigating stairs. Moreover, power outages may compromise residents with electrical medical devices or disable air conditioning during a combined flood/heat event, which can lead to heat stroke or other illness. The elderly and medically compromised are particularly vulnerable (Manuel, 2013). Health risks from utility outages are discussed in Yoon et al., (2024).

During cloudburst events and coastal storms, health risks are higher for those living in basement apartments and those with mobility limitations or other disabilities. A substantial number of basement apartments are often without adequate emergency exits or windows, leaving residents unable to exit during flood events (City of New York, 2022; City of New York Housing Preservation and Development, 2022a). This phenomenon is not unique to New York City; flooding in Seoul, South Korea due to record rainfall in the summer of 2022 also resulted in drowning fatalities in semi-underground apartments (Mackenzie, 2022).

Power Supply: Given that the loss of lifeline utilities is one of the largest contributing factors to ill health effects after a major storm, NYC has made efforts to improve the power resiliency of buildings. These measures include cogeneration to provide emergency power and retrofitting initiatives to increase energy-efficiency to slow down heat/cooling loss (City of New York Office of the Mayor, 2013). Similarly, NYCHA and other property owners are elevating electrical and boiler equipment above areas vulnerable to flooding (e.g. basements) (Barnes & Temko, 2022). Power supply may also impact function of elevators, which are critical to accessing high-rise apartments.

Public Realm: In parks, beaches, and surface waters around New York City contaminants from urban runoff caused by flooding can expose people using these for respite, play, and recreation (Lapointe et al., 2022), though better tools and data are needed to characterize the contaminants and human exposure.

Water Supply: There are multiple potential pathways for flooding and SLR to impact NYC drinking water supply, distribution, and quality. Sea level rise could cause salt front movement in the lower Delaware River, adding pressure to release more water from reservoirs and impairing supply (Zimmerman et al., 2019). Downpours in the watershed could increase turbidity and potentially runoff of other pollutants. Flood damage could potentially impair the integrity and function of parts of the distribution system (Zimmerman et al., 2019). Increased turbidity is often used as an indicator of increased microbial contamination, which can increase the risk of gastrointestinal illness (Graydon et al., 2022; J. Schwartz, 2000).

Transportation: NYC transportation systems, including roadways which serve as conveyances and buses and subway cars that move people, continue to be overwhelmed during cloudburst events (Short et al., 2021). Sidewalks, underpasses, subway access stairs, and tunnels continue to flood (Negret & McNulty, 2021), compromising transit and introducing toxins to riders trying to leave subways or navigate city streets. These transportation challenges further compromise New Yorkers' ability to safely move about the city and may disrupt health care services.

3.3 Air Pollution

3.3.1 Synopsis of NPCC2 assessment

The NPCC2 (Kinney et al., 2015) projected increases across the New York metropolitan region in morbidity and mortality attributable to climate change through effects on air pollution, especially increases in ground-level ozone but also from increased emissions from electric power generation for cooling during hot weather. The magnitude of projected ozone changes depended on future emissions scenarios, and the greatest increases were projected in more suburban counties outside the city (Knowlton et al., 2004). Health impacts of air pollution will continue to depend on demographic and neighborhood variation in vulnerability to air pollution, long evident within NYC, especially disparities in asthma prevalence. Also highlighted was the potential for combined health effects of heat waves and associated high ozone levels. Building-level resilience and vulnerability factors include the potential for air conditioning to reduce indoor ozone and pollen exposure and for tighter building envelopes for energy efficiency to increase exposure to some indoor allergens. Finally, black carbon in PM2.5 deposited on surfaces has the potential to accelerate both atmospheric warming by absorbing solar visible and infrared radiation in the atmosphere and snow and ice melt by darkening the surface (Kang et al., 2020; Valenzuela et al., 2017).

3.3.2 Projected climate change and influence on future air pollution exposure

Air quality is affected by local and regional emissions and by weather. For ozone, higher warm season temperatures and more long, sunny days increase its formation in the atmosphere from chemical reactions involving precursor emissions including nitrogen oxides (NOx) and volatile organic compounds (VOCs). Braneon et al., (2024) project that rising temperatures observed from 1991-2020 will continue for the next several decades. Increases in average precipitation levels are projected, but in larger amounts and with greater confidence during the winter season. Smaller increases or possibly decreases during the summer and fall may occur. Thus, weather conditions favoring ozone formation during the summer will occur more frequently in the region, with the net effect depending on trends in regional ozone precursor emissions. However, the climate change penalty to ozone air quality is an area of active research, and knowledge gaps and uncertainties remain due to complex dynamics of ozone chemistry and feedback mechanisms not accounted for in models (Fu & Tian, 2019). For example, NOx is both an important precursor and when present in high concentrations can "quench" of ozone (react chemically with it) and reduce its concentration, especially at night and during the winter. Falling NOx emissions have contributed to higher ozone concentrations during the winter and in the warm season at night (Jhun et al., 2015). Nonetheless, heat waves in NYC, which are projected by NPCC4 to increase in frequency and intensity, cause metro area increase ozone levels to exceed health advisory levels, driven in part by short term increases in local emissions of ozone precursor pollutants (K. Zhao et al., 2019).

Local and regional $PM_{2.5}$ concentrations are also influenced by weather, albeit less directly than ozone. Higher electric power demand for summer cooling can increase emissions from fossil fuel power plants – including more polluting peaker plants located within the city– -- of both primary $PM_{2.5}$ and precursors that form secondary $PM_{2.5}$. A national modeling study predicted increases in average population-weighted $PM_{2.5}$ and ozone exposures in the coming decades, but the projections varied between two climate models used and were substantially reduced when reduced emissions anticipated by 2040 were assumed rather than stable 2011 emissions (Fann et al., 2021).

Higher temperatures and drought can cause wildfires that emit large quantities of smoke $PM_{2.5}$ and other pollutants. Modeling and monitoring show a modest fraction of $PM_{2.5}$ in the region from 2005-2018 was caused by wildfire smoke, enough to cause roughly 0.3% of asthma ED visits in the Northeast. From 2005-2020, marked increases in smoke $PM_{2.5}$ levels from 2005-2020 in the Western US caused little if any increase in smoke $PM_{2.5}$ pollution in the Eastern US and New York State (Childs et al., 2022). As noted below, $PM_{2.5}$ levels in NYC continued to decline during this period, thanks to reductions in local and regional emissions (City of New York Department of Health and Mental Hygiene, 2022i).

The potential for local air quality progress to be reversed by wildfire smoke was made clear in June 2023, when smoke from wildfires in Canada caused a dramatic increase in $PM_{2.5}$ pollution levels at real-time monitors in southern Ontario, New York, and other northeast states (United States Environmental Protection Agency, 2023c). Concentrations of $PM_{2.5}$ in the NYC metro area exceeded any measured at regulatory monitors since regular measurements began in 1999 (United States Environmental Protection Agency, 2014b). State and city officials issued air quality health advisories (New York State Department of Environmental Conservation, 2023b; Notify NYC, 2023), advising that outdoor activity be limited, that masks be worn outdoors and will be distributed, and that people close windows and use air conditioning if possible. Several school districts in New York State canceled outdoor activities. The potential effectiveness and limitations of advisories and public health measures to reduce risks of acute air pollution episodes is discussed in Section 4.

3.3.2.1 Recent observed local and regional trends of key pollutants (NOx, ozone, $PM_{2.5}$)

Even as NYC temperatures have risen in recent decades (see Ortiz et al., 2024), regional emissions contributing to climate-sensitive pollutants have fallen. Across the NYC metro area, annual average $PM_{2.5}$ and nitrogen dioxide (NO_2) concentrations were more than 40% lower in 2015-2019 than in 2000-2004; the average of the fourth highest daily maximum ozone concentration (used by the EPA for regulatory purposes) fell by about 20% (United States Environmental Protection Agency, 2022b). Air quality has improved within the city as well (City of New York Department of Health and Mental Hygiene, 2022i). Because of both regulations and economic influences on fuel usage, a reduction in emissions of upwind, regional and local sources of $PM_{2.5}$ contributed to NYC $PM_{2.5}$ concentrations falling by close to 50 percent from 2002 to 2018 (Pitiranggon et al., 2021). The air quality improvement was attributable to reduced emissions from multiple sources, conversion to cleaner heating fuels in large NYC buildings, natural gas replacing coal in regional electric power generation, and reduced tailpipe emissions in trucks, buses, and passenger vehicles (Kheirbek, Haney, et al., 2014; Pitiranggon et al., 2021; Zhang et al., 2021). See also

BOX 2.

3.3.2.2 Updated health effects epidemiology

Research continues to expand the recognized health effects of air pollution beyond those long-established: exacerbation of cardiovascular disease and respiratory diseases, including asthma, and respiratory tract cancers. Because common air pollutants from fuel combustion are ubiquitous worldwide and statistical power is more limited in local studies, pooled evidence from multi-city studies and global research is increasingly used to estimate health burden and determine policy. The most recent review of global evidence on air pollution and health found sufficient evidence to quantify health impacts of $PM_{2.5}$ on birthweight, gestational age, lung cancer, COPD, lower respiratory infections, type 2 diabetes, ischemic heart disease, and stroke; and of ambient ozone pollution on COPD (Global Burden of Disease Collaborative Network, 2020). Health effects of wildfire smoke are usually studied via contributions to total ambient $PM_{2.5}$ concentrations and include exacerbation of asthma and other respiratory diseases. Other effects may include exacerbation of cardiovascular conditions, all-cause mortality, and mental health outcomes. Children, seniors, and other groups may be more vulnerable. Exposure assessment challenges and method differences are limitations in current evidence (Heaney et al., 2022; Reid et al., 2016).

Ozone has long been known to cause lung inflammation and decreased lung function, as well has exacerbating asthma and COPD, leading to hospital and emergency department visits; emerging evidence suggests ozone exposure may exacerbate diabetes and contribute to complications (United States Environmental Protection Agency, 2020). Traffic-related air pollution as indicated by exposure to NO_2 is linked not only to exacerbation of asthma, but to its onset and to impaired lung development. Growing evidence also links air pollution exposure to functional impairments and diseases affecting nearly all organ systems, neurologic and behavior disorders and cognitive function in young children and older adults (Perera & Nadeau, 2022; Shi et al., 2020). Lower birthweight and preterm delivery effects can produce lasting harm on child health and development (Global Burden of Disease Collaborative Network, 2020). A number of local studies have observed health effects in NYC, consistent with national and global evidence (e.g. Ito et al., 2011; Johnson et al., 2016; Margolis et al., 2016; Savitz et al., 2015). Health harm from air pollution occurs at levels well below US National Ambient Air Quality Standards (NAAQS) (Weichenthal et al., 2022). Thus, measures to reduce ambient pollution can have large health benefits, even where NAAQS are already met.

BOX 2. Gas stoves, indoor air pollution, and health

Gas stoves are used in more than 75% of NYC metro area dwellings (*American Housing Survey (AHS) - AHS Table Creator*, 2021). While climate change is not expected to directly affect gas stove emissions or health impacts and the contribution of gas cooking (including methane leaks) to NYC greenhouse gas emissions is likely small compared to emissions related to heating, (nationally, cooking accounts for less than 5% of residential natural gas use (U.S. Energy Information Administration, 2023)), replacing gas stoves with electric induction stoves could have important health benefits.

Modeling and measurement studies show that: 1) emissions form natural gas burners in unvented kitchens can rapidly increase concentrations of nitrogen dioxide (NO_2) and carbon monoxide (CO), potentially to levels that exceed health-based standards and guidelines for short-term exposure to NO_2; 2) replacing gas with electric stoves effectively reduces indoor NO_2 concentrations while exhaust hoods effectiveness varies.(Lebel et al., 2022; Logue et al., 2014; Mullen et al., 2016; Paulin et al., 2014).

A pilot study in NYCHA apartments demonstrated that increases in indoor NO_2 concentrations caused by use of gas stoves was prevented by replacement with electric induction stoves, which were preferred by households receiving them (WE ACT for Environmental Justice, 2023).

An extensive body of evidence, mostly focused on ambient air pollution, links higher NO2 concentrations to exacerbation of asthma, lung inflammation, and impaired lung growth (Raju et al., 2020; United States Environmental Protection Agency, 2020). Because outdoor NO_2 concentrations are an indicator of a mixture of other pollutants from fuel combustion, including diesel exhaust particles, NO_2 concentration-response relationships may not apply to other settings and emission sources, (Raju et al., 2020) such as household exposure to gas stove emissions. Nonetheless, studies focused on indoor exposure to gas cooking and NO_2 exposure have shown associations with respiratory symptoms, including asthma and wheezing (Hansel et al., 2008; W. Lin et al., 2013). Gas cooking could account for an estimated 18% of asthma cases in New York State (Gruenwald et al., 2023).

At present, direct evidence of the effectiveness of replacing gas stoves with electric ones on occupant health is limited. A randomized study of an air cleaner intervention showed a benefit of particle filtration but not NO_2 removal on symptoms of children with asthma (Gent et al., 2023).

Another health benefit of replacing gas stoves would be eliminating a source of interior gas leaks that can contribute to deadly explosions and fires.

3.3.3 Vulnerable populations

3.3.3.1 Health, social, and demographic factors

Children are more susceptible to air pollution because rapid development of their lungs and other organ systems, greater respiration rates relative to body size, and the potential for air pollution harm to have lifelong consequences (Perera & Nadeau, 2022). Older adults are at higher risk of death and serious illness caused by air pollution, in part because they are more likely to have chronic cardiovascular, respiratory, and metabolic conditions that air pollution exacerbates (United States Environmental Protection Agency, 2022a). Nationally and in NYC, Black, Latino, Indigenous, and low-income populations also have higher burdens of chronic diseases that are exacerbated by air pollution (City of New York Department of Health and Mental Hygiene, 2023i). Improved management of conditions exacerbated by air pollution can help reduce impacts (Hadley et al., 2022); disparities health care access and quality may contribute to vulnerability. Research suggests that chronic psychosocial stress, associated with social disadvantage, shares biologic pathways with air pollution, effects, increasing susceptibility to health effects (Bandoli et al., 2016; Clougherty et al., 2007; Thomson, 2019).

3.3.3.2 Geography and physical environment

Nationally, communities with higher proportions of Black, Latino, Asian and low-income residents have higher than average exposures to $PM_{2.5}$ (Jbaily et al., 2022), and are more likely to be located near busy highways, refineries, and other industrial facilities (American Lung Association, 2023; Y. M. Park & Kwan, 2020). In NYC, air pollution concentrations are associated with the density of emissions from buildings, including heating and commercial cooking, and from motor vehicles. Large buildings and their emissions are most abundant in parts of Manhattan, while traffic is more widely distributed, with the greatest contributions to emissions from diesel trucks and buses. As a result, in NYC, disparities in community ambient air pollution concentrations differ from the national pattern, with more affluent neighborhoods in Manhattan having concentrations of $PM_{2.5}$ and NO_2 that are among the highest in the city; when sensitivity to air pollution harm because of population health is accounted for, communities with more Black, Latino, and low-income populations are by far the most impacted (City of New York Department of Health and Mental Hygiene, 2022d). Traffic-related air pollution exposures, especially from heavy-duty diesel vehicles, is more concentrated in low-income NYC neighborhoods, where populations are most vulnerable and traffic pollution impacts are greatest (Kheirbek et al., 2016). Household exposures and health effects of some outdoor air pollutants, including ozone, $PM_{2.5}$, and pollen, are greater among occupants of dwellings lacking air conditioning or high efficiency particle filters (Bell et al., 2014; Jhun et al., 2014; D. Zhao et al., 2015; Zuraimi et al., 2011). Disproportionate exposure to industrial land use and hazardous pollutants among low-income people of color is addressed further in NPCC4, Foster et al. (2024).

Despite steady citywide improvements (City of New York Department of Health and Mental Hygiene, 2022i) (Figure 7a-d), higher $PM_{2.5}$ and NO_2 pollution levels within the city are observed in locations with more nearby boilers using heating oil or natural gas, traffic density, industrial structures, commercial cooking, and ship traffic (Ito et al., 2016). Reductions in emissions during the spring 2020 COVID-19 shutdown were associated with $PM_{2.5}$ and NO_2 levels in NYC decreasing by roughly 25%, with the greatest improvements in the central business district due to reduced commercial cooking and traffic (Perera et al., 2021; Pitiranggon et al., 2022).

Citywide, annual average levels of four key pollutants have gone down between the first year of monitoring, 2009, and the most recent year of data, 2021: Fine particles ($PM_{2.5}$) -40%, Nitrogen Dioxide (NO_2) -38%, Nitric Oxide (NO) -58%, Sulfur Dioxide (SO_2) -97%. Maps for all pollutants monitored are available in a full report on methods, trends, and sources of spatial variation in air quality (Figure 7).

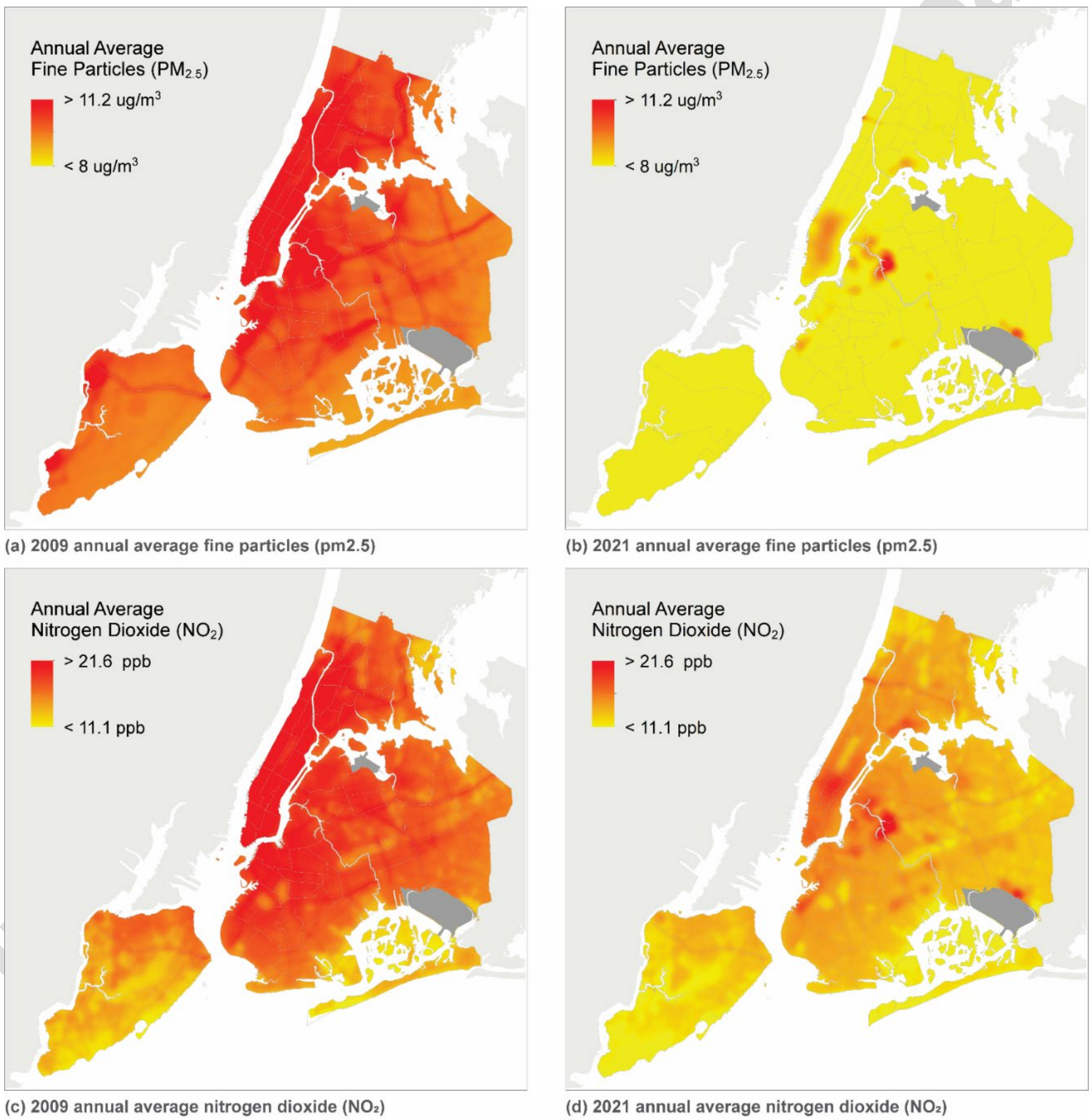


Figure 7: Pollutant distribution throughout New York City in 2009 and 2021. Particulate Matter 2.5 micrometers or smaller (PM2.5) in panels a and b; Nitrogen Dioxide (NO2) in panels c and d. Source: (City of New York Department of Health and Mental Hygiene, 2022i)

3.4 Aeroallergens

3.4.1 Pollen

The NPCC2 health assessment noted the potential for climate change, the urban heat island, and increased CO_2 concentrations to lengthen the seasons for and increase concentrations of allergenic pollen in NYC. Local epidemiologic studies demonstrated that pollen from several tree species common within the city are important contributors to allergic illness, including allergic rhinitis and increases in emergency department visits for asthma, during the spring season. Grass and ragweed pollen also contribute to seasonal allergies in the late summer and early fall (Kinney et al., 2015). Consistent with the NPCC2 assessment, across 60 pollen monitoring locations in North America, warmer weather caused by climate change has led to earlier, longer pollen spring seasons and higher average pollen concentrations during the period 1990 to 2018. However, pollen trends varied geographically; the northeast region showing little or no average trend in pollen concentration or spring onset date (Anderegg et al., 2021). A prior study of New York metro area tree pollen levels from 1990-2007 observed a shift to an earlier spring tree pollen season with a decline in average concentrations, attributed to regional construction and land use change (Kavosh et al., 2009).

NPCC2 also noted that studies of the role different tree species play in seasonal allergy could inform urban tree planting programs (Kinney et al., 2015). Since then, studies have added to local evidence pointing to the importance of local tree species in seasonal allergy. In NYC, pollen counts from trees peaking in the middle of spring pollen season (maple, birch, beech, ash, oak, and sycamore/London plane tree) are associated with over the counter allergy medication sales (an indication of seasonal allergy symptoms) and emergency department visits for asthma syndrome (Ito et al., 2015). In NYC and other locations, nearby tree canopy cover increases average springtime ambient tree pollen levels (Lara et al., 2020; Weinberger et al., 2016). In a birth cohort study of children born to women living in Northern Manhattan and the Bronx, tree canopy coverage near the prenatal address was associated with tree pollen allergic sensitization and asthma at age 7 (Lovasi et al., 2013). As with air pollution and health disparities, differences in the burden of asthma as well as in access to and quality of care could contribute to greater vulnerability to pollen-related asthma exacerbation in low-income communities and among Black and Latino populations.

3.4.2 Mold and fungi

The NPCC2 health assessment briefly summarized the influence of climate change on mold and health, noting that increased temperatures, coastal flooding, and heavy precipitation events can promote growth of mold and other fungi indoors, which in turn may cause respiratory symptoms and exacerbate asthma. Workers and residents could be exposed to unhealthy levels of mold during post-flood mold remediation without proper precautions (Kinney et al., 2015).

Studies and reviews of evidence since NPCC2 have largely been consistent in concluding that climate change and especially flooding events will promote indoor mold growth and increase risks to human health among residents of affected homes and workers involved in mold remediation. Health impacts include respiratory illnesses and exacerbation of asthma in sensitive individuals (Eguiluz-Gracia et al., 2020; Poole et al., 2019; Sampath et al., 2023). Outdoor concentrations of fungal spores involved in allergy and respiratory disease are also influenced by weather and climate change (Anees-Hill et al., 2022; Hanson et al., 2022).

Excess moisture in homes, whether from flooding, leaking roofs or walls, chronically damp basements, or inadequately vented bathrooms can contribute to mold growth in building materials that provide a suitable growth medium. Occupants of these homes, particularly children, are more likely to experience respiratory illness (Thacher et al., 2017). Mold growth on moist building materials in a basement can contaminate other living spaces of a typical single family home through passive air movement (Hegarty et al., 2019). In 2017 in NYC, occupants reported leaks in an estimated 13% of dwellings; those living in low-income communities in northern Manhattan, the Bronx, and central Brooklyn were more likely to report leaks compared with residents of other neighborhoods (City of New York Department of Health and Mental Hygiene, 2023g). These same communities have greater proportions of people with asthma who are more susceptible to mold and other aeroallergens in the home (City of New York Department of Health and Mental Hygiene, 2022c). Compounding these impacts, with COVID-19, those with lung damage from mold are at greater risk (e.g. populations in public housing, elderly populations, young children, people with asthma & other respiratory comorbidities, disabled populations and lower-income populations) (B. Hirsch, 2020).

3.5 Vector-borne pathogens

3.5.1 Synopsis of NPCC2 assessment

NPCC2 noted that some mosquito- and tick-borne illnesses such as West Nile virus (WNV) and Lyme disease are endemic in New York State. Climate change, including warming temperature and changes in precipitation patterns, can shift the seasonal cycle and/or spatial distribution of mosquito and tick vectors of these and other diseases affecting humans. Locally, climate change is expected to produce warmer weather in all seasons of the year as well as more flooding from extreme rain, rising sea levels, and coastal storms. Without adaptation, climate change will increase the risk of vector-borne illnesses among New Yorkers, including the potential introduction of diseases not currently transmitted in the metro area. However, climate change is only one of multiple factors influencing vector habitat and disease risk for humans, (Kinney et al., 2015).

3.5.2 Climate change projections and influence on risk

Life cycles, population, and activities of mosquitos and ticks are sensitive to interactions among climate variables including temperature and rainfall. One national study showed increased temperature, humidity, and heavy precipitation to predict human WNV infection rates in the US (Soverow et al., 2009), but more recent studies show the importance of drought preceding WNV epidemics (Paull et al., 2017; Shaman et al., 2005). Climate change is shifting and will continue to shift the geographic distribution of ticks that transmit Lyme and other human diseases (Alkishe et al., 2021).

While climate is undoubtedly important, complex, dynamic interactions among climate, animals, land use, human settlement and behavior patterns limit the utility of climate-disease modeling for predicting future vector-borne disease risks and informing prevention strategies (Bardosh et al., 2017). Historical trends show how complex, non-climate factors introduced malaria and yellow fever to the Americas, and the role these factors likely played in their elimination in the US. Malaria and yellow fever likely came to the Americas during the slave trade in the 17th century and caused recurrent outbreaks in NYC and as far north as New England (Eastman, 2021; Moreno-Madriñán & Turell, 2018). Because humans are the primary host for amplifying these mosquito borne diseases, improved living conditions that reduced indoor mosquito contact, such as screens, elimination of open cisterns, and air conditioning, likely played a major role in eliminating sustained local transmission of malaria and yellow fever in the US (Eastman, 2021; Moreno-Madriñán & Turell, 2018).

The Fourth National Climate Assessment concluded that climate change will alter the geographic range, seasonal distribution, and abundance of disease vectors, but also the influence on future risks of interactions with "changing ecosystems and land use, demographics, human behavior, and the status of public health infrastructure and management" (USGCRP, 2018). Future risk estimates depend on how these complex interactions are modeled. For example, an increase in WNV, the most common mosquito-borne illness in NYC, is anticipated under a changing climate (City of New York Department of Health and Mental Hygiene, 2022l; Keyel et al., 2021), but in one study, a mosquito biology model contradicted a climate model, predicting decreased WNV-risk in currently high-risk locations leading to an overall decline in population-weighted risk (Keyel et al., 2021). In addition, human acquired immunity after regional outbreaks may also limit WNV transmission (Paull et al., 2017).

Similarly, a warming climate is expanding the northern range of the blacklegged tick (Ixodes scapularis) – the vector for Lyme disease (Alkishe et al., 2021), and Lyme disease cases and exposure to the tick vector in New York State are associated with warmer days and mild winter temperatures (S. Lin et al., 2019), but non-climate factors have also played a role as described in Section 3.5.3.2.

3.5.3 National, regional, and local vector-borne disease (VBD) trends

3.5.3.1 West Nile virus and other mosquito-borne illnesses

The West Nile virus (WNV) in the US was first identified in NYC in 1999, and it has remained a threat to public health ever since. Nationally, more than 55,000 cases and 2600 deaths from WNV have been reported to CDC from 1999 through 2021, with the highest rates of neuroinvasive disease among older adults and residents of West North Central, East South Central, and Mountain regions.(Centers for Disease Control and Prevention, 2022b). Cases have fluctuated substantially from year to year during that period; national rates were fairly stable from 2013-2018 (McDonald et al., 2021).

Within NYC in 2015-2020, reported cases ranged between 6 and 38, with no clear trend (City of New York Department of Health and Mental Hygiene, 2019). 377 cases of neuroinvasive (severe) presentations of West Nile and 47 deaths have been recorded in NYC residents from 1999-2021 (Bajwa W, Slavinski S, Shah Z, Zhou L, 2022). WNV infection is asymptomatic in 70-80% of cases. People with symptomatic infection can experience fever, headache, weakness, muscle, and joint pain. Less than 1% of cases will develop WNV encephalitis and/or myelitis meningitis, which is inflammation of tissues surrounding the brain, brain stem, or spinal cord and can lead to serious morbidities and even death (Centers for Disease Control and Prevention, 2023c). Because most infections are asymptomatic and symptoms are variable, reported cases are much less than the true number of infections.

NYC collects and tests pools of mosquitos for the presence of WNV at 53 permanent locations across the 5 boroughs, with additional collection sites deployed based on surveillance data. In 2022, the number of WNV-positive mosquito pools, 1555, was the highest ever detected (Baisas, 2022; City of New York Department of Health and Mental Hygiene, 2023m). This could be due to increased extreme precipitation events, warmer air temperature, lack of behavioral vigilance, or some combination. Summer of 2022 in NYC was its 6th hottest in recorded history, and rainfall was four inches below average (Davitt, 2022). The combination of hotter temperatures and dry conditions could have contributed to an increase in WNV infected mosquito pools.

Aedes aegypti, the species of mosquito that most commonly transmits chikungunya, dengue and Zika, is not found in NYC, and cases of these diseases among New Yorkers are typically attributed to travel to other places with this vector (Bajwa et al., 2022). Aedes albopictus is present in NYC and is capable of transmitting Zika, dengue, chikungunya, and other viruses, but less efficient at doing so compared to *Aedes aegypti* (Centers for Disease Control and Prevention, 2023d).

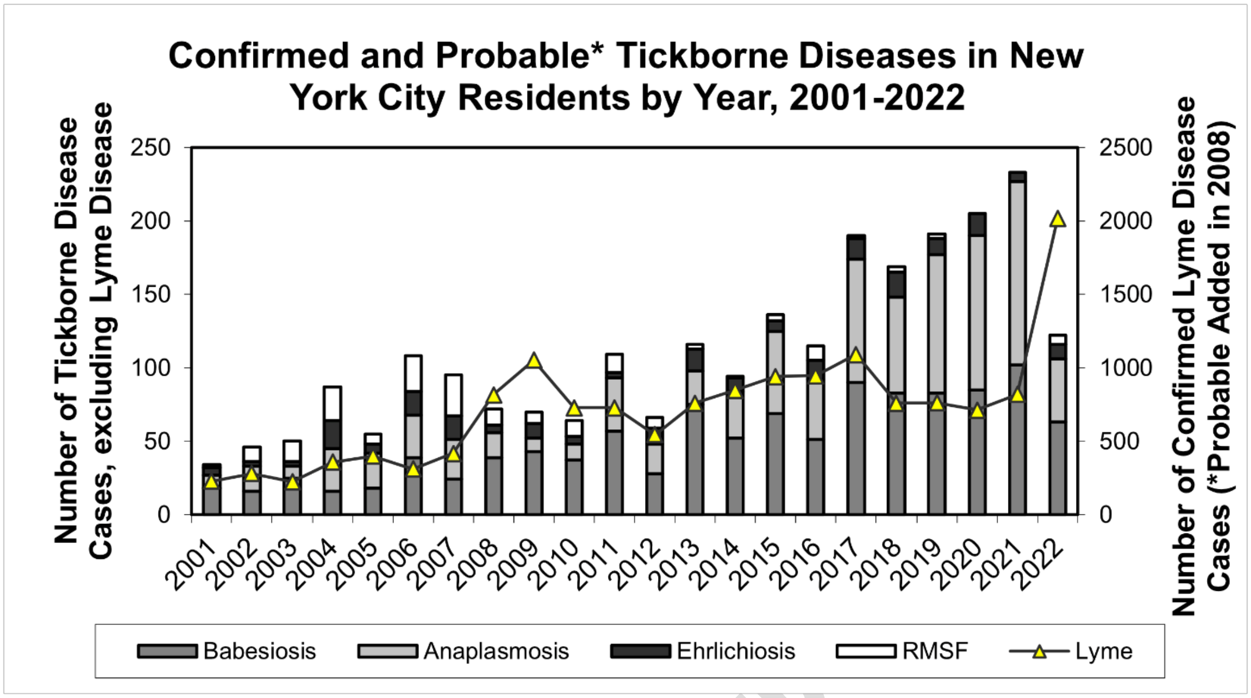
3.5.3.2 Lyme disease and other tick-borne diseases (TBDs)

Nationally, between 30,000 and 40,000 Lyme disease cases are reported annually; the number of confirmed and probable cases fluctuated with no clear trend between 2008 and 2019 (Centers for Disease Control and Prevention, 2022c). According to the most recent NYC Health Department surveillance report, (City of New York Department of Health and Mental Hygiene, 2022a) Lyme and other TBD cases among NYC residents have been trending upward for more than 15 years (Figure 8). The abrupt increase in 2022 Lyme diseases cases is an artifact of a changed CDC case definition (City of New York Department of Health and Mental Hygiene, 2023n). Tick-borne diseases (TBD) among New Yorkers are mainly acquired through travel outside of NYC to surrounding areas where the diseases are endemic. Locally acquired Lyme disease cases are most common in Staten Island (City of New York Department of Health and Mental Hygiene, 2023n; Goldstein, 2023). Lyme disease remains the most reported TBD.

People acquire TBDs when bit by a tick carrying the infectious agent, usually during outdoor activity among residents or visitors to regions with a temperate climate and local habitat that supports the lifecycles of the tick vector. For Lyme disease, the blacklegged tick (*Ixodes scapularis)* is the vector, and the causal agent is the spirochete *Borrelia burgdorferi*. Lyme disease cases can occur at any time of the year, but are highest in the spring and summer, both due to the activity of the nymphs and an increase in outdoor activities (Bush & Vazquez-Pertejo, 2018).

New and emerging tick vectors and TBDs are being detected in New York State and in the city. In addition to the blacklegged or deer tick vector for Lyme disease, anaplasmosis, babesiosis, and Powassan virus, the American dog tick, which can transmit Rocky Mountain spotted fever, the lone star tick, a vector of ehrlichiosis, the Asian long horned tick, and Gulf Coast tick have been detected in NYC (City of New York Department of Health and Mental Hygiene, 2022a).

The Asian long-horned tick and lone star ticks are also established in Staten Island and parts of the Bronx. The Asian long-horned tick was first reported in the US in 2017 but has not yet been shown to transmit disease, though internationally they have been shown to spread several animal and human diseases (Pritt, 2020). The American dog tick is found in all five boroughs of NYC (City of New York Department of Health and Mental Hygiene, 2017). The Gulf Coast tick is also in Staten Island. These established ticks, along with the blacklegged tick, have tested positive for multiple pathogens (City of New York Department of Health and Mental Hygiene, 2023n).



*Probable added to Lyme disease case definition in 2008: Physician diagnosis with positive lab results and no erythema migrans or late manifestations

Figure 8: Case counts are by year of diagnosis. The 2022 increase in Lyme Disease cases is attributed to changes in the Centers for Disease Control and Prevention (CDC) case definition. Source: (City of New York Department of Health and Mental Hygiene, 2023n)

3.5.4 Factors influencing population vulnerability

The differences in population vulnerability to a mosquito- or tick-borne illness is influenced by a combination of individual health and behavioral factors, socioeconomic factors and living conditions, and nearby landcover, habitat, and ecosystem factors that influence disease vectors abundance, behavior, and encounters with people.

3.5.4.1 Mosquito-borne illness

Those considered the most susceptible to severe West Nile virus (WNV) infections include the elderly, homeless, and those with underlying conditions or compromised immunity (Ronca et al., 2021). Outdoor workers are at increased risk of exposure to WNV-infected mosquitos (Centers for Disease Control and Prevention, 2022a). Those living in homes with poorly fitting doors and windows or without door and window screens are also at increased risk (Bajwa W, Slavinski S, Shah Z, Zhou L, 2022).

Landcover, including both natural, agricultural, and urban features, can create mosquito breeding habitat. These interact with climate and nearby populations, living conditions, and behaviors to influencing potential exposure to mosquitos carrying WNV and other diseases (DeGroote & Sugumaran, 2012; Keyel et al., 2019). Examples of places where standing water can support mosquito breeding include puddles, pools, catch basins, bird baths, rain gutters, portable swimming pools, and puddles (Bajwa W, Slavinski S, Shah Z, Zhou L, 2022). The NYC Health Department recorded 1,661 complaints of standing water in NYC in 2021 for mosquitoes (Bajwa W, Slavinski S, Shah Z, Zhou L, 2022).

In addition to climate change influencing trends in locally endemic mosquito-borne illness, another concern is the risk of reintroduction and sustained local transmission of once endemic diseases. A recent report documents locally transmitted cases of malaria in 2023 in Florida (7 cases), Texas (1 case), and Maryland (1 case), the first in the US since 2003. While the risk of sustained local transmission of malaria in the US remains extremely low, these cases demonstrate the importance of public health surveillance and prompt treatment of human cases (Centers for Disease Control and Prevention, 2023e).

Human hosts are also important for local transmission of the mosquito borne illnesses dengue, chikungunya, and Zika viruses. Each year, multiple travelers return to NYC with active dengue or malaria infections acquired in places where those diseases are endemic, but *Aedes aegypti*, the insect vector for these diseases, is not currently found in NYC and local transmission has not been sustained. This could change if *Aedes aegypti* or another competent insect vector became established locally (Bajwa W, Slavinski S, Shah Z, Zhou L, 2022; Moreno-Madriñán & Turell, 2018).

Socioeconomic and living conditions are another factor that could influence the risk of these diseases becoming locally endemic. For example, a study comparing the incidence of dengue fever in adjacent towns of Nuevo Laredo, Mexico and Laredo, Texas found a higher risk in Nuevo Laredo despite the greater abundance of dengue-carrying mosquitos in Laredo. Differences were attributed to living conditions, including Laredo's having more residential screens, air conditioning, spacing between homes, and more indoor space per occupant (Reiter et al., 2003).

Land cover change and mosquito control efforts likely also played a role in controlling mosquito borne diseases in the US. These factors will remain important in shaping the future risk for diseases like WNV, which require animal, rather than human hosts to sustain local populations and transmission. The development and urbanization of the mid-Atlantic and northeast states in the 20th century resulted in salt marsh wetlands being modified or lost to alternative uses or for mosquito control efforts. Over time, integrated marsh management (IMM) methods have been developed to support or enhance habitat (Wolfe et al., 2022) and aid in the control mosquito vectors of human disease in combination with integrated pest management (IPM) methods, such as those employed by NYC's mosquito control program (Bajwa W, Slavinski S, Shah Z, Zhou L, 2022).

3.5.4.2 Tick-borne illness

Nationally, reported Lyme disease is more common among men than women; the age distribution of cases is fairly uniform, but the proportion with neurologic, arthritic, or cardiac manifestations is highest among children and middle-aged adults (A. M. Schwartz, 2017). In a survey of people reported with Lyme disease in Pennsylvania, lack of health insurance was a risk factor for delayed treatment, which in turn is a risk for more serious and post-treatment symptoms (A. G. Hirsch et al., 2020). An electronic health record study in Pennsylvania found access to primary or urgent care was protective and that Medicaid-insured patients were at higher risk of more severe illness (Moon et al., 2021). Among occupations, agricultural and forestry workers are at increased risk (Magnavita et al., 2022).

Because Lyme disease is the most common tick-born illness in the US and NYC area, its vector, the blacklegged tick, has been extensively studied. Historically, its range may have spread in the northeastern US as forest habitat and deer populations expanded during the last century (Dennis et al., 1998). Today, blacklegged ticks are established in Staten Island, in Pelham Park in the Bronx but not in Manhattan, Queens, and Brooklyn (City of New York Department of Health and Mental Hygiene, 2022h). A study of NYC parks showed that the density of nymph blacklegged ticks and carrying the spirochete causing Lyme was greatest in parks with high connectivity and vegetated buffers, favorable habitat for the white-tailed deer, which is a host species for adult ticks (VanAcker et al., 2019). Since 2006, the NYC Health Department has conducted tick surveillance annually in a subset of NYC parks, however, the department notes that information on tick populations in the city is limited (City of New York Department of Health and Mental Hygiene, 2023j).

3.6 Water-borne Pathogens and Other Contaminants

Globally, increasing temperatures and flooding related to climate change can increase water borne disease risk such as from enteric pathogens and legionella (BOX 3) (Semenza, 2020). Local waterborne disease risks and their relationship to climate change are highly dependent on infrastructure, including that involved in drinking water supply and treatment, wastewater and stormwater management and treatment, and building systems including potable water supply, cooling towers, and fountains. For NYC's drinking water supply to be impacted, damage to the upstate source watershed and/or water mains typically would have to occur. However, power outages will cause loss of potable water supply in tall buildings when rooftop tanks are exhausted (NYC Department of Environmental Protection, 2022).

Yet, there are multiple potential pathways for flooding and SLR to impact NYC drinking water supply, distribution, and quality. Sea level rise could cause salt front movement in the lower Delaware River, adding pressure to release more water from reservoirs and impairing supply (Zimmerman et al., 2019). Downpours in the watershed could increase turbidity and potentially runoff of other pollutants. Increased turbidity has been associated with an increased risk of gastrointestinal illness (GI), though by itself does not cause GI illness (Graydon et al., 2022; J. Schwartz, 2000).

Pathogen growth and availability increase with warmer temperatures, so flooding in warmer months, such as that with Hurricane Ida, introduces additional risks (Escobar et al., 2015; Trtanj et al., 2016). Vibrio bacteria naturally live in coastal salt and brackish waters and include species that cause human infections, most often gastrointestinal illness caused by ingestion of raw or undercooked shellfish. Less often, vibrio contact with open skin wounds can cause infection. About 110-140 vibrio infections are reported to the NYC Health Department annually. Recently, the US

CDC issued a national health alert concerning potentially life-threatening infections caused by *Vibrio vulnificus* that have been associated with warming coastal waters. In 2023, so far, one *Vibrio vulnificus* case was reported in an NYC resident (compared to about one to three annually), who reported eating shellfish but not exposure to coastal waters (City of New York Department of Health and Mental Hygiene, 2023a).

In general, water-borne illnesses reported after major storms demonstrate increases in cases of gastrointestinal illness due to resident exposures to sewage contaminated floodwaters (Liang & Messenger, 2018). Following extensive flooding caused by Post-Tropical Cyclone Sandy, the overall risk of food and waterborne illness in the NYC area receiving inpatient or outpatient treatment did not increase, but there was a small increase in outpatient food and waterborne illness among those age 65 and older (Greene et al., 2013).

BOX 3. Legionella

Legionella bacteria are present in the environment and can grow in potable water systems and in cooling towers commonly used for air conditioning and commercial refrigeration in large NYC buildings. If released in aerosol form, community outbreaks of legionella pneumonia can occur (Paschke et al., 2019). Warm temperatures and humidity are associated with increased rates of Legionnaire's disease (Simmering et al., 2017), likely related both to favorable conditions for growth of the agent and use of cooling towers. In 2015 an outbreak of Legionnaire's Disease in the Bronx resulted in 138 confirmed cases and 16 deaths. The source was traced to a single cooling tower (Weiss et al., 2017). A local law and health regulations enacted that same year, created requirements for permitting, maintenance, and inspection (City of New York Department of Health and Mental Hygiene, 2023d).Coordinated surveillance connecting human, animal, and environmental health can help with early detection of water-borne disease outbreaks (Semenza, 2020).

Degradation in surface water quality around the city is a risk after any major rain or flooding event, potentially exposing recreational water users. This is because combined mains handle stormwater runoff and sewage in many parts of the city can overwhelm treatment facilities during significant rain events and cause discharge of untreated sewage. The NYC Department of Health and Mental Hygiene (2023h) maintains beach monitoring and surveillance and issues advisories and closures during the summer season.

Harmful algal blooms (HABs) are caused when algae and cyanobacteria grow rapidly in bodies of water. Illness in people and pets is most often from exposures to toxins produced by these organisms via skin contact, inhalation, ingestion of contaminated water, or consumption of contaminated seafood. HABs are more common in warm months and in fresh water. A wide range of symptoms and illnesses can result, including skin and respiratory tract irritation from contact with contaminated water or inhalation of droplets, gastrointestinal and neurologic illness from ingestion of contaminated food or water. Dogs, livestock, and wildlife are also harmed by HABS (Centers for Disease Control and Prevention, 2023b).

A global increase in HABs is being driven by climatic and non-climatic factors. National data also show an increase in the number, types, and geographic range of HABs (Gobler, 2020). The increase in HABs driven by several factors, including climate change and rising water temperatures, improved detection and reporting, nutrient pollution, introduction of species to new areas (D. M. Anderson et al., 2021). In New York State, HAB reports increased in frequency from 2012-2020 (Gorney et al., 2023), and HABs regularly impact some NYC freshwater ponds and lakes (City of New York Department of Parks & Recreation, 2023b). More recent, detailed state level data are available, and show 53 HABs reported for water bodies within the five boroughs from 2019 through 2022 (New York State Department of Environmental Conservation, 2023a).

3.7 Other Compound Impacts

Hot summer weather combined with the risk of COVID-19 transmission for the first time in summer 2020. Indoor gatherings such as at public cooling centers, which can provide a respite for those unable to stay cool at home, were limited. A pilot survey of members of an environmental justice organization during the summer of 2020 suggested people were more likely to stay indoors, avoid crowded green spaces, and rely on home AC units (WE ACT for Environmental Justice, 2021). A racial disparity in access to AC was also shown, consistent with prior surveys. Another evaluation study of the short-term impacts of an NYC program that distributed and installed 73,000 air conditioners in summer 2020 indicated that program participants were more likely to report that they stayed home during hot weather compared to non-participants, with similar levels of staying home among the two groups in 2019. Program participants were also less likely to report that hot weather made them, or household members feel sick at home during summer 2020. Concern about cost of cooling, a hallmark of energy insecurity, was common among both groups and was a barrier to accessing air-conditioning (Lane et al., 2023). Limited access to outdoor green space was noted in another survey (Bock et al., 2021, 2021); power outages during hot weather would amplify these risks (Watkins & Southall, 2019). The co-occurring emergencies of extreme heat and COVID-19 highlighted the need to continue, expand, and evaluate efforts to address disparities in cooling access, energy affordability, and green space in high heat-vulnerable neighborhoods (City of New York Department of Parks & Recreation, 2023a). Similarly, urban flooding preparations, as well as efforts to address basement apartments, were interrupted due to COVID-19 demands for budget reallocations (City of New York, 2016).

Other compound impacts have been considered in earlier sections, including the co-occurrence of hot weather and higher ozone levels, amplification of heat and flooding impacts by power outages, and the potential for hot weather and flooding to cause exposure to pathogens and other contaminants in water. Hurricanes and other storms that cause power outages and occur during hot or cold weather can be dangerous. The 2017 example of Hurricane Irma in Florida is discussed in Yoon et al., (2024). Most recently, when extreme heat combined with wildfire smoke, as prominent in June 2023, potential concurrent exposures introduced greater health risks (Rosenthal et al., 2022) increasing the importance of residential air conditioning for protecting vulnerable people.

4 Reducing Future Impacts

Many cities are implementing measures to provide immediate public health protections from the health impacts of climate change. Several of NYC's measures and plans as well as those of some other cities are discussed below. Structural measures that rely less on behavior change and individual efficacy are generally more effective at the population level. Hence, measures that advance health, equity, and safety by adapting the built and natural environment, while enhancing natural features and ecosystems and supporting greenhouse gas reduction targets where feasible, are the most important.

4.1 Public Health Messaging and Risk Awareness

General principles: Climate risks to health vary greatly among communities and populations, making clear, actionable communication, especially to vulnerable groups, essential for effective emergency preparedness and response. Vulnerable populations are most reliant upon government services when an evacuation order is issued, making the timely deployment of those services and their context-dependent response extremely important to reduce negative health impacts. Evacuation behavior and response may differ throughout the population of NYC for a wide variety of reasons, so a coordinated effort from the city to address this reality will improve outcomes, particularly for those in public housing, those who have health conditions and disabilities, and the elderly. Public health strategies reliant on individual agency and behavior change are inherently less effective than structural interventions that address socioeconomic determinants or the environmental context for health (Frieden, 2010). Thus, to reduce future climate change impacts on health, policies and investments that reduce housing and energy insecurity and ensure the resilience of dwellings and infrastructure are essential complementary approaches to effective public health communication. A population that is informed about climate risks and options for avoidance of risks will be better able to engage in collective advocacy for structural measures and act in the near term to reduce exposures and risks. Specific strategies and approaches are described below.

Heat-health warning systems: NYC activates its heat emergency plan when the National Weather Service (NWS) forecasts extreme heat. The NWS definition of extreme heat – two or more days when the maximum heat index is predicted to reach 95°F or any period when it reaches 100°F – is based on analyses of NYC heat and mortality data (Metzger et al., 2010a). One study estimated that reducing the heat emergency threshold from 105°F to these lower levels in 2008 reduced heat-related illnesses among Medicare beneficiaries in NYC in the two years after 2008 compared to the two years before (Benmarhnia et al., 2019). During emergencies, NYC officials disseminate public messaging about the health dangers of heat to the public, health care and social service providers, and faith- and community-based organizations. People are urged to use air conditioning if they have it or visit an air-conditioned space, such as a Cooling Center. Messaging around setting AC to low-cool or 78°F is also typically included to help with costs of cooling and reducing energy use to protect the power grid. Members of the public are also asked to check in on family, neighbors and friends who may be at risk during hot weather to help them stay cool (See NYC's *"Be a Buddy"* program (City of New York Mayor's Office of Climate & Environmental Justice, 2022)). More outreach workers are deployed to offer shelter to people experiencing homelessness, and shelters are open to anyone who needs them (City of New York Department of Homeless Services, 2023).

It is important to note that warning systems have several limitations. People without air conditioning who have limited mobility may have difficulty accessing public cooling resources, people may be reluctant to leave home during heat waves to visit a cooling center (see section on Cooling Centers below), and emergency warnings are released only on the hottest and most dangerous days to avoid alert fatigue. These limitations highlight the need to couple emergency warning and response systems with other strategies to maintain safety throughout the warm season, including hot but not extreme heat days.

Surveys have also shown that while heat warning awareness is generally high among New Yorkers, awareness is lower among those who may be more at risk, which may be in part due to perceived lack of risk of hot weather, which occurs every summer, and because messages may not effectively reach those most at risk. Trusted messengers for heat-health warnings and information included health professionals, local TV health and medical correspondents, and meteorologists (Lane et al., 2014).

Flood risk awareness: Additional measures to help New Yorkers to understand the health and property risks associated with flooding are needed. FEMA recently published a series of online resources that highlight ways that building owners and tenants can reduce flood risks in urban buildings (Federal Emergency Management Agency, 2023b). Emergency preparedness education, such as *Know Your Zone* and *ReadyNYC*, are ongoing local programs to increase awareness of neighborhood risks. Education on finding safe local shelters as well as sheltering in place are important to limit compound risks from transmissible illnesses. Existing programs could be enhanced by increasing awareness of precipitation-driven flooding. Recent NYS legislation to inform renters and homeowners of flood history (Assembly Bill 2023-A1967, 2023), or to improve community awareness of climate hazards, requires sustained engagement to become part of the New York experience. Assuring translation into multiple languages and offering multiple means of delivering these messages, with assistive technologies for sight, hearing, or mobility impairment is key. Otherwise, those with vision or hearing impairments and without assistive technology may not receive such warnings. NYC Emergency Management translates public materials, outreach materials, and Notify NYC messages and website into the 10 languages designated by Local Law 30 (Local Law 30, 2017) as well as two additional languages, Yiddish and Italian, which are two of the top 10 languages spoken in NYC hurricane evacuation zones. To assess and support Local Law 30 implementation, the Mayor's Office of Immigrant Affairs works with NYC Emergency Management and other agencies and issues regular public reports (NYC Mayor's Office of Immigrant Affairs & NYC Mayor's Office of Operations, 2022). While most of these resources are accessible online, 16% of households in NYC remain without broadband access. Finally, it is important to help New Yorkers to understand how personal choice impacts flooding in NYC. For example, DEP's ongoing WAIT program encourages New Yorkers to monitor and where possible to reduce their potable water use during flooding events, in turn reducing the amount of sewer water combining with stormwater outflows (City of New York Department of Environmental Protection, 2023b).

Air quality health advisories and related public health measures: High levels of $PM_{2.5}$ caused by wildfire smoke and high levels of ozone during hot weather generally cause poor air quality across the NYC metro area. Computer models of weather and pollutant emissions as well as monitor data are used to forecast harmful pollution episodes. The New York State Department of Environmental Conservation (NYSDEC) and the NYS Department of Health issue regional air quality health advisories when "DEC meteorologists predict levels of ozone or $PM_{2.5}$" that are greater than national ambient air quality criteria for short term exposure (New York State Department of Environmental Conservation, 2023b). These advisories use the EPA's Air Quality Index (AQI), a ratio of the forecast or measured pollutant level to a "short-term national ambient air quality standard for protection of public health" (United States Environmental Protection Agency, 2023b). Advisories recommend actions to reduce exposure, such as reducing outdoor exercise during times of high pollution. NYSDEC shares data with the national AirNow program, which makes data and advisories publicly available through smartphone apps and weather forecasts, via a partnership with the National Weather Service (United States Environmental Protection Agency, 2023a). Air quality health advisories are almost always for elevated ozone or $PM_{2.5}$ concentrations. Prior to 2023, $PM_{2.5}$ advisories in the NYC metro area were infrequent in recent years. The AQI (based on a 24-hour average $PM_{2.5}$) was 100 or greater fewer than 3 times per year from 2010 through 2022, and the maximum $PM_{2.5}$ AQI was 154. Smoke from wildfires in Canada caused the $PM_{2.5}$ AQI to exceed100 9 times to date in 2023, reaching a maximum of 254 (United States Environmental Protection Agency, 2023e) (concentrations were much higher over shorter averaging times)

Experts have noted the limitations of an AQI based on a single-pollutant's regulatory threshold, noting that air pollution harm is not limited to concentrations above regulatory standards and much more common days with moderate levels of multiple pollutants do not trigger warnings (Laumbach et al., 2021). Evidence shows some benefits of actions recommended by air quality advisories, but with important limitations. Staying indoors and avoiding physical activity during times or near locations with elevated air pollution and using room or central air filtration may reduce exposures and health risks, but more studies are needed to better quantify effectiveness, safety, and cost (Laumbach et al., 2021).

The use of particle filtering masks outdoors by the public has not been part of standard guidance issued with air quality health advisories but was widely recommended during the recent smoke episodes affecting NYC. Some evidence shows that if properly worn, masks can reduce exposure and provide health benefits in some settings and populations. But important evidence gaps and implementation concerns remain. Patients with pre-existing lung or heart conditions may have difficulty tolerating some masks, improper fit or use may greatly reduce effectiveness, and evidence of improved outcomes is limited to short term use in populations and settings not directly comparable to regional air pollution episodes. It is important to note that particle filter masks do not reduce exposure to ozone, other gaseous pollutants, or ultrafine particles (Carlsten et al., 2020; Laumbach et al., 2021). Indoor central heating, ventilation, air-conditioning (HVAC) and portable air filtration systems can effectively improve indoor air quality during wildfire smoke pollution events, but further study is needed of longevity and maintenance of equipment, pollution mixture effects, and actual health benefits (Davison et al., 2021).

Modeling studies suggest that for most people, the large health benefits of regular physical activity, especially for active transportation, outweigh risks of air pollution (Tainio et al., 2021). Experts note the need for more research to understand these tradeoffs and caution against a too low threshold and frequent advisories to limit outdoor activity, could have little benefit or might even be harmful (Carlsten et al., 2020; Laumbach et al., 2021).

Equity and practical concerns have also been raised about advice given during air pollution episodes. Knowledge and resource limitations make it harder for some populations to understand concepts like the AQI or comply with recommended actions (D'Antoni et al., 2019; Laumbach et al., 2021). During hot weather, households lacking air conditioning can't close windows to reduce ozone or use portable filtration devices without risking harmful heat exposure (Davison et al., 2021).

Preventing tick-borne illness: Strategies for preventing tick borne illness include promoting awareness of where and how encounters with disease-bearing ticks occur, proper use of insect repellents effective against ticks for people and pets (especially dogs), integrated pest management practices to minimize tick habitat, populations, and contact in yards and parks, body checks for ticks at least daily, and awareness of signs and symptoms of tick-borne illness and the importance of seeking care promptly for diagnosis and treatment (Centers for Disease Control and Prevention, 2021; City of New York Department of Health and Mental Hygiene, 2023l). These depend heavily on public education and behavior change and should emphasize risks from outdoor activity in locations where disease-bearing ticks are most likely to be encountered.

4.2 Emergency Response

Cooling and warming centers: Like many other cities, NYC officials encourage people who cannot stay cool at home during periods of extreme heat to visit cooling centers during periods of extreme heat. Cooling centers are senior centers, libraries, community centers, and other public places with air conditioning. Although these spaces are always typically open to the public, during heat events they are advertised as cooling centers and will often open for longer hours. During a heat wave, members of the public can visit an online cooling center finder or call 311 to find their closest center. A NYC Comptroller's report (Office of the New York City Comptroller & Urban Ocean Lab, 2022) recommends the development of Resilience Hubs which broaden cooling center functionality to include complementary community supports, and the city's 2023 sustainability plan includes an initiative to create Resilience Hubs (City of New York Office of the Mayor, 2023a). NYC Speaks (2023) summarizes ongoing Resilience Hub activities.

Population-based NYC surveys indicate that there is a strong preference for staying home during hot weather, even when someone cannot stay cool at home (Lane et al., 2014; Madrigano et al., 2018). About 10-15% of those without AC or those who have it but do not use it often report going to a public place similar to a cooling center (Lane et al., 2014; Madrigano et al., 2018). A 2021 audit of a subset of NYC cooling centers by WE ACT for Environmental Justice found that more signage, information, and consistent standards were needed and recommended, among other measures, more funding and increased community input in center operations (WE ACT for Environmental Justice, 2021). Transport and risk perception may also be barriers to use (Berisha et al., 2017; Lane et al., 2014). A 2022 NYC Comptroller's report noted a need for more centers in under-served, high heat vulnerability areas, more centers on weekends, and more options for younger adults, since many senior centers are for people aged 60 and older (City of New York Bureau of Policy and Research, 2022).

Assessments of cooling center utilization in Phoenix (Maricopa County) found that 22% of respondents used the centers primarily to avoid heat, but most were visiting to access other services offered at the centers. In addition to individuals experiencing homelessness or who did not have home AC, many used cooling centers because they cannot afford the cost of running their home AC (Berisha et al., 2017).

There have been few, if any, studies conducted to examine cooling center effectiveness in reducing heat-health impacts. A Centers for Disease Control and Prevention (CDC) review on the evidence base for use of cooling centers to prevent heat-health impacts did not identify any research linking cooling centers to health outcomes but noted that there is strong evidence that staying in a cool environment generally is beneficial to health. The review concluded that cooling centers can be useful as part of a larger heat-health response strategy, not as a stand-alone measure (Widerynski et al., 2017). Another recent commentary also noted cooling centers have limited potential benefit in the absence of more comprehensive measures and that even with optimistic assumptions about their effectiveness, extremely large numbers of people would need to use them to achieve a meaningful reduction in mortality risk (Bedi et al., 2022). Challenges with cooling centers and Covid-19 in summer 2020 are discussed in Section 3.7.

In NYC, warming centers are not typically opened because of strong heating laws in place during cold weather and right to shelter laws for people experiencing homelessness. However, warming centers and warming buses were used following power outages due to Post-Tropical Cyclone Sandy. FEMA and the National Guard also conducted door-to-door welfare checks on residents affected by the flooding and widespread power outages.

Evacuation shelters: Immediately prior to a hurricane, it is common to provide resources to allow residents to get out of harm's way if safe shelter at home is not possible. This includes community-based evacuation centers. New Yorkers demonstrate a preference for staying home versus evacuating, as demonstrated prior to Post-Tropical Cyclone Sandy (Schmeltz et al., 2013). In fact, mutual aid proved more effective in preparing and providing for communities (Schmeltz et al., 2013). But for residents of basement apartments in flood prone areas, sheltering at home during flood events is not a viable solution. Additional support for evacuation center sustained operations and neighborhood awareness campaigns could help to socialize options available to community members. COVID-19 created a compound risk and additional barrier to using congregate evacuation shelters[1] (Sawano et al., 2021).

For those with chronic health issues or disabilities, flood evacuation requires additional support. However, the NYC Emergency Management website notes that those in wheelchairs or with other disabilities affecting mobility should call NYC 311 for evacuation assistance if they have no other options for evacuating safely (City of New York Office of Emergency Management, 2022; New York City Housing Authority, 2022). With prior planning, those most dependent on others for their evacuation, and for ongoing support while away from home, can gain more control over how their health needs are met. NYCEM guidance in the My Emergency Plan workbook notes that those with disabilities can be taken to an accessible evacuation center, in a hospital outside of the evacuation zone (via ambulance) but will not have the option of giving the evacuation team a specific address.

Household disconnection prevention: Disconnection protections vary by jurisdiction and circumstance but can offer important protections during extreme weather. In NYC, residential electricity disconnections for non-payment are suspended for all residential customers just before, during, and for two days after hot days using criteria based on the heat index. In 2022, Los Angeles prohibited the Department of Water and Power from practicing water or power shutoffs as a debt collection tool for income-qualified residents and seniors (Hayley Smith, 2022). Health risks of utility disconnections and prevention measures are discussed in more detail in NPCC4, Yoon et al. (2024).

Information access: NYC has telephone services such as the 311 call line which in an emergency is regularly updated with information from NYC Emergency Management that can be then conveyed in more than 160 languages (NYC Mayor's Office of Immigrant Affairs & NYC Mayor's Office of Operations, 2022).

4.3 Community & Social Supports

Strengthening community social networks, cohesion, and community-based organization capacity: Social resilience programs that seek to increase community resources, networks, and connections, led by community groups or community members, may also be beneficial. Direct financial and technical assistance approaches with community participation and co-creation are being used. Some examples include:

- In 2017, the NYC Health Department and Mayor's Office of Resiliency launched *Be a Buddy* as an initiative of Cool Neighborhoods NYC, a citywide heat protection strategy (City of New York Mayor's Office of Resiliency, 2017). Through partnerships with Brooklyn Community Services (Brownsville), The Point Community Development Corporation (Hunts Point) and Union Settlement (East Harlem), *Be A Buddy* provided assistance and support to over 1,300 New Yorkers through over 60 volunteers. The partner organizations built and fostered hyperlocal networks to provide heat-health information to neighbors, help them identify community resources, and make and implement emergency plans (City of New York Department of Health and Mental Hygiene, 2022k; Schramm et al., 2020).
- The *Billion Oyster Project* now hosts a Citizens water quality testing site to encourage community awareness of water contamination risks as it aligns with their mission. The project directly addresses community and student engagement while also working to improve harbor water quality and reduce coastal storm damage. Most importantly, the project connects more than 15,000 volunteers, 100 NYC

[1] In September 2020, FEMA issued special guidance on COVID-19 planning considerations for evacuation and shelter-in-place (FEMA, 2020). This guidance provided a structured approach for hospitals and residential care facilities, for mass care and sheltering services, and for tourist populations to review existing protocols in relation to evacuation needs and COVID-19 factors.

schools, over 8,000 students, and 60 restaurants in a community science initiative with substantive adaptation benefits (Billion Oyster Project, 2023)

- Other states such as Virginia and Kansas are garnering attention for their community-focused city-led policy responses such as the *Neighborhood Relief Project* through which various organizations and citizens volunteer to help those vulnerable to extreme heat, such as seniors, people with disabilities or medical conditions (Maricopa Association of Governments, 2023).

Community cloudburst planning: Recognizing that FEMA flood zones, even with updated mapping, do not accurately reflect cloudburst flood areas requires broader approaches to capturing cloudburst impacts to help New Yorkers in those neighborhoods better understand their risks. Flood warnings reach those signed up through *Notify NYC*. However, prior to and during the Ida Remnants cloudburst event, although 29 alerts were dispensed, less than a million of NYC's 8 million+ population received those alerts (A. Walker, 2021). Moreover, the high volume of notifications may result in a dismissal of the threat's severity and delay critical action (Short et al., 2021). Or, conflicting warnings may create confusion (e.g. take shelter from strong winds in basement/find higher ground in case of flooding) (City of New York, 2021). Cities that experienced catastrophic events, such as Hurricane Katrina, turned to social and behavioral programs to build risk readiness in standing community activities. In New Orleans, community groups organized neighborhood events in the places where evacuation buses picked up residents who lacked the means to evacuate on their own. Such habituated events intend to strengthen community cohesion while reinforcing the message of evacuation planning (Kinney et al., 2015). Similar strategies could be considered for NYC in concert with Community Boards or Community-based Organizations. While NYC Emergency Management (NYCEM) preparedness resources identify flash flooding as a risk, community readiness arguably lags. Recent efforts such as the *Rainfall Ready NYC Action Plan* attempt to prepare residents for such events and to help with speed of recovery (City of New York Department of Environmental Protection, 2022b). However, there is significantly more preparation required given the health impacts of local flooding types.

Smart technologies: Smart technologies can be used to connect people with information about flood risk areas, flood monitoring, warnings, MTA routing, and navigation apps, and housing resources like *StreetEasy* to improve awareness. There is also potential in communication tools used during COVID-19, like LINK messaging (nyc covid vaccine appointments [@nycshotslots], 2021), to communicate about climate risks. Resident notification about flooded bus stops/routes and/or subways alongside alternative routing to sustain connections would offer benefits.

4.4 Health Care Provider Roles

Patient interactions and counseling: Through their relationships and interactions with patients, health care providers can play key roles in preventing health impacts from dangerous weather. For example, health professionals can identify patients at risk of heat-related illness, counsel patients and caregivers, and educate other populations and those that interact with them. Studies to evaluate effectiveness are limited, but clinical judgement and an understanding of climate-related illness risk factors and vulnerabilities support several strategies as proposed for preventing heat related illness: 1) target strategies to specific groups, such as general population, occupational risk groups, and athletes, 2) identify vulnerable individuals, 3) provide tailored education and anticipatory guidance to patients, caregivers, coaches, employers and others about illnesses, prevention, and preparedness strategies (Sorensen & Hess, 2022). Several of these strategies are included in health advisories provided by the NYC Department of Health and Mental Hygiene (2022e) to providers at the beginning of the summer season and when heat advisories are issued.

Health professionals could also be encouraged to ask patients about their household energy landscape (e.g., energy use, protective or coping behaviors) and serve as the link between patients and resources to reduce energy insecurity (Cook et al., 2008; Hernández, 2018). Research has demonstrated the efficacy of connections to medical services for protection against energy insecurity, with connections to medical services sometimes leading to referrals to other resources, such as free legal programs to claim settlements for household energy-related damages (e.g., malfunctioning heating systems leading to health consequences) (Cook et al., 2008; Hernández, 2018). Some screening tools of social determinants of health have already incorporated questions about energy insecurity, asking whether one suffers from lack of heat or malfunctioning stove or oven (Hager et al., 2010). Comprehensive screening tools could help systematically identify patients suffering from energy insecurity and refer them to appropriate resources, such as food, financial, legal, tenants' rights services as well as government energy cost and weatherization assistance programs (Hernández, 2018).

Climate-health trainings for providers: The American Public Health Association (APHA) declared climate change a public health emergency in 2022 (American Medical Association, 2022), and some medical schools now host curricula specifically focused on training for climate change risk awareness and response (American Lung

Association, 2019; Columbia University Mailman School of Public Health, 2022a, 2022b). Private health service providers are only beginning to prepare for climate impacts, however. Organizations such as the Medical Society Consortium on Climate and Health (MSCCH) now solicit physicians to support such training and are in the midst of building case studies and curricula to share with physicians (L. Walker, 2023). Health Aid Training and Patient Education need further attention as there are few home-health worker training programs related to climate change and fewer patient resources to offer guidance on climate impacts to health. Trainings for home-health aides were included in the city's *Cool Neighborhoods* heat mitigation and adaptation plan (City of New York Mayor's Office of Resiliency, 2017). Healthcare without Harm also provides applicable guidance (U.S. Health Care Climate Council, 2019). Mental health care providers and emergency responders are also potential partners for patient-level education and intervention (See Community & Social Supports).

4.5 Interventions in the Housing and Energy Sectors

Reducing emissions: Local and regional emission reductions are the best way to reduce local air pollution exposures and health impacts. Air quality health impact assessments described in Balk et al., (2024) estimate the benefits of reduced illness and death already achieved and possible in the future through measures such as *NYC Clean Heat*, achieving NYC's 80x50 greenhouse gas emission reduction targets, and reducing traffic related air pollution (Johnson, Haney, et al., 2020; Kheirbek, Haney, et al., 2014; Kheirbek et al., 2016). NPCC4, Yoon et al. (2024) considers more fully the potential challenges and opportunities for reducing emissions from the energy sector, while ensuring affordable, reliable energy for all New Yorkers.

Residential cooling: Ability to afford home air conditioning and energy to run it is a major driver of indoor temperature. Air conditioning can lower indoor temperatures and increase ventilation. Improving home AC access can also reduce health inequities by race and income (Madrigano et al., 2018). Some types of facilities housing at-risk people are already required to maintain safe indoor temperatures during hot weather. For example, federal legislation requires long-term care facilities that participate in Medicare and Medicaid to provide comfortable and safe temperatures, and facilities certified after 1990 are required to keep temperatures in a range from 71 to 81°F (National Archives, 2023). Some jurisdictions, such as Dallas, Tucson, and Tempe, require that rental properties have cooling equipment (The Times Editorial Board, 2022).

In 2023, NYC announced plans to develop maximum indoor temperature policies to protect all residents by 2030 and require cooling in all new construction by 2025 (City of New York Office of the Mayor, 2023a). Energy efficiency measures, such as higher thermostat settings (Ortiz et al., 2022) can help reduce cooling cost burdens, as can cool roofs that are painted with white reflective paint to reflect rather than absorb heat, which can reduce indoor temperatures (Bock et al., 2021; Y. Sun et al., 2021). Green roofs also have benefits to the indoor environment but are more expensive to install and maintain. Air conditioning, energy use, and equity is discussed further in Balk et al., (2024) and Yoon et al., (2024).

Reduce household flood risk: Recommendations from the NYC Special Initiative for Rebuilding and Resiliency (SIRR) and examples from NYCHA's and Enterprise Community Partners' recent guidance on retrofits offer paths forward to help NYC residents understand what they can do as renters or as owners to reduce their home flood risks. Reducing risk includes addressing basement apartments by making them safer where possible or removing them where flooding is not manageable otherwise. This should occur in concert with increasing safe affordable housing outside of flood prone areas. Supporting home recovery after flooding, to enable re-occupancy as soon as possible, or to offer alternative housing if extended recovery is required (City of New York, 2018; City of New York Housing Preservation and Development, 2022b; City of New York Office of Emergency Management, 2022; Faber, 2015; Hernandez et al., 2019, 2019; Hornbach et al., 2022; Limaye et al., 2019; New York City Housing Authority, 2022; R. R. Thompson et al., 2017; Weichselbaum, 2012; Yong, 2017).

However, as can be seen in places like both New York and Seoul where affordable housing options are extremely limited (Morris, 2022), people will continue to reside in converted cellar or basement apartments and remain at risk. NYC began a basement apartment conversion pilot program in 2019 (Kully, 2020), initially limited to East New York and Cypress Hills, to help middle- and low-income homeowners convert their basement or cellar into safe spaces that could be rented out through low- or no-interest loans, but participation in the program was very low (McDonough, 2023). In November 2023, the city announced the launch of another program to fund 15 homeowners to build or retrofit accessory dwelling units (ADUs), including basement apartments, in an effort to inform plans to increase the availability of affordable housing. These plans, outlined in the *City of Yes* proposal, aim to ease zoning restrictions and legalize more basement and other dwellings to create up to 100,000 new affordable homes (City of New York Department of Housing Preservation and Development, 2023; City of New York Office of the Mayor, 2023b; Hughes & Marroquin, 2023). It will be essential that measures are taken to ensure that location and design of ADUs created through such plans protect the dwellings and occupants from flooding.

For long-term strategies related to homeowner/building-owner options, *FloodHelpNY* (Center for NYC Neighborhoods, 2023) offers retrofitting suggestions that range in expense and disruption to daily life. On the more expensive and disruptive end, one suggestion is to fill in the basement, which is an adaptation measure that blocks off the area that could be flooded. Other suggestions for single-family homes include elevating a residence, moving critical mechanical, electrical, and plumbing services out of the basement, installing flood vents, and installing a backwater valve (or check valve), which prevents flooding from sewage overflow which can occur during heavy rains and is incredibly damaging to property and can cause lingering health risks. The site also offers more budget-friendly options, such as replacing carpeting with non-porous tiles, replacing porous finishes in below-ground areas with non-porous materials and installing a sump pump, which helps remove water during and after flooding.

The *Climate-Driven Rain Response Plan*, released in July 2022, is a citywide action plan specifically meant to address the risks of flash flooding and includes an interactive map to help renters and homeowners determine the risk-levels of their neighborhoods and streets to flooding. The plan also organizes workshops to spread awareness of techniques that can minimize damage and risk to homes, and distributed sandbags and signage at 75 likely-to-be-flooded locations in the summer of 2022. The installation of 1,300 more green infrastructure assets is also an initiative within the plan, which will help divert water away from taxed sewer systems and basements by providing more pervious surfaces during heavy rainfall (City of New York Department of Environmental Protection, 2022b). A network of sensors, starting with 50 and expanding to 500 by 2026, will help populate a publicly available map of flooded areas for monitoring.

In 2023 the city further renewed its green roof tax rebate program, which provides incentives for the addition of pervious surfaces throughout the city. To further research what can be done during cloudburst events like Ida, a Cloudburst Resiliency Planning Study is running two pilot projects in Southeast Queens as well as a check valve study, which could prevent sewage from backing up into homes when the sewage system overflows during a storm. DEP's *Wait* campaign tries to spread messaging about delaying water-intensive activities such as laundry until after a storm passes (City of New York Mayor's Office of Resiliency, 2021).

The topics of relocation from flood prone areas, such as through buyouts of property owners, and the risk of basement apartment flooding is considered in NPCC4, Rosenzweig et al. (2024), NPCC4, Balk et al. (2024), and in the *NYC Climate Vulnerability, Impact, and Adaptation Analysis (VIA)* (McPhearson et al., 2024).

4.6 Occupational Health Protections

While most deaths and admissions for heat-related illness in NYC occur in residential settings, heat-related illnesses can occur in a variety of occupational settings – both indoors and outdoors – as described above. There are no specific federal policies to address worker safety from heat exposure. The Occupational Safety and Health Administration does not require employers to provide air-conditioned (or, in the winter, heated) workplaces, though they recommend that employers implement heat safety plans (Occupational Safety and Health Administration, 2022). In 2021, the agency began a process to create heat safety standards but has not completed the process. In the absence of federal protections, a handful of states, including California, Oregon, Minnesota, Colorado, and Washington have instituted worker protections, including mandating that water, shade, and rest breaks be provided, and that extreme heat response plans be developed and implemented for outdoor workers (Adewumi-Gunn & Constible, 2022). The National Institute for Occupational Safety and Health (NIOSH) has guidelines for working in heat and also recommends that workers be provided with water, shade, rest, and safety training, among other measures (National Institute for Occupational Safety and Health (NIOSH), 2020).

Advocates have noted, however, that enforceable national safety rules are lacking and while these state-level policies are important, most of them still have large gaps, including a need for indoor safety standards, adequate enforcement and penalties, and heat-health safety trainings for workers (Adewumi-Gunn & Constible, 2022). In addition, including clothing absorptivity in the WBGT equation for outdoor workers could improve workplace heat protections by establishing more realistic standards, if WBGT workplace guidelines such as those created by the International Standardization Organization, were enforced (Parsons, 2006). As noted above, though, even those workplace standards that exist are rarely enforced (Constible et al., 2020). Undocumented workers are at increased risk of abusive workplace practices and may not report workplace safety issues for fear of immigration-related retaliation by employers (McConnell, 2019).

4.7 Interventions for the Public Realm and Shared Environments

Controlling mosquito-borne illness: The NYC Department of Health and Mental Hygiene takes numerous measures to prevent West Nile Virus transmission in the city. Standing water sources are removed, larvae are treated with biological agents to prevent them from growing into adult mosquitos, and public education outreach programs are implemented to increase awareness about the risks of standing water and West Nile virus (WNV) (Bajwa W, Slavinski S, Shah Z, Zhou L, 2022). Through surveillance data, the NYC Health Department can identify high transmission risk a few weeks in advance by testing traps for WNV a few weeks before it presents a risk to the public. If more serious measures are needed, such as the use of insecticides to reduce adult mosquito populations (adulticiding) then these can be identified and deployed. Requiring window screens in residential buildings may prevent human infections and appear to prevent sustained local transmission of mosquito-borne illnesses that depend on human hosts, such as dengue, chikungunya, and Zika viruses, and are not currently endemic in the NYC area (Moreno-Madriñán & Turell, 2018; Reiter et al., 2003).

Public realm, flooding, and heat exposure: There are now smartphone applications to provide insights on flooded streets and offer alternative and accessible routes to move about safely before and during a flood (FloodMapp, 2022; Wetlands Watch, 2022). Cloudburst strategies with priorities to provide accessible pathways in critical areas could be a next step. Recognizing that all buildings and open spaces will not offer the same level of adaptive capacity, a complementary retrofit tactic is to develop accessible pathways that enable safe pedestrian movement between locations (City of New York Mayor's Office of Resiliency, 2021). As an example, in Yalding, United Kingdom, a raised walkway provides a mode of egress/access in the event of a flood, which could be a helpful solution in areas with many older buildings or where flooding retrofits are infeasible due to costs or other practical reasons (Barsley, 2020).

Messaging to alert residents to these strategies and how to manage during flood events is a critical health contribution, as is coastal and riverine flood management in parks, at the rivers, and at the beaches to reduce floodwater exposure and associated messaging to keep community members informed of their risks. Continued focus on combined sewer overflow (CSO) prevention is needed as these are amplified with flooding and impact respite areas throughout the coastal and riverine parks of New York. In the Futures and Transitions chapter of this assessment, repurposing space in the public right of way is considered as a strategy for increasing green space to mitigate the urban heat island, prevent flooding, and provide cooler, shaded places for healthy active mobility and outdoor socializing.

Climate adapted street trees: NYC Parks has developed an approved tree species list (City of New York Department of Parks & Recreation, 2023c) for new and replacement street trees that are well adapted to NYC climate and urban conditions and do not add to levels of the most allergenic tree pollen.

5 Opportunities for Future Research

5.1 Summary of Knowledge Gaps

5.1.1 Heat and health

The effects of hot weather on mortality and other health outcomes have been extensively studied in New York and other cities with similar climates. Important knowledge gaps and research opportunities remain, however, and include a need to better understand:

- The projected relationships among higher temperatures, humidity, and other heat metrics under a changing climate.
- Occupational heat exposure and health impacts in NYC, including impacts on food vendors and delivery workers.
- Exposure and health benefits of urban heat island mitigation measures, such as green space.
- Improved data on indoor temperatures and health risks in different types of dwellings and structures.
- The impact of heat exposure on populations experiencing homelessness, both sheltered and unsheltered.

5.1.2 Flooding

5.1.2.1 Economic costs of health impacts from climate sensitive events in NYC

As part of an ongoing Climate Vulnerability, Impact, and Adaptation Analysis (VIA) to study climate change's impacts on decision-making in NYC, a research team is reviewing published reports on the impacts of climate-sensitive events in NY from 2000 to 2020, then evaluating their health-related costs (McPhearson et al., 2024). Health-related costs are not typically estimated and are largely absent from climate change damage estimates (Limaye et al., 2020).The evaluation of health-related costs will inform analyses of associated past, current, and future health costs under plausible climate change scenarios, which will be published in forthcoming work (McPhearson et al., 2024) (also see Section 4.2.1 in NPCC4, Balk et al. (2024)).

5.1.2.2 Location information about compound flooding impacts and areas

As with coastal storm surges, the risk of death from cloudburst flooding during storms like the Ida Remnants Cloudburst and its long-term consequences for survivors were shaped by both geographic location and dwelling characteristics. Most obvious and tragic were drowning deaths in basement apartments. While recent city administrations have undertaken apartment improvement programs, and issued studies relating to basement apartments and subways, the deadly combination of scant affordable housing, illegal basement apartments, and climate change-fueled increases in extreme rainfall events merits further study to inform sustained, effective, and widespread action.

Residents and policymakers could benefit from more information about the vulnerability and resilience of residential buildings at risk of flooding from storm surge, cloudburst events, or sea level rise. Critically important for protecting health is data on the locations of basement dwellings in relation to pluvial and coastal flood hazards. Data on multi-family dwellings that have flood hardened building mechanical systems would be useful for both designing resilience strategies and planning for flood response. For existing renters and owners, having greater flood risk awareness can inform negotiations with landlords and co-op or condo boards and management companies, and help in developing strategies to reduce exposure. This is particularly pertinent for basement and ground floor apartment dwellers who may be unaware of their risks. The *NYC Stormwater Resiliency Plan* includes initiatives to ensure that relevant stakeholders know how to interpret and understand flood maps and preventative measures, as well as targeted messaging for people living in basement apartments prior to a storm. Also recent NYS legislation (Assembly Bill 2023-A1967, 2023) guarantees "right to know" for prospective buyers and complements 2021 legislation which does the same for renters (Assembly Bill A3360A, 2021). However, for those already occupying residential buildings, there is no other mandate to provide information on flood-related health risks and existing residential building capacity to manage those risks.

In addition to improving understanding of risk awareness, an important knowledge gap is the capacity of households living in basement dwellings to receive and respond to timely evacuation warnings, given the relatively limited lead time and spatial uncertainty of cloudburst forecasts, the possibility that warnings will arrive will residents are asleep, that they may have mobility impairments, and may suffer stress, warning fatigue, and other adverse effects from false positive alerts. As the city improves its capacity for understanding the impact of cloudburst events (City of New York Department of Environmental Protection, 2023c) and weather forecasting improves, residents could benefit from receiving such information, helping to raise risk awareness and connect the types of rainfall events and their local weather announcements to household decision-making and, where applicable, the need to shelter elsewhere.

With the latest information in PlaNYC regarding voluntary mobility (City of New York Office of the Mayor, 2023a), New Yorkers could also benefit from additional research on resettlement implications of the latest climate science (see NPCC4, Balk et al. (Balk et al., 2024)).

5.1.3 Vector-borne disease

The influences on human risk of vector-borne disease (VBD) are complex, involving climate, landcover, living conditions, ecosystems, and interactions among these and with humans and animals that can be infected and serve as hosts for further transmission. Further research is needed to understand these factors and better anticipate and control VBD risks in NYC and the metro area. Additionally, improved research and surveillance can help evaluate and improve control measures. For example, mosquito control strategies using integrated pest management (IPM) principles have been widely implemented in response to the spread of WNV in the US. While evidence supports effectiveness in reducing mosquito populations, few studies have used outcomes of reduced human cases or surrogates for WNV risk (Nasci & Mutebi, 2019).

5.1.4 Mental health and social isolation

In addition to the well-established vulnerabilities to climate health risks among people with mental health conditions, climate anxiety is an emerging, but not well studied phenomenon. It disproportionately affects younger people nationally and globally (Crandon, Scott, et al., 2022). While not an NYC-specific phenomenon, studies on its causes, relation to news and messaging about climate change, and vulnerable subgroups are needed to inform effective prevention and care for those affected (Charlson et al., 2022). Recent research describes the effects of climate stressors on dementia risk and those living with cognitive decline (Zuelsdorff & Limaye, 2023). Cities like NYC have an opportunity to shape municipal adaptation responses to better meet the needs of this population.

Social isolation at all ages is associated with worse health outcomes and often associated with mental health conditions. While distinct from living alone (which is fairly easy to measure), social isolation, which increases with age, is much harder to measure. As such, how social isolation influences health outcomes associated with vulnerability to heat, flooding and other climate-stressors presents an important knowledge gap.

5.1.5 Air pollution advisories and public health measures

As this assessment is being written, wildfire smoke has caused several days of poor air quality across much of the eastern US and in NYC. While the issuance of air quality health advisories and guidance based on the Air Quality Index (AQI) is a long established practice in the US, important questions remain about the appropriateness of the AQI and advisory thresholds, the effectiveness of some recommended personal measures to reduce exposure, the ability of different populations to understand and implement recommended actions, and tradeoffs between recommended activity restrictions and health benefits of regular physical activity (Carlsten et al., 2020; Davison et al., 2021; Laumbach et al., 2021).

6 Sustained Assessment

Sustained assessment of NYC climate-health risks, impacts, and vulnerabilities should include monitoring quantitative indicators, city plans and actions to reduce them, and greater public and stakeholder awareness, feedback, and civic engagement to spur ongoing evidence-informed actions with continuity across mayoral and city council terms.

A comprehensive indicator and monitoring system for NYC has been recommended by NPCC in the past (Blake et al., 2019; Solecki et al., 2015) but has not yet been funded or implemented. For climate-health risks, a number of useful climate and health indicators and visualizations are available at the NYC Environment and Health Data Portal (City of New York Department of Health and Mental Hygiene, 2022g). Drawing from these and other previously adopted indicators and coordinating reporting on those indicators alongside the climate change implications could be an early step. Another could be working within the existing Mayor's Management Report and expanding the Health and Human Services component to be inclusive of climate change impacts on health (City of New York Mayor's Office of Operations, 2023a, 2023b). Public web portals provide the possibility of soliciting input and ideas from a much greater range of public stakeholders and organizations than those able to attend scheduled meetings. An example is the interactive Vision Zero Input Map, rolled out at the launch of that initiative, (City of New York Mayor's Office of Operations, 2015). The public, journalists and advocacy groups can now access and visualize safety intervention, crash, injury, and fatality data to assess changes over time (City of New York, 2013).

Future sustained assessment efforts could be enhanced by implementing the roles, communications functions, and regular interactions among the NPCC, the Climate Change Adaptation Task Force (CCATF), and the NYC Mayor's office envisioned in the local law that established the NPCC (Local Law 42, 2012). This, in addition to NPCC engagement with the Environmental Justice Advisory Board (EJAB), the Sustainability Advisory Board, and the Climate Knowledge Exchange (CKE) can enhance the reflection of diverse stakeholders and technical expertise in the NPCC work products. This NPCC has also prioritized sustained assessment through the publication of a public NPCC website, which hosts up-to-date information on NPCC projects, and the production of public- and policymaker-facing, plain-language summaries of their research products.

Specific to the health sector, cultivating a community of health professionals in concert with community members in an ongoing knowledge exchange, deepening, or developing, ongoing relationships within communities to encourage climate and health conversations and to create supportive pathways to ask for help is an important shift. For example, a health ambassador program could offer a possible way forward. The Climate for Health Ambassador Training Program and the NextGen Climate and Health Ambassador Program are examples. To fairly compensate community members for their contributions (Climate for Health, 2023; Physicians for Social Responsibility, 2022), the EPA's Water Ambassador Program offers another example (United States Environmental Protection Agency, 2018).

7 Traceable Accounts

Key Message 1: Climate change-related health risks are a threat to all New Yorkers, but especially those most vulnerable because of age, poor health, and racial and social inequities. Inequities in household and neighborhood physical environments also mediate vulnerability to climate-health impacts. Addressing key environmental and social drivers of vulnerability is an essential adaptation strategy. Many current NYC policies and strategies, (e.g., improving access to residential air conditioning, tree planting), aim to accomplish this. These efforts can be informed and evaluated using data on climate-health vulnerabilities, such as components of the heat vulnerability index (HVI) and a flooding vulnerability index (FVI) under development.

Description of Evidence: Multiple studies in NYC and urban areas with similar climate show that climate change is increasing risks to health from exposure to heat, flooding, and other climate-sensitive exposures (City of New York Department of Health and Mental Hygiene, 2023b; Kinney et al., 2015; Lane et al., 2013; New York City Panel on Climate Change, 2019; Parks et al., 2021, 2022; Weinberger et al., 2020). Evidence of greater vulnerability due to age, pre-existing health conditions, and racial and social inequities is also extensive(City of New York Department of Health and Mental Hygiene, 2022b, 2022g; Cui & Sinoway, 2014; Ebi et al., 2021; Gamble et al., 2013; Hooper et al., 2014; Larose et al., 2013; S. Lin et al., 2009; Madrigano et al., 2018; Meade et al., 2020; Millyard et al., 2020; Sasai et al., 2021). Disparities in home and neighborhood physical environments have been demonstrated to modify health risks (City of New York Department of Health and Mental Hygiene, 2022b, 2022g; Madrigano et al., 2018).

Remaining Uncertainties: Uncertainties and knowledge gaps are summarized for each specific climate exposure below.

Assessment of Confidence Based on Evidence: There is high confidence that NYC climate-related health risks, especially from heat and flooding, will increase, that vulnerable populations have been identified, and that adaptation can reduce risks.

Key Message 2: Heat waves are, on average, the deadliest type of extreme weather in NYC and in much of the US. Even hot, but not extreme, summer weather also causes serious illness, death, and other harms to wellbeing. Because of climate change, NYC will experience more dangerous hot weather. Most heat-related deaths are due to exacerbation of chronic health conditions, such as cardiovascular disease. Indoor exposures can be especially deadly for people without air conditioning who have one or more physical or mental health conditions, are energy insecure, are older adults, or have jobs exposing them to unsafe indoor or outdoor temperatures. These risk factors can be consequences of structural racial, social, and economic inequities. Adaptive measures are needed that protect vulnerable populations from season-long heat-health risks, including from non-extreme but hot weather. Evidence-informed strategies include enhanced access to air conditioning, reducing energy insecurity, engaging community and health provider networks to reach vulnerable populations, and augmenting tree canopy cover.

Description of Evidence: Multiple assessments of the IPCC, US National Climate Assessment, and NPCC state that temperatures will rise, extreme heat events will worsen, and support the conclusion that temperature increases will have a negative impact on health (Intergovernmental Panel on Climate Change, 2023; USGCRP, 2018). Many epidemiologic studies focused on NYC, other parts of the US, and internationally have described the large, negative effect heat currently has on human health, including morbidity and mortality (B. G. Anderson & Bell, 2009; Curriero, 2002; Fletcher et al., 2012; Gasparrini et al., 2015; S. Lin et al., 2009; Metzger et al., 2010b; Nori-Sarma et al., 2022; Parks et al., 2020; S. Sun et al., 2021; Tobías et al., 2021; Weinberger et al., 2020; Z. Xu et al., 2016; Yoo et al., 2021). These studies often identify groups at higher risk; other studies focus specifically on associations and risk factors for heat mortality and morbidity. In addition, several studies and assessments describe multiple pathways through which persistent racism can negatively affect health for people of color through multiple pathways, including through inequitable heat exposure (Bailey et al., 2017; City of New York Department of Health and Mental Hygiene, 2022b; Gamble et al., 2013; Hoffman et al., 2020b; Lewis et al., 2019; Madrigano et al., 2015; O'Neill et al., 2005). Most heat-related deaths are caused by heat exacerbation of chronic conditions (excess mortality) (City of New York Department of Health and Mental Hygiene, 2023b; Kinney et al., 2015; Weinberger et al., 2020). Comparisons of mortality burden across extreme weather types are limited because excess deaths from hurricanes have not been as well-documented, a field that is currently emerging (Parks et al., 2023). Even so, existing and recent evidence continues to support the conclusion that heat is deadliest type of extreme weather in NYC and in the US, on average.

Remaining Uncertainties: There is evidence about the indoor temperature in NYC and US urban areas demonstrating that it can be elevated in the absence of air conditioning during and after hot weather (Vant-Hull et al., 2018; White-Newsome et al., 2012), but there are few studies measuring indoor temperature in relation to health, and less available evidence about indoor temperature thresholds appropriate for vulnerable populations, for example those who are older adults or people with chronic or mental health conditions. However, heat stress and heat-exacerbated deaths are more frequent in NYC residences compared to other settings, underscoring the risk of indoor settings (City of New York Department of Health and Mental Hygiene, 2023b; Madrigano et al., 2015; Wheeler et al., 2013). Some heat adaptation strategies have been assessed or evaluated (Berisha et al., 2017; Lane et al., 2023; WE ACT for Environmental Justice, 2021), but there have been no or limited evaluations of the implementation and effectiveness of many heat interventions. In addition, there are limited studies of long-term or chronic heat exposure effects as well as heat-health effects that do not result in interactions with the healthcare system, with most studies focused on acute and/or severe health effects.

Assessment of Confidence Based on Evidence: There is high confidence that hot weather causes serious illness and death among vulnerable New Yorkers exposed indoors, that the burden is cumulatively greater from hot, but non-extreme weather, and that air conditioning can reduce risk.

Key Message 3: Public health can be impacted before, during, and after flooding, which exposes New Yorkers to risks of drowning and other injuries, stressful evacuation, short- or long-term displacement from home, and exposures from clean up, repair, water contaminants, and mold from water damage. Climate projections for NYC anticipate an increase in extreme precipitation days and sea level rise contributing to more frequent flooding over wider areas. Socioeconomic disadvantage, pre-existing health conditions, and flood-vulnerable housing and infrastructure amplify health impacts of flooding. Adaptation strategies that modify these factors can reduce future flooding impacts on health.

Description of Evidence: National and northeast regional evidence supports the connections between climate change, flooding, and associated health risks (Frankson et al., 2022; Huang et al., 2017; USGCRP, 2018). The wide range of health risks and impacts associated with flooding includes premature mortality from drowning, physical injuries during flooding and from post-event cleanup, asphyxiation from improper use of space heaters, exposures to waterborne pathogens and chemical contaminants, increases in respiratory ailments from mold growth on water-damaged infrastructure, healthcare service disruption caused by flooding, increased risks of adverse pregnancy outcomes, and lasting mental health consequences, such as anxiety, depression, and post-traumatic stress disorder among affected communities (Hegarty et al., 2019; Lane et al., 2013; Limaye et al., 2019; Mendez-Figueroa et al., 2019; Mort et al., 2018; Parks et al., 2021, 2022; Partash et al., 2022; Paterson et al., 2018; Semenza, 2020; Smalling et al., 2016; Thacher et al., 2017; USGCRP, 2018; Wertis et al., 2023). The array of strategies to address these risks now includes efforts to improve the power supply resiliency of buildings, developing ways to increase safe affordable housing outside of flood-prone areas, supporting home re-occupancy or alternative occupancies post-flood, developing more community awareness of long-term sea level rise risks, and use of new technologies like phone applications that can provide insights on safer access routes before and during flooding, among others (Barnes & Temko, 2022; City of New York Department of Housing Preservation and Development, 2017; FloodMapp, 2022; Hornbach et al., 2022; Seip, 2022).

Remaining Uncertainties: Uncertainties exist around the interaction of sea level rise, coastal flooding, pluvial, fluvial, and groundwater flooding to create location-specific compound flooding risks, since these complex systems and events are challenging to simulate with computer modeling. Better predictive capacity regarding the impacts of cloudburst events will help in evaluating localized flooding risks. Furthermore, data on the economic costs associated with flooding-related health impacts are not routinely collected, creating uncertainties as to the full range of flooding-associated societal costs. Uncertainties also exist regarding the factors that can maximize voluntary, timely participation in flood evacuations, New Yorkers could also benefit from additional research on resettlement implications of the latest climate science.

Assessment of Confidence Based on Evidence: Given the evidence and remaining uncertainties, there is high confidence that without significant intervention and reduction of vulnerabilities, New Yorkers' health will be harmed by multiple types of flooding, including pluvial, fluvial, coastal, and groundwater flooding, and their compound flood hazards.

Key Message 4: Hotter weather can increase concentrations of harmful air pollutants, including fine particles and ground-level ozone, by increasing emissions of precursor pollutants and the formation of ozone on warm, sunny days. These pollutants are harmful to health for all New Yorkers, but especially for the very young and old, people with certain chronic health conditions, those without residential air conditioning, and those living where emissions from buildings and traffic are concentrated. Most of these vulnerability factors are more common among Black, Latino, and low-income households. Despite a warming climate, air quality has improved in New York City because of reduced local and regional emissions. Recent wildfire smoke plumes affecting much of the eastern US indicate the potential to reverse a trend of improving air quality. Efforts to further reduce emissions and exposures of vulnerable populations can prevent or mitigate climate-related air quality impacts.

Description of Evidence: The relation of weather to harmful air pollutant concentrations has been thoroughly studied, demonstrating the potential climate change to increase ambient concentrations health risks, especially for ozone. (Kinney et al., 2015; Knowlton et al., 2004; K. Zhao et al., 2019). The national and global body of evidence of health effects from $PM_{2.5}$ and ozone are extensive and robust (Global Burden of Disease Collaborative Network, 2020; United States Environmental Protection Agency, 2020). Physiologic mechanisms and epidemiologic studies have demonstrated the influence of age and chronic health conditions (Perera & Nadeau, 2022; United States Environmental Protection Agency, 2022a). Evidence for physical environment factors influencing vulnerability, including residential air conditioning and proximity to traffic emissions is also substantial (Bell et al., 2014; Jhun et al., 2014; D. Zhao et al., 2015; Zuraimi et al., 2011) as is data showing Black, Latino, and low-income households having a greater burden of health and physical environment vulnerabilities (City of New York Department of Health and Mental Hygiene, 2023i). Robust local data show improving air quality in NYC because of reduced emissions (City of

New York Department of Health and Mental Hygiene, 2022i; Kheirbek, Ito, et al., 2014; Pitiranggon et al., 2021; Zhang et al., 2021).

Remaining Uncertainties: Air pollution epidemiology continues to identify additional health effects at levels well below regulatory standards and current health burdens are likely to be underestimated. Future risks of severe wildfire smoke episodes, like that impacting NYC in the summer of 2023 are yet to be quantified as is the potential for them to reverse decades of progress in reducing $PM_{2.5}$ exposure in NYC. Questions remain about the appropriateness of public health response strategies for acute air pollution episodes, including the AQI and advisory thresholds, the effectiveness of some recommended personal measures to reduce exposure, the ability of different populations to understand and implement recommended actions, and tradeoffs between recommended activity restrictions and health benefits of regular physical activity (Carlsten et al., 2020; Davison et al., 2021; Laumbach et al., 2021). The exposure-response relationship of indoor NO_2 pollution from gas stoves is uncertain and direct evidence of the health benefits of replacing gas stoves with electric ones is limited.

Assessment of Confidence Based on Evidence: Based on high quality local and national studies, there is high confidence that: air pollution will continue to cause substantial public health impacts in New York City, especially among vulnerable populations and that reducing local emissions has and can continue to improve local air quality. There is moderate confidence that climate change will increase the risk of wildfires that can adversely affect NYC air quality. There is substantial uncertainty about the future frequency and severity of wildfire smoke episodes in NYC and the effectiveness of measures to reduce local exposures and health risks.

Key Message 5: Nationally, climate change is causing an earlier, longer, and possibly more intense plant pollen production season, but this trend is less evident in the northeast. Within New York City, pollen from several common tree species contribute to pollen exposure, seasonal allergic rhinitis, and asthma exacerbations. Communities with less access to health care, more household asthma triggers, and less well-managed asthma are more vulnerable. Air conditioning and filtration can reduce indoor pollen exposure. Attention to local tree cover density and species composition along with improved access to care, evidence-based asthma management, and patient education can reduce pollen exposure, vulnerability, and future allergic illness.

Description of Evidence: High quality national and local studies published since NPCC2 (Kinney et al., 2015) add to the weight of evidence available for that assessment that the pollen season timing and intensity are being influenced by climate change and that pollen exposure and allergic illness is influenced by local land cover with plant species producing allergenic pollen (Ito et al., 2015; Lara et al., 2020; Lovasi et al., 2013; Weinberger et al., 2016). Evidence has also grown that climate influences indoor and outdoor mold growth and that mold exposure can cause or exacerbate respiratory illness (Anees-Hill et al., 2022; Eguiluz-Gracia et al., 2020; Hanson et al., 2022; Poole et al., 2019; Sampath et al., 2023).

Remaining Uncertainties: Local data on trends in pollen and mold exposure is limited and there are uncertainties in the relative influence of climate change versus trends in local landcover and housing construction and condition on these exposures. This adds uncertainty to knowledge of recent local trends and future projections of local allergic illness risk from these climate change sensitive aeroallergens.

Assessment of Confidence Based on Evidence: Confidence is high that climate change is influencing and increasing national aeroallergen exposure. Confidence is moderate that climate change will increase local health aeroallergen exposures and health risks, which are also influenced by multiple non-climate factors.

Key Message 6: In the northeast, changes in climate, landcover, and ecosystems continue to shift the spatial and seasonal distribution of mosquitos and ticks that are current or potential vectors of human illness. Within New York City, the spatial distribution of these vectors and potential for human infection and serious illness varies with differences in the built environment, natural habitat and host animal abundance, human behaviors, and population vulnerability. Seniors, those with chronic illnesses, and people who are homeless are more susceptible to complications from West Nile virus (WNV) infection. Lyme disease risk among New Yorkers is increased among those engaged in outdoor activities mostly outside the city, but also in Staten Island and a limited area in the Bronx. Vector-borne disease (VBD) risk is also increased by international travel to and immigration from disease-endemic areas. Disease surveillance, vector monitoring and control, and public and clinician awareness can reduce future risks in a changing climate.

Description of Evidence: High quality local and national studies demonstrate sensitivity of the range and abundance of mosquitos and ticks to climate change and complex interactions among climate variables (Alkishe et al., 2021; Kinney et al., 2015; S. Lin et al., 2019; Paull et al., 2017; Shaman et al., 2005; Soverow et al., 2009). Evidence is also strong that non-climate variables, including human settlement and behavior patterns, and their interactions with climate also influence exposure and health risks from vector-borne pathogens (Bardosh et al., 2017; Keyel et al., 2021; Paull et al., 2017; USGCRP, 2018). Robust local surveillance data shows that tick-borne diseases are most often acquired by New Yorkers during travel outside NYC and that locally acquired infection occurs mostly in Staten Island.

Remaining Uncertainties: The influences of the complex, multiple climate and non-climate factors influencing human risk of VBD make it difficult to project future risks of currently endemic VBD in NYC and the metro area. Even more uncertain are future risks of new or emergent VBD. Additionally, improved research and surveillance can help evaluate and improve control measures. For example, mosquito control strategies using integrated pest management (IPM) principles have been widely implemented in response to the spread of WNV in the US. While evidence supports effectiveness in reducing mosquito populations, few studies have used outcomes of reduced human cases or surrogates for WNV risk (Nasci & Mutebi, 2019).

Assessment of Confidence Based on Evidence: There is high confidence that locally endemic VBDs will continue to cause illness in New Yorkers, that the risk of exposure will vary spatially and with changes in weather, and that robust local surveillance of insect vectors and human infections is essential to early identification and control of outbreaks. There is moderate confidence that changes in climate, international migration, and habitat could cause cases of locally transmitted malaria or other VBD not currently endemic in NYC but high uncertainty concerning the future risk of sustained local transmission.

Key Message 7: Climate change may increase the risk of exposure to water-borne pathogens in surface waters and wastewater in and around New York City and could threaten its drinking water sources and distribution system. Increased flooding can cause exposure to contaminants flood and surface waters from combined sewer overflows (CSOs) and sewer backups. Rising temperatures facilitate the growth and spread of pathogens such as bacteria that cause gastrointestinal illness, Legionnaire's disease, and a range of illnesses from harmful algal blooms. Extreme weather and climate change impacts on New York City's source and distribution infrastructure could compromise water quality and quantity. Continued maintenance and adaptation of infrastructure along with coordinated surveillance of water quality, human, and animal health can help prevent and control quality impacts on health.

Description of Evidence: Global and national studies demonstrate the potential for flooding, higher temperatures and rising humidity caused by climate change to increase risk of waterborne gastrointestinal, respiratory, and other illnesses (D. M. Anderson et al., 2021; Escobar et al., 2015; Liang & Messenger, 2018; Paschke et al., 2019; Semenza, 2020; Simmering et al., 2017; Trtanj et al., 2016). In New York State, HAB reports increased in frequency from 2012-2020 (Gorney et al., 2023). Locally, climate risks to New York City's drinking water supply are more complex because of its protected upstate watershed (Zimmerman et al., 2019). Local data shows the potential for flooding to exposure to water contaminants through sewage backups and combined sewer overflows that affect surface water quality around the city (City of New York Department of Health and Mental Hygiene, 2023h), for legionella outbreaks from cooling towers (Weiss et al., 2017), and for harmful algal blooms to affect local water bodies (New York State Department of Environmental Conservation, 2023a).

Remaining Uncertainties: New York City's unique and complex drinking water infrastructure and behaviors influencing contact with surface water makes it difficult to quantify future waterborne illness risk caused by climate change.

Assessment of Confidence Based on Evidence: There is moderate confidence that, absent adaptation, climate change can increase the local risk of exposure to waterborne contaminants from flooding and to legionella aerosols from cooling towers.

Key Message 8: Climate risks can be compounded when they disrupt lifeline infrastructure systems or overlap with non-climate public health emergencies. Examples include power outages during recent extreme heat events and the COVID-19 pandemic creating potential disease transmission risks in cooling centers and other publicly accessible indoor spaces. The health risks from compound hazards can be reduced through investing in lifeline and other critical infrastructure and building mechanical systems that are adapted to extreme weather, redundant, and flexible. Rapid, flexible, collaborative, multi-sectoral responses are needed to respond to pandemics and other unanticipated compound hazards.

Description of Evidence: In addition to compound risks caused by damage to lifeline infrastructure during extreme weather, covered earlier, local studies demonstrated the compound risks to health created by hot summer weather co-occurring with COVID-19 transmission (Bock et al., 2021; Lane et al., 2023; Watkins & Southall, 2019; WE ACT for Environmental Justice, 2021) or wildfire smoke (Rosenthal et al., 2022).

Remaining Uncertainties: Currently available data does not allow for quantifying the local added burden of human illness caused by the co-occurrence of hot weather with COVID-19 or with wildfire smoke exposure.

Assessment of Confidence Based on Evidence: Confidence is high that compound hazards can amplify climate-health impacts but low concerning the burden of illness caused by the interaction of climate risks and recently emerging hazards of COVID-19 and wildfire smoke.

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Acknowledgements

Liv Yoon and Peter Marcotullio developed substantive work on energy insecurity in earlier versions of this manuscript. The relationship between health and energy insecurity and NYC's climate hazards was a formative part of the structuring of this manuscript. This work now is a separate chapter, NPCC4: Climate Change, Energy, and Energy Insecurity in New York City (Yoon et al, 2023).

Deborah Balk, Kim Knowlton, and Jenna Tipaldo have received ancillary support from the Department of Citywide Administrative Services (DCAS), with the Mayor's Office of Climate and Environmental Justice (MOCEJ), Town+Gown Task Order-funded activity Vulnerability, Impacts and Adaptation (VIA) Analysis (Task 4), to the New School, CUNY and Columbia University. While that work is separate from this Assessment, its content is complementary and we therefore acknowledge it here.

The Health Working Group recognizes the invaluable feedback on earlier versions of this manuscript provided by the NYC ICAT team members Tallant Burley, Senior Policy Advisor, MOCEJ, New York, NY and Melissa Umberger, Director of Recovery and Risk, NYC Emergency Management, New York, NY, by External Advisors Joan Casey, PhD, Assistant Professor, Department of Environmental Health Services, Columbia University, New York, NY, Rob Moore, Senior Policy Analyst, Natural Resources Defense Council, Carolyn Olson, MPH, Assistant Commissioner, Bureau of Environmental Surveillance & Policy, NYC Department of Health & Mental Hygiene, New York, NY, Perry Sheffield, MD, MPH, Icahn School of Medicine, Mount Sinai, New York, NY, and Sally Slavinski DVM, MPH, Dipl ACVPM, Director Zoonotic and Vector-borne Disease Unit, Bureau of Communicable Disease, NYC Department of Health & Mental Hygiene, New York, NY, and by Leo Temko, MSc, General Partner, Climate Adaptation Partners, New York, NY.

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Abstract:

This chapter of the New York City Panel on Climate Change 4 (NPCC4) report provides an overview of energy trends in New York City (NYC) and the State of New York, as well as accompanying challenges and barriers to the energy transition – with implications for human health and wellbeing. The link between energy trends and their impact on health and well-being is brought to the fore by the concept of 'energy insecurity', an important addition to the NPCC4 assessment.

Keywords:

Climate Change, Energy Insecurity, Health & Wellbeing, Energy Transition, NPCC4

Recommended Citation:

Yoon, .L., Ventrella, J., Marcotullio, P., Matte, T., Lane, K., Tipaldo, J., Jessel, S., Schmid, K., Casagrande, J., Elszasz, H., (2024). Climate Change, Energy, and Energy Insecurity in New York City. Interim Report.
https://climateassessment.nyc

Table of Contents

1 Chapter Summary

In the local pursuit of sustainable development and addressing global climate change challenges, it is crucial to not only focus on improving energy efficiency and lowering carbon intensity but also to consider how these processes affect the accessibility and use of energy by all who live and work in the city. Energy insecurity (EI) refers to the inability to meet, or stresses involved in meeting, household or community-level energy needs that are essential for health and wellbeing. Assertively addressing the issue of energy insecurity as New York City (NYC) pursues these challenges helps to bring this tension to the forefront of climate policy as it integrates energy, health, and social inequities.

1.1 Key Messages

Key Message 1: *While recognizing the urgency to reduce energy use and GHG emissions to meet the City and State's ambitious climate goals and mitigate the impacts of climate change, actions must be approached deliberately, considering energy insecurity and health. Challenges – including reducing fossil fuel use, acquiring renewables, adapting the grid to meet higher demand, and securing sufficient dispatchable generation to ensure reliability during peak periods when solar and wind generation is low – can all have implications for energy affordability and reliability. While the transition offers opportunities for economic growth, improved air quality, and promoting active transport, equitable implementation, and reliable energy supply particularly during extreme weather events are important considerations for NYC.*

Key Message 2: *Energy is not only vital for economic growth, but also for human health and well-being – a connection that the concept of energy insecurity (EI) highlights. EI can be caused by high energy costs relative to income, by frequent energy outages and unreliability, or both. Addressing EI both influences, and is influenced by, various domains such as public health, transportation, energy, and housing sectors – all compounded by climate change as a threat multiplier.*

Key Message 3: *EI can harm public health directly – via inadequate heating or cooling, indoor air pollution, and reduced ability to reliably use medical devices and refrigeration necessary for health needs – and indirectly when high energy costs reduce spending on other essential items like healthcare and food. Populations most vulnerable to EI include those of any citizenship and immigration status with lower incomes, people who have experienced systemic racism, people with underlying health conditions, disabilities, or dependent on electric powered medical equipment, and renters, who are less able to access energy subsidies.*

Key Message 4*: Climate resilience investments in energy infrastructure and mitigation plans for the transition from fossil fuels to renewable energy and the electrification of buildings and transportation could impact future energy reliability and costs. Vulnerable populations are most at risk from any potential increases in power outages or energy costs, which may be exacerbated by projected climate extremes in NYC, such as extreme heat, cold, and flooding. Equitable and just policies and investments in the energy and housing sectors can reduce future health risks from energy insecurity and shape a more resilient and equitable future.*

2 Introduction

2.1 Chapter Scope and Context

Reducing global greenhouse gas (GHG) emissions to mitigate climate change, coupled with implementing local adaptation measures, is essential for effectively minimizing local climate-related health risks. This approach underscores the critical need to improve energy trends, such as increasing renewable energy capacity. NYC, which already has much lower per-capita GHG emissions than the state and surrounding suburbs, has made significant strides towards a more sustainable future with less GHG emissions and reduced indoor and outdoor air pollution through policies, and projects that advance electrification, energy efficiency, and renewable energy generation for both city government operations and in the private sector. However, focusing solely on these positive trends without addressing energy insecurity would be an incomplete and shortsighted approach. For instance, as climate change worsens and energy transition plans take effect, electricity demands will increase as we use more energy to cool our buildings and electrify the building and transportation sectors, potentially overwhelming the electricity grid and local distribution infrastructure in the absence of advanced planning. This may cause more frequent blackouts and brownouts during peak periods of energy use, often associated with extreme weather events like heat waves and cold snaps, – an issue we have already witnessed in the Texas storms of February 2021 (Flavelle et al., 2021). Electricity demand will also change as the city and state work toward achieving the GHG emissions and clean energy targets of New York State's Climate Leadership and Community Protection Act (CLCPA) and Local Law 97 of 2019 (LL97) (CLCPA, 2019; Local Law 97, 2019). These policies will result in buildings and transportation shifting from fossil fuel combustion in buildings and vehicles to electric vehicles, heat, hot water, and cooking appliances utilizing an electric grid that is anticipated to be increasingly supplied with renewable and low- or zero-carbon sources. As heating systems electrify, peak energy demand in NYC will shift from summer to winter in the coming decades (New York Independent System Operator, 2023c; Urban Green Council, 2021). As new renewable energy sources come online, the city and state must balance decommissioning fossil fuel infrastructure that contributes to air pollution and disproportionately harms low-income and communities of color in NYC while maintaining reliability and addressing energy insecurity. Energy insecurity reveals the stark disparities in the ability to meet daily energy needs – both impacting, and impacted by, existing inequities. Under-resourced communities, including low-income communities and communities of color, often bear the brunt of energy insecurity facing challenges such as limited access to reliable and affordable energy supply, high energy cost burden, and higher energy use due to inefficient heating and cooling, systems, appliances as well as poorly insulated buildings.

BOX 1. Local Law 97 (LL97)

In 2019, the NYC Council passed Local Law 97 (LL97), which amended the city charter and NYC administrative code to achieve reductions in greenhouse gas emissions by 2050. The law set goals such as a 40% reduction of greenhouse gas levels by 2030 compared to baseline 2005 levels and carbon neutrality by 2050. LL97 applies, with some exceptions, to buildings larger than 25,000 gross ft^2 as well as to two buildings that together exceed 50,000 ft^2 which are either on the same tax lot or governed by the same board of managers of a condo association. Building types that are exempted from LL97 or have delayed compliance timelines include industrial power generation facilities, city buildings, houses of worship, and buildings on land owned by the New York City Housing Authority (NYCHA) or that are rent-regulated accommodations.

LL97 incentivizes large buildings to reduce emissions in several ways, such as through investment in energy efficiency, electrification, and renewable energy. Other mechanisms such as offsets and credits may also help buildings meet allowable emissions targets. The compliance period begins in 2024 and sets emissions limits per ft^2 that differ by type of property, or occupancy group. Under the law, large buildings may face penalties for exceeding emissions limits, or also for failing to report emissions annually or making false statements.

The law also established a LL97 advisory board and required reports on the law's adaptation and implementation, the first of which was submitted to the Mayor and City Council in December 2022. The advisory board is responsible for making recommendations for implementation of the law such as regarding owner and tenant responsibilities, incentives for reduced energy use at peak times and for electrification, and to assist properties with compliance through mechanisms like offsets and credits, with special attention to buildings in environmental justice areas.

For More Information, please see Local Law 97 of 2019, §28-320 and §28-321 of the NYC Administrative Code, and the December 2022 Local Law 97 Advisory Board Report, available at https://www.nyc.gov/assets/sustainablebuildings/downloads/pdfs/ll97_ab_report.pdf.

2.2 Chapter Organization

This assessment will provide an overview of energy trends in NYC and New York State, as well as accompanying challenges and barriers to the energy transition – with implications for human health and wellbeing. The link between energy trends and their impact on health and well-being is brought to the fore by the concept of 'energy insecurity' (EI), an important addition to this assessment. Energy insecurity includes dimensions of individual energy cost burden and the potential for outages at the household or community level[1]. Furthermore, energy insecurity has human health consequences and increased financial burdens on government. For instance, inadequate heating or cooling can contribute to respiratory illnesses, which can impose significant costs on healthcare systems and further harm those without access to health care. This topic must be considered alongside energy trends in the context of NYC's climate action planning as it highlights fissures that could otherwise be overlooked. A large and growing body of evidence demonstrates how energy insecurity can amplify overall climate impacts on health and their inequitable distribution among communities and populations (Hernández, 2013, 2016a; Hernández & Siegel, 2019; Lane et al., 2022). In

[1] Using data from the 2017 American Community Survey, the City conducted an energy cost burden analysis and found that 41% of low-income families (<200% FPL) in New York City are energy cost burdened compared to only 7% of non-low-income families. https://www.nyc.gov/assets/sustainability/downloads/pdf/publications/EnergyCost.pdf

addition, protecting public health requires that local, state, and national energy transition policies and investments reduce energy insecurity and preserve and enhance the reliability and resilience of NYC's energy system. Concerns for energy insecurity must therefore complement city- and state-level policymaking to ensure that neither progress in energy trends nor likely scenarios of increased future demand result in worse outcomes for those already facing challenges in meeting everyday energy needs.

3 Energy in New York City: Trends, Challenges and Opportunities

According to the US Department of Energy (US Energy Information Administration, 2023), New York State has the third largest and one of the most energy efficient state economies in the nation. New Yorkers consume less total energy per capita than the residents of all but two other states (Hawaii and Rhode Island) (US Energy Information Administration, 2023). Importantly, per capita energy consumption in New York's transportation sector is lower than in all other states; only the District of Columbia uses less. The state's energy efficiency results in part from the use of mass transportation in New York's densely populated urban areas, especially in NYC. In 2019, nearly three-tenths of state residents used public transit to commute to work, six times the national average (US Census Bureau, 2010, 2019). Given the state's energy efficiency, in 2020, New York's per capita energy-related CO_2 emissions were lower than those of any other state in the nation (US Energy Information Administration, 2023).

NYC was ranked 2nd most energy-efficient city in the USA[2], behind Boston(Samarripas et al., 2021). It has also been identified as a low GHG emitter among 100 US metropolitan areas (Brown et al., 2009; Sovacool & Brown, 2010). It should be noted, however, that in a global study of urban GHG emissions, North American cities were the largest contributors and had the mean highest per capita emissions (Marcotullio et al., 2013). In an analysis of global urban carbon footprints, NYC was estimated to be the third largest total GHG contributor, behind Seoul and Guangzhou, but was the 91st largest urban emitter per capita (Moran et al., 2018).

Notwithstanding high energy efficiency, New York State has committed to strong reductions in GHG emissions through the Climate Leadership and Community Protection Act (CLCPA), as has NYC, reflected in the city's commitment to the Climate Mobilization Act (New York City Council, 2019), the centerpiece of which is Local Law 97 (BOX 1). New York State has committed to an energy transition through a decrease in the use of fossil fuels (lower carbon intensity) and the increase in generation of renewable energy, while at the same time, electrifying transportation and building energy and creating greater energy efficiencies (lowering energy intensity) where possible. Given the substantial share of NYC in the state's overall energy use (30% of total electricity use of the state (New York State Energy Research and Development Authority, 2023e)), success in meeting the state's goals depends upon how successfully the city addresses the energy transition.

NYC faces challenges in meeting its goals, particularly as climate change is shifting essential energy needs. For example, as summers have become warmer, cooling demand has increased. In the future, as the city electrifies, peak demand is expected to shift from summer to winter, and the demand is also expected to increase. At the same time, extreme weather events are increasingly causing power outages (Horton et al., 2010; U.S. Government Accountability Office (GAO), 2021). While the shift from natural gas to wind, solar, and other clean forms of energy and accompanying electrification (homes, businesses, vehicles) will take place, there is concern over keeping up with energy demand and providing adequate dispatchable generation (e.g. from battery, thermal, or other forms of storage) and the risk of grid failure especially during times when most people are using electricity (Clack et al., 2017; Fekete et al., 2023; Mideksa & Kallbekken, 2010; Nierop, 2014).

An important challenge in meeting the goals is to do so in an equitable manner. For example, heat waves are affecting New York residents disproportionally, with Black and low-income residents more affected than their White and upper-income counterparts (City of New York Department of Health and Mental Hygiene, 2023b). When power outages occur, those in under-resourced communities are more affected than others (Casey et al., 2020) and currently, 311-calls for power outages are significantly higher in these under-resourced communities compared to others (Marcotullio, Diko, et al., 2023). The costs of a more resilient grid infrastructure and of decarbonizing energy generation, which will be collected in utility rates, could further strain low-income household budgets, therefore increasing energy insecurity. As renewables come online the ability for all New Yorkers to benefit could be undermined by differences in neighborhood hosting capacities.

[2] Urban areas in North America are typically more energy efficient than suburban and rural areas. Hence, not only is NYC one of the most energy efficient cities, but it also is made up of some of the most energy efficient counties in the country.

3.1 New York City's Energy System

This section outlines the city's energy system and the challenges of creating an equitable transition. It first outlines the basics of NYC's energy system and how the system is changing. Importantly, current equity issues and implications of the energy transition on environmental justice are highlighted. NYC's energy system

NYC's energy system is intricately connected to the larger state, regional, and national energy system. This section attempts to outline the city's energy system through infrastructure including electricity generation, transmission, distribution, gas, steam and liquid fuels systems, and energy end use for buildings, transportation, and industry. In describing the current system and future transition we point out energy-related environmental justice issues.

Figure 1 visualizes the flows of energy from sources to end uses in NYC. Although simplistic, the figure attempts to demonstrate the size and complexity of the energy system within the city. According to the (City of New York Mayor's Office of Climate & Environmental Justice, 2022), the city consumed approximately 1.04 Quad Btu in four sectors (residential, commercial, industrial and transportation) in 2022. Another 430 TBtu was used for electricity production.

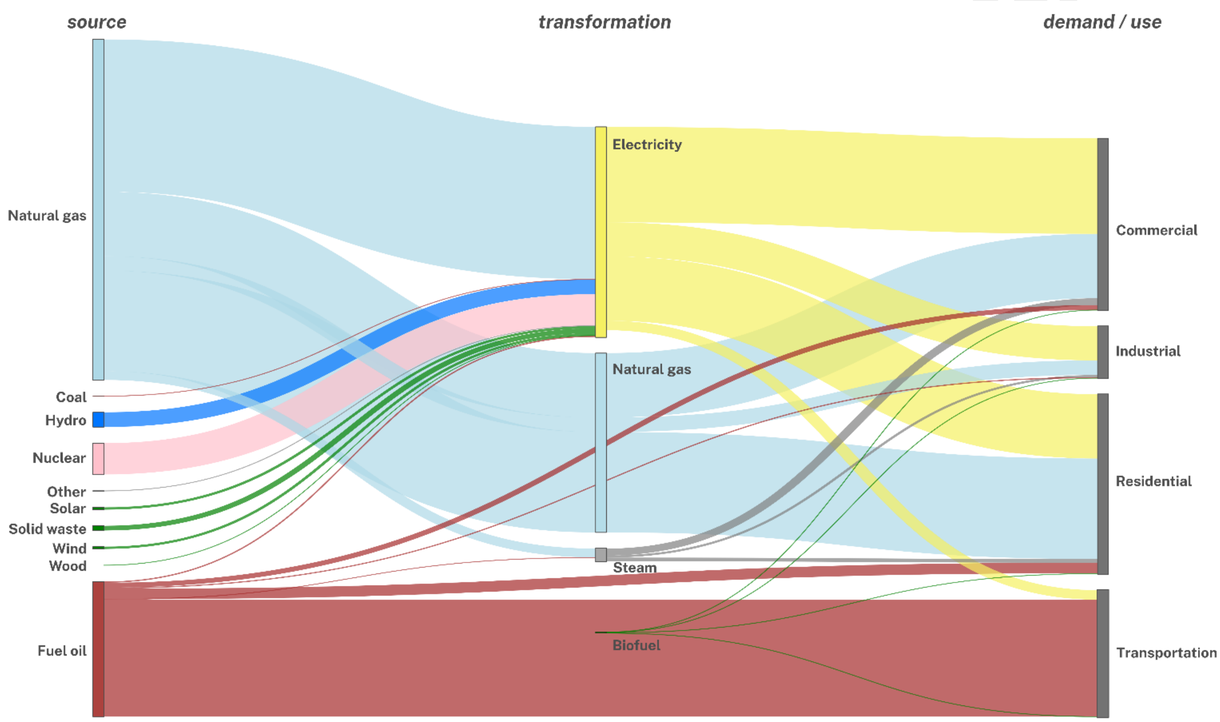

Figure 1. Sankey diagram of NYC energy end use 2022 (1.04 Quad Btu total). Note: the figure does not show rejected energy or waste heat. Data Source: (City of New York Mayor's Office of Climate & Environmental Justice, 2022)

3.1.1 Electricity system infrastructure

While the electricity system is integrated with larger systems, there are specific infrastructures that are critical to its performance. These infrastructures can be categorized in terms of three main elements: generation, transmission, and distribution.

3.1.1.1 Generation

Multiple companies and a state public authority own and operate 24 thermo-electric generation plants with a total capacity of over 9,000 MW of power in NYC (New York Independent System Operator, 2023b) . About 70% of the fleet is more than 50 years old and runs on inefficient and high-emitting technologies (City of New York Office of the Mayor, 2013b; Rueb, 2017). The in-city power plants rely primarily on fossil fuels—nonrenewable resources like natural gas and oil which emit high levels of pollutants when burned, including the GHGs responsible for warming our planet and sulfur and nitrogen oxides, particulate matter and heavy metals (Johnson et al., 2020). There has been an increase in the use of natural gas in the generation system as the Indian Point nuclear power plant was taken offline in 2021. The pollutants from fossil fuel use damage natural ecosystems, degrade water and air quality, enhance climate risks, and harm public health.

The generation system is working at 50% during a typical day, when the city is able to import cheaper electricity generated largely upstate to meet demand (City of New York Office of the Mayor, 2013a). Within New York State, approximately 91% of the electricity from upstate is from renewable resources, while approximately 89% from in-city sources is from fossil fuels (New York Independent System Operator, 2023d). The entire in-city generation runs, however, during hot summer days when upstate generation is not available at competitive prices and demand is high (demand can reach 11,000 MW during heat waves). During periods of high demand, an arsenal of 14 clusters of "peaker" plants may be used to keep the grid powered, the number that are dispatched depends on the capacity needed (Rueb, 2017). Approximately 50% of peaker plant generation runs when temperatures are 50°F (PSE, 2020). These plants can ramp up quickly but emit more criteria pollutants and GHGs than other base load plants (NYC Environmental Justice Alliance et al., 2020) and are expensive to use (City of New York Office of the Mayor, 2013b). These plants are largely located in the South Bronx, Sunset Park, and other under-resourced communities and environmental justice (EJ) communities (City of New York Office of the Mayor, 2023). As a result, EJ communities have developed health disparities and vulnerabilities from the air pollution emitted by these fossil-fuel energy infrastructures (NYC Environmental Justice Alliance et al., 2020).

Due to commitments to the CLCPA, the city is currently undergoing a transition in energy generation. An important component in this transition is distributed generation (DG). This includes combined heat and power (CHP or cogeneration) and smaller renewable generation infrastructure, including solar, offshore wind, and geothermal energy. CHP are found in certain large residential and industrial complexes, hospitals, and universities. Many of these systems are used consistently, while others are only for backup power (i.e., during power outages) (City of New York Office of the Mayor, 2013b). There are over 200 CHP systems in New York, with the biggest being the Brooklyn Navy Yard plant which can generate approximately 322 MW (Power Technology, 2022) and Con Edison's 500 MW East River plant (City of New York Office of the Mayor, 2013b). Excluding these larger utility-scale systems, there exists approximately 150 MW of CHP within NYC (New York State Energy Research and Development Authority, 2023f).

To meet its goal of 70% of its electricity from renewable resources by 2030, New York State must add 20 GW over the next eight years, which will almost triple current levels (New York State Office of Budget and Policy, 2023; Office of the New York State Comptroller, 2021). In 2019 NYC consumed about a third of the State total and nearly all was generated by fossil fuels (New York State Department of Public Service, 2020). Therefore, increasing renewable generation in the city is a necessary part of meeting the State's goals. NYC has set a target to deploy 1,000 MW of solar citywide by 2030. . Thus far, the city has installed 476 MW of solar generation (New York State Energy Research and Development Authority, 2023f). The city also has a goal of installing 100 MW of solar on city-owned buildings by 2025. As of 2022, 22 MW of solar PV panels were installed across 110 buildings, fulfilling 16% of the city's goal (NYC DCAS, 2023).

Community solar includes solar panels at offsite locations and therefore allows apartment renters, who may have no say about solar panels on their buildings, to benefit from solar energy. It also is beneficial to property owners, who can then split installation and maintenance costs for solar infrastructure. Currently, there are 43 MW generated by community solar in NYC (New York State, 2023a).

Not all communities may be able to take advantage of these technologies, however. Hosting capacity, or an estimate of the amount of distributed energy resources (such as solar) that may be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades, varies across the city. Figure 2 demonstrates that hosting capacities of the grid in Manhattan are different from that of the Bronx and parts of Brooklyn.

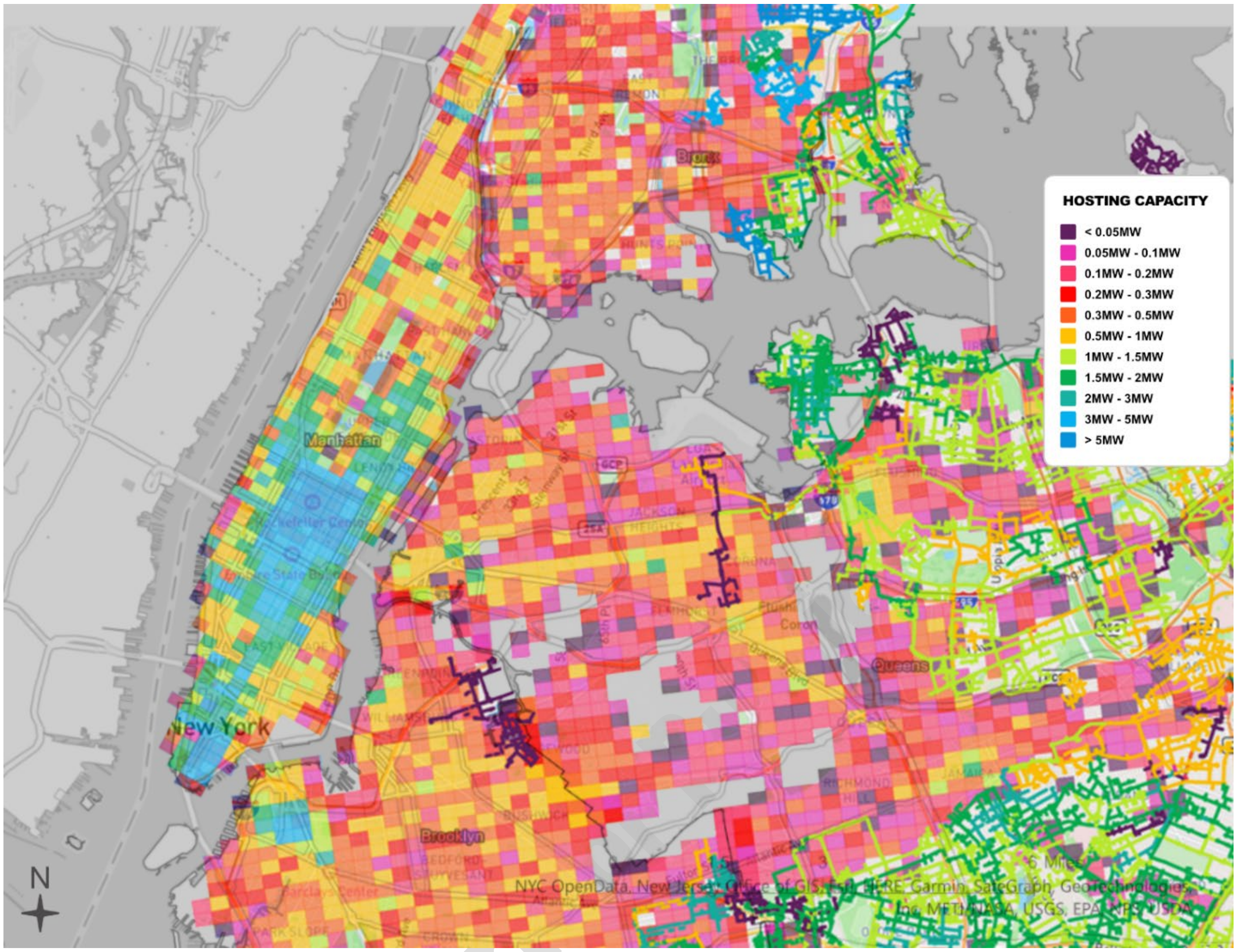

Figure 2. Hosting capacity differences across parts of NYC (14:00, 31 August 2023). Source: NYSERDA (2023c)

The city is also seeking to procure offshore wind energy. Wind projects are projected to reduce NYC's fossil fuel use for electricity by over 80% by 2030 (New York City Economic Development Corporation, 2021; New York State Energy Research and Development Authority, 2023d). Offshore wind projects that will serve NYC are under development in the New York Bight (Figure 3). The State issued competitive solicitations for offshore wind energy and contracts with offshore wind developers to purchase offshore renewable energy certifications (ORECs). There have been three solicitations to date. In 2018 two projects were awarded; Empire Wind (Equinor US Holdings, Inc.) and Sunrise Wind (Bay State Wind LLC, a joint venture of Ørsted A/S and Eversource Energy). These projects total 1,696 megawatts (MW) and are slated for Empire Wind 1. In 2020, two more projects were awarded, Empire Wind 2 and Beacon Wind, both with Equinor Wind US LLC (Equinor). Combined, the projects will deliver 2,490 megawatts (MW) of renewable energy. Empire Wind 2 is slated for a location near Empire 1, but Beacon Wind will be located south of Martha's Vineyard and Nantucket Island. In 2022, the most recent solicitation was awarded to three new offshore wind projects, representing 4,032 megawatts (MW) of clean, locally produced energy. The winders include Attentive Energy One (1,404 MW) developed by TotalEnergies, Rise Light & Power, and Corio Generation; Community Offshore Wind (1,314 MW) developed by RWE Offshore Renewables and National Grid Ventures; and Excelsior Wind (1,314 MW) developed by Vineyard Offshore (Copenhagen Infrastructure Partners). The Excelsior project will be located close to Empire 1 & 2 (within 22 miles of NYC). Both Attentive Energy One and Community Offshore Wind are located further south (located between 54 and 64 miles from NYC) in New York Bight. PSEG-LIPA has also been awarded a project. The proposed points of interconnection where the wind power will be brought into the State grid, are located across Long Island and NYC. There are also several planned port facilities, located throughout the lower New York State area where cutting-edge technologies, including the nation's first offshore wind tower manufacturing plants, will be located (New York State Energy Research and Development Authority, 2022b, 2022c, 2023b). Con Edison is developing the Brooklyn Clean Energy Hub to host the future offshore wind interconnection infrastructure for up to 1,500 MW of renewable wind energy (Consolidated Edison Company of New York, Inc, 2022b).

The city's Offshore Wind Vision plan includes the creation of 13,000 green jobs and generation of $1.3 billion in average annual investment (City of New York, 2021). Across the USA, energy technology innovation, private- and public-sector investments, and state, local, and federal energy and climate policies have propelled economic development and supported the creation of millions of jobs. An analysis of these data suggests differential opportunities for employment by race and ethnicity (National Association of State Energy Officials & Clean Energy Initiative, 2021). For example, benefits have not been equally available by gender and race particularly within the skilled trades, technology innovation and commercialization, and upper-level management of high-growth industries such as renewable energy development (IREC, 2022; Kapor Center, 2021; Keyser & Tegen, 2019; Muro et al., 2019). However, the city has secured commitments from offshore wind developers to direct 40% of job and investment benefits toward women, minorities, and environmental justice communities (New York City Economic Development Corporation, 2021).

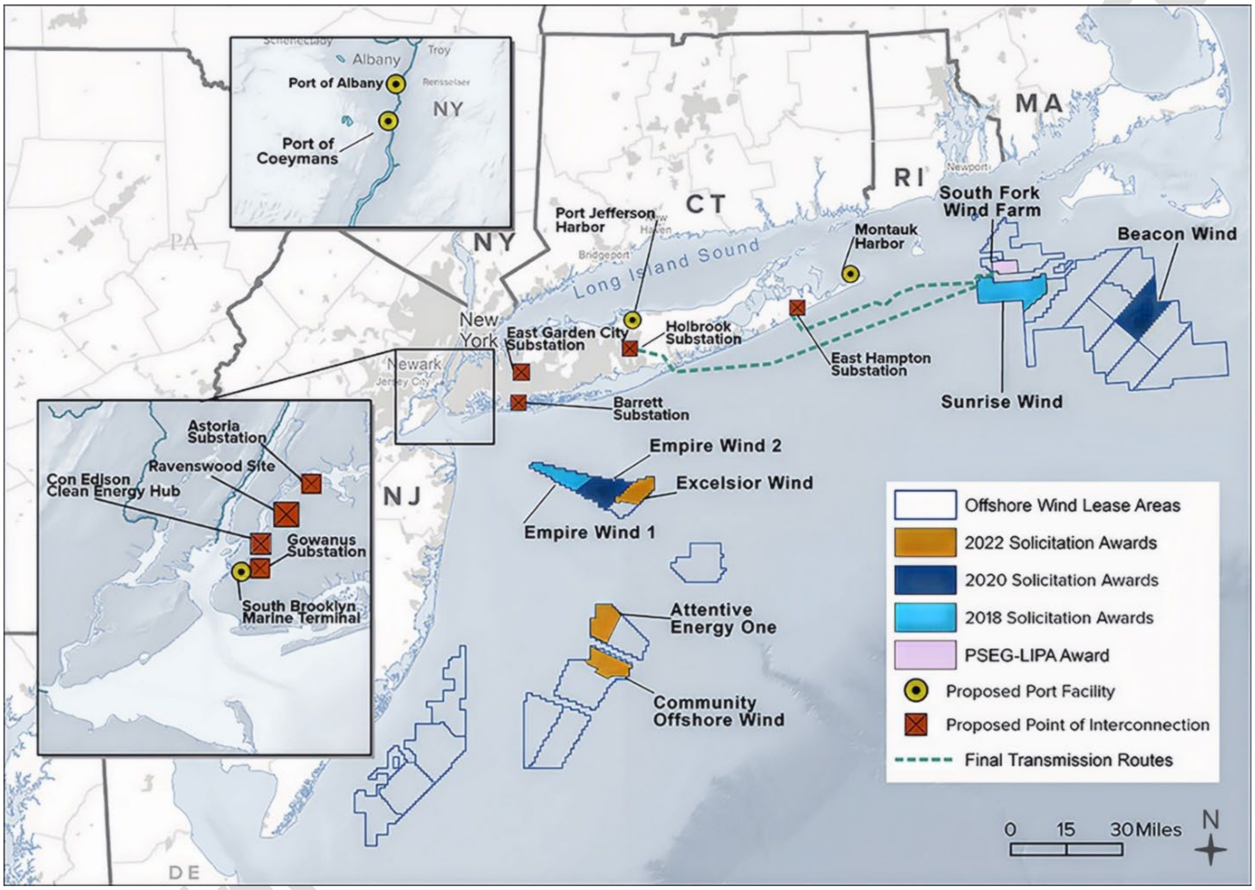

Figure 3. Offshore wind projects close to NYC. Source: NYSERDA (2023d). The New York State Energy Research and Development Authority (NYSERDA) has five offshore wind projects in active development, totaling more than 4,300 megawatts. In July 2022, NYSERDA launched a third offshore wind solicitation to procure at least 2,000 additional megawatts of offshore wind energy for New Yorkers.

Solar or wind power will produce output that is variable over time and imperfectly predictable, making it difficult to match generation and load at every instant. Battery energy storage systems complement variable renewable resources; and therefore, the city is planning for battery storage and thermal energy network development. However, these infrastructures have not yet been built. The city has established a goal of developing 500 MW of energy storage capacity within the city by 2025 and 1,000 MW by 2030. Currently, however, there are limited amounts of storage. For example, the NYC Department of Citywide Administrative Services has 10MW of energy storage projects in development (City of New York Mayor's Office of Climate & Environmental Justice, 2023c). Con Edison is about to begin operating a 7.5 MW battery system in Staten Island (Larson, 2023). According to the NYC Mayor's Office of Climate and Environmental Justice, there is approximately 400 megawatts (MW) of storage potential on City-owned unused vacant land and parking lots that could be used to deploy battery storage projects of greater than 1 MW. Currently, 300 MW of energy storage projects have passed initial review by relevant City agencies (City of New York Mayor's Office of Climate & Environmental Justice, 2023c).

Battery storage has important implications for environmental justice. On the one hand, there are safety concerns. A fire at a battery storage facility in Monterey County, California designed, constructed and operated by Pacific Gas & Electric (PG&E) and Tesla broke out in 2022, which brought national attention to large battery storage facilities (Ciampoli, 2022). NYC also has had experiences with battery fires, but these are from unregulated batteries used in e-bikes and scooters. For example, by the end of August 2023, there were 108 fires and 13 fatalities related to lithium-ion batteries in the city, many associated with low-income delivery service employees (Ly & Murphy Kelly, 2023). On the other hand, battery storage can reduce the need for in-city peaking plants to operate or may eventually replace them altogether, improving local air quality for affected under-resourced communities while still providing energy reliability (PSE, 2020). Batteries and energy storage projects also have the potential to provide local good paying jobs and workforce training opportunities for environmental justice communities (City of New York Mayor's Office of Climate & Environmental Justice, 2023b). To address fires concerns, the city requires energy storage systems authorized for installation to undergo rigorous safety testing (e.g., UL certification), have required project design and equipment reviews and inspections by permitting authorities (e.g., FDNY), and are equipped with built-in safety precautions (City of New York Mayor's Office of Climate & Environmental Justice, 2023d). The city also is pursuing strategies to regulate and improve the safety of e-bike and micro-mobility batteries (Hu, 2023).

The city is also committed to pursuing a district-scale geothermal demonstration project (New York Independent System Operator, 2023d). Geothermal heat pumps, or ground-source heat pumps, rely on the constant temperature beneath the Earth's surface to provide clean and efficient heating and cooling, while using less electricity than other types of heat pumps. NYC has already built building-level geothermal projects, including at the FDNY Rescue Company 2 facility in Brooklyn (Arch Daily, 2022) and at PS 62 on Staten Island (Wang, 2016). The city is now evaluating the feasibility of district-scale systems that connect multiple buildings to shared infrastructure, which can realize further efficiencies and maximize environmental benefits through balanced loads and a diversity of thermal sources and sinks.

3.1.1.2 Transmission

Long-distance high voltage transmission lines currently bring up to 6,000 MW of electricity from different parts of New York State, northern New Jersey, and Pennsylvania. These lines connect to 24 high-voltage transmission substations within the city that also receive energy from in-city generation sources, which decrease the voltage of the electricity and direct the electricity to either customers or the hub of smaller "area substations." There, smaller transformers decrease voltage once again and feed the local distribution system. Area substations typically serve one or two neighborhood-level "networks" or "load areas" of customer demand, each of which includes tens of thousands of customers.

A substantial amount of electricity is imported from outside NYC's generation system. On a typical day, about 50% of NYC's electricity is imported from New Jersey and locations in New York, which is carried into the city by various transmission cables (Rueb, 2017). Given the need for large amounts of renewable energy to meet state mandates, the city will need to increase its imports of energy. Therefore, two infrastructure projects are being implemented (New York State Energy Research and Development Authority, 2021). In December 2022, work began on the longest stretch of a transmission line that would bring renewable energy from Canada to NYC, the Champlain Hudson Power Express (CHPE), which is expected to deliver 1,250 MW of hydropower energy, about 20% of the city's electricity demand (Lisa, 2022). Cable lines will be installed underground and underwater for an estimated cost of $2.2 billion. The transmission line is expected to start full operations in the spring of 2026 and reduce the city's carbon emissions by 37 million metric tons in its first 10 years (Transmission Developers and CHPE LLC, 2023). The second project is called the Clean Path NY. This $11 billion infrastructure project includes more than 20 wind and solar generation projects located in New York State and a new 175-mile, underground transmission line that will deliver more than 7.5 million megawatt-hours of emissions-free energy into NYC every year (Clean Path NY, 2023).

According to the NYISO, however, as the grid transitions to intermittent renewable generation and electrification of buildings and transportation, at least 17,000 MW of fossil-fuel generating capacity may be needed in order to reliably supply electricity on high demand "peak" days (New York Independent System Operator, 2022). The NYISO argues that there will be a reliability need before the CHPE project is scheduled to be in service and starting as soon as 2025 (New York Independent System Operator, 2023e) and will grow over time and over the medium-term (past 2031) exist even with the CHPE (Figure 3). Moreover, the CHPE was already delayed from its originally anticipated in-service date of late 2025 due to several factors, including a longer than anticipated regulatory review process and supply chain logistics for key construction components. These concerns are particularly important for under-resourced communities, as these are the neighborhoods that are currently suffering from the highest number of electricity interruptions in the city (Marcotullio, Braçe, et al., 2023). Another concern is that if CHPE is delayed, the absence of this resource could contribute to projected energy deficits forcing NYC's electricity system to continue using fossil fuels.

Other concerns include claims from environmental advocates that the CHPE project will impact river and lake biodiversity (Riverkeeper, 2022; Sierra Club, 2022) while other claims that the price for energy delivered over CHPE is likely to be above market rate (EnergyZT Advisors, 2020).

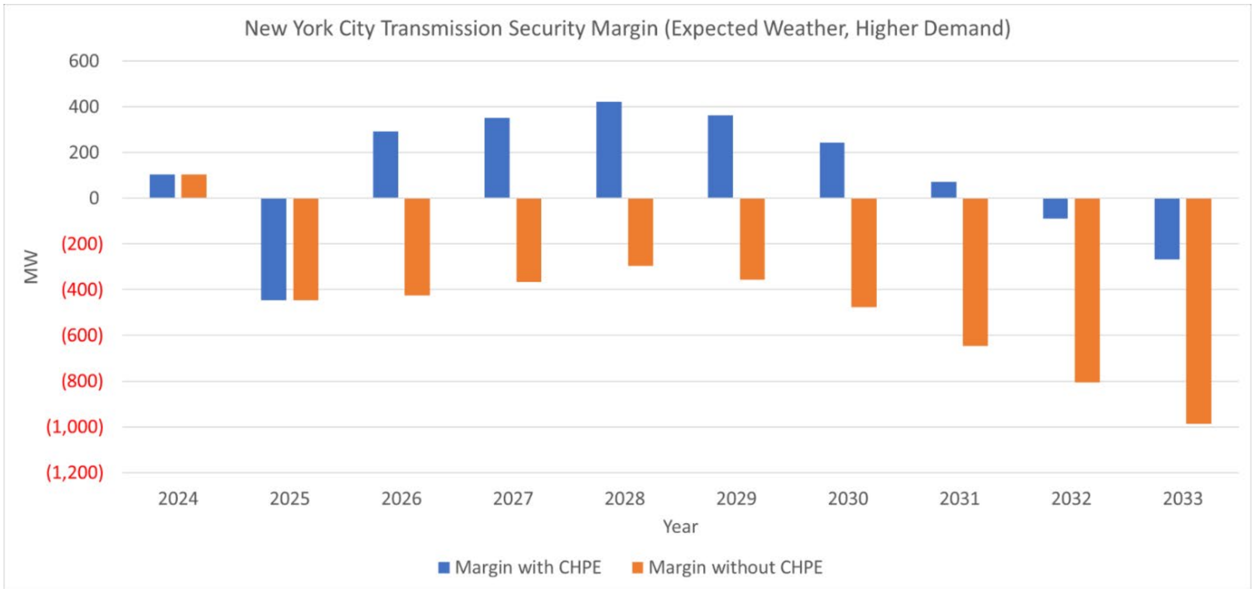

Figure 4. NYC Transmission Security Margin: With and Without CHPS. Source: New York Independent System Operator (2023e, p. 6)

3.1.1.3 Distribution

The electricity distribution system carries power between transmission substations and consumers. From area substations, electricity is distributed to end users through an underground transmission system or overhead loop systems and radial lines. In NYC, distribution infrastructure is primarily underground, however overhead lines carry 14% of the electrical load in areas of the outer boroughs. The underground system works as a network with multiple paths to any one customer. The overhead system is simpler and has fewer redundant pathways in which energy can get to customers. At the same time, it is cost prohibitive to bury all electrical lines throughout the city (Office of Long-Term Planning and Sustainability Office of the Mayor, City of New York, 2013). The distribution service lines are then connected to building electrical equipment. In many cases, high-rise buildings or campus-style complexes have dedicated transformer equipment, located beneath sidewalks, which serves these individual customers.

The Energy of Information Administration (Energy Information Administration, 2021) estimates approximately 5% loss of electrical energy between generators and customers in New York State and generally most of that loss occurs in the distribution system (MIT, 2011). Research suggests that the number and duration of large-scale electricity interruptions in the US are changing. The average U.S. electricity customer experienced nearly 20 more minutes of power interruptions in 2020 (the warmest year on record) than in 2017 (National Centers for Environmental Information, 2021). When major events are excluded, however, the average duration of interruptions customers experienced was consistently around two hours annually (U.S. Energy Information Administration, 2021f). More than 80% of interruptions were due to problems in the distribution system (Chowdhury & Koval, 2009; MIT, 2011).

In NYC, 311-calls reporting power outages are clustered in under-resourced communities and often occur during the warm season (June, July and August) (Marcotullio, Diko, et al., 2023). An important consideration is that with electrification of residential energy, the peak load on the electric grid will shift from the summer to the winter as building heating systems are electrified and we start to use more electricity in the winter than the summer. Currently, the city's peak power demand is 42% higher in the summer than in the winter (Urban Green Council, 2021). The shift is projected to occur around 2035-2040 (Figure 5) (New York Independent System Operator, 2023d). As building heating systems are electrified, the risk of winter outages during peak demand or during winter storms could lead to a new set of challenges related to keeping people safe in their homes. Given the impact of electricity interruptions on the health of the population (Anderson & Bell, 2012a; Casey et al., 2020; Dominianni, Lane, et al., 2018) addressing these challenges in an equitable way is essential (National Centers for Environmental Information, 2021).

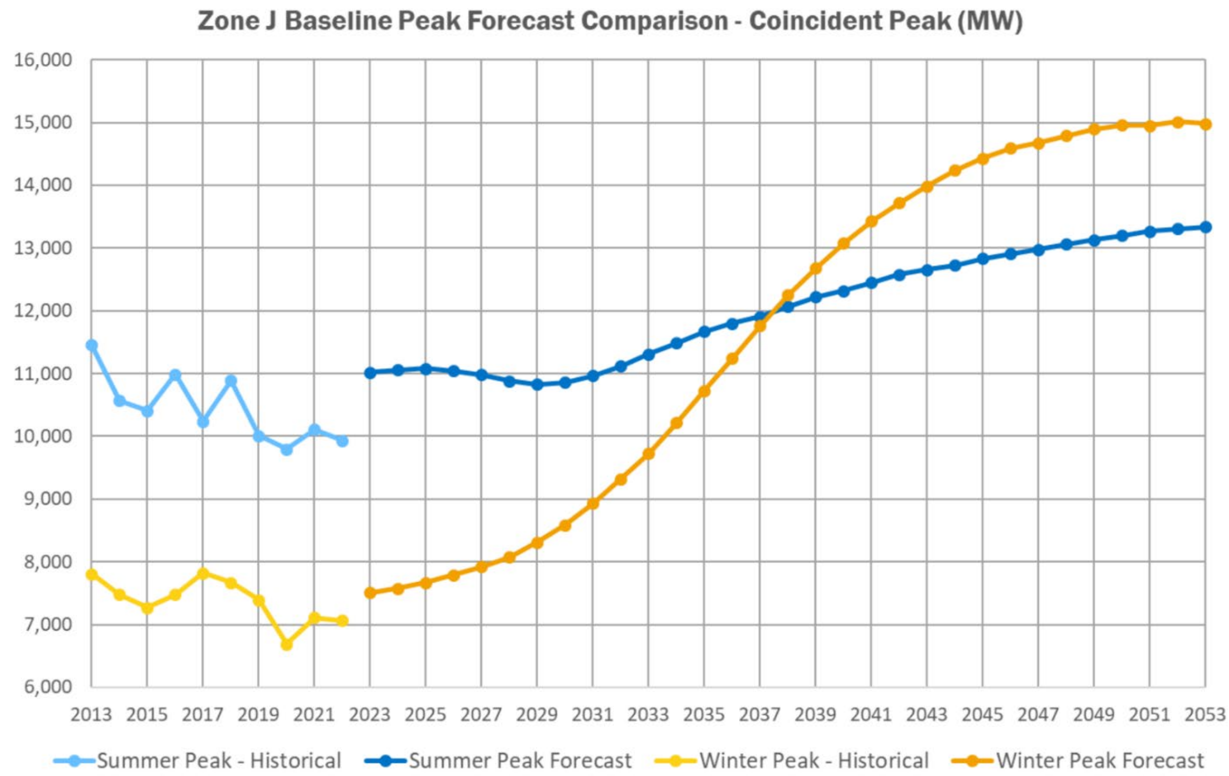

Figure 5. Zone J (NYC) Baseline Peak Forecast Comparison – Coincident Peak (MW). Source: New York Independent System Operator (2023a)

The increased penetration of renewable distributed generation also will pose challenges for the design and operation of the distribution system. The distribution system will need the integration of new communications infrastructures, sensor technologies, and advanced information technology that enable new system capabilities such as distribution automation (automated fault detection, isolation and restoration and optimization of system voltages and power flows) and advanced metering that stores and communicates energy consumption as a function of time (MIT, 2011).

3.2 Natural Gas System

Natural gas is transported from the Gulf Coast, Western Canada and other production regions to NYC through four private interstate pipelines.[3] The pipelines reach numerous interconnection stations called "city gates." From the city gates, high-pressure gas comes via an intra-city transmission system called the New York Facilities (City of New York Office of the Mayor, 2013b). Much of the natural gas that comes into the city is used for power generating and building heating systems in the city. For individual consumers, the gas pressure needs to be reduced, which is performed at regulator points, before it enters into the main distribution structures underground (City of New York Office of the Mayor, 2013b). The gas travels throughout the city through approximately 117 miles of pipelines that transport natural gas within the five boroughs (U.S. Department of Transportation Office of Pipeline Safety, 2023). On typical days, 98% of the in-city electricity generation is powered by natural gas and used for approximately 65% of heating for the 1 million buildings in the city (City of New York Office of the Mayor, 2013b).

The city's natural gas demand usually peaks on cold winter days, when it can exceed the capacity of the four interstate pipeline connections. On those days, utilities ask electric generating plants and other large users subject to interruptible utility rates to switch to liquid fuels (City of New York Office of the Mayor, 2013b).

Natural gas use in NYC has increased dramatically over the past two decades. In 2005, the total natural gas energy use exceeded 764 TBtu and by 2021, it was over 1,000 TBtu, or a 33% increase during that period. Much of this

[3] See DOE EIA https://www.eia.gov/naturalgas/archive/analysis_publications/ngpipeline/interstate.html

increase was in the buildings sector, although the industrial sector also experienced an increase. Gas utilities in New York are increasing their investments in their high fixed-cost pipeline networks despite the growing risk that those networks will become obsolete due to competition and climate policies. Over the past 10 years, the undepreciated balance of New York's gas utilities' investments in gas distribution infrastructure has more than doubled, from $13 billion to $29 billion (Walsh & Bloomberg, 2023). Con Edison suggests a continuation of providing natural gas to customers over the long run but at a lower level by replacing fossil methane gas with a mix of renewable natural gas (RNG) and hydrogen (Con Ed & Orange & Rockland Utilities, 2023). Decisions about natural gas transitions have equity considerations, as the costs of replacing pipelines will be borne by remaining ratepayers, who might see their bills increase (Walsh & Bloomberg, 2023).

3.3 Steam System

NYC's steam system, owned and maintained by ConEd, is one of the largest district steam systems in the world, providing heat and hot water to over 1,500 customers in Manhattan—including hospitals and many of the city's largest institutions---as well as air conditioning to a portion of those customers. Steam systems free customers from owning and maintaining boiler systems and require them to maintain on-site steam traps and condensate pumps.

Six natural gas- and fuel oil-fired steam generating facilities in Manhattan, Brooklyn, and Queens can collectively produce over 10 million pounds of steam per hour, either cogenerating this steam along with electricity, or producing steam alone. A network of 105 miles of underground pipes transports this steam to customers.

Since 2005, however, the energy generated by ConEd's steam plants available to end use sectors has decreased. In 2005, the city was generating approximately 67 TBtu, but by 2021, steam energy use dropped to approximately 35 TBtu or a 48% decrease (City of New York Mayor's Office of Climate & Environmental Justice, 2022). The decrease in steam use has been due to customer attrition, energy efficiencies and changing customer behaviors as a result of the COVID19 pandemic (see also section 3.4.3 'Industry' below).

3.4 Liquid Fuel System

There are more than 190,000 miles of liquid fuel pipelines in the United States. These pipelines connect oil-producing areas to refineries and chemical plants. A separate network of pipes then brings the refined petroleum products to retailers and consumers. Annually, the Northeast receives over 1 billion barrels of crude oil and petroleum products through pipelines, although some of the flow is redirected to other areas (U.S. Energy Information Administration, 2023a).(U.S. Energy Information Administration, 2023a). Two of the largest pipelines within the New York Area are the Colonial and Buckeye Pipelines. The Colonial Pipeline system, the largest in the US, can move 2.7 million barrels a day of refined petroleum products from refineries in the Gulf Coast (PADD 3) to the East Coast (PADD 1). The system provides states along the eastern seaboard about half of their total requirements for fuels such as gasoline, jet fuel, and heating oil, which accounts for about one-third of America's total petroleum product consumption (Medlock III, 2021). The Buckeye pipeline carries approximately 3.6 million gallons of jet fuel to JFK Airport. In addition, another 660,000 gallons per day of jet fuel runs through a branch pipeline to LaGuardia Airport. The pipeline also moves 2.7 million gallons of gasoline, diesel fuel and home heating oil to Long Island City daily. A total of nearly 10 million gallons of turbine fuel, gasoline, diesel fuel and home heating oil, 4.2 million for airports and 5.6 million for NYC consumers, are transported every day through pipelines from 62 storage tanks Buckeye owns in Linden, New Jersey, across the Arthur Kill to Staten Island, Brooklyn, Queens and Nassau County (Gentilviso, 2007). Most of the petroleum fuel supply arrives through ports under the jurisdiction of the Port Authority of New York and New Jersey. The downstate area is one of the world's largest fuel trading hubs and serves as a regional node for fuel distribution across the Northeast. Infrastructure includes 117 storage terminals with more than 25 million barrels of storage capacity, equating to 49 percent of the State's total (Hallman & Wei, 2016; ICF International, 2014).

Use of fuel oil in residential and commercial sectors has dropped over time. In 2005, the residential sector used 61 TBtu and the commercial sector used 17 TBtu, but by 2021, these figures dropped to 19.6 TBtu and 8.6 TBtu, respectively (City of New York Mayor's Office of Climate & Environmental Justice, 2022). This drop is in part due to the city's Local Law 38 (City of New York Department of Environmental Protection, 2021, p. 38), which required the phase out of No. 6 and No. 4 fuel oil, and conversion to either No. 2 fuel oil or other power sources. NYC established the Clean Heat Program to eliminate the use of residual heating oil which was a major source of air pollution in the city and linked to multiple adverse health outcomes, including cardiovascular disease (Columbia University Mailman School of Public Health, 2021). This policy led to significant improvements in NYC that were experienced in both low- and high-income neighborhoods (L. Zhang et al., 2021).

3.5 End Use Sectors

3.5.1 Buildings (residential and commercial)

There are over 1 million buildings in NYC (Table 1). The vast majority of these structures are strictly residential (approximately 950,000 buildings accounting for over 52% of the total building floor area in the city). There are another 65,000 buildings that are mixed residential and commercial structures (6% of total structures and about 18% of the total building floor area of the city). Commercial buildings account for about 2% of all buildings (24,000 buildings and about 14% of total building floor area). The remaining buildings are a mix of public, industrial, open space, transportation and miscellaneous structures (City of New York Department of City Planning, 2023b).

According to the NYC Mayor's Office of Climate and Environmental Justice (2023), in 2021, NYC buildings used 1.2 Quad Btu or 77% of the total energy used in the city that year. This energy use included approximately 11.6% of the fuel oil, 78.9% of the electricity, and 92% of the natural gas and 83.7% of the steam used during that year. The building sector is a major source of energy use for the city. Buildings also contribute about 70% of the city's GHG emissions.

Table 1. Building statistics for NYC, Source: (City of New York Department of City Planning, 2023b)

Building Type	Number of buildings	Total floor area (million sq. ft.)	Share of buildings (%)	Share of floor area (%)
One family	431,642	519	39.8	9.2
Two family	325,170	585	30.0	10.3
Multi-family walkup	175,404	736	16.2	13.0
Mixed residential/commercial	64,762	998	6.0	17.6
Commercial & Office	23,734	784	2.2	13.8
Multi-family elevator	17,398	1,131	1.6	20.0
Public & institutions	17,212	554	1.6	9.8
Industrial & manufacturing	11,903	196	1.1	3.5
Transport & utility	7,623	82	0.7	1.4
Parking	5,743	29	0.5	0.5
Open space & outdoor rec	3,309	37	0.3	0.7
Miscellaneous	1,740	14	0.2	0.2

Given that residential buildings account for a large percentage of the number of buildings and total floor area of all city buildings, energy use in these structures is of high interest. Common residential uses of energy include space heating, water heating, air conditioning lighting, refrigeration, cooking, and operation of a variety of other appliances (U.S. Energy Information Administration, 2021a). In 2020, energy consumption in the U.S. residential sector exceeded 12 quads Btu, which represented approximately 17% of total energy consumption and 20% of total carbon emissions for the nation (U.S. Energy Information Administration, 2021d, 2021e). A recent study of the residential energy use in the NYC metropolitan area suggests that between 1993 and 2009, residential energy use per household decreased, but that this decrease was due to declines in space heating, while energy use for water heating, cooling, and appliances all increased (Rio et al., 2022). This study also demonstrated that household energy use in the metropolitan core (5 boroughs of NYC) was lower than those in the outlying suburban areas.

Electrification of the city's housing stock will bring reductions in air pollution (Urban Green Council, 2021). However, there are important energy use differences between multi-unit and single and two-family buildings. The Department of Energy collects residential energy consumption data regularly at about 4-year intervals in the Residential Energy Consumption Survey (RECS). The data are divided into census regions and averaged. The Northeast Region includes New York State. The most recent survey presents data on the average energy consumption by housing type, both by household and square footage demonstrates differences in energy use between single family (detached and attached) housing and other types of buildings and also between owned and rented users. For example, within the Northeast region, average household energy use for single family detached housing is approximately 120.7 million Btu annually (

Table 2). Alternatively, the average energy use for households living in apartments buildings with 5 or more units is 36.2 million Btu, or over 3-fold less. On the other hand, among all household types, energy use per floor space is larger for units in apartment buildings with 2-4 units. While the energy use of renters is less than that of building owners, the lower use of energy in apartment versus single family households remains similar across these categories.

Table 2. Summary of annual household energy consumption in the Northeast USA, 2020. Source: DOE EIA RECS (2023b).

All homes	Total Northeast	Total (trillion Btu)	Per household (million Btu)	Per household member (million Btu)	Per ft^2 (thousand Btu)
Housing unit type					
Single-family detached	11.23	1,355	120.7	45.6	47.9
Single-family attached	1.95	167	85.4	31.7	47.4
Apartments in buildings with 2-4 units	3.15	214	68.0	27.2	65.4
Apartments in buildings with 5 or more units	5.10	184	36.2	19.9	41.6
Mobile homes	0.50	36	72.1	31.4	66.7
Ownership of housing rent					
Owned	13.77	1,526	110.8	43.0	47.9
Single-family	11.89	1,402	117.9	45.3	47.3
Apartments	1.50	96	64.0	26.7	54.6
Mobile homes	0.38	28	74.1	31.8	63.9
Rented	8.15	430	52.7	24.2	52.5
Single-family	1.29	120	92.9	30.2	55.8
Apartments	6.74	302	44.8	22.3	50.8
Mobile homes	0.12	8	65.6	29.8	79.0

Major trends in the NYC building sector include policy driven efficiencies, but there are environmental justice concerns about these efforts. Most NYC residents (more than 60%) live in multi-family buildings. While multifamily buildings in general tend to use less energy per capita than other residential buildings, most of the existing residential building stock in NYC pre-dates energy codes, uses inefficient, centralized fossil-fuel based heating systems, primarily steam, and has little insulation. Electrification and deep decarbonization is especially challenging for several reasons: (1) heat pumps may require additional electrical service, (2) electricity costs may be higher than fossil-fuels so that even when equipment efficiency is improved, utility costs could rise, and (3) insulating the building to compensate for rising costs is especially difficult for lot-line and masonry buildings typical in NYC. Furthermore, heat pumps provide both heating and cooling, which can introduce a shifting of utility costs from owners to tenants and is difficult to regulate. Electrification at scale will result in increasing grid demand which could lead to power outages in the winter. Current laws are targeting large buildings, including residential buildings, which already demonstrate high levels of efficiency rather than targeting single and 2-family buildings. Over 30% of building emissions are from these smaller residences and they house about half of the those living in larger apartment buildings. Moreover, the evaluation of energy uses the ENERGY STAR evaluation technique (U.S. Environmental Protection Agency, 2021). Including floor area may not demonstrate the same significant differences as per person. Using floor area can misrepresent the relative energy consumption in heating large floor areas, particularly for small households (and pied-à-terre investments). Even if heating the large space per floor area was equal to that of something smaller, the overall energy use would be higher than the smaller space. A more equitable comparison, therefore, would be per person. Finally, it can be more difficult to retrofit (e.g., to electrify or complete energy-efficient projects in) multifamily buildings than private homes because of the way the building is managed, or the way costs are allocated across owners, tenants, and shareholders. Efforts to electrify building systems may increase the cost of heat, hot water, and cooking for residents, and the consequence of electrifying buildings at scale may result in increasing demand in the winter, when extreme weather and storms present challenges to reliability distinct from summer heat waves.

3.5.2 Transportation

NYC has a massive transportation network comprised of several discrete but interconnected systems, including private and public vehicles and ferries, subways and heavy rail systems, and a growing bicycle and micro-mobility infrastructure.

Roads and private passenger vehicles: In 2021, there were over 2 million registered motor vehicles in NYC (Komanoff, 2023). On an average day, 34.6 million vehicles use bridges and tunnels, and 715,000 cars enter Manhattan. Prior to the pandemic, approximately 100,000 Taxi and for hire vehicles made approximately 315.9 million annual trips (NYC DOT, 2019).

Of the 3.1 million households in the city, approximately 1.4 million households (45 percent) own a car. About 3 percent of households own three or more cars. Ownership is lowest in Manhattan (22 percent) and highest in Staten Island (83 percent). Queens ownership (62%) is also above the city average, while the Bronx (40 percent) and Brooklyn (44 percent) look more like the city as a whole (NYC EDC, 2018).

In 2021, on-road vehicles used approximately 14.1 percent of the city's total final energy use (City of New York Mayor's Office of Climate & Environmental Justice, 2022) possibly an underestimation as energy used in segments of trips outside the city boundaries may be excluded). At the same time, on-road vehicles use over 83.4 percent of the liquid fuel (petroleum) used in the city. The total energy from fuel oils in the on-road transport sector declined from 244 TBtu in 2005 to 226 TBtu in 2021. During this period, private passenger car energy use declined from 229 TBtu to approximately 214 TBtu (City of New York Mayor's Office of Climate & Environmental Justice, 2022).

The city is currently installing congestion pricing infrastructure for Manhattan's Central Business District. Scholars debate environmental justice with congestion pricing focused on whether there are disproportionate burdens on low-income drivers. Studies have demonstrated that wealthy drivers are less burdened than those that spend a larger share of their income on transportation energy use (Chronopoulos, 2012; Hosford et al., 2021). While congestion pricing can have regressive effects, these can be balanced through the redistributed benefits to public transit (Eliasson & Mattsson, 2006; Levinson, 2010). Increased public transit and reduced car traffic also have health benefits through reduced air pollution, which disproportionately affects the urban poor (Levinson, 2010; Manville & Goldman, 2018) depending upon how the improvements are geographically distributed (Anas & Lindsey, 2011) A review of the impacts of congestion pricing found greater benefits inside tolling zones than outside, but there is a lack of studies on the relative socio-demographic makeup of beneficiaries (Hosford et al., 2021). Congestion pricing should be designed with clear equity objectives such as directing funding to improve transit in EJ transit-desert communities, which is currently part of the fund split among involved transportation agencies (Litman, 2023; Slevin, 2019).

Public transit: The New York City Transit Authority (NYCTA, publicly known as MTA New York City Transit as part of the Metropolitan Transportation Authority) operates roughly 5,900 buses within NYC. These buses move 2.2 million people on an average weekday or about 678 million people annually across 234 local, 20 Select Bus Service and 73 Express Bus Routes in the city. All of the MTA buses are wheelchair accessible. NYC's bus system carries more passengers than Los Angeles, Chicago and San Francisco's systems (the 2nd, 3rd and 4th largest in the country) combined. The MTA Bus Company was created in early 2005 to take over routes from private bus operators; plans are to eventually merge the MTA New York City Transit buses with MTA Bus (MTA, 2022).

NYC is known for its subway that operates on a 24 hour-7 day a week schedule. The subway system includes 6,684 subway cars, 472 stations and 248 miles (399 km) of routes (Foran & Kane, 2019). The system moves approximately 1.7 billion people annually. The NYC system has the world's largest number of stations (CityMetric, 2015). The subway system operates largely on electricity. Generally, the system used approximately 15 TBtu which has been stable from 2005 to 2021. There was a significant drop during COVID19 (2020) when the subway electricity energy fell to 12.6 TBtu for the year. It rebounded in 2021 to 13.6 TBtu (City of New York Mayor's Office of Climate & Environmental Justice, 2022; CityMetric, 2015).

Freight: Freight arrives in NYC through air, ship, rail, truck or combination any of the modes and moves through a system of highways, marine terminals, rail lines and yards, airports and distributions centers. In 2016, 198 million tons of freight passed through NYC, including industrial inputs and various manufactured products (26%), followed by consumer products (22%), construction materials (17%) fuels (16%), food (10%) and waste and scrap (9%) (New York City Economic Development Corporation, 2018). There are 8 freight hubs and three marine terminals in the city. The hubs are located within each borough with 2 in Queens and Staten Island. Some freight hubs directly connect to the national rail network and others, like the freight hub in the Bronx, connect to USDOT's marine highway network via the East River and Long Island Sound. The marine terminals include GCT New York in Staten Island, Red Hook Container Terminal in Brooklyn, and the South Brooklyn Marine Terminal also in Brooklyn. About 8 percent of the city's freight arrives through these terminals annually.

NYC has over 90 miles of rail freight track and 9 railyards that connect the city to the national rail network. The freight rail network runs through the Bronx and connects to Queens and Brooklyn. A separate railway runs in Staten Island. Approximately 70,000 freight rail cars move through NYC each year (equivalent to 280,000 trucks). Total rail freight handles about 2% of the city's total freight (New York City Economic Development Corporation, 2018).

Most freight movement (90%) is across the road network, through the use of trucks. An average of 120,429 trucks crossed into or out of NYC every day. At the borough level, the most trucks cross the Queens boundary (130,300), followed by Manhattan (125,600), the Bronx (103,600), Brooklyn (73,500), and Staten Island (26,400). The top three zip codes for daily freight deliveries and shipments are located in Midtown Manhattan, next to the Lincoln Tunnel (City of New York Department of Transportation, 2021). A significant proportion of the freight traffic is destined to residential buildings. Approximately 45 percent of New Yorkers received a delivery of some kind at their home at least once a week with the top five orders categories of groceries and gourmet food, home and kitchen, health and beauty, electronics and accessories, and apparel and accessories (City of New York Department of Transportation, 2021).

3.5.2.1 Transportation trends

As the city is working towards a transportation energy transition, two different but important trends are emerging. First, trends in motor vehicle ownership and use are shifting. Both passenger car and truck volume have increased in NYC. Passenger car registration has increased, as automobile-ownership increase can be seen across boroughs. From 2012 to 2021, the number of registered vehicles grew by 52,000 in the Bronx (22%), 59,000 in Queens (8.4%), 66,000 in Brooklyn (13%), 23,000 in Manhattan (13%) and 23,000 in Staten Island (10%). At the same time, the share of city households reporting zero motor vehicles in 2021, 53.9 percent, was down from 56.5 percent in 2012. Three boroughs — Bronx, Brooklyn and Manhattan — are still majority-car-free, but the share of car-free households dipped by two to three percentage points in every borough (Komanoff, 2023). Overall, traffic volumes have grown by 12% between 2015-2018. (Komanoff, 2023).

Increasing vehicle ownership and use has been encouraged by lower gas prices over the course of several years and Uber and Lyft's ascendency in the shared ride industry. Uber's ascendancy more than doubled for-hire drivers from 47,000 in 2013 to 103,000 in 2018 (Hu, 2018) likely accounting for a percentage of the overall 223,500 rise in five-borough registered vehicles during the seven-year period (Komanoff, 2023). Government policies have encouraged car ownership, such as the Bus rapid transit program that never took flight, the 7-line extension and the new Second Avenue Subway together contributed only a few miles of track and curbside parking pricing that never was implemented in the city (Komanoff, 2023).

Truck traffic volumes have grown faster than passenger car volumes. Truck use in NYC has grown by 21% between 2015 and 2018. During this period, small, single unit 2-axle trucks accounted for more than 50 percent of the growth in truck volumes. The increase in truck volume can been seen in the major bridge and tunnel crossings between New York and New Jersey, where truck volume increased at a faster rate than automobile volumes (New York City Economic Development Corporation, 2018).

Truck freight traffic has experienced an increase due to the dynamics of the e-commerce sector, which has exploded over the last decade with consumer demand for online goods surging by over 33% between 2019 and 2020 alone (Brewster, 2022). E-commerce has grown, on average, 15 percent annually since 2009 and will account for 15 percent of all retail commerce by 2020. Market researchers estimate that more than 500 million packages were delivered to NYC in 2018, up 13 percent from 2017 (City of New York Department of Transportation, 2021). Increasing demand for online goods and retail same- or next-day services have encouraged the development of "last-mile" warehouses. These structures are for the final stage of delivery, from which items are shipped to the customer's doorstep. High concentrations of last-mile warehouses impact air quality, GHG emissions, and noise pollution due to high numbers of truck trips, the use of diesel fuels by these trucks (which emit high levels of particular matter and nitrous oxides) (U.S. DOT, 2023). the large square footage needed to house items and the hours of operation (sometime 24 hours a day, 7 days a week). These structures are disproportionately located within lower income communities and communities of color (Nowlan, 2023). In NYC last-mile warehouses can currently be built directly adjacent to residential neighborhoods predominantly communities of color and lower-income communities, without any review or mitigation of traffic, public safety, or air quality impacts (Last Mile Coalition, 2023).

Industrial traffic is also important. Within industrial business zones (IBZs), the busiest truck destinations include JFK Airport, Hunts Point, North Brooklyn, Maspeth, and Southwest Brooklyn with seven industries (retail, wholesale, accommodation and food services, modal transportation, construction, and health care) accounting for 84 percent of freight deliveries. The exact type of industrial traffic, however, varies by borough (City of New York Department of Transportation, 2021). The highest number of truck volumes during morning and evening peak periods are the Goethals Bridge (connecting Staten Island to New Jersey), the Major Deegan Expressway (connecting the Bronx to Yonkers), the Cross-Bronx Expressway, and the Throgs Neck Bridge. Many of the communities in these parts of the cities are under-served, communities of color.

The city has under-invested in rail, maritime, and distribution infrastructure while freight volumes are projected to grow 68 percent by 2045 (New York City Economic Development Corporation, 2018).

As the city intends to electrify transportation, including these new trends will put additional demand on the grid, which may affect reliability during periods of peak demand, particularly in load pockets where local electric distribution infrastructure is insufficient.

While passenger car travel and freight have increased, there have also been positive trends in transit and non-motorized vehicle transport. From 2010 to 2017, subway ridership also increased from 1.60 to 1.73 million; bus ridership dropped from 817 to 724 million during the same period. During 2020, however, due to COVID19, subway ridership plunged to 640,000 people, or a drop of a third, from pre-pandemic levels in 2020 (Metropolitan Transportation Authority, 2020). Ridership increased to 760,000 for 2021, which was about 48% of pre-pandemic levels. A 2023 snapshot found that subways ridership was at 67% of pre-pandemic levels as of February of 2023, suggesting that some pandemic trends will persist into the future (NYC Comptroller, 2023). The bus system has undergone a similar trend with a drop of121 million rides in 2019 to 66,000 in 2020 or 46% of pre-pandemic levels. Ridership increased to 71,000 in 2021 and a 2023 snap shot showed an increase to 65% of pre-pandemic levels (Metropolitan Transportation Authority, 2020; NYC Comptroller, 2023). Generally, NYC has an enormous and effective mass transit system. (NYC Comptroller, 2023). This system is conducive to lowering transportation energy use, increasing air quality and improving health. How the transit system evolves in the future will help to determine efforts to reduce emissions and improve air quality and health for all New Yorkers, but particularly for middle- and low-income residents that depend upon these relatively cheap transportation modes.

Another important trend related to non-motorized traffic is the dramatic increase in micromobility. E-Bikes now crisscross New York Streets as riders deliver goods, including food, drink, and other services. Micromobility trends are new, in part, to new EV bike laws. As of November 23, 2020, all e-bikes (Classes 1-3) are legal. Moreover, the city has expanded the number and safety of bike lanes. NYC DOT is on track to install a record number of protected bike lanes in 2023, to harden more than 10 miles of existing bike lanes, and to use sturdier materials in new bike lanes. NYC DOT will also launch a public awareness campaign on the safe operation of e-bikes (NYC DOT, 2023). Bicycle ridership grew from 250,000 a day to 490,000 a day from 2010 to 2017 (NYC DOT, 2019).

3.5.3 Industry

New York's industrial energy use ranks 30th among states (U.S. Energy Information Administration, 2021c). In 2021, in NYC, industrial energy use accounted for approximately 8.7% of total energy use (City of New York Mayor's Office of Climate & Environmental Justice, 2022) while the share of industrial energy use for the nation was 32.4% (U.S. Energy Information Administration, 2021c). After decades of employment losses in the NYC industry, however, the sector has stabilized and is growing again. Between 2011 and 2014, the city registered a net gain of 880 manufacturing jobs (a 1.2% increase) while New York State lost 6,615 manufacturing jobs (a 1.4 percent decline) (Bowles, 2015). While NYC lost 83,100 jobs, due in large part to COVID19. (Bowles, 2015), by 2021, the city gained 349,800 jobs in manufacturing (NYS BLMI, 2021). Thus, as many cheaper and lower-paying manufacturing jobs continue to relocate overseas, NYC has seen a corresponding rise in technical manufacturing. This includes computer products, mobile devices, video games, 3-D printing, and general software engineering tools. These jobs tend to pay well above the average state wage (Ross, 2021).

A recent study of the city's economy states that there are 11 significant industries[4] in NYC and most are in business services (NYS BLMI, 2021). They include heavy and civil engineering construction; couriers and messengers; warehousing and storage; other information services; securities, commodity contracts, investments; professional, scientific and technical services; administrative and support services; educational services; ambulatory health care services; social assistance'; and food service and drinking places. Most of the jobs in these industries are in service or the tertiary economic sector. Many of these activities take place in commercial buildings and are therefore accounted for in the commercial sector. Second, while manufacturing industries such as food manufacturing, apparel, fabricated metal product manufacturing, furniture and related product manufacturing, nonmetallic mineral product manufacturing, and plastics and rubber product manufacturing are still important employers, they make a small percentage of the total city labor force; 1.2% (City of New York Department of Labor, 2023). In 2021, the commercial sector in NYC used approximately 33% of total final energy use for the city, while manufacturing was responsible for only 8.7% of total final energy use. During that year, industry used 16.7% of all electricity, 8% of natural gas, 16.3% of

[4] An industry was designated as "significant" by the US Bureau of Labor Statistics with reference to the following characteristics: 1) The industry experienced above-average job growth (in either net or percentage terms); or 2) The industry had more than 150,000 jobs; or 3) The industry's projected employment growth for 2018-2028 was above average in the region (+12.2%); or 4) The industry paid above-average annual wages for the region ($106,300).

steam and less than 1% of liquid fuel use (City of New York Mayor's Office of Climate & Environmental Justice, 2022).

The New York economy is globally oriented, encouraging the concentration of global business and other services (e.g., financial markets). The service sector is a lower energy-consuming sector than manufacturing. Consequently, New York State accounted for about 6% of the U.S. population in 2016, but it consumed only 1% of the country's industrial energy (U.S. Energy Information Administration, 2021b).This is also a reason why NYC's emissions per capita are among the lowest among cities in the nation (Berger, 2019).This is not to suggest that manufacturing is not an important component of the labor market. Manufacturing offers avenues for low-skilled workers to gain employment and skills as well as jobs for middle-class workers (Bowles, 2015). In terms of environmental justice, the challenge is to secure equitable job opportunities in these industries for low-income and under-served community residents.

Energy policies for these industries have environmental justice implications as there are many jobs in commercial industries that are low-wage, low-skills (i.e., janitorial, fast-food service, hotel housekeeping service, etc.). Policies to reduce energy in these industries must consider how costs will be borne for these employees. Manufacturing, alternatively, provides opportunities for the middle class and skilled work.

3.6 Summary

New York State has a large economy significantly driven by activities in NYC. At the same time, however, it is also an energy efficient state, again helped by high energy efficiency in NYC. The energy system in NYC is massive and complex, providing reliable energy for residential, commercial, transportation and industrial uses. The system is also undergoing a transition, driven by the need to provide clean energy and reduce climate change. The energy transition, however, does not guarantee that the future energy system will be sustainable, as there is a need to be mindful of institutionalized environmental injustices.

Electrifying our buildings and transportation, building new renewable energy and storage infrastructure, and emphasizing energy efficiencies must be approached with consideration of the current inequitable access to the benefits, and burdens of the energy system on some communities and the projected impacts of climate change. This is all the more important as those communities that contribute the least to climate change are burdened the most by its effects.

Electrification of the energy system with clean renewable energy, the use of heat pumps in homes and apartments, and the proliferation of clean electric vehicles will go a long way to reducing GHG emissions, improving air quality and improving the general health and well-being of the city residents. The transition is necessary to fight the existential threat of climate change. However, the transition must also include attention to the inequitable access to resources, burdens, and opportunities across NYC neighborhoods. For example, as pointed out trends in the transportation sector are moving away from the city's climate goals. Bringing transportation trends back into line should be accomplished equitably, allowing all who want electric vehicles access to charging stations, and all who desire other modes of mobility the ability to do so safely (i.e., walking, biking, using public transit). Abrupt changes or hasty decisions in energy policy can inadvertently exacerbate energy insecurity and health disparities, particularly for those already marginalized. For instance, the closing of Indian Point without a viable alternative energy source for electricity disproportionately impacted low-income households and underserved communities through increased prices of energy.

The next section provides an overview of 'energy insecurity' that captures these conditions and challenges and demonstrates why a holistic approach, taking into account energy insecurity and health implications is warranted to ensure a just and sustainable energy transition that benefits all.

4 Opportunities and Challenges to achieving the city's CLCPA and LL97 Goals

NYC and State, with their commitment to the CLCPA and Local Law 97 (LL97), are positioned to lead the nation in transitioning to a more sustainable energy system. This shift includes a strategic move from gas to electricity in buildings, underscored by the city's building electrification law (Local Law 154, 2021), and heightened building efficiency driven by LL97 (Local Law 97, 2019). Fuel power sources can be replaced with renewables including solar, wind, and hydropower. Annual fuel oil energy use is over 7% of total residential energy fossil fuel use and natural gas use is over 75% of total residential fossil fuel use for NYC. Together these account for over 212 trillion Btu of residential energy use annually. To achieve the goal of total electrification, the current grid will need to dramatically change. By 2030, New York will need to more than double the share of the electricity generated from wind, sun, and water to 70% (Barnard & Ashford, 2021). However, one estimate suggests that solar alone could only power up to 14% of the city's current total annual electricity use (Murphy et al., 2019; Navarro, 2011). Moreover, renewable generation projects have tradeoffs. For example, certain stakeholders argue that the energy brought to NYC by CHPE is not clean (has associated GHG emissions) and the CHPE project will impact river and lake biodiversity and take land from indigenous people (Center for Biological Diversity, 2020; Deng, 2023; New York Independent System Operator, 2022; Riverkeeper, 2023). According to the NYISO, reliability concerns emerge as early as 2025, as 'peaker' plants are scheduled to close and these issues will increase if the CHPE project is delayed (Energyzt Advisors, LLC, 2020; New York Independent System Operator, 2022; New York State Energy Research and Development Authority, 2022a).

Why should NYC's energy transition be approached with caution? This transition offers a unique opportunity for NYC to become a model for energy efficiency with a focus on equity, particularly considering the CLCPA's requirement that disadvantaged community groups receive 40% percent of overall benefits of spending on clean energy and energy efficiency programs, projects or investments (CLCPA, 2019). To realize this equity-oriented goal, electrifying our buildings, transportation and building new renewable energy infrastructure as outlined in the above sections should be approached with caution and a mindful consideration of the potential inequitable access to the benefits, or possibly overall improvements at the cost of marginalized populations, who may be further disenfranchised in the process. For example, as NYC has gotten warmer, the essential energy services needed to protect health have changed, while the inequitable access to energy services has not. Access to adequate air conditioning has grown to become nearly ubiquitous in commercial establishments, and highly prevalent in middle- and upper- income households, while low-income households, communities and people of color continue to be much more likely to lack air conditioning or the means to pay to turn it on (City of New York Department of Health and Mental Hygiene, 2022d; Cong et al., 2022a; Consolidated Edison Company of New York, Inc, 2022a, 2022c; Dominianni, Lane, et al., 2018; Jessel et al., 2019; Madrigano et al., 2018; Maldonado, 2022; Mukherjee et al., 2018; New York State Energy Research and Development Authority, 2023a; Ortiz et al., 2022; Stone et al., 2021; Zimmerman et al., 2019). While the resilience of electricity grids varies regionally and generally has improved in the northeast in recent years (Shen et al., 2018), in June 2021, a major electricity outage during a heat wave was narrowly averted, and many neighborhoods, the majority of which were in Brooklyn with the largest outage occurring in Williamsburg, were affected by localized outages and voltage reductions (Noor, 2021). At times when electric demand is high and could threaten overall grid reliability, utilities may intentionally reduce customer supply voltage to reduce the overall electric load. In July 2019, at the tail end of a severe heat wave, ConEd cut off power to more than 30,000 customers in a high heat vulnerability index neighborhood to avert a wider blackout in the city from high demand and grid strain (Perper, 2019).

The urgency to transition to renewable energy cannot be overstated. The adoption of renewable energy is crucial not only to mitigate the impacts of climate change but also to rectify the longstanding injustices of the current energy system. A transition to renewable energy offers an opportunity to address systemic inequities laden in the current energy system, improving health outcomes and economic stability for those most affected by the existing disparities. However, this crucial transition must be done in a manner that considers both the possible scenarios brought about by worsening climate change, as well as the reality of inequitable access to resources across marginalized populations. Abrupt changes or hasty decisions in energy policy can inadvertently exacerbate energy insecurity and health disparities, particularly for those already marginalized. For instance, sudden increases in energy prices or the closure of traditional energy sources without viable alternatives can disproportionately impact low-income households and underserved communities. The next section provides an overview of 'energy insecurity' that captures these possibilities, and demonstrates why a careful and holistic approach, considering energy insecurity and health implications is warranted to ensure a just and sustainable energy transition that benefits all. A carefully considered approach does not mean a slow transition. Instead, it implies a thoughtful, inclusive strategy that rapidly advances adoption of renewables while ensuring equitable benefits and mitigating risks for marginalized populations.

5 Energy Insecurity (EI): Health Impacts and Vulnerabilities

5.1 Introduction: EI at Household and Community Levels

The World Health Organization (WHO) notes the underappreciated importance of energy to global health: "Energy is essential to meet our basic needs: cooking, boiling water, lighting, and heating. It is also a prerequisite for good health -- a reality that has been largely ignored by the world community" (Rehfuess & World Health Organization, 2006). In the US, one in three households have energy insecurity[5], meaning they are unable to adequately meet their energy needs. The three main dimensions of household energy insecurity are physical (due to substandard built

[5] For an in-depth discussion about the differences between various terminology used to characterize energy-related hardship, such as 'fuel poverty', 'energy burden', and 'energy poverty', please refer to Hernández et al., 2022.

environment of the household), economic (financial burdens that high energy expenditures impose), and behavioral (strategies to cope with the economic and physical dimensions of energy insecurity), all of which are associated with environmental, health, and social consequences (Hernández, 2016a; Yoon & Hernández, 2021) (**Error! Reference source not found.** 6). The context for energy insecurity's influence on health in NYC and in the US is different from that in countries where many lack access to reliable, modern energy services for basic needs (IEA et al., 2022). In countries with more extensive physical infrastructure and for many decades in the US, widely available household energy services have provided telecommunications, refrigeration, air conditioning, and plumbed hot water. However, even when these appliances are available, not everyone may be able to access or use them. For example, if a household owns an air conditioner but cannot afford to run it, its health benefits will not be realized, and negative health impacts could occur (City of New York Department of Health and Mental Hygiene, 2023a). Researchers have also recognized that more widespread adoption of AC will further increase electricity demand (see NPCC4, Balk et al (Balk et al., 2024), and so policies to expand air conditioning ownership and use could also be accompanied by measures to reduce the need to use AC in both residential and commercial buildings. Households may also experience utility disconnections for non-payment, which can be life threatening (Haag, 2018). In the context of climate change impacts on vulnerable US populations, the need for more research and interventions to address energy insecurity has long been recognized (Hernández, 2013).

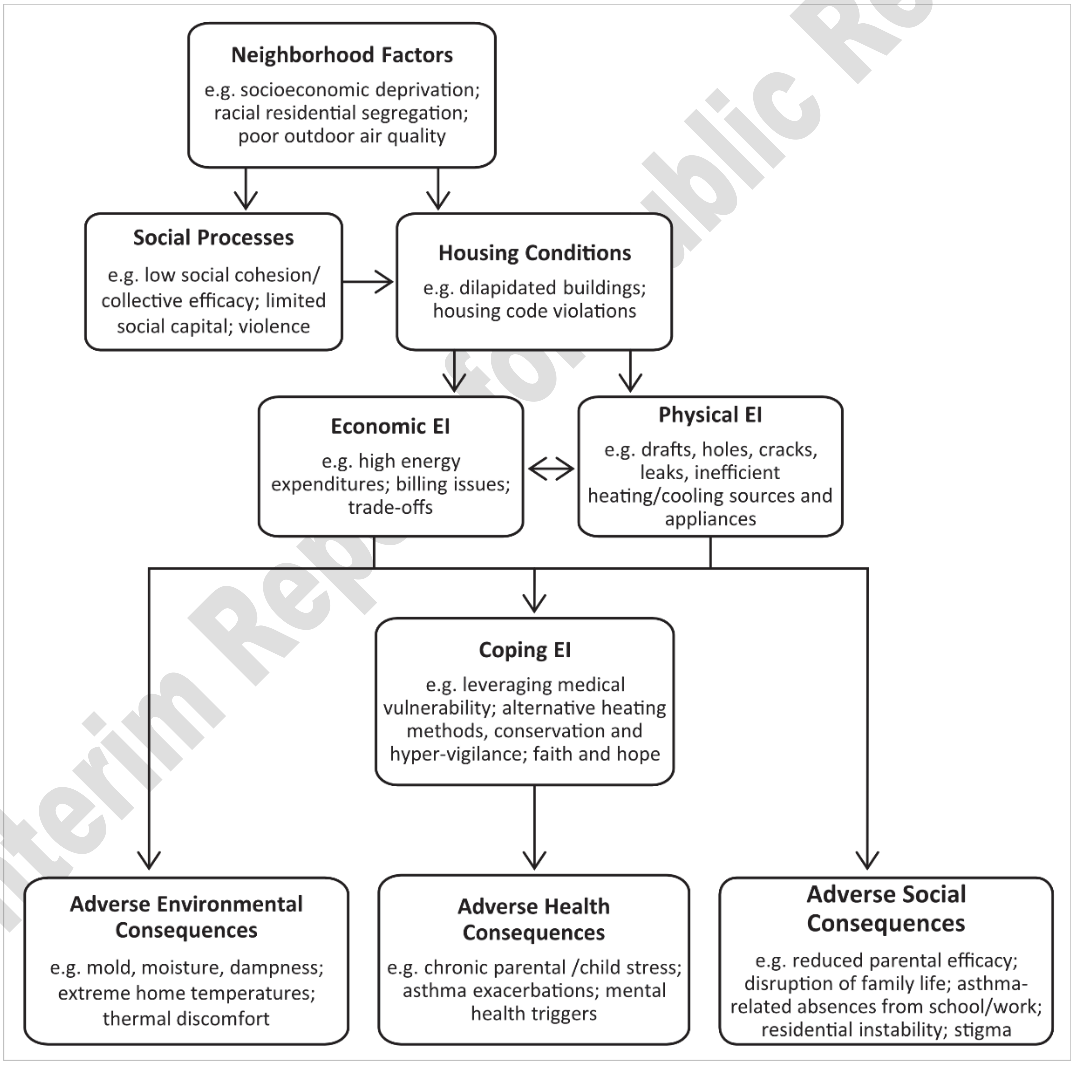

Figure 6. Energy insecurity: a pathway to disease and disadvantage. Source: (Hernández, 2016b, fig. 1)

This assessment also considers community-level energy insecurity in NYC, meaning energy infrastructure and energy services in buildings that do not reliably meet essential community needs. Analogous to household energy insecurity, community energy insecurity has physical, economic, and behavioral dimensions. These relate, respectively, to the physical robustness of the energy supply, local distribution infrastructure, and vulnerability to outages caused by extreme weather or equipment failure; the economic dimensions of energy markets and regulations that affect the distribution of costs among energy uses and communities; and behavioral factors that influence energy consumption, costs, and reliability at the community level.

For under-resourced NYC households and communities, energy insecurity often reflects not a lack of access, but high cost burden, inefficient housing and appliances, and infrastructure prone to outages (Hernández, 2018; Hernández & Siegel, 2019; Kontokosta et al., 2020) - despite living in a state and country where most have had modern, affordable energy for generations.

Research about household and community-level energy insecurity and its implications for health is still developing. More information on the national and international dimensions of energy insecurity and power outages can be found in some recent scholarly reviews which helped inform this assessment (Casey et al., 2020; Hernández, 2016a; Hernández & Siegel, 2019; Jessel et al., 2019). More on the global and historical context of energy insecurity is Annex A.

5.2 What Are the Health Impacts of EI In New York City?

5.2.1 Household EI

Essential daily life activities such as cooking food, lighting a home, staying warm in the winter and cool in the summer, and sleeping and working in adequate thermal comfort are only possible when a household is energy secure. A compromise to any of these activities brings health consequences.

Inadequate heat is one of the leading causes of 311 calls from low-income communities across the city (Donavan, 2022; Office of the New York City Comptroller, 2023). Living in a cold home has pervasive adverse health effects for people of all ages, including respiratory problems in children, arthritis and rheumatism, and mental health challenges (Dear & McMichael, 2011) as well as indirect long-term effects such as negatively affecting educational attainment, emotional resilience, and forcing nutritional and other compromises to alleviate the financial burden of heating a poorly insulated home (University College et al., 2011). Energy insecurity is associated with household food insecurity, and for children, poorer overall health and greater risks of developmental problems and hospitalizations (Cook et al., 2008).

Locally, a study in Washington Heights found that energy insecurity was significantly associated with poor respiratory health (e.g., asthma, pneumonia), mental health, and sleep outcomes (Hernández & Siegel, 2019). Energy Insecurity may harm respiratory health through coping mechanisms such as using gas stoves for heat, releasing indoor air pollutants, including nitrogen dioxide and potentially deadly carbon monoxide. Candles (Schwirtz & Vadukul, 2013), stoves, and space heaters create fire risks. Heating equipment is the leading national cause of home fires (R. Campbell, 2021); a malfunctioning space heater ignited a devastating Bronx apartment fire in January 2022, killing 17 New Yorkers (Hernández, 2022). A study of low-income households in the South Bronx showed the complex ways energy insecurity interacts with other factors to harm health; overlapping economic hardship, poor quality housing, and physical health challenges contributed to stress and coping behaviors that increased cost and exacerbated stress (Hernández et al., 2016).

Energy insecurity is a national issue that has received growing media attention in recent decades, often associated with climate change coverage, considering adverse health impacts from both extreme heat as it was with extreme cold, and variation in emphasis by region (Yoon & Hernández, 2021).

5.2.2 Community EI: power outages

In the 2021-2022 heat season (October 1, 2021 to May 31, 2022), utility outages, including power, gas and water, have increased to 3605 compared to 2872 from the previous heat season (Cerro, 2023). Whether caused by extreme weather events, infrastructure failures, or inadequate supply, utility outages have adverse and deadly health impacts. For example, prolonged gas outages in NYCHA complexes in Red Hook forced residents to forego meals or spend hundreds of dollars on take-out food on already tight budgets (Sandoval, 2021). While all utility outages can have adverse health impacts, most prominently researched among them are power outages. An August 2003 blackout affecting the northeast – during warm but not extremely hot weather – and lasting less than two days, caused a 25% increase for non-accidental cause deaths and an overall increase of 28%, or roughly 90 excess deaths in NYC alone (Anderson & Bell, 2012b).

Hurricane Maria likely caused more than 5,000 excess deaths in Puerto Rico during the months after storm impact; massive infrastructure damage, a prolonged lack of access to electricity, and interruption of medical care caused many more deaths than the official direct count of 64 (Kishore et al., 2018). On average, households went 84 days without electricity, which had wide detrimental impacts, such as the inability to use medical equipment that required electricity (Kishore et al., 2018). These large-scale power outages highlight all the more the existing environmental justice issues disproportionately burdening certain communities, such as those experiencing economic hardship, chronic health conditions, and rural populations (Andrade et al., 2022; Niles & Contreras, 2019).

The Texas power outage of February 2021 – the worst in the state's history – demonstrated how deadly cold weather blackouts can be (while also illustrating aspects unique to the Texas system, such as energy landscape and housing infrastructure). An initial estimate of deaths directly caused by the outage – 246 (Hellerstedt, 2021) – was much lower than a more complete estimate of 702 excess deaths (Aldous et al., 2021; Buchele, 2022). NYC's very different housing stock would mitigate some of the risks faced in Texas and amplify others. For example, while carbon monoxide (CO) poisoning from portable generator use constitutes the majority of adverse health outcomes linked to power outage (Johnson-Arbor et al., 2014; Worsham et al., 2022), NYC may see less CO poisoning and cold-related mortality as high-density multi-unit residential building residents are less likely to have, and run, a portable generator and are better able to retain heat during a power outage (Urban Green Council, 2014). However, urban dwellers – particularly the elderly, the chronically ill and the poor – nevertheless face challenges in accessing safe, backup power (Mango et al., 2021).

In addition to deaths from widespread outages, a range of health outcomes have been linked to power outages of various sizes. Limitations of available data on small outages likely mean health impacts are missed or underestimated. Nonetheless, localized power outages in NYC were associated with increased mortality from all causes and with more cardiovascular disease hospital admissions when they occurred during cold weather and with renal disease hospitalizations during the warm season (Dominianni, Lane, et al., 2018). Power outages in New York State have been linked to increased chronic obstructive pulmonary disease (COPD) hospitalizations, gastrointestinal illness (Marx et al., 2006), respiratory illness (Prezant et al., 2005), and food and water-borne diseases, comorbidity and medical costs (Lin et al., 2021; W. Zhang et al., 2020). One review found evidence that power outages of various scales can cause carbon monoxide poisoning, temperature-related illness, gastrointestinal illness, as well as increases in natural cause mortality and hospitalizations (Casey et al., 2020). Following Super Storm Sandy, there was a large increase in calls to the New York poison center for carbon monoxide poisoning, with indoor grilling and generator use accounting for a substantial share of cases (Chen et al., 2013). This and other power outage-related exposures may have contributed to excess mortality in the weeks following the storm, which increased up to 30% compared to the same period in 2010-2011 (Howland et al., 2015).

5.2.3 Individual and social vulnerability

5.2.3.1 Household energy insecurity

Energy insecurity has been recognized as a 'mediator' between structural conditions of disadvantage, environmental exposures, and poor health (Figure 7) (Hernández, 2016a; Jessel et al., 2019). Individual, social, and physical environmental factors all influence one's ability to access and afford essential energy. Energy insecurity disproportionately affects those marginalized along race and class lines through mediating factors of poverty, discrimination, and structural neglect resulting from a history of segregation, redlining, and housing disinvestment (Lewis et al., 2019). Economic and social barriers to investment in housing and energy efficiency contribute to disproportionate energy cost burdens for people of color across income levels. Those with disabilities or existing conditions that necessitate reliance on electric medical equipment are also rendered at disproportionate risk (Friedman, 2022). As such, many face intersecting and compounding burdens, such as those with worse baseline or lack of access to healthcare who are unable to refrigerate their medication during a power outage (Mango et al., 2021).

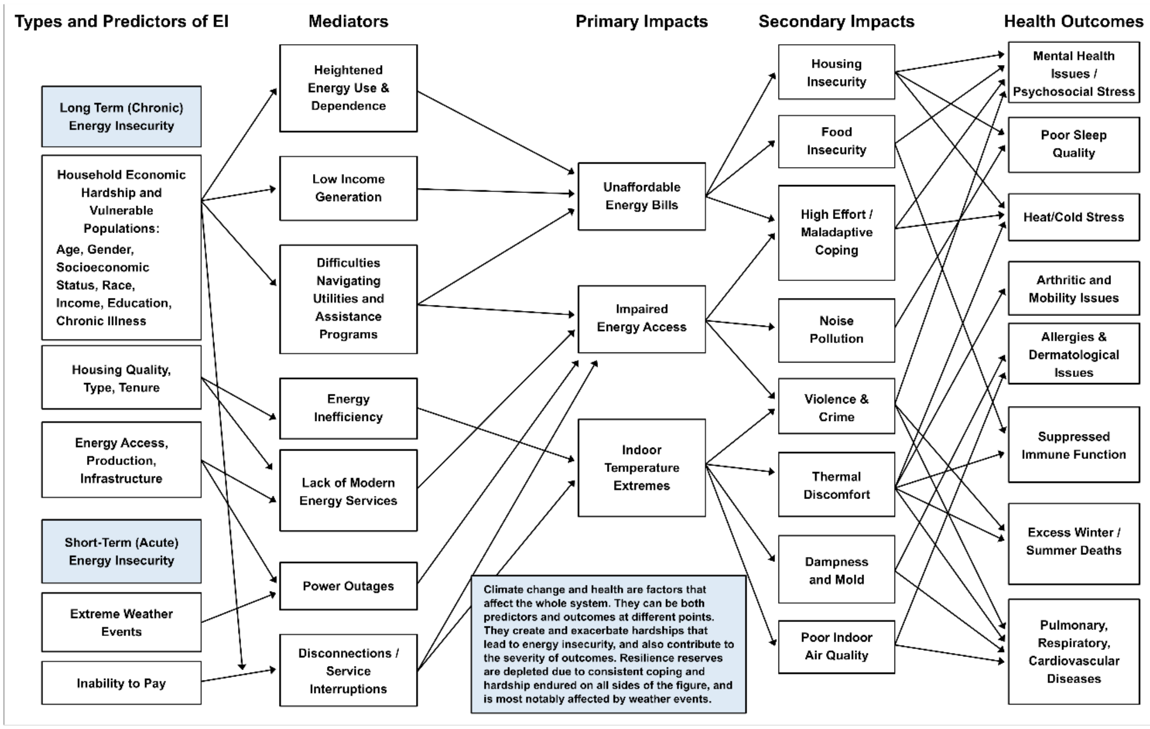

Figure 7. Connection Between Household Energy Insecurity (EI) and Health. Source: (Jessel et al., 2019, fig. 2)

Strong associations of social and economic disadvantage with energy insecurity are consistent; absolute estimates can vary with definitions and methods. Nationally, energy insecurity is patterned by socioeconomic status, race, age, and housing condition (U.S. Energy Information Administration, 2020); 82% of those 50% under the federal poverty line experience energy insecurity (Hernández et al., 2014). Energy insecurity is more common among Black and Hispanic households compared to white households, households with young children, those with a person using an electronic medical device, and low-income households - all for whom disparities were exacerbated by the COVID-19 pandemic (Memmott et al., 2021). Additionally, energy insecurity is more prevalent among renters than owners, and Black and Hispanic New Yorkers are also overrepresented in rental units (City of New York, 2018; Lyubich, 2020). Lyubich (2020) found that Black households spend more in energy expenditures in absolute terms than white households in the U.S., even after controlling for income, household size, homeowner status, home type, and city of residence. A recent study of two U.S. cities found a racial effect distinct from income, with non-white city block groups in the lowest-income stratum reporting about 40% higher annual energy costs than block groups with more white residents (Tong et al., 2021).

The unequal burden of energy insecurity is also seen in NYC, where an estimated 18% of residents were energy cost burdened in 2017, paying significantly more than the Governor's commitment to 'no more than 6% of household income going towards energy bills' (NYC Mayor's Office of Sustainability & Mayor's Office for Economic Opportunity, 2019). In New York State, households in the lowest quintile (20%) of income spend an average of 9.5% of pretax income on home energy and nearly 18% when vehicle fuel and public transit costs are included. This compares to just 1.5% and 4% of pre-tax income, respectively, for the most affluent (top 20%) of households (Figure 8) of pre-tax household income, by income quintile (U.S. Bureau of Labor Statistics, 2021).

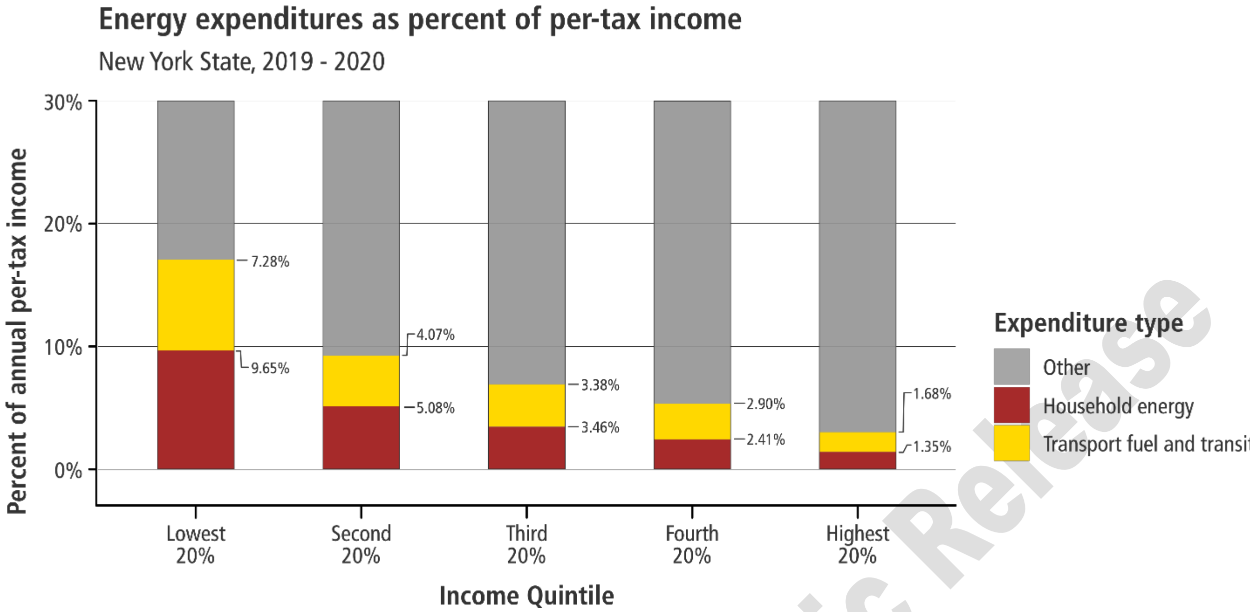

Figure 8. Energy expenditures, percent of pre-tax household income, by income quintile, New York State, 2019-2020. Data Source: U.S. Bureau of Labor Statistics (2022a).

The NYC housing code sets standards for indoor temperature during the heating season, but inadequate heat is one of the most common reasons for calling 311. Such complaints rose 25% between October 1st, 2022 to January 10th, 2023 and are most frequent in low-income communities of the Bronx, Northern Manhattan, and parts of Brooklyn (RentHop, 2023). While there are no existing requirements around cooling in summer, PlaNYC 2023 sets out an agenda to establish a maximum indoor temperature policy during summer months (City of New York Office of the Mayor, 2023).

Utility disconnections are more common in the Northeast than other regions of the US (Hernández & Laird, 2021). Currently, New York State only offers protection from utility disconnection from November 1 to April 15 when there is a threat of hypothermia, but no statewide equivalent exists during the summer months (National Center for Appropriate Technology, 2022). In NYC, electric service for any residential customer may not be disconnected for non-payment just before, during, and for two days after hot days using the 90°F heat index criteria, and on any day with a minimum windchill reaching 32°F or lower (City of New York Mayor's Office of Climate & Environmental Justice, 2023c).

Among a sample of primarily low-income and older New Yorkers in NYC, Black New Yorkers were nearly three times more likely to experience disconnections than non-Latinx white New Yorkers (Lane et al., 2022). They are also more likely to face the 'heat or eat' dilemma, having to choose between spending on essential food and medicine and paying their energy bills (Bansah et al., 2011; Cook et al., 2008), and to cope by using the stove or oven for heat. For vulnerable populations, power disconnections can be especially deadly. For example, 68-year-old New Jersey woman Linda Daniels – who was on an electric-powered oxygen tank she used to breathe – died after Public Service Electric and Gas Company shut off her power (Haag, 2018).

5.2.3.2 Power outages

Power outages, like power disconnections experienced by households with energy insecurity, are life threatening for vulnerable people that depend on electric-powered medical devices (Casey et al., 2020), have health conditions that are exacerbated by heat or cold stress, take medications requiring refrigeration, have mobility limitations, or need help with daily activities. 7.6% of all NYC households use electric medical equipment, with the figure as high as 16% in some low-income and racialized neighborhoods such as East Harlem (City of New York Department of Health and Mental Hygiene, 2022c, 2023c). Following Super Storm Sandy, when power was out for much of lower Manhattan, ED visits and hospital admission at a nearby hospital that remained open increased the most among older patients (Gotanda et al., 2015). Among older adults (≥ 65 years) in NYC, and study respondents with household members who require assistance with daily activities or depend on electric medical devices, only 58% reported being prepared for an outage and only 40% those with electric-dependent medical equipment reported being enrolled in the power outage notification program (Dominianni, Ahmed, et al., 2018), a service offered by Con Ed and other energy utilities. Residents of facilities like nursing homes are nearly all at risk from power outages if backup systems fail or if outages occur during extreme heat. Backup systems are currently not required to be powerful enough to run air conditioning, presenting an additional layer of risk during extreme heat events.

In September 2017, Hurricane Irma made landfall in Florida as a category 4 storm. The storm caused extensive damage, including leaving 6.7 million utility customers without power (Issa et al., 2018; State of Florida Division of Emergency Management, 2017). Local health officials documented at least 17 heat stress deaths among people who lacked air conditioning, of which 14 were residents of a nursing home that was unable to run its air conditioning because of the outages (Dosa et al., 2020; Issa et al., 2018). Outdoor temperatures were in the 80s and heat indices in the mid-90s but conditions inside the nursing home were much hotter and the facility could not maintain the federally required safe temperature maximums without air conditioning (Dosa et al., 2020; Minority Staff of the US Senate Committee on Finance, 2018). A study of nearly 55,000 Florida nursing home residents found that power outages were associated with increased odds of death at one week and at 30 days following the storm (Williams, 2019). In addition to the deaths, more than 200 residents were evacuated and treated for dehydration and heat-related illnesses (Minority Staff of the US Senate Committee on Finance, 2018). Following Irma, Florida passed a law requiring nursing homes and assisted living facilities to have generators that can keep comfortable temperatures for four days after power loss (Walters, 2018).

5.2.4 Physical environment factors

5.2.4.1 Household energy insecurity

Energy, the built environment, and health are connected, all of which influence and are influenced by social inequities (Hernández, 2013). Socioeconomic deprivation is associated with substandard housing conditions, such as: having cold drafts through holes and cracks; leaks and mold; and malfunctioning heating and cooling sources and cooking appliances – all of which leads to inefficient energy use and increased costs. Energy insecurity plays a key role in pathways linking housing deficiencies, economic hardship, health, and chronic stress (See Figure 9). Physical environment and energy insecurity linkages are further echoed in studies that identify older, substandard, and inefficient housing as a leading contributor to energy insecurity in the US and disproportionate impacts on Black Americans and others marginalized by race and income (Dubois, 2012; Hernández & Siegel, 2019; Memmott et al., 2021; Min et al., 2010; Reames, 2016b; Santamouris et al., 2007). High energy costs or compromised ability to meet daily energy needs, in turn lead to adverse physical and mental health outcomes (Lewis et al., 2019).

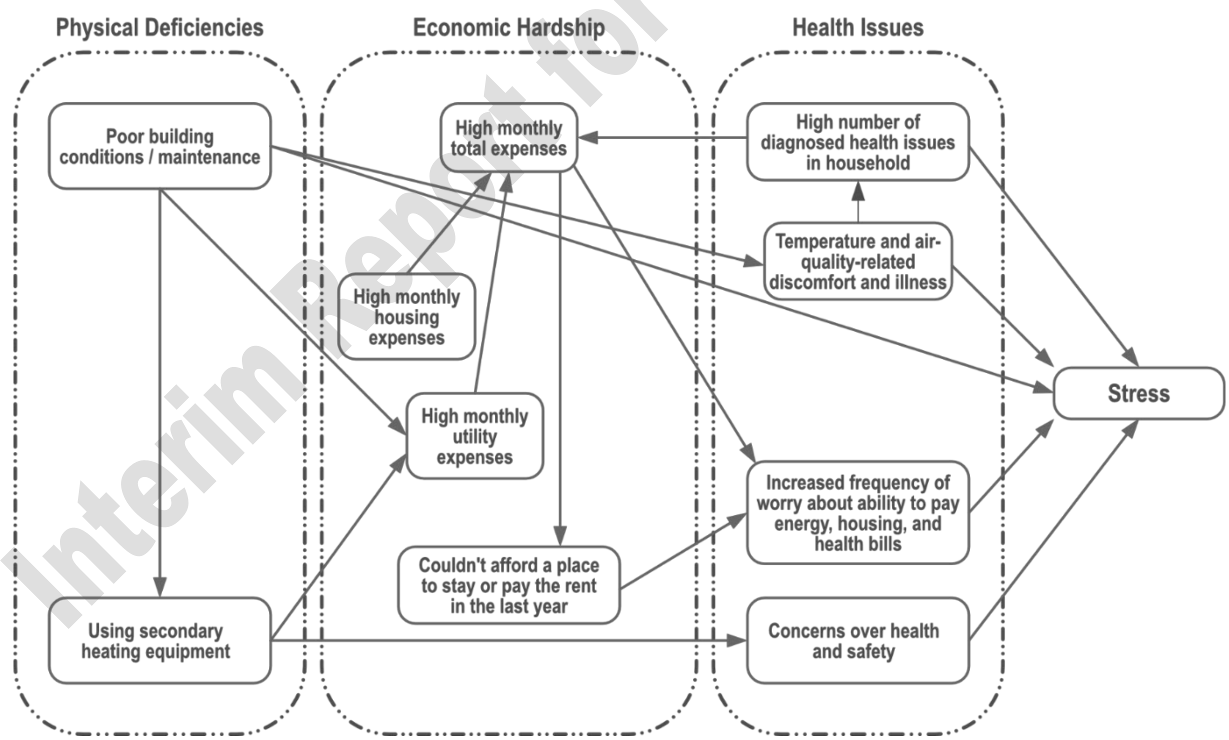

Figure 9. Housing, energy and health pathways to stress. Source: (Hernández et al., 2016, fig. 1)

Locally, a study in the Washington Heights neighborhood found that energy insecurity was not limited to the lowest-income households (annual household incomes ≤ $20,000); nearly 25% of those who earn $60,000-$80,000 annually experienced energy insecurity at least episodically (Hernández & Siegel, 2019). Renters face particular challenges and may have limited ability to regulate indoor temperature or cope with older appliance failures. They may experience high rent burdens as rising energy costs for heat and hot water are priced into rents and considered in affordable housing rent regulation, compounded by COVID-related price hikes and other subsequent financial burdens (Rent Guidelines Board | City of New York, 2019).

Among housing types, for a given household income, average energy cost and cost burden is substantially higher in single family homes than it is for units within multi-family buildings (US Department of Energy Office of State and Community Energy Programs, 2022). Single family homes may be less able to retain heat during a cold weather power outage (Urban Green Council, 2014). Although relatively infrequent in NYC, cold-related (i.e. hypothermia) deaths with indoor exposures occur and are likely linked to being unable to pay for home heating. Most of these deaths involve people aged 60 or older, with mental health or cognitive conditions who live in single family or row homes, all without heat (Lane et al., 2018).

Other health and climate risks can be compounded by energy insecurity. Environmental justice neighborhoods in particular are already dealing with these interacting exposures. For example, residents who live in the Mott Haven-Port Morris area of the South Bronx face a variety of environmental and health challenges such as poor housing quality, air pollution health impacts, multiple climate risks, and a high prevalence of health conditions that make people more vulnerable (City of New York Department of Health and Mental Hygiene, 2022a).

A lack of access to household air conditioning is another important dimension of energy insecurity. In NYC, between 2012 and 2021, all heat stroke deaths among people exposed at home did not have air conditioning or were not using it (City of New York Environment and Health Data Portal, 2023). Households in low-income communities, and non-Hispanic Black people are more likely to lack air conditioning or report being unable to pay the added electricity cost (City of New York Department of Health and Mental Hygiene, 2022d; Lane et al., 2014; Madrigano et al., 2018) (City of New York Department of Health and Mental Hygiene, 2022b). Air conditioning and other cooling technologies are considered in more depth in Section 6.1. Data on adults with air conditioners (City of New York Environment and Health Data Portal, 2007), household air conditioning (City of New York Environment and Health Data Portal, 2017) and older adults with air conditioners (City of New York Environment and Health Data Portal, 2013) by boroughs are available on the Environmental and Health Data Portal.

5.2.4.2 Power outages

Power outages in NYC disproportionately affect marginalized communities, as shown by ConEd data (Figure 10). From 2017 through 2021, networks with more outages appear to have disproportionately impacted environmental justice neighborhoods (defined using the Climate Justice Working Group's draft disadvantaged community criteria) in the outer boroughs.

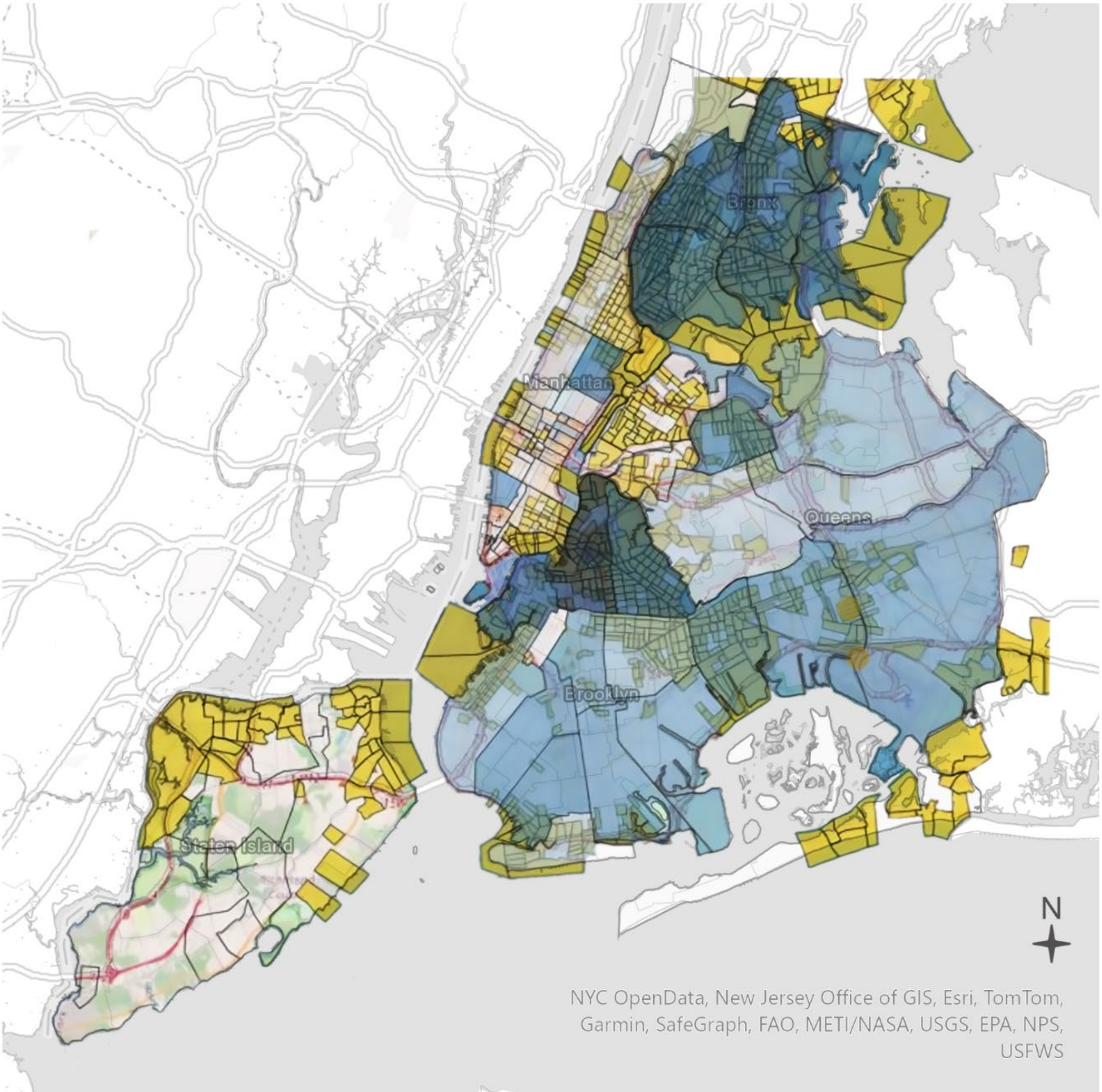

*Figure 10. Census tracts identified as disadvantaged communities by the Climate Justice Working Group (yellow) and upper decile of outage incidents, or most customers affected by outages from 2017 to 2021 (blue) as reported by Con Edison. The network outage data were taken from responses to City 19-292 and City 19-298. (Source: Adapted from City of New York testimony to PSC (*Prepared Direct Testimony of New York City Policy Panel before the New York State Public Service Commission: In the Matter of Consolidated Edison Company of New York, Inc. Case 22-E-0064 and Case 22-G-0065*, 2022).*

Calls to 311 for power outages from 2014 through 2022 (NYC311, 2023) during the summer rise sharply on extremely hot days. Their spatial distribution is largely consistent with the outage data. Power outage calls were most frequent in neighborhoods in northern Manhattan, much of the Bronx, central Brooklyn, and other places with more low income, Black or Hispanic households (Figure 11). More details on an analysis of 311 calls for power outages and their relationship to weather, neighborhood demographics, energy cost burden and heat health risks are in Annex

B(Marcotullio, Braçe, et al., 2023).

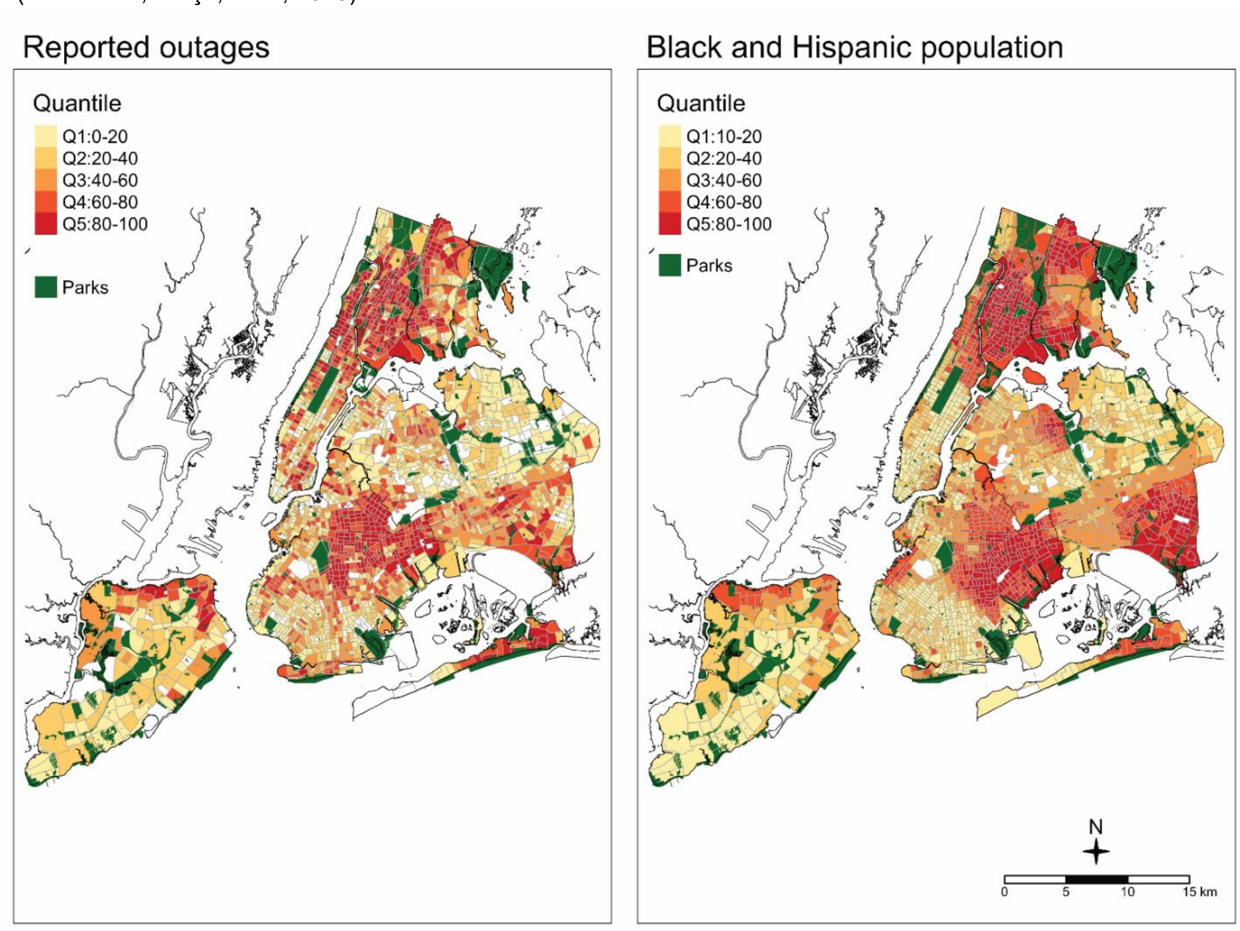

Figure 11. (left) Quantiles of the distribution of absolute numbers of 311 calls for "electric supply" or "power outage" in NYC from 2014-2021 by census tract: (right) Percent of households that are Black or Hispanic.

Assessing how infrastructure influences these disparities is beyond the scope of this assessment. But the findings call for the need to prioritize investments in grid- and building-level resilience measures in the most vulnerable neighborhoods. As NYC addresses its climate change mitigation and energy transition ambitions, there will be a growing need for technology and infrastructure that can improve efficiency and reliability for all communities. This challenge is discussed in more detail below, in NPCC4, Balk et al (Balk et al., 2024), as well as in Annex C.

6 Reducing Future Impacts

6.1 Current Policies

In the near term, energy insecurity and its health impacts can be reduced through a range of strategies: direct, need-based, subsidies for energy costs and home energy efficiency improvements; reducing energy prices; considerations for building codes; targeted investments in clean energy infrastructure and backup energy systems within NYC; and community-led renewable energy programs. The provision of subsidies and reductions in electricity rates would have to be undertaken at the state level by the Public Service Commission. The strength of evidence supporting effectiveness of different implementation approaches varies, but proven approaches can be expanded, and promising ones further tested and evaluated. It should be noted that many benefit programs designed to help address energy insecurity are not available to people who are not US citizens due to existing state and federal policy.

Household disconnection prevention: Disconnection protections vary by jurisdiction and circumstance but can offer important protections during extreme weather. Most states, including New York State (New York State Department of Public Service, 2023), provide some protections from utility disconnections to vulnerable customers during dangerously hot or cold weather. In NYC, residential disconnections for non-payment for all residential customers are suspended just before and after hot days using criteria based on the heat index and on cold days using criteria based on wind chill. In Los Angeles, on the other hand, a motion passed in 2022 that prohibits the Department of Water and Power from practicing water or power shutoffs as a debt collection tool for income-qualified residents and seniors (Smith, 2022).

Many states also provide time-limited disconnection protection for those with certain medical or other vulnerabilities. Some social services agencies provide one-time emergency grants to help people avoid disconnection; the NYC Human Resources Administration or HEAP emergency assistance programs are examples (City of New York Department of Human Resources Administration, 2023). Early in the Covid-19 pandemic, the New York State Public Service Commission prohibited disconnection of residential or small business customers for non-payment. In a May 2022 testimony of the NYC Policy Panel to the NYS Public Service Commission, city practitioners advocated for stronger protections against disconnections, and submitted that customers need greater protections than shareholders (Berkman et al., 2022).

Residential cooling: Ability to afford home air conditioning and energy to run it is the main driver of indoor temperature. Air conditioning can lower indoor temperatures and, in some cases, can increase ventilation. Increasing home AC access can also reduce health inequities by race and income (Madrigano et al., 2018). In place of AC, split heat pumps are another cooling technology that are typically more efficient than a standard AC and also provide electric heating (U.S. Department of Energy, 2023). Some types of facilities housing at-risk people are already required to maintain safe indoor temperatures during hot weather. For example, federal legislation requires long-term care facilities to provide comfortable and safe temperatures, and facilities certified after 1990 are required to keep temperatures in a range from 71 to 81°F (National Archives, 2023). Some jurisdictions, such as Dallas, Tucson, and Tempe, require that rental properties have cooling equipment (The Times Editorial Board, 2022).

In addition to increasing AC prevalence for communities without access, NYC has taken measures to reduce the need for AC consumption through temperature setpoint policies and cooling strategies. In 2023, NYC announced plans to develop maximum indoor temperature policies to protect all residents by 2030 and require cooling in all new construction by 2025 (City of New York Office of the Mayor, 2023; Ostapiuk, 2023). Advocacy groups have also proposed a minimum temperature setpoint for larger buildings, such as commercial or office buildings (WE ACT for Environmental Justice, 2023a). Energy efficiency measures can help reduce cooling cost burdens, as can cool roofs that are painted with white reflective paint to reflect rather than absorb heat, which can reduce indoor temperatures (Bock et al., 2021; Sun et al., 2021). Green roofs (i.e. roofs covered in vegetation) and other forms of green infrastructure that can provide shade and cooling also have benefits to the indoor environment and stormwater maintenance but are more expensive to install and maintain.

Utility subsidies: The federally funded Low-Income Home Energy Assistance Program (LIHEAP) provides financial assistance to households that meet income and other criteria to help with energy costs. Examples of health benefits from LIHEAP for households include reduced prevalence of undernutrition in young children (Frank et al., 2006). New York, like other states, receives a block grant and establishes its own guidelines for distribution within a set of federal policies. In complement to LIHEAP, the NYS Public Service Commission can approve subsidies for utility costs. During the Covid-19 pandemic, at the request of the city, the NYS Public Service Commission approved a small monthly subsidy, roughly $35 per month, to assist 440,000 low-income families in NYC and Westchester with costs of operating air conditioners in summer 2020 (City of New York, 2020). Limitations of the current LIHEAP program in New York State include not reaching 46% of qualifying households, limited assistance to renters who have heat included in their rent, limited funds available for air conditioning purchase, and currently there are no funds for summer utility assistance (Office of Community Services, 2022). A New York State extreme heat action plan proposed increasing LIHEAP cooling assistance funding and potentially providing summer utility assistance (Hochul et al., 2022). National legislation to greatly increase LIHEAP and weatherization funding has been proposed (Ed Markey: United States Senator for Massachusetts, 2022).

Energy efficiency and weatherization assistance: The New York City Department of Housing Preservation and Development (HPD) launched its HomeFix program in November 2019, which provided financial assistance and individualized support for home repairs. As of the time of this writing the program us not accepting new applicants (City of New York Department of Housing Preservation and Development, 2024). The state-administered Weatherization Assistance Program (WAP) provides energy efficiency audits and weatherization for qualifying low-income households. Nationally, in addition to reduced energy use and costs, multiple health benefits have been tied to WAP including reductions in asthma morbidity, better prescription adherence, less illness from cold and heat stress, reduced fire and CO poisoning risk, less need for food assistance, and increased productivity from improved sleep (Tonn et al., 2014).

Locally, a pilot evaluation of 20 low-income Bronx households receiving energy efficiency upgrade assistance found that participants experienced greater thermal comfort and temperature control, reduced energy costs, and less need for supplemental heating (Hernández & Phillips, 2015). As with LIHEAP, WAP funds are not sufficient to reach most qualifying households, and often considered inaccessible and underused particularly by renters. Reaching more households and renters may require a community-based and context-dependent approach based on the needs of individual communities (Reames, 2016a). Older households with lead, mold, or other contaminants may be denied access to weatherization upgrades and there is no current state funding for this type of pre-weatherization remediation (New York State Division of Housing and Community Renewal, 2023; WE ACT for Environmental Justice, 2023a). One recommendation that has been offered is that the state create and fund pre-weatherization remediation programs (WE ACT for Environmental Justice, 2023a). There is a 'split-incentive barrier' to energy efficiency, as those (i.e. landlords) who decide and pay for energy efficiency improvements do not necessarily benefit from the investment (Bednar & Reames, 2020; Bird & Hernández, 2012). Given the pervasive, inequitable harms from inefficient housing on energy insecurity and health among people of color and low-income households (Jessel et al., 2019) – and in particular Black Americans (Lewis et al., 2019) - expanding access to energy efficiency and weatherization assistance can contribute to restorative justice.

Reducing energy prices and debt forgiveness: NYC households have long been burdened by high energy costs. In 2016, the New York State utility regulator, the Public Service Commission, set a target energy cost burden for low-income households at 6 percent. Even before the Covid-19 pandemic, more than half a million NYC residents had costs above this threshold, and 460,493 low-income families in NYC are still paying over 6% of their pre-tax income toward their energy bills (NYC Mayor's Office of Sustainability & NYC Mayor's Office for Economic Opportunity, 2019). The economic damage from the COVID-19 pandemic, spikes in natural gas prices caused by war in Ukraine, and an increase in natural gas use for electricity after the Indian Point nuclear plant closed in 2021 further raised energy cost burdens. By March 2022, one in eight residential energy customers in the state were in arrears, the majority in NYC and Long Island (New York State Office of the New York State Comptroller, 2022). In response, the state and the Public Service Commission announced programs to help customers with these unprecedented levels of debt (New York State Office of the New York State Comptroller, 2022). In January 2023, the PSC approved financial assistance for past-due utility bills that accrued during the COVID-19 pandemic (New York State, 2023b). Because this path forgives the debt through a combination of state tax money and customer subsidization through electric rates, it does not result in a long-term reduction of energy prices. Other states have different rate structures, for example, using tiered rates based on income. Currently, programs for rate subsidies are only available to individuals who pay their energy bills, and not when operators of multifamily buildings pay the bill and roll those energy costs into rent. Given recent instability in energy markets due to the volatility in wholesale electricity prices from national and global factors (e.g., COVID pandemic, Russian invasion of Ukraine, increased electricity demand during heatwaves and winter storms, coal labor shortages that caused increased demand for natural gas), ongoing monitoring and evaluation of these programs are needed (New York ISO, 2022; Wholesale U.S. Electricity Prices Were Volatile in 2022, 2023).

Community clean energy ownership: The clean energy transition provides opportunities to sustainably reduce energy costs while providing more benefits to local communities. Community-owned clean energy typically refers to clean energy projects where a community can exercise control over the generation, use, and/or sale of energy resources and where the community plays an active role in decision-making. These projects may use different clean energy sources, such as wind or solar, at varying scales and capacities (Berka & Creamer, 2018). An example is WE ACT for Environmental Justice's 'Solar Uptown Now' campaign that has organized residents of upper Manhattan to buy and install solar power in multifamily housing together, sharing the up-front costs and longer-term energy savings (WE ACT for Environmental Justice, 2022). These types of projects have been implemented or proposed in other geographic contexts, for example, community-owned wind farms across Scotland (Community Energy Scotland, 2021) and community solar rooftops in Delhi, India (Kumar, 2023). For other examples of community clean energy and climate resilience projects in NYC, see *NPCC4 Advancing Climate Justice in Climate Adaptation Strategies for New York City* (Foster et al., 2024, sec. 2.2 and 5.1).

Resilient and clean energy infrastructure: Reducing secondary impacts due to infrastructure failure will be beneficial during multiple hazards, including heat waves, hurricanes, and flooding events. As the transition to low-emissions energy supply advances, the need for and development of technology and infrastructure that can improve efficiency and reliability, such as battery storage and demand response, is growing. High-efficiency technologies for buildings such as ground source heat pumps can also serve to lower peak electric demand (Buonocore et al., 2022). Following the passage of Local Law 2 in 2022, the city is evaluating the technical feasibility of district-scale geothermal systems (City of New York Mayor's Office of Climate & Environmental Justice, 2023a). These clean energy technologies have the potential to provide substantial health and equity co-benefits if they are deployed and sited using a framework that explicitly prioritizes these goals (Krieger et al., 2016). One potential solution to improve efficiency and reliability while increasing the uptake of renewables is to increase energy storage. In addition to large utility scale batteries for storage, another need in NYC is for resilient energy backup systems suitable for multi-family dwellings, which have a different permitting structure than large-scale outdoor batteries. Such systems are being developed to provide electricity during blackouts to common refuge areas for powering life-sustaining equipment, heating, cooling, lighting, and refrigeration of perishables (Clean Energy Group, 2022; Mango et al., 2021). Such systems can use rooftop solar, including community-owned systems that help reduce peak load grid strain and energy costs. The city of Toronto, Canada now mandates resilient building energy systems in all new mid- and high-rise developments (City of Toronto Planning and Development, 2023). In the aftermath of prolonged building-side outages following Super Storm Sandy, NYCHA has retrofitted 73 buildings with flood protected backup generators (New York City Housing Authority, 2021). Achieving NYC's targets for reducing GHG emissions by 2050 could avoid 160 and 390 premature deaths and 460 hospitalizations and emergency department visits for respiratory and cardiovascular disease each year, with a societal benefit of $3.4 billion (Johnson et al., 2020).

7 Opportunities for Future Research

7.1 Summary of Knowledge Gaps

In the context of climate change impacts on vulnerable US populations, the need for more data, research, and interventions to address energy insecurity has long been recognized (Hernández, 2013). Below we outline a few prominent gaps in research that warrant attention.

7.1.1 The need for more household energy use and outage data

There is an opportunity to enhance our understanding of energy use at the household level if data are available. Understanding how households use and do not use energy can help provide vital information to stakeholders. For example, Cong et al. (Cong et al., 2022b) used residential electricity consumption data to identify energy use behaviors in comparison to income-based measures of energy poverty, uncovering a previously hidden gap in energy equity. In addition, timely, spatially granular power outage data is not currently available in NYC. Over the past 9 years over 50,000 calls for power outages have been collected by the 311-call service, but why these claims have been made (why the household experienced a power outage) remains unknown. In addition, relying on 311 calls includes shortcomings such as differential reporting based on socio-demographics and the historical exclusion of NYCHA residents (Marcotullio, Braçe, et al., 2023). More information on the details of the circumstances would help stakeholders to identify outage hotspots, housing and electrical infrastructure or other problems and allow for tracking of outages with an equity lens at the community and individual level. Utilities also have data on outages but are not required to publicly share historical records of power outage data, which can include the cause of outages and their duration.

7.1.2 Equity implications of electrification and transition to renewable energy in the context of energy insecurity and health

As the city electrifies and transitions away from fossil fuels and to renewable energy, there are questions about whether communities will be able to benefit equitably, and how benefits and burdens will be distributed. There are also questions about whether hosting capacity differences will pose challenges across different neighborhoods. Low-income households in the NYC metropolitan area have a median energy burden of 9.3%, compared to 2.9% city-wide, and 25% of low-income (≤200% FPL) households have an energy burden greater than 16.8% compared to 3.4% for non-low-income households (Drehobl et al., 2020). The implications to the energy cost burden of transitioning away from fossil fuels to renewables and increasing electrification of the building sector are not yet fully understood or accounted for. Ensuring equitable access to building electrification and the indoor air quality benefits it can provide will require identifying and implementing strategies to address barriers to building electrification, particularly in older buildings and NYCHA-owned and affordable housing, such as high upfront or ongoing costs, access for renters, cost shifting concerns for tenants, a lack of skilled labor for installations, and upgrades to electricity infrastructure and other building modifications for new wiring (Cohn & Wang Esram, 2023; WE ACT for Environmental Justice, 2023b). NYCHA has a goal to reduce its greenhouse gas emissions 80 percent by 2050, which will require rehabilitation of its buildings so they can undergo energy retrofits and electrification. The quality of NYCHA's building stock has been challenged by deferred maintenance and underinvestment in public housing (Campion, 2023), which complicates the achievement of its GHG reduction goals. In addition to the benefits of building electrification to indoor air quality, the transition away from polluting peaker plants to cleaner forms of energy can improve outdoor air quality. NYPA commissioned a study in consultation with the PEAK coalition that assessed options for replacing NYPA's existing peaker plants (NYPA, 2022). However, as NYISO attempts to maintain reliability standards, they have warned that peaker plants may need to stay on for longer than planned (New York Independent System Operator, 2023c). The distribution of benefits and burdens related to exposure to poor outdoor air quality and grid reliability challenges will depend on the ability to introduce alternatives like demand response, rooftop solar, and battery storage and balance the pace of increasing renewables and efficiency with decreasing fossil fuels.

7.1.3 Transportation

The expansion of public transit, including Select Bus services in areas such as Eastern Queens holds the potential to improve employment, education, shopping, and other opportunities for local communities. By providing efficient and reliable transportation options, expanded public transit services can enhance mobility and connectivity, enabling easier access to job opportunities, educational institutions, and commercial centers, particularly for individuals who may have faced challenges in commuting to distant locations (Heyward & Khalifeh, 2023). Additionally, improved access to shopping areas can enhance the availability of goods and services, contributing to economic development and community well-being. However, further research is needed to assess the actual impact of the public transit expansion on employment rates, educational attainment, local economic growth, and overall community development. Addressing this knowledge gap will provide a better understanding of the potential benefits and inform decisions regarding public transit expansion to support equitable opportunities and enhance quality of life in these communities.

8 Traceable Accounts

Key Message 1	While recognizing the urgency to reduce energy use and GHG emissions to meet the City and State's ambitious climate goals and mitigate the impacts of climate change, actions must be approached deliberately, considering energy insecurity and health. Challenges, including reducing fossil fuel use, acquiring renewables, adapting the grid to meet higher demand, and securing sufficient dispatchable generation to ensure reliability during peak periods when solar and wind generation is low can all have implications for energy affordability and reliability. While the transition offers opportunities for economic growth, improved air quality, and promoting active transport, equitable implementation, and reliable energy supply particularly during extreme weather events are important considerations for NYC.
Description of Evidence	Currently, in NYC there are disparities in environmental burdens such as energy use, costs and electricity interruptions between Black and Hispanic and low-income communities and White and high-income communities (Drehobl et al., 2020; Marcotullio, Diko, et al., 2023; Ortiz et al., 2022) with significant health implications (City of New York Department of Health and Mental Hygiene, 2023a; Dominianni, Lane, et al., 2018). There are also significant differences in opportunities including access to energy-related jobs (National Association of State Energy Officials & Clean Energy Initiative, 2021). The Challenges of reducing energy-related fossil fuel emissions can further exacerbate these disparities if not addressed adequately. Inadequate solutions that exacerbate disparities include reducing grid reliability (NYISO, 2022), placement of infrastructure, such as last mile warehouses in low-income and Black and Hispanic communities and continued job opportunity exclusion (IREC, 2022; Muro et al., 2019).
New Information and Remaining Uncertainties	Remaining uncertainties include: the pace of the transition and its potential implications for energy insecurity; the identification of suitable locations and technologies for renewable energy generation; the development of energy storage solutions to address variability in renewable energy production; the precise economic and health benefits associated with the transition; the potential challenges related to energy equity and how they will be addressed; and strategies for ensuring energy supply reliability during extreme weather events.
Assessment of Confidence based on the Evidence	Given the evidence base, there is **high** confidence that New York State will reduce fossil fuel use and transition to renewables, although the precise pathway remains unclear. The confidence in the feasibility and timeline for achieving the state's climate goals accordingly is **moderate**, given the complexities involved in transitioning an entire energy system. The confidence in the potential economic and health benefits could also be **moderate** and depends on specific policy decisions and implementation. Confidence in equitable implementation and energy supply reliability during extreme weather events may also be **moderate** and require careful planning and policy development.

Key Message 2	Energy is not only vital for economic growth, but also for human health and well-being – a connection that the concept of energy insecurity (EI) highlights. EI can be caused by high energy costs relative to income, by frequent energy outages and unreliability, or both. Addressing EI both influences, and is influenced by, various domains such as public health, transportation, energy, and housing sectors – all compounded by climate change as a threat multiplier.
Description of Evidence	A growing body of literature around the concept of household and community energy insecurity inform its consideration as part of a sustainable development strategy, particularly as it relates to human health and well-being (Hernández, 2013, 2016a; Jessel et al., 2019). The prevalence and causes of energy insecurity, including high energy costs and energy outages, are documented (Energy Information Administration (EIA), 2017; NYC Mayor's Office of Sustainability & NYC Mayor's Office for Economic Opportunity, 2019; U.S. Energy Information Administration, 2020). Information on the measures, policies, and programs that have been implemented to address energy insecurity and other energy-related issues nationwide and in New York is available (Carley et al., 2021; Murray & Mills, 2014; NYC Mayor's Office of Sustainability & Mayor's Office for Economic Opportunity, 2019).
New Information and Remaining Uncertainties	Uncertainties remain about New York-specific strategies and initiatives aimed at reducing energy insecurity; effectiveness of existing policies and programs in alleviating energy insecurity; and how energy insecurity may evolve in response to changes in energy systems and costs.
Assessment of Confidence based on the Evidence	Given the strong body of evidence, confidence in the link between energy, human health and well-being is **very high.** Confidence in specific measures and policies to address energy insecurity **may vary** and depend on their effectiveness in practice. Confidence in the interconnections between energy insecurity and various sectors may also **vary** and require further research and analysis.
Key Message 3	EI can harm public health directly -- via inadequate heating or cooling, indoor air pollution, and reduced ability to reliably use medical devices and refrigeration necessary for health needs -- and indirectly when high energy costs reduce spending on other essential items like healthcare and food. Populations most vulnerable to EI include those with lower incomes, victims of systemic racism, people with underlying health conditions, disabilities, or dependent on electric powered medical equipment, and renters, who are less able to access energy subsidies.
Description of Evidence	There is a large body of evidence that documents the myriad ways in which energy insecurity directly impacts health, such as through fires from compromised thermal safety (J. Campbell, 2022; Hernández, 2022); dangerous coping strategies (Hernández, 2016a; Middlemiss & Gillard, 2015; Simes et al., 2023; Yoon & Hernández, 2021) and resulting respiratory issues such as indoor air pollution attributed to the use of unsafe heating or cooking methods and exposure to carbon monoxide (Ahrens, 2017; Dennekamp, 2001; Nicole, 2014; WE ACT for Environmental Justice, 2023b); interruption in life-supporting electrical-powered medical equipment (Casey et al., 2021; Mango et al., 2021). Research also documents indirect impacts of energy insecurity on health, such as compromised spending on other life essentials such as medication (Harker Steele & Bergstrom, 2021; Memmott et al., 2021; Simes et al., 2023); food-borne illnesses from lack of refrigeration (City of New York Department of Health and Mental Hygiene, 2022c; Gotanda et al., 2015; Lin et al., 2021); and foregoing other essential daily needs (Bansah et al., 2011; Hager et al., 2010). Statistics show that New Yorkers who are racialized and low-income (Frank et al., 2006; Murray & Mills, 2014; Reames, 2016b), rely on electric-powered medical equipment (Casey et al., 2021; Yoon & Hernández, 2021), living with existing medical conditions (Hernández, 2018; Simes et al., 2023), and renters (Bird & Hernández, 2012; RentHop, 2023) are disproportionately impacted by energy insecurity.
New Information and Remaining Uncertainties	Energy insecurity remains a complex and evolving issue with several key uncertainties. Measuring energy insecurity lacks a universal standard, making comparisons challenging. Data availability and quality vary, hindering precise assessment. Long-term health impacts and interactions with other determinants of health need further exploration. Assessing the effectiveness of interventions and policies is also an ongoing challenge. Advancements in energy technology and their impact on access and health outcomes require further monitoring, as does the long-term effect of policies.
Assessment of Confidence based on the Evidence	Given the evidence base and remaining uncertainties, there is **very high** confidence that without significant and equity-oriented policies targeted at reducing energy insecurity, the direct and indirect consequences for New Yorkers' health will continue to be exacerbated.

Key Message 4	Climate resilience investments in energy infrastructure and mitigation plans for the transition from fossil fuels to renewable energy and the electrification of buildings and transportation could impact future energy reliability and costs. Vulnerable populations are most at risk from any potential increases in power outage risks or energy costs, which may be exacerbated by projected climate extremes in NYC, such as extreme heat, cold, and flooding. Equitable and just policies and investments in the energy and housing sectors can reduce future health risks from EI and shape a more resilient and equitable future.
Description of Evidence	NPCC4, Balk et al(Balk et al., 2024) provides evidence on the challenges and opportunities of transitioning from fossil fuels to renewable energy sources. There is an existing evidence base for potential impacts of climate resilience investments for future energy reliability and costs particularly on the potential impacts of electrification of the building and transportation sectors on the energy system (New York Independent System Operator, 2023c). These new investments and plans' potential disproportionate impact on vulnerable populations is supported by studies that have evaluated existing disparities of the energy system (Drehobl et al., 2020; Lane et al., 2022; Lyubich, 2020; Marcotullio, Diko, et al., 2023; Ortiz et al., 2022) The support for equitable policies and investments in the energy and housing sectors towards reducing future health risks from energy insecurity can be found in Lewis et al, Kreiger et al, and Jessel et al (Jessel et al., 2019; Krieger et al., 2016; Lewis et al., 2019). In particularly on, data on the potential impacts of electrification of the building heating and transportation sectors on the energy system are derived from NYISO (New York Independent System Operator, 2023c).
New Information and Remaining Uncertainties	The effectiveness of climate resilience investments in mitigating energy infrastructure risks is an evolving field, and strategies and innovations in the transition from fossil fuels to renewables continue to emerge. Uncertainties remain regarding the exact impacts of electrification on energy reliability and costs.
Assessment of Confidence based on the Evidence	There is **very high** confidence in this finding based on 1) well-documented support for the close links between EI, human health, and well-being, and 2) strong evidence about the disproportionate impacts of EI on marginalized populations. Confidence in the specific impacts of electrification on energy reliability and costs **may vary** and depend on local factors and technologies.

9 Sustained Assessment

A sustained assessment of energy and energy insecurity in New York stands as a critical endeavor for both the present and the future. As the state strives to reduce its carbon footprint and transition toward renewable energy sources, an ongoing evaluation of energy systems and their resilience is imperative. This comprehensive assessment should not only encompass the reliability and costs of energy but also acknowledge the profound interplay between energy access, resource and economic sustainability, and human health and well-being. In a landscape where vulnerable populations are most susceptible to energy-related challenges, the pursuit of equitable and just policies and investments in the energy sector becomes paramount. Table 3 includes indicators and key metrics to track progress on impact, vulnerability, resilience, and interventions towards climate-friendly energy futures without compromising household or community energy security.

This sustained inquiry into New York's energy dynamics promises to shape a more resilient, equitable, and sustainable future for all its residents. These indicators should be considered alongside those from NPCC4 (Foster et al., 2024; Matte et al., 2024), recognizing that energy security and the health and well-being of all New Yorkers are intrinsically linked.

Table 3. Energy and energy insecurity-related indicators

Climate risk		Indicator	Indicator Portal or Report	Data source	Initiative, recommended by	Distributional equity stratification
Energy industry and infrastructure benefits		Hosting capacity	NYSERDA	Con Edison, NYSERDA		Race, ethnicity, poverty, housing tenure, income
	Interventions (& co-benefits)	Newly created jobs		NYS Department of Labor, NYC Comptroller		Race, gender, ethnicity, income
		Quality of the newly created jobs (e.g., prevailing wage, benefits, security)		NYS Department of Labor, NYC Comptroller		Race, gender, ethnicity, income
		Sustainable and accessible public transportation from all parts of New York, particularly parts that currently are in lack (e.g., Southeast Queens)		NYC DOT		Race, ethnicity, income
		New jobs specifically for marginalized populations		NYS Department of labor, NYC Comptroller		Race, ethnicity, income
		EV purchases (bikes, cars, scooters, etc.)		NYC DOT (registrations)		Income
	Interventions	More and better data availability				
Electricity interruptions	Identification and descriptions	Location, length, and extent of outage	311 calls, outage records	Open data Con Edison		Race, ethnicity, income
	Energy security	Lived experiences of power outages				Race, gender, ethnicity, income
	Health	Morbidity/mortality hospitalizations, I		DOHMH, Health and Hospitals		Race, gender, ethnicity, income

Energy Insecurity	Impact	Power outages			NPCC2, 3	Race, Poverty concentration, Housing tenure status
		Secondary hazards from power outages (e.g., adverse health effects from food spoilage, thermal discomfort, inability to use electric powered medical equipment)			NPCC2, 3	Race, Poverty concentration, Housing tenure status, Age, Existing health conditions
	Vulnerability	Energy cost burden: percent of households spending more than 6% of income on energy bills	U.S. Energy Information Administration	Residential Energy Consumption Survey	New to this assessment	Race, Poverty concentration, Housing tenure status
	% without heat	% without air conditioning		New York City Housing and Vacancy Survey		Race, Poverty concentration, Housing tenure status
		Fires due to self-made heat (e.g., candles)		FDNY		Race, Poverty concentration, Housing tenure status
		Lithium-ion battery-related fires		FDNY		Race, Poverty concentration
	Interventions	EI mitigation policies				Race, Poverty, Housing tenure status

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The assessment does not represent the policy position of any agencies whose staff are co-authors.

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Annex A: Energy Insecurity - Global, National, and Historical Context

Energy or fuel poverty are terms that have been used internationally to describe a lack of access or means to afford modern energy services and products needed for health and development. In developing countries, a lack of clean household energy for cooking and heating[1] is a major cause of preventable illness and death. While energy access is improving in many developing economies, by one estimate 733 million people without access to reliable electricity and 2.4 billion people using dangerous and inefficient cooking systems.[2] Among this population, those that lack access to energy include those that simply cannot afford it. Access to electricity in the US is virtually universal, while in Malawi, for example, only about 11% of the population has electricity access[3] and more than 95% of people depend on solid household fuels. Globally, household air pollution from use of solid fuels for cooking and other needs caused an estimated 2.3 million deaths in 2019, from causes including childhood pneumonia, COPD, heart disease and strokes, diabetes, low birth weight and preterm birth.[4,5] Improving clean household energy access is a UN sustainable development goal (number 7).

A lack of energy access and excessive cost burden also exists in developed economies.[6] "Fuel poverty" was first studied intensively in the United Kingdom.[7] As with energy insecurity, fuel poverty considers all essential energy services (not just heating), what is needed (not only what is used), and housing energy inefficiency as a major cause.

In the United States, electricity came first to cities more than 100 years ago, and the need to expand access was recognized. The rural electrification program beginning in the 1930s improved electricity access in rural areas from less than 10% to near-universal. Among other benefits, a decline in infant mortality has been attributed to this program.[8] With modern energy connections becoming near universal in the US, excessive energy cost burden emerged as a major hardship for both urban and rural households. This concept has been the focus of many U.S. researchers who study the relative costs of energy to households. The energy burden focuses on the household energy bill as a percentage of the household's annual income.

For New York State, the energy burden is defined as households that spend more than 6% of their annual income on energy.[9,10] According to the US DOE's Low-Income Energy Affordability Data (LEAD) Tool the national average energy burden for low-income households is 8.6%, three times higher than for non-low-income households which is estimated at 3%. In some areas, depending on location and income, the energy burden can be as high as 30%.[11] Nevertheless, the extent of the energy household burden has been a persistent if underappreciated problem in the United States.[12] For example, urban and rural low-income households (defined as 80% of area median income or 150% federal poverty level) spend roughly three times as much of their income on energy cost as compared to non-low-income households (7.2% and 9% versus 2.3% and 3.1%, respectively.[13,14] Moreover, low-income, African American, Latinx, multifamily and renter households are disproportionately impacted by high energy burdens.[13] Out of a total of 118.2 million US households, in 2015, the US Energy Information Administration (EIA) estimated that 17 million households received an energy disconnect/delivery stop notice and 25 million households had to forgo food and medicine to pay energy bills.[15]

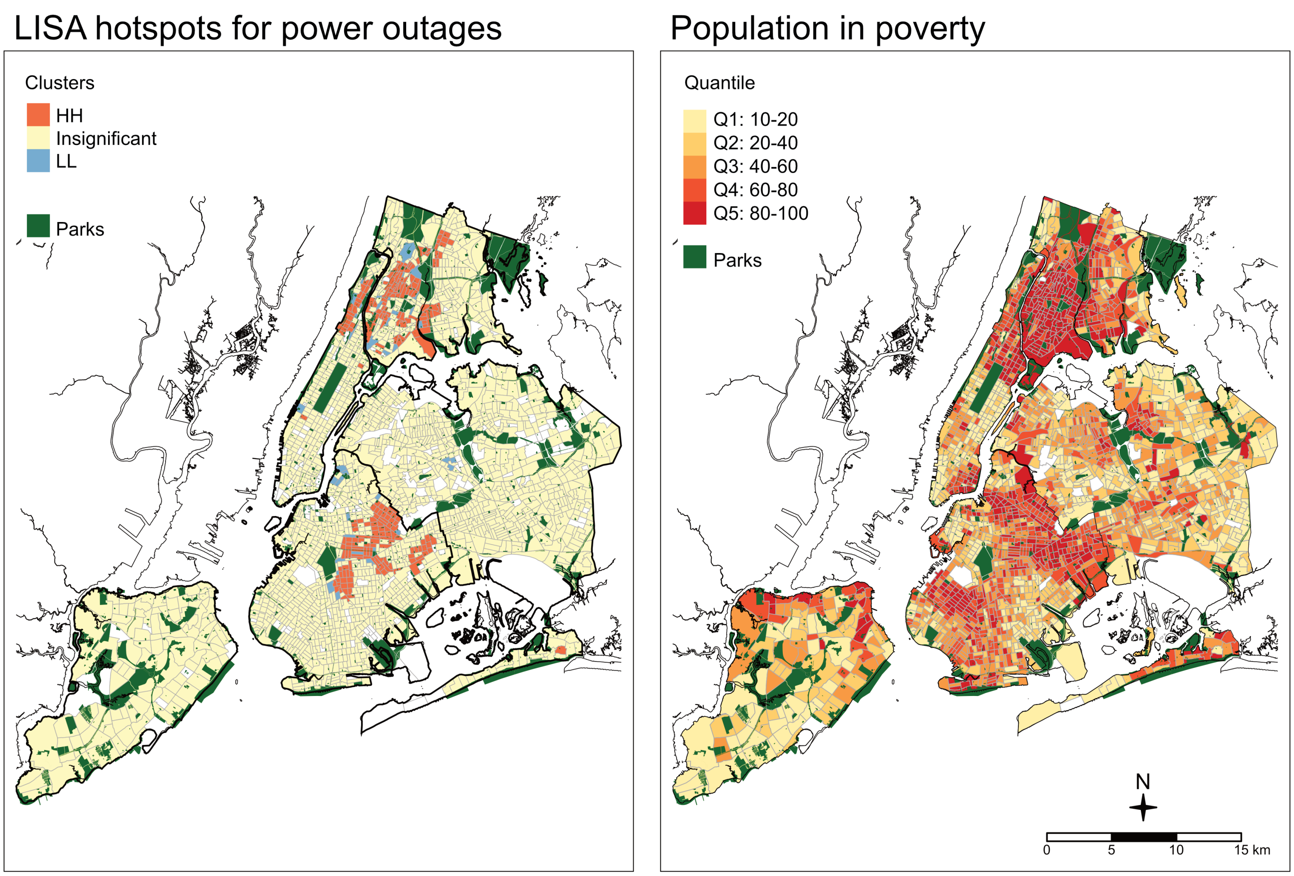
The results of the energy burden have been identified as energy insecurity, or the state in which households cannot meet their energy needs.[16] This term refers to the uncertainty that a household faces in being able to make utility bill payments.[17] The point emphasized from this concept is that the stress from insecurity creates significant health issues.[18] For example, the results of energy insecurity include extreme home temperatures, hazardous heating alternatives, and the constant threat of utility shut-offs or mounting arrears in utility bills because of nonpayment. This problem is especially acute for low-income residents such as single parents, the elderly, the disabled, and others with low or fixed incomes.[19,20] Those facing energy insecurity may be homeowners unable to invest in efficiency upgrades or may be renters living in housing units where landlords do not pay for the utilities and consequently have very little incentive to create more energy efficient units.[21] Energy insecurity is an important issue in the US. The DOE EIA Residential Energy Consumption Survey (RECS) data for 2015 suggest that 31% of U.S. households experienced some form of energy insecurity. That year, nearly seven million households had their access to heat interrupted at least once, and six million lost access to air conditioning at least once.[22] Adequate housing and income are central to energy justice. Energy justice is a branch of environmental justice[23,24] focused on the notion that all individuals should have access to energy that is affordable, safe, sustainable and able to sustain a decent lifestyle, as well as the opportunity to participate in and lead energy decision-making processes with the authority to make change.[25–27] Energy justice scholarship stresses that neither the adaptation to climate change nor the renewable energy transition is inherently just nor democratizing in terms of the distribution of technologies and benefits.[28] Energy justice is based upon disparities within energy systems closely associated with housing including, inter alia, notions concerning energy poverty, fuel poverty, energy burden and energy insecurity.

Annex B: 311 Calls for Summer Power Outages - Methods

Researchers tested whether the 311 calls were clustered, dispersed or randomly distributed throughout the city.[29] Using spatial statistical test, the research found that there is a clustering of high numbers of 311-calls made between 2013 and 2022. That is, high numbers of calls were spatially clustered together as were low numbers of calls. A specific test, called the Local Indicator of Spatial Autocorrelation (LISA) demonstrated the location of these different levels of calls. The results of this analysis are presented in Annex Figure B-1 (left panel). Across most of the census tracts in the city, there is no clustering of calls amounts, but high numbers of calls are clustered in Northern Manhattan, parts of the Bronx, central Brooklyn, and Southeastern Queens. Areas designated as High-High (HH) signal locations of high absolute numbers of 311-calls for power outages (i.e., above the mean level of 311-calls for power outages per census tract) and where the adjacent census tracts also had High absolute number of 311-calls for power outages. The HH designation indicates areas of spatially clustered high levels of 311-calls for loss of power. Alternatively, areas designated as Low-Low (LL) are areas of low absolute numbers of 311-calls for power outages (i.e., below the citywide mean for 311-calls for power outages per census tract) and the adjacent cells are also areas of low absolute numbers of 311-calls for power outages.

Selected socio-economic characteristics of the census tracts with different levels of 311 calls were also examined. The research identified that there is an association between the levels of calls and the level of poverty within the different clusters. The distribution of those in poverty is presented in Annex Figure B-1 (right panel). A statistical test (student's t-test) of the means of the percent poverty in census tracts in high call cluster areas and the percent of poverty in census tract of low call cluster areas is significant ($t = 3.5806$, $df = 84.929$, $p\text{-value} = 0.0006$).

The results suggest that there is a significantly higher percentage of the population in poverty within census tracts with high numbers of calls compared to the percentage of population in poverty in census tracts with low numbers of calls. The mean percent in poverty in census tracts with high cluster calls is 26.0% and the mean percent of poverty in the census tracts with low cluster calls is 19.3%.



Annex Figure B 1. Local Indicator of Spatial Autocorrelation (LISA) results for 311 calls for power outages by census tract from January 1, 2014-January 1, 2023 (left). The distribution of percent population in poverty by quantile and census tract in New York City 2020 (right)

Annex C: Energy Transition Plans, Reliability, and Affordability - Challenges for NYC

As NYC addresses consistency with the Climate Leadership and Community Protection Act (CLCPA) and the commitment to carbon neutrality, there will be a growing need for technology and infrastructure that can improve efficiency and reliability. Over the course of the next few decades, New York State has committed to an energy transition. The transition is slated to occur through a decrease in use of fossil fuels to generate electrical power, while electrifying transportation and building energy services including heating, hot water, and cooking. Plans call for replacing fossil fuels with renewables including solar, wind, and hydropower.[30] The role of nuclear power remains an open question.

NYC will play a significant role in the energy transition, as the city's energy use is a major share of state energy use (30%) and the city produces 40% of the state's GHG emissions. The City also has committed to carbon neutrality by 2050.[31] At the same time, the City faces significant challenges in reducing the use of fossil fuels, acquiring renewables and electrifying sectors. The City's commitment to carbon neutrality is envisioned through the use of increased renewable energy generation, battery storage, and renewable energy transmission from up-State and beyond. All transportation and building energy demand are slated to be met by renewable electricity, meaning that electricity demand will increase dramatically. In order to meet low carbon fuel goals and reduce emissions, the City plans three important strategies:

1. Transform the electricity system to deliver 100% zero-emission electricity to buildings and the capacity to provide the same for more than a million zero emission vehicles (ZEVs);
2. Transform the current natural gas system to deliver low carbon gas (e.g., such as hydrogen or renewable natural gas) for end uses too costly and complex to fully electrify; and
3. Provide low carbon steam system for heating and cooling to some of the largest and most difficult buildings to decarbonize.[32]

According to New York Independent System Operator (NYISO), given current trends and conditions, annual baseline energy use will increase from 49,230 GWh in 2023 to 68,810 GWh in 2050 (40% increase) and baseline peak demand is projected to increase from 11,023 MW to 13,200 MW over the same period.[33] Energy storage to allow for renewable energy use is currently 22 MW and is projected to increase to 704 MW by 2050, and this storage will increase energy provision from 3 GWh in 2023 to 686 GWh in 2050[33] (about 10% of annual electricity demand during that 2050 period). Two transmission lines will deliver renewable energy to NYC; the Champlain-Hudson Power Express (CHPE) project that will deliver hydropower from Canada directly to Queens, and the New York Power Authority (NYPA)-led proposal, known as Clean Path NY, which proposes to deliver renewable energy from upstate New York directly to NYC.

There are at least four concerns to meeting carbon neutrality given current plans. The first is that many of the technologies to meet carbon neutrality goals are not yet commercially available. As a NYC study states, additional innovation is needed as battery storage technology is untested and undeveloped at the scale required to decarbonize NYC.[32] For example, Fekete et al.[34] points out that current battery storage technologies have limited capacity that may not meet the need for base load given seasonal variation in renewable energy generation. Current research suggests that studies of net-zero decarbonization include carbon capture and sequestration (CCS).[35] In fact, many studies suggest that CO2 emission reductions of great than 50% will not be possible without CCS.[36] CSS was not considered in the City's plans, suggesting contrary to research that the City's transition could indeed reduce carbon emissions without it. New York State is currently in the process of defining what constitutes 'zero emissions' that meet CLCPA targets,[37] to which there have been environmental, equity and justice-related concerns about the implications of fuels and technologies that may be included (e.g., nuclear, biofuels, hydrogen).[38]

Second, there are reliability concerns with the transition to a larger role of the electricity grid. Recently, the New York Independent System Operator (NYISO) finds that thinning reliability margins over the next decade present increased challenges to reliability for NYC.[39] NYISO quarterly assessment of reliability of the bulk electric system found a deficit in reliability margins for the NYC area beginning in summer 2025. The deficit is as large as 446 MW, driven primarily by the combination of a forecasted increase in peak demand (through the electrification of the transportation and building sectors, continued economic growth following the pandemic) and the unavailability of certain generators (Peaker plants).

Third, the electricity costs and affordability are important concerns. New York State is among the top 10 states with the highest electricity costs in the country. In 2023, cost of residential electricity was 21.92 cents/KWh compared to 15.92 cents/KWh for the country.[40] Costs will be increasing, as in June 2023, Con Ed requested another increase in electricity rates resulting in a roughly 12% increase for customers over the next three years.[41] These increases will go towards financing upgrades to the company's electricity delivery system, funding renewable energy plans and improving overall infrastructure. Continual rate increases can be critical for some NYC residents as approximately 610,000 families (representing 18% of total families in the city) pay greater than 6 percent of their household income and are therefore considered energy cost burdened.[9] Moreover, as there are large areas in the city that have low hosting capacity there will be a need to further upgrade the electricity grid in these locations so as to provide equitable renewable energy access.

Finally, there is concern whether Con Edison will be able to provide enough electricity distribution necessary to meet the increased demand for heating and transportation during the transition and if this increase can be accomplished while keeping affordability in check.

Annex D: Overview of City and State-Level Energy Policy

Table D1:Overview of City and State-level Energy Policy

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
STATE				
Climate Leadership and Community Protection Act (CLCPA)	New York State Public Service Commission (PSC), New York State Energy Research and Development Authority (NYSERDA), New York State Department of Environmental Conservation (DEC), Climate Action Council (CAC)	6,000 MW of distributed solar installed by 2025, 185 trillion BTU reduction in total energy consumption, including electrification to reduce fossil fuel use in buildings by 2025, 3,000 MW of storage installed by 2030, 70% of load supplied by renewable resources by 2030, 9,000 MW of offshore wind installed by 2035, 100% of load supplied by zero emissions resources by 2040.	Transformation of the power grid, necessitating changes in market structures, planning processes, flexible load, and investment in bulk power system infrastructure.	The Climate Act mandates that no less than 35% with a goal of at least 40% of our climate action benefits will go toward New York's disadvantaged communities. The aim is to address the challenges and barriers these communities are facing.
Tier 4	New York State, New York City, New York State Public Service Commission (PSC)	TIer 4 is an innovative approach to supporting the development of transmission infrastructure at the state level while also providing clean energy to the state's most challenging load center.	Tier 4 addresses the imbalance of renewable energy access within the state grid. Administered by the New York State Energy Research and Development Authority (NYSERDA), the program procures renewable energy attributes in the form of Tier 4 Renewable Energy Certificates (RECs), which are tied to the delivery of renewable generation in New York City.	After a thorough project evaluation and negotiation process, two contract awards were recommended for projects: Clean Path NY (CPNY), and Champlain Hudson Power Express (CHPE). This renewable energy will help increase grid reliability and provide clean energy to New York City.
"Peaker Rule" Ozone Season Oxides of Nitrogen (NOx) Emissions Limits for Simple Cycle and Regenerative Combustion Turbines	NYS DEC	Reduce ozone-contributing pollutants associated with New York State-based peaking unit generation. Compliance obligations phased in between 2023 and 2025.	Reduction of fossil fuel use.	The Peaker Rule was issued to remove the legacy environmental harms in environmental justice communities and has resulted in the pursuit of deactivation by some of the city's oldest and dirtiest Peaker plants, allowing these sites to be redeveloped for energy storage and renewable energy infrastructure.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
STATE				
NYS Accelerated Renewable Energy Growth and Community Benefit Act (AREA)	Office of Renewable Energy Siting (ORES) within the NYS Department of State, NYPSC, NYSERDA	Provides for an accelerated path for the permitting and construction of renewable energy projects other than the Article 10 power plant siting law, calls for a comprehensive study to identify cost-effective distribution, local and bulk electric system upgrades to support the state's climate goals, and to file the study with the New York State Public Service Commission. Calls for use of NYISO's competitive Public Policy Process to meet transmission needs to meet CLCPA goals.	Intended to help accelerate siting of eligible renewable resources and establish new transmission investment priorities to facilitate the achievement of state climate and energy policies.	This legislation aims at improving the siting and construction of large-scale renewable energy projects in an environmentally responsible and cost-effective manner. Communities have input on reviews and potentially can receive compensation benefits for hosting major renewable facilities. All project approvals include provision for host community benefits.
Indian Point Deactivation	Agreement between New York State and Entergy	Deactivate Indian Point units 2 and 3 by 2020 and 2021, respectively.	Remove this nuclear power plant from the grid. NYISO Deactivation Assessment found no reliability need with loss of 2,311 MW. Three gas powered plants were subsequently used to make up baseload.	Deactivation resulted in the replacement of energy by natural gas. The closure of Indian Point has resulted in higher electricity prices.
Regional Greenhouse Gas Initiative (RGGI)	New York and other RGGI states	Reduce carbon dioxide emissions cap by 30% from 2020 to 2030 and expand applicability to currently exempt "peaking units" below current 25 MW threshold.	The NYS DEC proposed to expand applicability in NYS to generators of 15 MW or greater, whereas currently rules do not apply to generators less than 25 MW.	Power sector carbon mitigation policies' focusing on aggregate emissions reductions have largely benefitted non-environmental justice communities and have not redressed the fundamental problem of disparities in pollutant burdens between EJ and non-EJ communities.
Offshore Wind development	New York State Public Service Commission (PSC) / New York State Energy Research and Development Authority (NYSERDA)	NYSERDA currently has five offshore wind projects in active development, totaling more than 4,300 megawatts – nearly half of the State's goal for 9,000 megawatts by 2030. In July 2022, NYSERDA launched a third offshore wind solicitation to procure at least 2,000 additional megawatts of offshore wind energy for New Yorkers.	In addition to greening the grid, the offshore wind industry can bring thousands of new jobs to NYC and help revitalize our working waterfronts–like the efforts currently underway to transform the South Brooklyn Marine Terminal into an offshore wind staging site.	New York has entered into agreements to provide new jobs to EJ communities. The New York City Public Design Commission (PDC) has approved Equinor's design for the offshore wind operations and maintenance building to be constructed at the South Brooklyn Marine Terminal (SBMT). The approval from the PDC allows for advancement of New York's first-ever, purpose-built offshore wind operations and maintenance facility, marking an important step in revitalizing a working waterfront at this historic port. Jobs from this operation can help residents from disadvantaged communities.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
CITY				
Local Law 43 (2010) and Local Law 32 (2023)	New York City	Eliminate combustion of fuel oil numbers 6 and 4 in NYC.	Removal of "dirty" oil fuel use in residential and commercial buildings.	The Clean Heat program, related to this effort, reduced air pollution emissions in both high and low-income neighborhoods.
Local Law 97 (2019)	New York City	Requires reduced building greenhouse gas emissions by 40% by 2030, with compliance starting in 2024, and 100% by 2050.	Mandate applies to any building in NYC 25,000 square feet or larger; the law was updated in 2020 to include buildings in which up to 35% of units are rent regulated, starting in 2026. Officials estimate the law would apply to roughly 50,000 of the city's more than one million buildings.	Local Law 97 focuses on NYC's large buildings, both residential and commercial. Large residential buildings, where about two thirds of the city's population live, are already more efficient than single and two-family homes. Moreover, measurement of efficiency is based upon square footage, and it would be more effective to focus on per capita or household level emissions. To address this NYC launched the ElectrifyNYC (Electrify New York City), a free program that helps NYC homeowners in 1-4 unit buildings with green and efficient home upgrades so they can save money, make their homes more comfortable, and clean the air.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
CITY				
Local Law 24 (2016)	New York City	To enhance public awareness of the city's efforts to install 100 MW of solar by 2025. The city is required to assess the solar PV potential of all City-owned buildings over 10,000 gross square feet once every two years. Special focus is given to identifying and quantifying potential capacity at solar-ready buildings, which are defined as buildings that have roofs that are no more than 10 years old and in fair or good condition. The City has initiated the "Solar 100" project goal to install 100 megawatts (MW) of solar photovoltaic (PV) electricity generation capacity across municipal buildings by 2025. The Department of Education (DOE) partners with Solar One (a 501(c)(3) organization fostering sustainability education, training and technical assistance), on programs that support climate education and climate-related workforce development opportunities for public schools.	Increase in renewable solar energy generation within NYC.	There is a difference in hosting capacity across NYC neighborhoods which brings up questions of whether this will affect solar installation and energy storage capacity in EJ communities.
Local Law 92 and Local Law 94 (2019)	New York City	These laws require all buildings undergoing roof decking replacement and any newly constructed buildings to have a sustainable roofing zone—a solar PV system, a green roof, or a combination of both.	Enhance the development and implementation of solar energy in NYC.	NYC Accelerator program provides resources, training, and one-on-one expert guidance to help building owners and industry professionals improve energy efficiency and reduce carbon emissions from buildings in NYC.
Local Law 2 (2022)	New York City	Requires the creation of a demonstration program for geothermal exchange systems, pending results of the ongoing feasibility study.	Geothermal heat pumps provide clean and efficient heating and cooling, while using less electricity than other types of heat pumps. The project can realize further efficiencies and maximize environmental benefits through balanced loads and a diversity of thermal sources and sinks.	Geothermal power can potentially provide EJ communities with clean and efficient heating and cooling.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
CITY				
Local Law 99 (2019)	New York City	Assessing the feasibility of replacing in-city gas fired power plants with battery storage powered by renewables, and assessing the readiness of NYC's electric grid to accommodate anticipated increases in customer electricity demand due to building electrification.	Providing background on replacing fossil fuel power plants with clean energy and battery storage.	Background material can be used to provide information one energy storage access in EJ communities.
Local Law 248 (2017)	New York City	A law that requires NYC to create a long-term energy plan in 2019, every four years after and also establishes a City energy policy advisory subcommittee.	Provides a plan for energy use, a review of the current energy supply and capacity; a summary of the current citywide energy demand and a projection of the future citywide energy demand over the next four years, or such longer period as the advisory subcommittee may deem appropriate, including (i) an identification of factors that may affect demand; (ii) specific recommendations regarding the capacity that could be added to the current energy supply to meet such projected demand after consideration of such factors; and (iii) actions the City could take in connection with such recommendations.	Background material can be used to provide information on availability of wind generation in EJ communities.
Local Law 104 (2018)	New York City	A Local Law to amend the administrative code of the City of New York, in relation to the creation of wind maps demonstrating wind energy generation potential within the city.	Promote wind generation in NYC.	Background material can be used to provide information on removing highly polluting plants from EJ communities.
Local Law 181 (2019)	New York City	Studying the feasibility of installing utility-scale energy storage on private buildings throughout the city.	Provision of utility scale storage systems to allow for use of renewable energy.	Background material can be used to provide information on energy storage availability to EJ communities and what is feasible to use in lieu of Peaker plants.
Local Law 17	New York City	To direct the mayor’s office of long-term planning and sustainability to study the feasibility of different types of renewable energy sources combined with battery storage on Rikers Island.	Provide background on renewable energy to Riker's Island.	Provide renewable energy to officers, staff and inmates at Riker’s Island facility.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
CITY				
Local Law 154	New York City	To amend the administrative code of the City of New York, in relation to the use of substances with certain emissions profiles.	No person shall permit the combustion of any substance that emits 25 kilograms or more of carbon dioxide per million British thermal units of energy, as determined by the United States energy information administration, within such building.	Reduction of carbon dioxide emissions and electrification of EJ community buildings.
Local Laws 60 and 64	New York City	Assess the environmental equity issues in NYC and develop a plan to incorporate environmental justice into the fabric of City decision making. The law covers Power plants, Substations, distribution, and transmission Citygate stations, High-pressure regulators stations over 300psi; any boilers burning fuel oil #4 or #6 with or without waivers from City agencies; renewable energy systems, including solar PV, wind, microgrids, and energy storage, Generators required to be registered with DEP.	A report, an online EJ portal, and a plan are available. This legislatively mandated work, known as Environmental Justice New York City (EJNYC), represents a historic investment from the City of New York to study environmental inequities affecting how and where low-income communities and communities of color live, and to provide all residents the tools to advocate for the best outcomes for their communities.	The report on future investment decisions includes energy infrastructure in and affecting EJ communities.

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New York City Panel on Climate Change 4th Assessment
Concepts and Tools for Envisioning New York City's Futures

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Abstract:

This chapter of the New York City Panel on Climate Change 4 (NPCC4) report discusses the many intersecting social, ecological, and technological-infrastructure dimensions of New York City and their interactions that are critical to address in order to transition to and secure a climate-adapted future for all New Yorkers. The authors provide an assessment of current approaches to "future visioning and scenarios" across community and city level initiatives and examine diverse dimensions of the NYC urban system to reduce risk and vulnerability and enable a future adapted NYC. Methods for the integration of community and stakeholder ideas about what would make NYC thrive with scientific and technical information on the possibilities presented by different policies and actions is discussed. This chapter synthesizes the state of knowledge on how different communities of scholarship or practice envision futures and provides brief descriptions of the social-demographic and housing, transportation, energy, nature-based, and health futures and many other subsystems of the complex system of NYC that will all interact to determine NYC futures.

Keywords:

Futures, Scenario Planning, Climate Change, Complex Systems, NPCC4

Recommended citation:

Balk, D.,McPhearson, T., Cook, E. M., Knowlton, K.,Maher, N., Marcotullio, P., Matte, T., Moss, R., Ortiz, L., Towers, J., Ventrella, J.,Wagner, G., & Barnes, J. (2024). Concepts and tools for envisioning New York City's futures – Interim Report. https://climaeassessment.nyc

Table of Contents

1 Chapter Summary

This chapter provides the first of its kind of assessment for New York City (NYC) of positive future visions, scenarios, and their intersections with current challenges, which can inform new modes and models for equitable climate change policy, planning, and engagement across the diverse social and infrastructural fabric of the city. Here we consider additional aspects of NYC's built, social, and natural infrastructure that were not fully considered in NPCC3 (New York City Panel on Climate Change, 2019) but have become especially salient in the time since. We discuss the many intersecting social, ecological, and technological-infrastructure dimensions of the city and their interactions that must be simultaneously considered to transition to and secure a climate-adapted future for all New Yorkers. We assess current approaches to futures research, visioning, and scenarios across community and city-level initiatives and discuss multiple dimensions of the NYC urban system to reduce risk and vulnerability and to enable an NYC that is adapted to future climate change. In doing so, we synthesize the state of knowledge on social-demographic, economic, transportation, housing, health futures, and many other subsystems of the complex system of NYC that will all interact to determine NYC futures.

1.1 Key Messages

Key Message 1: *NYC is projected to be hotter, wetter, and more flood prone, with multiple types of tropical and winter storms that are likely to increase in frequency, intensity, and severity. At the same time, the population of the city is expected to age. Long traditions of in- and out-migration have shaped the city and are expected to continue to be an important part of its future, anchoring it in the region and the nation. The built environment will largely remain in place, yet changes in land use and land cover, including conversions in impervious and natural areas, are expected. Managing and planning the future NYC to be more adapted and resilient to diverse climate, economic, and social pressures will require understanding these diverse futures that also interact dynamically in real-time.*

Key Message 2: *Future complexity and uncertainty due to climate change demands new ways to plan our cities. Scenario-based planning can incorporate important urban dynamics and complexities and uncertainties common to the non-anecdotal challenges of the Anthropocene that other planning tools cannot, partly by addressing uncertainty over the mid-to-long term. By incorporating scenario planning into NYC futuring exercises, a range of new opportunities for envisioning and shaping health, social, environmental, economic, and population change outcomes can be applied to meet broad or sectoral adaptation and mitigation planning.*

Key Message 3: *Equity and social justice should be explicitly centered in future climate adaptation goals, implementation efforts, and future planning. Planning without centering equity will likely result in unintended negative consequences, such as green gentrification or displacement, which exacerbate inequity. Centering equity in climate adaptation and mitigation actions provides an opportunity to decrease impacts on the most vulnerable.*

Key Message 4: *NYC is dynamic, and the scale and complexity of NYC requires managing interacting socio-economic, ecological-biophysical, and technological-infrastructure components. However, there is often a lack of understanding by planners of the fundamental drivers of behaviors and patterns that are important for planning and designing more resilient, equitable, and adapted NYC and metropolitan region. Inherent in these interdependencies are trade-offs between temporal and spatial scales in planning activities, as well as between sectors; identifying these trade-offs is integral to transparency in planning and adaptation. Incorporating approaches that acknowledge interdependencies in future planning will prevent a siloed understanding of trade-offs and uncertainties.*

Key Message 5: *In the context of climate change risks in NYC and the metropolitan region, changes in key sectors and deployment of technologies have included some which are adaptive and beneficial and others that are unintentionally maladaptive, causing risks and inequities that are costly to reverse. The adaptive or maladaptive potential of such changes have depended on the extent to which their costs, benefits, and risks are balanced and equitably distributed. Local examples considered in this chapter include mechanical cooling, flood protection measures,* *and spatial allocation of the public right of way (ROW, mainly streets and sidewalks). Maladaptation can be caused by ignoring climate risks and equity considerations and by siloed planning, within and among sectors, levels of government, government agencies, non-governmental institutions, and the private sector. Potential for maladaptive and inequitable effects of climate adaptation strategies and other sectoral actions influencing climate risks should be weighed to ensure that near-term actions are not maladaptive in the long term.*

Key Message 6: *Without shared positive visions for the future, it is unlikely that plans made now will achieve the equity, justice, sustainability, and resilience goals desired for the future of NYC and its communities. Participatory processes are critical in co-developing shared visions that bring together diverse perspectives and forms of knowledge, and a sustained engagement process is critically needed to identify the City's climate research priorities and co-produce a future public climate research agenda for the city. Co-produced visions, goals, and strategies can involve perspectives across multiple sectors, scales, and communities to gather the full range of ideas, innovations, and possible actions to address trade-offs and inform transitions toward a climate-adapted future for NYC. However, tools for longer-term (beyond 2050) transitions and pathways to achieve future plans for NYC are currently missing and needed to guide efforts to secure an inclusive climate resilient future for all New Yorkers. In order to track progress towards these goals, periodic and systematic monitoring and evaluation are necessary.*

Key Message 7: *Transitioning the built environment to be more climate resilient while addressing fundamental challenges to equity and sustainability requires policies and investments to retrofit, rebuild, and improve the built infrastructure to support population health. Prioritizing active and sustainable modes, including transit, walking, and cycling can provide multiple, equitable health benefits through increased physical activity, reduced air pollution exposure, more affordable transportation options, and reduced risk of conditions that increase vulnerability to climate change. At the same time, reducing miles driven by private motor vehicles within, into, and out of the city will reduce greenhouse gas (GHG) emissions and expand space available on streets and sidewalks for uses that provide climate resilience and social and equity benefits.*

Key Message 8: *Nature-based solutions are critical for addressing climate adaptation needs in the city and can simultaneously provide co-benefits for public health, society, and natural systems that help create a resilient city. Planning, implementation, and management of nature-based solutions to achieve equitable distribution and holistic resilience in a complex city system is still a developing practice.*

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2 Introduction

2.1 Chapter Scope and Context

Prior NPCC reports and other scientific assessment bodies have established that the future climate of New York will very likely be hotter, more flood-prone, and battered by a range of climate induced weather hazards from cold snaps, drought conditions, extreme rainfall, coastal storms, heat waves and potential for overlapping weather extremes (Braneon et al., 2024; González et al., 2019; Gornitz et al., 2019; Orton et al., 2019). Loss of life and damages from these and other climatic hazards are occurring across the globe and the United States, and billions are being spent annually to recover from or moderate future damages. In the US, from 1980 to 2005, the total normalized (inflation adjusted) losses for the 66 major weather events total over $500 billion. Fifty-seven of these disasters occurred during the 1988- 2005 period with total unadjusted damages/costs of over $370 billion (Lott & Ross, 2006). From 1988 to 2017, increased precipitation costs alone were estimated to contribute about one-third (36%) of the cost of flood damages in the country with a cumulative total of approximately $73 billion (Davenport et al., 2021). These recent events suggest that adaptation will be critical to advance with as much political will and financial investment as mitigation efforts in NYC and the broader region. However, in addition to projected climate hazards – including potential exposure of vulnerable populations, critical infrastructure, and ecosystems – there are myriad socio-demographic, economic, infrastructure, and ecological futures that will unfold in the complex urban system of NYC that in turn will impact the city's future risk and resilience to climate change. While there is high confidence in the broad outlines of future climate threats and their impacts, there is a need to develop plans for the future that are robust to uncertainty in the details of exactly when and how in the city's complex human geography these damages will occur.

In this chapter, we discuss the many intersecting social, ecological, and technological-infrastructure dimensions of the city and their interactions that are critical to address in order to transition to and secure a climate-adapted future for all New Yorkers. Here we provide an assessment of current approaches to "future visioning and scenarios" across community and city level initiatives and examine diverse dimensions of the NYC urban system to reduce risk and vulnerability and enable a future adapted NYC. We review methods for integrating community and stakeholder ideas about what would make NYC thrive with scientific and technical information on the possibilities presented by different policies and actions. In doing so, we synthesize the state of knowledge on how different communities of scholarship or practice envision futures and provide brief descriptions of the social-demographic and housing, transportation, energy, nature-based, and health futures and many other subsystems of the complex system of NYC that will all interact to determine NYC futures. For further consideration of energy and energy insecurity, and related issues in the transportation and building sectors, in the context of NYC's future, see NPCC4, Yoon et al., (2024). This chapter is a novel contribution to planning the city of the future through the new NPCC Futures and Transitions Working Group. The NPCC3 inventoried multiple NYC critical infrastructure domains and infrastructure resilience strategies to address climate risks (New York City Panel on Climate Change, 2019). Here we consider additional aspects of NYC's built, social, and natural infrastructure that were not fully considered in NPCC3 but have become especially salient. We provide the first of its kind of assessment for NYC of positive future visions, scenarios, and their intersections with current city challenges that can inform new modes and models for climate change policy, planning, and engagement across the diverse social and infrastructural fabric of the city. We hope the chapter contributes to assessing alternative visions, scenarios, imaginaries, and possibilities for a climate adapted, sustainable, and equitable future NYC.

2.2 Chapter Organization

In this chapter, we examine the state of knowledge on alternative futures and scenarios across sectors and approaches for NYC and assess how current planning and policy can take advantage of multiple tools for transformative climate action to achieve a more resilient, equitable, and sustainable future for the city.

NYC can only be resilient if it articulates inclusive visions, goals, targets, and clear strategies for ensuring an equitable city as well as the means to evaluate progress made towards these goals, strategies and implementation efforts (Blake et al., 2019; Jacob et al., 2010; Solecki et al., 2015; Solecki & Rosenzweig, 2020). Inclusiveness in resilience also requires that justice and equity be centered in all actions designed to address the growing climate challenge in the city (Foster et al., 2019).Thus, there is a clear need for many tools, and a plurality of perspectives, both to envision the future of NYC that is more resilient, equitable, and sustainable, but also to backcast from those visions to interrogate how current planning, policy, and actions at multiple scales are, or are not, creating the mechanisms for transforming and transitioning the city along trajectories that will lead us to the normative futures we aspire to.

The city already employs a wide range of practices to plan for its future and enable transitions for a climate adapted NYC. The concept of transition is a powerful tool with which to understand the dynamics of system change during development. Transitions can be defined as breaks in long-term trends and include both the quantities and rates of change in quantities of interest (National Research Council, 1999). Transitions may occur in any sector (such as energy) or process (such as population change). The community of climate and climate-related research offers additional concepts and tools for predicting the future. These concepts and tools differ largely by discipline with implications for how concepts and tools are used across temporal, spatial, and thematic scale, as well as opportunities for engagement. Yet, scholars have been increasingly interested in the concept of transitions as a way to manage change. There is a growing consensus that continuing to operate in a business-as-usual manner is insufficient for keeping humanity within a 'safe operating space' (Rockström et al., 2009).

In the sections that follow, we review some of the main concepts and tools and what they already tell us about the likely trajectory of the social fabric and climate of NYC. Much of the content of this chapter details methodologies that may be technical for some readers; our goal was not to alienate a broad audience but rather to be as transparent as possible to help move collectively into an interdisciplinary space. Though the focus of this chapter is largely on climate adaptation and resilience, climate mitigation goals and actions are discussed in context of how they can be addressed alongside adaptation strategies.

3 Concepts and Tools for Exploring the Future

This section outlines a number of useful planning approaches, beginning with an overview of the City's major planning exercises to place current efforts in context. Throughout this chapter, we refer to short-term as pertaining to the next decade, medium-term as referring to a period out 30-50 years (and frequently mid-century is used as a reference point) and long-term as referring to the future 80-100 years out, roughly at the end the 21st century. As the NPCC's end-of-century climate projections make evident, there is a commensurate need for long-term scenario planning in order to be resilient to climate challenges anticipated in coming decades, until the end of the century, and beyond.

3.1 Historical Context for New York City Comprehensive and Strategic Planning

Futures planning for NYC has a long history dating back to, at least, 1811, when the commissioners of the City developed the NYC grid to expedite the future of parcel sales and city growth (Jackson et al., 2010). Subsequent planning efforts included a number of important, but *ad hoc* efforts, such as the financing of the Erie Canal and the development of the city's water supply system (Jackson, 1993). The modern city planning era began with the City's 1916 Zoning Resolution.

It was the completion of the 42-story Equitable Building in Manhattan, NYC, in 1915, which set the stage for the nation's first comprehensive citywide zoning resolution. The law governing land use was a response to the perceived lack of sun and air and had enormous future impact on the development of the city as it established height and setback controls and designated residential districts that excluded other incompatible uses. The 1916 Zoning Resolution was amended frequently with major shifts in population and land use.

Eventually, powerful business associations, newspapers, real estate groups and influential residents pressed for an agency to administer the zoning regulations in a systematic fashion. Under Mayor Fiorello La Guardia, in 1936, the New York City Planning Commission was established, headed by Adolph A. Berle, who was shortly replaced by Rexford Tugwell, and included other notable New Yorkers such as Lawrence Orton, Cleveland Rodgers and Arthur V. Sheridan (City of New York Department of City Planning, 1989).

The City Planning Commission provided the structure for the professional application of comprehensive planning principles that replaced the previous haphazard development and zoning decisions driven by politically connected interest groups. The new Department of City Planning, headed by the City Planning Commission, was mandated to develop scientific processes that helped to identify the goals and aspirations for community development. The idea of comprehensive planning emerged in the 1920s and was embraced by Rexford Tugwell, previously a member of Franklin Delano Roosevelt's "Brain Trust" and head of the Resettlement Administration from 1935 to 1937 (Alvey, 2019). Comprehensive planning was based upon the notion that long term goals for a broad array of urban services important for the common good could be developed through consensus (Soomro & Williams, 2021). The comprehensive plan was promoted as the anecdote to "spot zoning".

Despite the promise of a scientific comprehensive plan for the city, however, efforts were met with fierce opposition (Nelson, 2018). For example, Tugwell's idea of a strong government that could deliver a unified vision for the city's growth, was harshly criticized by Robert Moses. Moses rejected the concept of government-sponsored master planning and preferred to pursue projects based upon available funding, the needs of private developers and his own political agenda (Chronopoulos, 2012). He successfully stopped early comprehensive efforts by the City Planning Commission for the next several decades (Alvey, 2019).

NYC underwent dramatic changes, particularly during the 1950s and 1960s. The Lindsay administration, in an attempt to address increasing poverty, white flight, urban renewal failures, and racial inequality, attempted the first comprehensive plan for the city, published in 1969 entitled, "*Plan for New York City: A Proposal*" (New York City Planning Commission, 1969). The focus of the plan was on employment opportunities, housing needs and community improvement, and community participation in development decisions. The plan also attempted to respond to critiques of comprehensive planning as representative of unrealistic and top-down approaches; rationalism involving the search for the 'optimal' strategies that either do not exist or are too difficult to implement (Boyer, 1986; Van der Heijden, 1996). What was different about this plan was that the Lindsay administration divided the city into 62 community districts (now 59) and subsequently held 62 separate public hearings on the plan itself. These meetings were intended to galvanize public support. Each community district was provided detailed information on the then-current trends within their regions, including, *inter alia*, the number of schools, quality of transportation and local development. The plan recommended municipal expenditures of $52 billion at the time (when the total city expenditures were around $8 billion), for projects that would last into the 1970s (Stein, 1976; Tolchin, 1971).

The attempt to garner community support ultimately failed as the plan drew criticism as a top-down approach that presented results to communities as a *fait accompli* with limited ability for local feedback (Gupte, 1973). Also, urban advocates, such as Jane Jacobs, were developing notions of the human, smaller scale, approaches to planning and along with anti-statists rejected "Big Planning" notions that were emblematic to comprehensive planning (Klemek, 2007, 2009). Indeed, the plan was never implemented.

The debate in NYC mirrored the national discussion over urban planning. Some advocated for comprehensive planning while others called for incremental methods (Lindblom, 1959). Incrementalists advocated for planning without radical change but rather for making land use decisions that could be implemented (Slusser, 2007). This often translated into planning for small areas or even individual parcels. When John Zuccotti headed the City Planning Commission in 1973, the notion of comprehensive planning was put aside. Zuccotti, sided with real estate and other non-statists to advocate for incremental methods. In 1975, the City Charter was amended, and the comprehensive plan requirement was repealed. Subsequently, the planning provision in the Charter was replaced by a provision for plans for the development, growth, and improvement of the city and of its boroughs and community districts, giving communities a larger voice in land use decisions (see the New York City Charter, Chapter 8, Section 197a (City of New York, 2023b)). This new mandate helped to stimulate community planning efforts. At the same time, the new charter made provisions for the Uniform Land Use Review Procedure (ULURP) (Eldredge, 2015). ULURP, and later, the Environmental Impact Assessment review, both of which reviewed individual development proposals, became the major tools to assess and regulate the city's land use for the next several decades. The thinking behind these procedures was to allow the affected communities the opportunity to stop a development or find common ground and come to a compromise with the developer. The 197a and ULURP provisions were the compromise that continued efforts to control development but prevent Robert Moses-like large infrastructure projects (Eldredge, 2015). The result of these rules was to make comprehensive planning for the city difficult if not impossible.

During the following decades, NYC underwent further dramatic transformations as its economic base shifted to business and professional services, which along with an international attractiveness and strong national political and cultural status, drove its growth to new heights. It was one of the first identified global cities (Sassen, 1991). During this period, NYC experienced a rebirth as crime dropped and population increased. Planners responded during this era with new future planning approaches, including strategic planning. Strategic planning is a flexible on-going process that attempts to identify major goals, mandates, and challenges for the future. It is a deliberative and iterative process that helps organizations address what they do and why (Bryson et al., 2018). Typically, strategic plans are for the near term (3-10 years), are not as all-encompassing as comprehensive plans and are not mandated by statute. At the same time, strategic plans help decision-makers allocate resources to attain goals. Strategic planning is somewhere in-between incremental and comprehensive planning. The Department of City Planning (DCP), under Mayor Rudolph Giuliani, developed a strategic plan for the "Far West Midtown", which outlined the development of the area from 8th Avenue to the Hudson River and 42nd St to West 24th street, now almost completely built. Subsequently the DCP produced other strategic plans in 2011 and 2018 (City of New York Department of Environmental Protection, 2023b). These strategies helped to outline a vision for a particular area of the city and encourage private development to meet these goals. These strategies often included rezonings.

In the background of growth and global city status, however, were larger processes that were gaining the attention of scholars, practitioners, advocates, and residents. Sustainability and climate change concerns mounted as information on environmental degradation, pollution, biodiversity loss and a changing climate mounted. These trends have brought significant uncertainty to futures and the need to adapt quickly to major changes has become a crucial factor for planning success. Hence futures planning demanded the timely production of accurate information on widespread political, environmental, economic and societal changes (Chermack & Lynham, 2002; Varum & Melo, 2010).

The Bloomberg administration turned the City's attention to environmental concerns through what they termed a "comprehensive sustainability agenda," which included 127 policy initiatives to achieve ten overarching goals to improve the infrastructure, environment, and quality of life in the city (City of New York Office of the Mayor, 2007). *PlaNYC, A Greener Greater New York* was followed by the *NYC Special Initiative for Rebuilding and Resiliency* (City of New York Office of the Mayor, 2013b, 2013a), another citywide report published after post-tropical storm Sandy hit the city. These plans were followed by the next administration, which included many of the same themes in their reports but put a focus on resilience and equity (City of New York Office of the Mayor, 2019).

These publications were not without critics, who argued that the mayors' "plans" were top-down, lacked important social considerations, and were developed without community involvement (Angotti, 2010; Marcuse, 2011; Rosan, 2012). While these documents lacked the elements that detractors mention, they also increased attention on the importance of critical infrastructure, broadened public responsibilities in provision of these services, focused on housing and transit-oriented development and were first steps toward addressing environmental justice for under-resourced communities (Mandelbaum, 2007; Rosan, 2012).

The publishing of the Bloomberg and de Blasio plans also brought back interest in comprehensive futures planning for NYC (New York City Council's Office of Strategic Initiatives, 2020; Soomro & Williams, 2021). The Regional Plan Association, working with a number of other groups, put together a comprehensive citywide planning framework that they claim would provide the rationale for bridging the dislocation of comprehensiveness and community participation for an "inclusive city" (Regional Plan Association, 2018). How comprehensive planning can offer a unified city vision through bottom-up participation remains unclear (Kahila-Tani et al., 2019; Wamsler et al., 2020).

3.2 The Emergence of Scenario Planning

An alternative approach that has increasingly been recommended as a tool to improve urban decision-making under increasing uncertainty is scenario planning. Scenario planning assumes that the world is unpredictable, and no single plan or strategy can be relied upon to address the future. The scenario approach focuses on identifying trends and uncertainties, so as to allow decision makers to overcome tunnel vision and siloed thinking (Schoemaker, 1995). Scenario planning also makes use of community participation that helps to create alternative representations of the future. Hence, scenario planning has been defined by Roubelat (2000) as a networking process that challenges strategic paradigms and forces organizations to rethink their internal and external boundaries. According to Finn and Miller (Finn & Miller, 2022) the value of scenario planning derives from both its use of scientific data, but more importantly its use of narratives and stories to engage a diverse public in deliberations around critical issues and potential strategic approaches to planning for the future. As opposed to merely, or only, scientific data or quantitative projections of the future, scenario planning relies heavily on the power of narrative and stories to engage participants.

The scenario approach was introduced into planning with adaptational impact assessment (Duinker & Greig, 2007) and formalized with the National Environmental Policy Act (National Environmental Policy Act, 1970), which had state and local spinoffs, including the New York State Environmental Quality Review Act (State Environmental Quality Review, 1975) and the New York City Environmental Quality Review Act (City of New York Office of the Mayor, 1973). These acts required the evaluation of different environmental impacts related to the proposed project as well as community input. The scenario component required the developer to provide a range of alternative schemes with subsequent environmental impact evaluation (NYS DEC Division of Environmental Permits, 2020). Environmental review, however, was only initiated when projects required approval from the City for discretionary actions, such as the issuance of permits, City funding requests, or agency rulemaking, and therefore were not universally applied to all developments.

Scenario planning was adopted widely by the mid 1990's (Chakraborty et al., 2011). The practice has been applied in some international and national contexts and is now being used at the urban scale (Chakraborty & McMillan, 2015). For example, in NYC, scenario planning is currently beginning to be used in the NYC business community (Crain's New York Business, 2022). The use of this approach has been given encouragement by the development of new computer tools that support spatial data and visualization (Klosterman, 2013). Moreover, the approach is the prescribed method in federally funded land use and transportation planning activities such as for Sustainable Communities Regional Planning Grants (City of New York Department of City Planning, 2011) and the Moving Ahead for Progress in the 21st Century program (Rep. Mica, 2012). Also, important for its increasing popularity is that planning groups, such as the American Planning Association (2023) and the Lincoln Land Institute (2023) are now supporting its implementation.

Scenario planning is alike, but not the same as climate scenarios. While climate scenarios include descriptions of historical key events, the focus of scenario planning is typically on the end-state, which is envisioned prior to the analysis (Finn & Miller, 2022). That is, scenario planning employs a backcasting approach to understand how the various futures emerge. Then the process includes development of strategies to help achieve desirable futures and avoid undesirable ones. Moreover, future scenarios need only be "a description of a possible or probable future" and not be quantitatively identified (Chermack & Lynham, 2002). As such, issues to watch out for include adequate consideration of uncertainties, an overemphasis on "picking" a preferred future (Chakraborty et al., 2011), and a lack of effective public involvement (Bartholomew, 2007). Nevertheless, the usefulness of scenario planning in the urban context is increasingly appreciated. Questions remain, however, about how best to move forward and incorporate scenario approaches in both private and public planning exercises.

We next turn to other planning frameworks that are used in the City and climate community.

3.3 Planning the Future Through Scenarios, Forecasts, and Projections

Different scientific and planning communities have adopted specific tools to conceptualize and estimate futures. In this section, we explore the dominant tools the climate community uses to envision the future. We focus broadly on scenarios as a tool for examining the future. Specifically, we review projection scenarios and tools, as well as other exploratory and normative scenarios, visions, and futuring processes that concern (drivers of), adapting to and responding to climate change and its impacts. Scenarios are plausible, coherent narratives about the future of a place or a situation that have a consistent internal logic (IPBES, 2019; Iwaniec et al., 2014; Moss et al., 2010; Reid et al., 2005). Scenario development approaches can consider future projections (prediction or forecasts of what will happen), exploratory scenarios (what can happen), and/or normative future scenarios (what should happen). Some communities of practice use these terms interchangeably while others do not, often creating confusion in interdisciplinary settings. We aim to use terms as specifically as possible here.

Projections of future conditions, sometimes called predictive scenarios or forecasts, extrapolate future conditions based upon predefined models of historic and existing trends. Predictive scenarios typically use quantitative models to suggest a specific outcome at a specific time in the future given a set of trend parameters. Examples of predictive, forecasted scenarios include business-as-usual projections of future land use change (Mustafa et al., 2021), NPCC climate and sea level rise projections (Gornitz et al., 2019), and local or national population projections, such as those from the NYC DCP (2013). Climate projections and international population projections provide a framework for understanding potential future changes with running 30-year averages centered on a decade, such as 2050s, 2080s, 2100s (See NPCC4, Braneon et al. (Braneon et al., 2024)). In order to project the future in 80-100 years, model projections require quantitative historic data, which is a requirement that limits projections to basic demographic or climatic futures.

Exploratory scenarios, and other normative future visions or narratives, are another important tool for cities to anticipate and explore climate adaptations. Exploratory scenarios are often developed in collaboration by many different disciplines and stakeholder communities. Thus, exploratory scenarios can be a tool to integrate diverse forms of data and knowledge about the future, challenge assumptions about anticipated future outcomes, integrate multiple drivers of change, compare alternative policies and pathways to achieve policy goals, and guide decision-making that is flexible and robust (Elsawah et al., 2020). While based on data representing past trends, exploratory scenarios and visions use other methods to imagine the future and thus have more thematic flexibility and ability to explain futures farther out in time.

Business-As-Usual (BAU) projections or scenarios are just that: Based on analysis of current trends using a variety of approaches discussed below to extrapolate emergent trajectories, this method is used both in projections and scenario development. Notably, the BAU conditions are often used as a baseline or reference projection or scenario to compare to more extreme projection assumptions or normative possibilities (Mustafa et al., 2021).

Tools for exploring the future have been widely developed at a global scale and applied by the international scientific community. However, less work has been done at regional or city scales (Reimann et al., 2021; Rohat et al., 2021). City planners and agencies routinely engage in planning exercises for NYC, including developing a range of scenarios and visioning processes. In the remainder of this section, we unpack some of the key aspects of each of these tools, the scale at which they occur, and the themes that they cover.

3.4 Projecting the Future

Prior NPCCs have made great strides in projecting future climate conditions and evaluating how risk is considered and planned for in the City (Solecki & Rosenzweig, 2019). Prior NPCCs have paid much less attention to scenarios and projections of how the built, natural, and social environment is likely to change and interact with changing climate hazard and other environmental conditions, though health concerns were introduced in NPCC2 (New York City Panel on Climate Change, 2015) and equity in NPCC3 (New York City Panel on Climate Change, 2019). Many sectors beyond climate variables – such as changes in the built environment and surface makeup – will influence how resilient or not an NYC urban future may be. Alternatives to climate futures are important for many reasons, not least of which is the opportunity to examine the dynamic interaction between other drivers of risk and vulnerability that are often created by urban development and decision-making (C. Rosenzweig & Solecki, 2018).

Projections of future climate parameters as well as flooding and demographic conditions are critically important – if used together – for understanding the challenges to achieving resilience. Yet, as we describe below, they are often at coarse spatial and temporal resolutions and lack utility without further downscaling efforts to describe potential future risks at the scale of neighborhoods (and potentially by types of households). Owing to their methodological differences and spatial and temporal resolutions (varying from 1-hour stormwater scenarios to decadal population futures), projections of climate and demographic futures are not frequently used together in local planning processes but rely on other approaches such as scenarios (described in the following section) to connect them. It is, therefore, useful to begin this review with the projection efforts themselves.

3.4.1 Climate projections

Since its inception, the NPCC has proposed a risk management framework to mitigation and adaptation (Yohe & Leichenko, 2010). In the selection of emissions scenarios, NPCC's risk management framework suggests that adaptation planning should consider outcomes with particularly adverse consequences, such as those found in projections that may not be likely but present high impacts. In the first report, this approach led to climate projections developed using the high emissions A2 scenario. Climate projections now use Representative Concentration Pathways (RCPs) to identify plausible scenarios for greenhouse gas concentrations (i.e., emissions) in future projections of temperature and precipitation. Subsequent reports use high emissions global climate scenarios such as RCP8.5 to represent the high risks linked with low to no mitigation at global scales throughout the 21st century alongside other scenarios with lower emissions and thus lower climate-related impact (Braneon et al., 2024).

In the IPCC AR6, there is a new framework that has been utilized to design scenarios that combine socio-economic and technological developments, known as the Shared Socio-economic Pathways (SSP) (Riahi et al., 2017). The SSPs are scenarios of projected socioeconomic changes across the globe through 2100 that are consistent with different emissions scenarios. An experiment named the Scenario Model Intercomparison Project developed a set of nine scenarios of future greenhouse gas emissions trajectories (O'Neill et al., 2016). These nine scenarios aggregate into two smaller groups; four scenarios that update the RCPs from the Coupled Model Intercomparison Project Phase 5 (CMIP5), which produce equivalent radiative forcing levels (2.5, 4.5, 6.0 and 8.5 W/m^2) and five new scenarios that were not included as part of the prior RCPs. NPCC4 climate projections follow this approach with the use of the AR6 scenario framework that combines SSPs with RCPs, using the SSP5-RCP 8.5 and SSP2-RCP 4.5 scenarios, which represent greenhouse gas emissions pathways with 8.5 W/m^2 and 4.5 W/m^2 by end of century, respectively. These two scenarios replicate those used in NPCC3.

Climate projections in NPCC were produced with the output of General Circulation Model (GCM) simulations from the Coupled Model Intercomparison Project 6 (CMIP6). An ensemble of 35 models across the two scenarios was used, producing a 70-member matrix of outputs for temperature and precipitation. This ensemble matrix was then used to produce projections of annual mean and extremes temperature and precipitation. GCMs produce information at spatial resolutions ranging from ~0.5° to ~1.5°. In order to develop projections for NYC, the data point over land that is closest to the city was selected to produce single-point projections. These projections are then presented as a range of low end (10th percentile), a middle range (25th to 75th percentile) and high end (90th percentile) estimates for several 30-year time slices of interest (i.e., the 2030s, 2040s, 2050s, 2060s, 2070s, 2080s).

3.4.2 Population projections

Population projections provide fundamental demographic information for socioeconomic and environmental outlooks. Using several different methods and approaches, models to project changes in population sizes, compositions, and spatial distributions cover a range of population trends and produce a set of plausible demographic futures. However, for local areas such as cities, these tend to be short-term (no more than 40 years out) (Balk et al., 2022). For example, the cohort-component model (Burch, 2018) is used by most state and local planning agencies as it is robust (i.e., replicable and verifiable), has simple data requirements (which have improved substantially in recent decades), and is transparent to a wide range of users (O'Neill et al., 2001). This method is based on the current size and age composition of the population and on assumptions of demographic change—fertility, mortality, and migration—rather than simply extrapolating trends in population counts over time. The cohort-component model examines not only change in the total population but also its demographic composition (age, sex) and sometimes other characteristics such as race and ethnicity (see for example, the State of California county-level projections (State of California, Department of Finance. Demographic Research Unit, 2023)). At a city or local level, the cohort-component model often encounters data limitations for population characteristics (or demographic traits) beyond age, sex, fertility, and mortality or cannot be applied at fine-scale geographies (such as neighborhoods or census tracts). Other models examine small-area population projections, such as the Hamilton-Perry Method (Hamilton & Perry, 1962) and methods that proportionally allocate projected city-level population to sub-city districts based on the current population distributions (Smith et al., 2002). Such approaches may be adequate for the short-term of 40 to 50 years (Swanson & Tayman, 2017), but cannot capture long term projections of population at sub-city scale.

The Population Division of the New York City Department of City Planning (DCP), produces short-to-medium term population projections for NYC's boroughs using the cohort-component model (City of New York Department of City Planning, 2013). These projections are part of a larger effort with the New York Metropolitan Transportation Council (NYMTC) (New York Metropolitan Transportation Council, 2020b), which is mandated by federal transportation legislation to produce county-level projections for the 31-county region for its Socioeconomic and Demographic (SED) forecasts to qualify for federal transportation funds, as described in Balk et al. (2022, p. 9). The methods used for the City's 5-borough projection and the NYMTC ones differ somewhat from one another – primarily by use of additional ancillary information in downscaling methods – and therefore both are described here. The cohort-component demographic model used for the projections for both NYC and the 26-county region outside of NYC relies on U.S. census data for the base population input, so projections are typically created soon after decennial data are released. The most recent population projections available on DCP's website are from 2013, which were used for the NYMTC 2050 Socioeconomic and Demographic (SED) forecasts, and DCP was tasked in 2018 to produce interim projections for the NYMTC 2055 SED forecasts, which were adopted in October 2020.

NYC's population projections were produced for each of the city's five boroughs by age and sex with 5-year intervals (City of New York Department of City Planning, 2013). Inputs include average county-level fertility, mortality, and net migration rates. Migration, net of both international and domestic flows, was calculated using a survival-rate method. For all but the youngest age groups, net migration is derived as a residual by applying mortality rates and "surviving" an enumerated population, yielding an "expected" population for each age/sex group five or ten years later. This *expected* population is then compared to the *observed* or actual population; the difference, or residual, is net migration (from which crude migration rates are derived). For the period of the projection, fertility is assumed to be unchanged, while survival rates increase by one-half of the US Census Bureau's national trend. In addition to the demographic model, DCP analyzes the demographic outputs in the context of a housing model to ensure that the resulting population could be reasonably accommodated given the City's current land use and zoning. Through an iterative process, DCP adjusts the crude migration rates to bring the population and housing model in sync. Assumptions on land use, zoning, and housing construction act in essence to limit population growth through adjusting crude migration rates. DCP's final projections are allocated down to transportation analysis zones (TAZ) (see https://www.nymtc.org/portals/0/pdf/SED/2040%20Final%20Draft_TAZ_report.pdf for the criteria upon which more than 3,500 TAZ units are defined), which are akin to census tracts and are based on projections of housing units and land use for these small areas.

Similar to the NYC county-level projections, NYMTC's projections for the 26-county region outside NYC also uses the cohort-component model. The migration rates for this set of counties incorporate a labor induced net migration adjustment to account for projected employment demand. NYMTC's projection with its focus on transportation also includes many additional variables in its model, including those derived from surveys (and other sources) on commuting, transportation, jobs and industry development, and more (New York Metropolitan Transportation Council, 2020a). For the 26-county region, a spatial allocation method was used to downscale population to TAZs, resulting in a final product that is spatially refined. Because NYMTC brings together representatives from many city and municipal agencies, part of the production of the final projection includes engagement with these stakeholders. The publicly available projections represent only one population future scenario: The scenario for NYC was based on a set of assumptions including current fertility levels remaining unchanged, increased survival rates based on national trends, and the adjusted crude migration rates by housing limits. For the non-NYC counties, the scenario was based on a set of assumptions including logarithmically projected fertility rates, increased survival rates based on national trends, and migration rates with labor induced migration adjustments (New York Metropolitan Transportation Council, 2015).

Additionally, DCP produces many tools and resources (City of New York Department of City Planning, 2023a) to interface with census data and showcase population and socioeconomic characteristics of the city from the neighborhood to city scale. While these tools are not intended for medium (20-40yrs)- or long-term (40-100yrs) population projections, they establish current patterns and trends showing spatial variation across the city, and are publicly available and easy to access, making them especially valuable for engagement with communities. DCP's tools include Population FactFinder with profiles of local communities, as well as a map reliability calculator, which shows how ACS data can be used reliably. Since much of the local-area data come from the US Census American Community Survey (ACS) which, unlike the full census head-count data, is drawn from a representative sample, those data are therefore subject to sampling error (Donnelly, 2013, 2020). The tool helps users understand how to reliably use ACS data at small geographic levels. DCP also produces reports of short-term (recent decadal) neighborhood change covering important topics like migration (City of New York Department of City Planning, 2023b) and racial and ethnic composition (City of New York Department of City Planning, 2021a).

To date, the City's projections do not yet include information about land use patterns associated with future climate (such as flood-prone regions) nor do they make assumptions about demographic futures that would be consistent with different emissions pathways and associated climate futures. As discussed in the next section, other tools are used to generate such population futures consistent with socioeconomic development pathways that are linked to different climate futures. These typically conform more to the specification of exploratory scenarios (even if the approaches blend the above methods with longer-term scenarios development) and are implemented at national or regional spatial scales rather than the city scale (see review in Balk et al. (Balk et al., 2022)).

3.4.3 Health valuation

As showcased below (BOX 4), one commonly used tool for evaluating whether a policy or investment in the future should be undertaken, as well as one other construct that can be used to evaluate plans or transitions to the future, is economic valuation of outcomes related to the impact of climate change. These tools are sometimes, but not usually, applied to health outcomes. Health-related costs of climate-related health conditions and deaths are not typically estimated, in and of themselves or as part of evaluating health or other sector policies to reduce the negative impacts of climate change (Limaye et al., 2019). As part of an ongoing Vulnerability, Impact, and Adaptation (VIA) Analysis to study climate change's impacts on decision-making in NYC, a research team is reviewing published reports on the impacts of climate-sensitive events in NY from 2000 to 2020, then evaluating their health-related costs (McPhearson et al., 2024). A wider range of societal costs to NYC for care of climate-sensitive illnesses and premature loss of life are being developed for the city and will be reported separately. The evaluation of health-related costs will inform analyses of potentially avoidable, associated past, current, and future health costs under plausible climate change scenarios (see NPCC4, Matte et al. (Matte et al., 2024)). Such valuations can be forward-looking by accounting for future population shifts (e.g., more older adults) and future climate projections (e.g., more hot days).

3.5 Exploratory and Normative Scenarios

Exploratory scenarios (sometimes called foresighting) explicitly consider emerging trends and uncertainties, while exploring a variety of possible "what if" future pathways and outcomes. Exploratory scenarios are created through identifying key drivers and how they might evolve based upon pathway assumptions, sometimes called storylines (Hunt et al., 2012; van Vuuren et al., 2012). In other words, rather than only examining 'what is most likely' as in predictive scenarios, exploratory scenarios anticipate a range of 'what is possible' based upon potential pathways in different storylines. No specific pathway has priority within the exploratory ensemble in defining the future, rather, exploratory scenarios are used to examine the interplay and influence of drivers. Examples of exploratory scenarios include the Shared Socio-Economic Pathways (SSPs) (O'Neill et al., 2014, 2020) and Millennium Ecosystem Assessment (2005) scenarios.

Normative scenarios are created by first defining a future target—often a desirable future outcome based on values and preferences that align with sustainability and resilience goals about "what should happen." After defining the normative future target, the process to identify the pathways of how to get from the present to this future often occurs through quantitative and/or qualitative backcasting (Vergragt & Quist, 2011) or scenario-discovery techniques (Gao & Bryan, 2017).

Examples of exploratory scenarios include the first ever citywide extreme rainfall driven flood projections for NYC, which it released as part of the first NYC Stormwater Resiliency Plan (2021). The projections include the output of a city-wide modeling effort to map urban flooding according to two rainfall scenarios: moderate and extreme. The moderate scenario corresponds to a 1-hour, 10-year storm (approximately 2 inches) and 2.5 feet of sea level rise above a 2000 baseline, based on the estimates for 2050 made by the NPCC. The extreme scenario corresponds to a 1-hour, 100-year storm (approximately 3.5 inches) and 4.8 feet of sea level rise (NPCC's 90th percentile estimate for 2080) (Gornitz et al., 2019) (see NPCC4, Rosenzweig et al. (B. Rosenzweig et al., 2024)). The NYC Stormwater scenarios released publicly as maps of potential flooding extent and depth provide a first attempt at mapping a source of urban flood risk that, unlike coastal and riverine flooding, is not mapped and accounted for in the U.S. Federal Risk Rating Map (Qiang et al., 2017). The release of these exploratory scenarios to examine potential future flood risk driven by extreme rainfall, however, focus on flooding in right-of-way locations such as streets and sidewalks, while private parcels, parks, and highways were not considered due to a lack of data related to their drainage infrastructure. This omission highlights ongoing data limitations for such detailed climate risk scenarios and both the need for improved data sources to support such model driven scenarios, but also for a plurality of scenario approaches to envision alternative futures for NYC.

3.5.1 Plausible versus desirable futures

In scenario development, it is understood that the future cannot always be accurately predicted and that many futures are likely. Thus, future visions for inclusive climate resilience must integrate perspectives across multiple sectors, scales, and communities to ensure a plurality of ideas, innovations, and actions. Moreover, positive, desirable visions are needed to guide urban planning as a counter to negative discourse on expected urban futures if there are no interventions. The process of positive visioning involves creativity, allows for radical departure from the status quo, and focuses on the pathways needed to achieve desirable outcomes. Building on the more sustainable, low-carbon lifestyle afforded by NYC's compact urban form, walkable neighborhoods, and transit access, a positive future scenario framing can be used to compare multiple, alternative future goals, pathways, and outcomes. Through positive visioning, we can explore both plausible and desirable futures.

Plausible and desirable futures look beyond just what is likely to happen and allow us to consider what is possible. Plausible futures address how we would like to respond, while accounting for the existing context and future projected challenges. In contrast, desirable, or aspirational, futures integrate normative perspectives on what the future should look like (Iwaniec et al., 2020). Desirable or aspirational visions typically have a long-term (multi-decadal) time horizon. The longer time horizon in future visioning is critical to overcome political barriers and allow adequate time and resources for the reconstruction of infrastructure and buildings (e.g., electrification of energy services). Examples include NYC 80x50 roadmap (City of New York, 2016).

Plausible visions can focus on short or longer-term actions. The plausible near-term actions can either be consistent with a desirable long-term vision (e.g., NYC streets master plan) or can lock-in or amplify maladaptive patterns of development (e.g., widening highways (Weinberger, 2022)). Just as some current policies and features are the result of decades of incremental change and are now understood to be maladaptive, near-term, feasible and desirable incremental changes can help build a pathway to a desirable future and avoid or reverse maladaptation.

3.5.2 Shared socioeconomic pathways (SSP) exploratory scenarios

Climate projections use Representative Concentration Pathways (RCPs) to identify plausible futures for greenhouse gas concentrations in future projections of temperature and precipitation. Similarly, the Shared Socioeconomic Pathways (SSP) describe alternative future socio-economic and demographic visions (BOX 1) consistent with those RCPs (O'Neill et al., 2020). Alternative spatial population projections are important for examining potential future changes in land use and land cover, energy use, greenhouse gas emissions, transit, and water availability that will have compounding and differential impacts on climate hazard exposure throughout the city (Güneralp & Seto, 2013; MacManus et al., 2021; R. I. McDonald et al., 2011; Meiyappan et al., 2014; Riahi et al., 2011; Sampedro et al., 2022; Shepard et al., 2012). Each SSP scenario represents a plausible and unique future based on estimates of future fertility, mortality, or education (KC & Lutz, 2014, 2017; van Vuuren et al., 2017) and assumptions about the spatial pattern of development and population distributions. Typically, the SSP's and demographic forecasting have been applied globally, and more work is needed to examine future population scenarios at a regional and city level (Balk et al., 2022; Hauer, 2019; Jiang et al., 2020; Kebede et al., 2018; Rohat et al., 2019; Striessnig et al., 2019). In particular, the SSP-RCP-SPA scenario framework has been used to construct local scenarios of particular outcomes (such as heat-related mortality) in Boston, MA and Houston, TX (Lino et al., 2019; Rohat et al., 2019) and infrastructure in Tokyo, Japan (Kamei et al., 2019).

The relationship between the RCPs and SSPs is visualized in Figure 1. Panel (a) compares RCPs in order of increasing mitigation action (Y-axis) and SSP narratives in order of increasing mitigation challenges (X-axis). The boxes represent the extent to which Integrated Assessment Models (IAMs) were able to successfully reach the RCP target within the greenhouse gas futures described by the SSP (Hausfather, 2018). For example, the numbers in the RCP 2.6/SSP3 box (0/4) indicates that four IAMs tried to achieve RCP 2.6 within the SSP3 narrative, and none was successful. Conversely, the four IAMs associated with RCP 3.4/SSP3 were all successful in reaching the RCP target.

Panel (b) illustrates energy use in 2100 by IAM (along the bottom) for each SSP (along the top). Energy sources embedded within each IAM are color coded in the bars (Hausfather, 2018).

Panel (c) is an overarching view of the SSP-RCP Scenario Framework, which integrates the climate futures described by Representative Concentration Pathways (RCPs), societal futures described by Shared Socioeconomic Pathways (SSPs), and climate policy responses represented by Shared Climate Policy Assumptions (SPAs) into a unified research framework (O'Neill et al., 2020).

Importantly, a future with low mitigation (therefore appearing to the right side of Figure 1, Panel a, as having high mitigation challenges) – which is represented by RCP 8.5 – is only found in one of the SSP narratives (i.e., SSP5). NPCC4 climate forecast includes RCP 8.5, and therefore the population projection should also include an SSP5 future, along with other SSPs (NPCC4 climate projects also use an RCP of 4.5.). Results of research underway that spatially project population out to 2100 for NYC consistent with RCP 4.5 (SSP2 and SSP3) and RCP 8.5 (SSP5) is reviewed in Section 5.

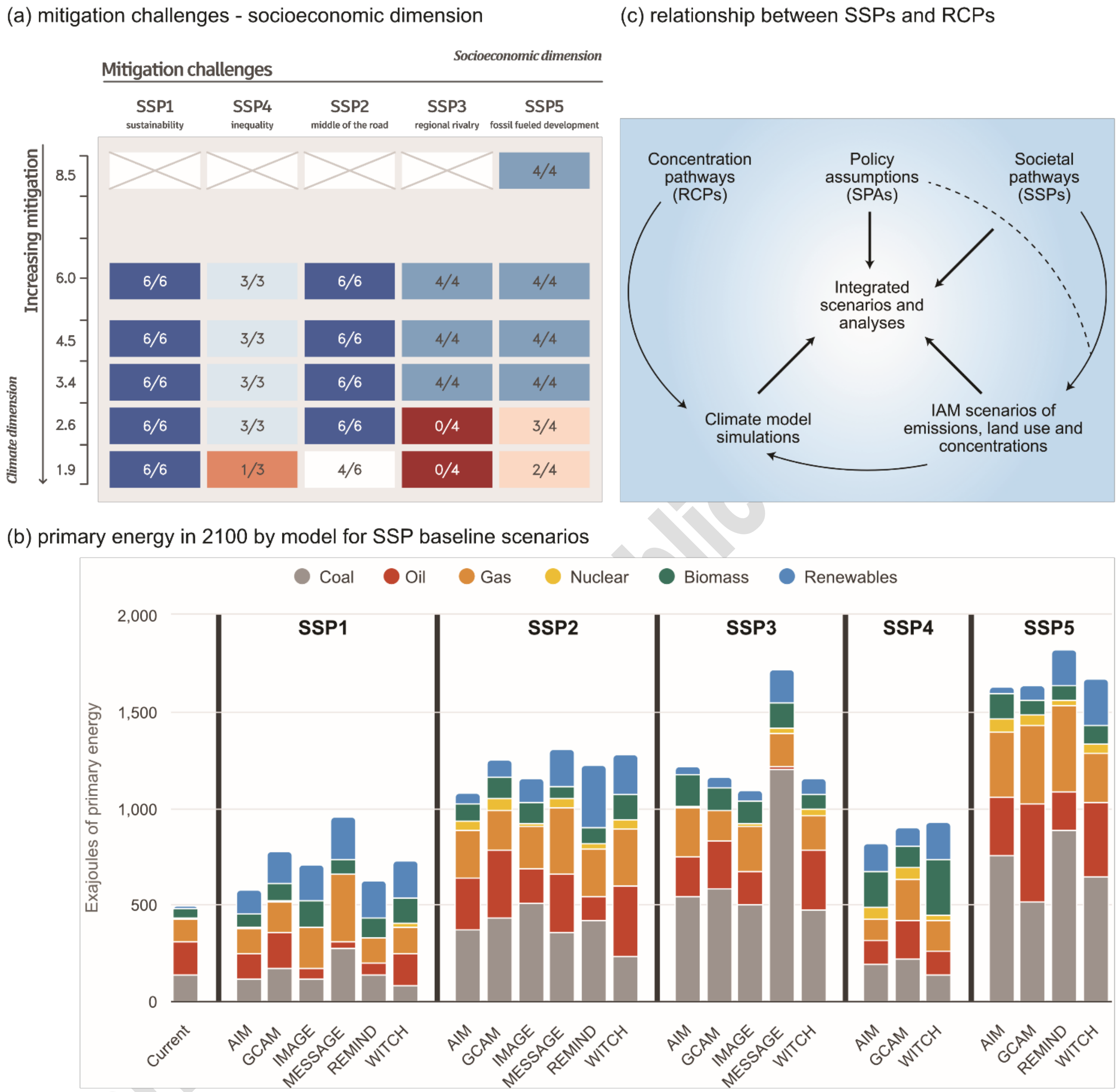


Figure 1: Panel (a).Mitigation challenges evaluated along a socioeconomic dimension. Chart by Carbon Brief (Hausfather, 2018); Panel (b) Global primary energy use by fuel type in 2100. Chart from Carbon Brief (Hausfather, 2018); Panel (c) The SSP-RCP Scenario Framework (O'Neill et al., 2020, p. 1075)

BOX 1: A brief description of five global Shared Socioeconomic Pathways (SSP)

SSP1 is a sustainable future. There is greater investment in education and health, and consequently greater equity; consumption in SSP1 is oriented toward low material growth and lower resource and energy intensity.

In an **SSP2** world, future patterns do not deviate much from historical patterns. Population growth is moderate, leveling off after mid-century. While some countries thrive in economic growth, others do not. Income inequality persists or improves slowly and vulnerability to societal and environmental changes remains.

An **SSP3** world is focused on competitiveness and security. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Investments in education and technology decline, economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized but high in developing countries.

SSP4 sees highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, leading to increasing inequalities and stratification both across and within countries. Over time, a gap widens between the globally connected knowledge and capital-intensive sectors and society, and fragmented lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Environmental policies focus on local issues in middle- and high-income areas.

SSP5 relies on competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital. The path to sustainable development is integrated with global markets and strong investments in health, education, and institutions to enhance human and social capital. These goals are coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles. Together, these lead to rapid growth of the global economy. Population peaks and then declines by the end of the 21st century. Local environmental problems like air pollution are successfully managed.

Full descriptions in Riahi et al. (2017) and Hausfather (2018).

NYC has used a variety of different exploratory scenarios in some sectors. Notably, the NYC Mayor's Office has articulated a series of visions, actions, and exploratory scenarios in the OneNYC 2050 Building Strong and Fair City report. OneNYC 2050 highlights goals for future just and equitable governance, economy, health, education, transit and housing services, and infrastructure, while acknowledging the impacts of future climate change (City of New York Office of the Mayor, 2019).

Another example comes from the NYC Housing Authority which uses advanced planning approaches driven by concerns about climate impacts and vulnerability. In 2014, NYCHA created an office of Recovery and Resilience within the Capital Projects Division to address damage from post-tropical storm Sandy, build resilience within buildings to similar storms that may occur in the future, and to analyze and advise on future climate hazards for the Authority. In 2020, after an examination of NPCC's climate projections, NYCHA analyzed vulnerabilities and developed a set of strategies with seven key goals including: enhancing resilience into NYCHA's capital budget, fostering the health the NYCHA's urban forests, expanding reliable, efficient cooling in NYCHA apartments, preparing NYCHA structures for heavier, more frequent flooding, protecting critical infrastructure at developments exposed to coastal flooding, preparing for additional hazards including rising groundwater and extreme winds, and investing in social resilience across NYCHA campuses.

The DCP has been working with communities throughout the flood hazard areas of NYC to identify zoning and land use strategies to help to reduce flood risk. This includes proposals to make permanent and improve upon existing zoning rules that were adopted on a temporary, emergency basis following Sandy. These zoning rules were formally adopted in 2021 (Zoning for Coastal Flood Resiliency, 2021). This strategy would enable new and existing buildings to comply with zoning and building code requirements in order to be better prepared to withstand future storms. Additionally, DCP recommended expanding the applicability of zoning rules to include areas that will be subject to high-risk flooding in the future. Doing so would allow buildings that are not currently required to meet flood resilient construction standards to also make resiliency improvements in advance of being mapped within the 1% annual chance floodplain. Finally, DCP also developed guides for flood-resistant building construction in urban areas.

While adaptation is an important climate goal it is clear from current planning in the City and from community-based plans that adaptation must also be implemented with equity as a goal. These two goals can sometimes be in conflict. For example, gentrification, or the displacement of populations from neighborhoods due to rising property values, increasing rents, upzoning, and other core gentrification drivers can also be partly related to greening and climate policies, an increasing concern among vulnerable communities in NYC (see NPCC4, Foster et al. (Foster et al., 2024)). There are examples of community residents who resist green infrastructure in their neighborhood because of concerns that greening may be part of a mix of drivers causing potential displacement. Communities, planners, academics, and the City have noted that resilience planning must include ways in which members of the community can also benefit from climate and greening policies (Amorim-Maia et al., 2022; Bautista et al., 2020; City of New York Mayor's Office of Climate & Environmental Justice, 2023; City of New York Office of the Mayor, 2023; Riverkeeper, 2022).

4 Futures Planning Considering New York City as a Complex System

Transforming NYC to be flexible, adaptive, and resilient requires the capacity to build, design, and plan for complexity (Chester et al., 2023; McPhearson, 2020). Cities have many interacting and interdependent social-economic, ecological-biophysical, and technological-infrastructure systems and NYC is at risk from climate change precisely because of its dense concentration of people, infrastructure, and economies. A key challenge is understanding and governing this complexity, with the additional pressure of climate change (Meadows, 2008) and imagining, planning, and implementing solutions that will be robust in the real-world context of the complex social-ecological-technological systems (SETS) of NYC is critical (McPhearson, Pickett, et al., 2016; Pineda-Pinto et al., 2021). Importantly this is the approach taken in the IPCC's 6th Assessment (Figure 2) to address the complex and cascading impacts of rapid-onset events (e.g., storm surge) and slow-onset chronic events (e.g., everyday flooding) that are likely to occur in cities (Dodman et al., 2022). Since cities are complex systems characterized by irreducible uncertainty, emergent properties, and non-linear behavior that can respond to and learn from changing conditions (Alberti et al., 2018), framing cities as complex SETS provides a conceptual foundation for examining how SETS dimensions interact and affect their individual and collective contributions to climate risk and resiliency.

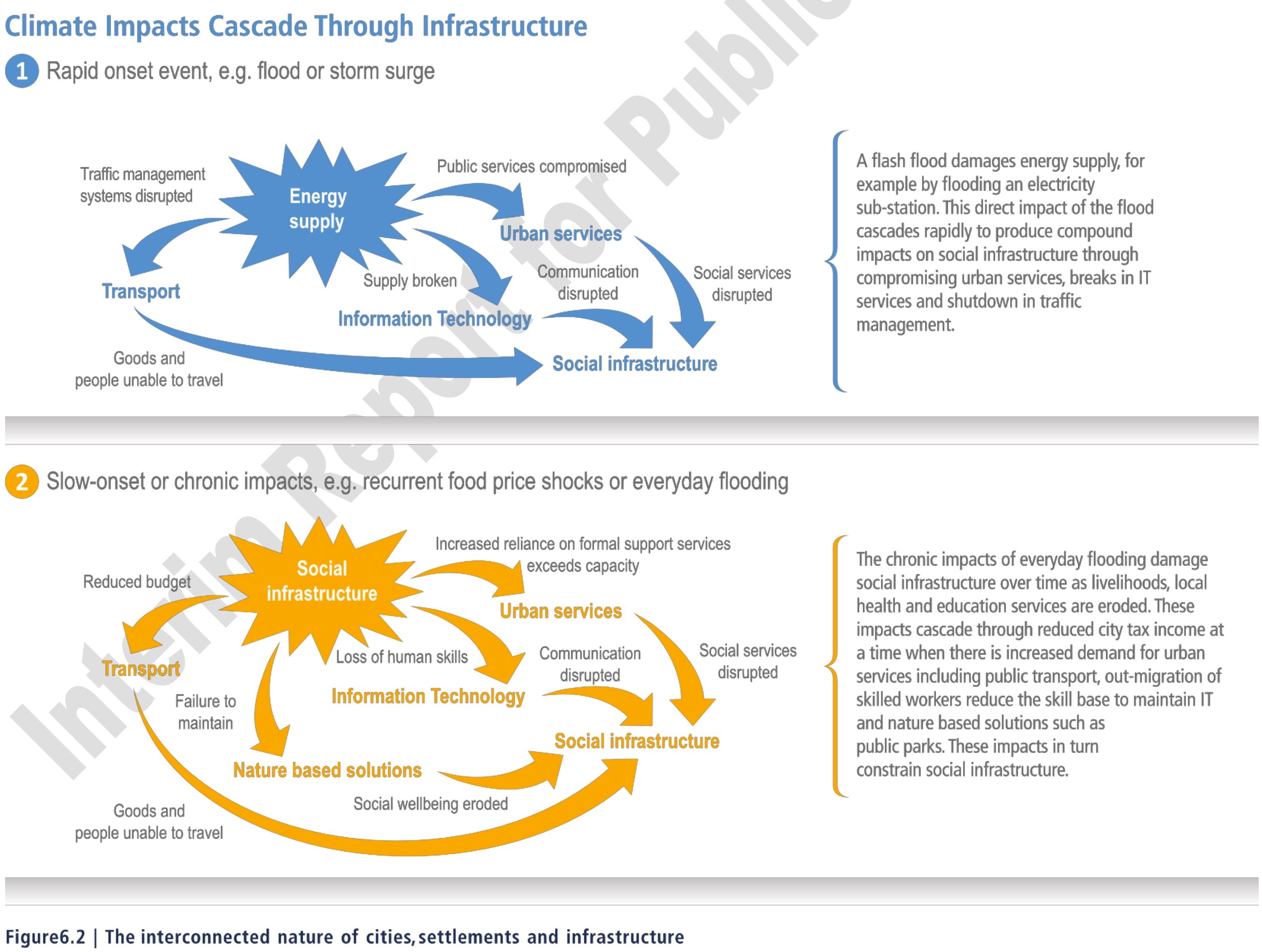


Figure 2: Multiple types of infrastructures including social, built, technological, and natural infrastructures interact to create climate risk and can limit or enable solutions. Source: IPCC Working Group II, Chapter 6 (Dodman et al., 2022, fig. 6.2).

Emerging urban systems science uses models and frameworks to make sense of the real-time dynamics of complex systems. To ensure that climate solutions don't create unintended trade-offs, or maladaptation, it is important to account for the interdependencies among social, ecological, and technological infrastructure components of urban systems (E. M. Cook & McPhearson, 2020; Grabowski et al., 2017; Grimm et al., 2016, 2017; McPhearson, Haase, et al., 2016; McPhearson, 2020; McPhearson et al., 2021, 2022a). Most traditional scientific approaches to improving resilience are siloed, with analytical efforts focused on one or two domains. Yet, as recent events have shown, extreme events can cause cascading impacts across domains. For example, flooding can simultaneously cause power and transportation disruptions, damage ecosystems, impact human health, and damage homes and critical infrastructure. Recent extreme events demonstrated failures or inadequacies not just in the built infrastructure but also in resources, institutions, information, and governance systems—components of the urban SETS—to prepare for, and respond to, events of this magnitude (Eakin et al., 2018). To advance governance for resilience means also advancing our ability to understand such complex urban dynamics and develop near and longer-term scenarios to guide decision-making.

The SETS framework builds on literature that demonstrates that social and ecological systems are linked through feedback mechanisms, and display resilience and complexity. Transitions in these literatures are commonly considered as co-evolution processes that require multiple changes in social-ecological or social-technological systems. Modeling approaches, such as machine learning, spatial projection, and mixed statistical approaches have been developed to explain how different policy mixes influence social–ecological or social–technical change. Complementing recent scholarship in social–technical or social–ecological systems research, the SETS conceptual framework has been used in multiple adaptation and sustainability planning process and policies – in Atlanta, Phoenix, New York, and San Juan (PR) – to examine the interactions and interdependencies between humans, the environment, and technological–infrastructure. It can be a way to analyze the potential of positive seeds of transformation to grow toward larger scale and more substantial changes.

In 2020, the U.S. National Science Foundation issued a call for Sustainable Regional Systems research and argued for SETS as the conceptual foundation to anchor systems approaches that can deliver sustainability across urban and rural interlinked systems (National Science Foundation, 2020). SETS aims to overcome the limitation of a purely socio-technological approach which tends to exclude ecological functions, or of social–ecological approaches which may overlook critical roles of technology and infrastructure, all of which are fundamental constituents and drivers of urban system dynamics. The SETS framework can therefore broaden the spectrum of the options available for more systemic identification of barriers (within existing actions, governance frameworks, economic constraints, and value systems) and generation of solutions for sustainable futures.

For example, processes, challenges, and solutions related to green gentrification can be addressed through a SETS approach. Community concerns are rising about green gentrification where urban greening efforts can be seen as potentially driving displacement of low income and minority populations. This perception is due to well understood impacts of neighborhood greening through tree planting, park development and investment, that can drive increases in real estate values and thus lead to increased costs of rent, taxes, and home ownership (Anguelovski et al., 2022; Keeler et al., 2019). To ensure that urban greening for climate adaptation and resilience does not result in displacement or negative outcomes for equity and justice suggests a clear need for more systemic and convergent approaches to adaptation that couple planning, policymaking, and decision-making across sectors and governance silos. Urban greening thus requires more than ecological investments in a neighborhood (Wolch et al., 2014). A SETS approach suggests that converging priorities for tree planting or park upgrades with solutions to eliminate risk of displacement would mean coupling greening with rent subsidies, low-income housing investments, and other approaches that cut across sectors, agencies, and nodes for decision-making. Plans and policies that couple greening, social policy, affordable housing, and other related dynamics in neighborhoods facing multiple challenges is an ongoing need and challenge for climate adaptation solutions to take up more convergent, systemic approaches to building resilience in NYC.

4.1 Diverse Sector and Cross-Sector Needs: Understanding Trade-offs Between Spatial and Temporal Scales and Thematic Breadth

NYC is part of a larger urban system comprising the greater metro area. Considering relationships and interdependencies at the neighborhood, city, and regional spatial scales, as well as in near- and longer-term timeframes, is essential for advancing resilience and avoiding maladaptation.

Figure 3 shows the spatial and temporal scales for a range of government and community plans to better understand the landscape of NYC resilience plans and identifies the timelines of community-based and government climate adaptation and resilience plans for NYC. The timelines highlight the spatial (neighborhood, city, regional, state) and temporal (short-, mid-, and long-term) scales and the climate hazard(s) each plan addresses (extreme heat, stormwater, coastal flooding, and multi-hazard).

Figure 3: Government-based (Upper) and community-based and non-governmental (Lower) climate adaptation and resilience plans based on their spatial and temporal scales and the climate hazard(s) they address. Note – this is not a comprehensive review of all community-based and government climate adaptation and resilience plans, rather it focuses on selected plans showing recent (from 2019 on) plans or plans still in-use. The timescale was identified by whether the plans included specific targets/deadlines for their strategies. If no long-term time scale was explicitly stated in the plan, they were assumed to be shorter-term. However, it's important to note that many if not all of the shorter-term plans will have lasting and long-term impacts when implemented. (Figure from NPCC authors)

Some planning initiatives by government agencies (shown in upper portion of Figure 3), especially those focused on sectors such as environment, energy, and water systems, have considered regional scale dynamics and has produced plans targeted for the region or state (Pirani et al., 2018; Regional Plan Association, 2018). The timelines of plans in NYC highlight that the included community-based plans mostly address multi-hazard climate impacts, as compared to the government-based plans, which explicitly focus on both individual hazards and multi-hazard planning approaches. Although there are fewer government plans with an explicit multi-hazard focus, many hazard-specific government plans will likely address multiple hazards through stated strategies. When comparing the temporal scales, the community-based plans (shown in the lower portion of Figure 3) generally take a shorter-term focus, compared to the somewhat longer-term nature of some of the government-based plans. The community-based plans that bring together multiple community organizations in a single plan, such as Rise to Resilience, tend to have a longer-term focus. However, long-term planning remains a gap in both city government and community-based planning.

4.2 Community-centered Climate Resilience Planning

Community-based organizations in NYC, such as the NYC Environmental Justice Alliance, The Rockaway Initiative for Sustainability and Equity (RISE), UPROSE, and WE ACT for Environmental Justice, are generating their own climate and sustainability plans that address concerns from transportation to energy to heat resilience. The vast majority of these plans include strategies that are within a short to medium-term time frame. Community-based plans are generally place-based, allowing for a more tailored and contextualized approach to addressing climate resilience based on specific neighborhood characteristics that can complement more general, broader city-level planning efforts. There is an opportunity to further build out and institutionalize the integration and centering of community-based plans in citywide agendas so that they are complementary and mutually reinforcing. Figure 3 highlights a few examples of community-based resilience plans and strategies and BOX 2 describes examples of climate resilience planning and agenda setting by diverse community-centered initiatives throughout NYC since 2020. For a more in-depth description of how these plans are being implemented on the ground, see NPCC4, Foster et al. (Foster et al., 2024).

As an effort to synthesize community-centered resilience goals, Regional Plan Association and Environmental Defense Fund worked with partners and stakeholders to identify climate resilience goals that have been articulated through community-based plans in areas at risk of coastal flooding. As part of this initiative, the team has also identified potential indicators that could be used to measure progress toward those goals. While there are many accepted measures or indicators of sea level rise, increased frequency of extreme events, rising temperatures and targets for greenhouse gas reductions, there are few established measurable targets for resilience to those climate impacts—particularly examined across spatial scales for communities and cities. Without measurable goals, targets, and data at a suitable scale for effectively redressing these risks, government officials and advocates alike are unable to effectively assess, track, and implement solutions. An online map, the NYC Climate Resilience Plan Mapper (Regional Plan Association, 2023) highlights the community-led climate resilience work in the context of government-led and academic plans. This project aims to lay the groundwork for the development of specific resilience performance measures or targets that are evidence-based, community-informed, easily updated, and could be used to support advocacy and decision-making over time. Further, the project also seeks to understand the similarities and differences between how communities, governments, and scientists define resilience goals.

BOX 2: Community-centered climate resilience planning and policy agendas.

These examples of climate resilience planning and agenda setting by diverse community-centered initiatives throughout NYC since 2020 highlight a range of initiatives developed by individual community-based organizations and collaborative coalitions across many organizations, and range in scope from local neighborhood to regional scale and from near-term to longer-term planning.

Community Visioning for Edgemere (Seip, 2022)

Focus: Coastal flooding from storm surges and 'sunny-day' tidal flooding, sea level rise, managed retreat, and development of vacant land and Edgemere Community Land Trust in the Edgemere neighborhood of Rockaway Peninsula, Queens

Process: In collaboration with RISE (Rockaway Initiative for Sustainability and Equity) and CCCE (Collective for Community, Culture, and Environment) and funded by The Nature Conservancy, this grassroots initiative centered the voices of local community members to envision a more sustainable future for their neighborhood through three community visioning and design forums.

Time frame: Near term (six months to five years)

Example strategies: Strategies and actions address a diversity of themes related to food security, recreation and exercise, beautification, economic development, education, arts, and culture.

Rise to Resilience: Our Communities, Our Future. Policies and Investments for a Climate-Resilient New York and New Jersey (Waterfront Alliance, 2020)

Focus: Recommending policies and investments to protect frontline communities in New York and New Jersey from coastal flooding resulting from sea level rise, storm surges, and extreme precipitation events

Process: The Waterfront Alliance and Resilience Task Force reached consensus through a coalition of community-based, environmental, business, government, and research entities in NY and New Jersey coastal region

Time frame: Near- and mid-term to 2050

Example strategies: Comprehensive strategies and actions range from improving cross-jurisdictional climate resilience governance to funding, public awareness and transparent communication, collective action to meet community needs, and economic development to environmental and infrastructure initiatives that restore ecosystem floodplains and increase resilient public infrastructure and housing.

Building an Equitably Green New York City (Riverkeeper, 2022)

Focus: Recommending strategies to bolster the City's Green Infrastructure Program to improve stormwater management during precipitation events and maximize co-benefits and equitable outcomes

Process: Riverkeeper led the development of the recommendations in partnership with community-based organizations such as Bronx River Alliance, Gowanus Canal Conservancy, the HOPE Program, NYC Environmental Justice Alliance, and more, and reviewed by City agencies like DEP, DOT, and Parks

Time frame: Near-term focus on NYC's Green Infrastructure Program 2030 milestone requirements

Example strategies: Some recommendations include prioritizing long-term maintenance and maintenance jobs, increasing interagency coordination, expanding green infrastructure development, changing the rate structure for water, increasing funding, creating public education campaigns, and evaluating all opportunities for stream daylighting.

2023 Extreme Heat Policy Agenda (WE ACT for Environmental Justice, 2023)

Focus: Addressing extreme heat impacts across all of NYC, especially for groups that are disproportionately affected such as people of color, low-income households, and elderly people

Process: WE ACT for Environmental Justice developed the policy agenda and collaborates with government agencies to implement recommendations

Time frame: Near-term (WE ACT sets an annual extreme heat policy agenda)

Example strategies: Policy recommendations range from expanding the Low-Income Home Energy Assistance Program (LIHEAP) to subsidize summer utility bills, to codifying and promoting cooling centers, coordinating emergency planning and communications, increasing green infrastructure and renewable energy, and supporting City policy reform.

Green Resilient Industrial District (GRID) Plan 2.0: A Just Transition Plan for Sunset Park (UPROSE, 2023)

Focus: A plan for a just transition to decarbonizing Sunset Park in Brooklyn that centers local economic development and prioritizes resilience to air pollution, extreme heat, and flooding

Process: In 2022, urban planning firm Integrated Urban Equity Solutions (IUES) updated the 2019 GRID plan, which was originally developed by urban planners in the CCCE for UPROSE and the Protect Our Working Waterfront Alliance (POWWA)

Time frame: Near- to mid-term to 2035

Example strategies: Strategies leverage the unique neighborhood assets and support frontline communities in participating in a just green and clean energy economy. Other focus areas range from building grassroots and institutional capacity, promoting transportation justice, and expanding transformative decision making that is matriarchal, intergenerational, and rooted in ancestral knowledge.

4.3 Multi-Hazard Scenario Planning: Adaptation Scenarios 2021 for Multi-Hazard, Cross-Sectoral and Long-Term Scenario Planning in New York City

An example of multi-sector, multi-scalar city-led planning includes the NYC Adaptation Scenarios for 2100 (E. Cook et al., 2022). Much of the dominant discourse about future forecasts is negative with visions of environmental and societal collapse, and "business as usual" forecasts that challenge planning and policymaking for more optimistic urban futures. Climate hazard projections in NYC can often paint a picture of a future city that is difficult or impossible to adapt to – and thereby may be considered dystopian. Such perceived inevitability of a negative future can become a barrier to action and long-term planning (Iwaniec et al., 2020; McPhearson, Iwaniec, et al., 2016). Ultimately, such dominant discourses may become self-fulfilling with negative future visions driving the city towards a negative future reality. However, research and practice demonstrate the role of *positive* visions that allow exploration of alternative and desirable futures to assist in developing positive plans, goals, and targets and delivering desirable outcomes for cities. Without shared positive visions for the future, it is unlikely that plans made now will achieve the equity, justice, sustainability, and resilience goals desired for the future of NYC and its communities.

In order to create space for positive visions, it is helpful to look to time frames far enough into the future in order to remove the present constraints that often make it hard to imagine desirable, normative futures. Existing planning efforts often focus on goals that are only 10, 20, or possibly 30 years into the future. While these shorter-term planning efforts will have long-lasting impacts, many future aspirations will take even longer to achieve, and short-term planning is not the same as setting long-term goals. Participatory processes are critical in co-developing shared visions that bring together diverse perspectives and forms of knowledge (E. Cook et al., 2022) (see BOX 3).

BOX 3: SETS Convergence Research Network

In Fall 2021, the New York City (NYC) Mayor's Office of Climate and Environmental Justice (MOCEJ) partnered with the National Science Foundation (NSF) Social-Ecological-Technological Systems (SETS) Convergence Research Network to facilitate the NYC Climate Adaptation Scenarios workshop series (E. Cook et al., 2022). Approximately 35 government practitioners from city, state, and federal agencies co-developed six distinct positive future visions for NYC in 2100 that are more just, equitable, and resilient in the face of extreme climate challenges. The envisioned future scenarios addressed: Multiple co-occurring hazards, Coastal flooding, Extreme heat, Winter extremes, Extreme precipitation, and Drought and shifting water demand. The goal of each future scenario was to radically transform the city's social, environmental, and physical infrastructure—including governance, green infrastructure, and water-energy-transit systems—and the City's ability to respond to extreme events.

We used a 2100 timeframe of approximately 80 years from today to create a rare space for long-term planning and positive visioning. Ultimately, the workshop activities were designed to develop long-term future visions that imagine what the future *ought* to be and consider more transformative strategies to achieve those visions without being constrained by the inner workings of the current system. Participants worked in small groups to envision six scenarios for the future of NYC in 2100. Scenario themes were developed in response to practitioner concerns and the City's sustainability and environmental management plans.

Participants envisioned a future NYC that is **resilient to multi-hazard risks from extreme heat, precipitation, and drought** with reliable, resilient, and interconnected infrastructure. The interconnected infrastructure addresses multiple risks and combines green and gray infrastructure solutions. The envisioned future infrastructure, including use of renewable technologies and nature-based solutions, will be interconnected and enable flexibility during co-occurring events. The interconnected systems will allow safer failure or a minimum service provisioning that avoids complete failures. In addition, a social contract would establish an inclusive and transformative governance system built on principles of trust, agility, and accountability. The inclusive governance system will integrate community participation, expertise, and cross-agency collaboration to better address future co-occurring hazards. Finally, this scenario envisioned that all New Yorkers would have equitable access to physical health, mental well-being, and economic stability that is not dependent on zip code, race, and privilege in order to be better equipped in the face of future events.

To ensure a future NYC that is **resilient to coastal flooding and storms**, participants envisioned collaborative governance based on a public-private-civic governance model to facilitate coordination across agencies and cross-sectorial decision-making. This future vision ensures residents are more resilient to future flooding through a variety of mechanisms, including equitable opportunities for relocation, housing, and flood insurance. Finally, this future focuses on a systems approach to developing a retrofitted city that integrates natural elements of nature-based solutions with hard, engineered infrastructure. The retrofitted city is centered on solutions that provide co-benefits and are multifunctional. Through a social-ecological-technological systems approach, the city's design integrates ecological elements and nature-based solutions, together with human health and well-being goals, into the built environment. This 'engineered with nature' approach spans policy, operation, maintenance, research, and design. The primary objectives include flexible or agile buildings or structures that are safe-to-fail, are able to buffer storm surges, sequester carbon, and do not emit contaminants.

Participants envisioned a future NYC that is **resilient to rising temperatures and extreme heat** would eliminate heat-related illness and mortality through a combination of infrastructure and health reforms. The future scenario relies on and maximizes the use of green vegetation and water features to mitigate heat. It ensures excess heat waste (e.g., from air conditioning) is reduced or reused through heat recovery systems to minimize new energy use. This will be achieved through updated building code to, for example, require the use of passive or low-energy building design, reduce the use of absorptive materials, and require green roof installation retrofits.

A future NYC that is **resilient to winter extremes** would minimize community vulnerability and improve preparedness. In addition, the future will maximize public well-being and mental health, ensuring residents are prepared for winter weather and can enjoy its benefits. Finally, the future will rely on investing in zero-carbon infrastructure. A three-pronged approach will be used to meet this zero-carbon infrastructure goal. First, a broad range of infrastructure will be built to withstand the increasing frequency of freeze-thaw cycles. Second, all infrastructure will meet decarbonization standards, including by utilizing fossil fuel-free energy sources, electrifying equipment, and overall regulating retrofits. There will be a particular focus on clean and reliable heating sources to reduce disruptions and increase resiliency during winter extremes. Finally, all infrastructure will also meet design standards that limit ecosystem harm – by phasing out the use of salt on icy sidewalks and roads.

To be **resilient to extreme precipitation**, participants envisioned that residents have agency in decision making to enhance individual and community resilience. New Yorkers would have the information, infrastructure, and ability to be both mobile and stable in the case of an extreme rain event. There would be prioritized and expanded affordable housing in low flood risk areas. In addition, the City will embrace living with water through integrated watershed management and combined natural-green and hard-engineered infrastructure to convey water in times of heavy rainfall. The focus will be on managing stormwater efficiently through integrated ecosystem-based and engineered solutions. Urban neighborhoods will be connected with natural systems and semi-naturalized streetscapes to recreate a natural watershed for stormwater conveyance and recreation. A network of compensated green stewards would help to manage these landscapes, eventually leading to the establishment of land trusts. With fewer cars on the road, transportation spaces like highways and tunnels could be repurposed for water conveyance.

Finally, participants envisioned a future NYC that is **resilient to drought and shifting water** demand that promotes the regional approach to maintain freshwater supply, ensures that all New Yorkers have equitable access to clean water, and minimizes potable water waste to protect water quality and quantity. In particular, landscapes are conserved and managed to be resilient and conserve water. For example, a shift to drought tolerant vegetation helps to protect water supply by reducing outdoor water use and enhances the resilience of the ecological system to severe drought conditions. The future also focuses on stormwater and water reuse infrastructures to ensure resilient water use and quality in the urban environment. Public, residential, and commercial properties will capture greywater and rainwater for on-site use and all water runoff from impervious surfaces is managed for future banking and security.

5 What Do We Know About the Future?

The future climate of NYC is described in the NPCC4 Climate Science Special Report (Braneon et al., 2024) and in this assessment (Balk et al., 2024). In short, NYC will be hotter, stormier and with greater variability in precipitation, and with rising coastal hazards. The spatial distribution of hazards is not evenly distributed across the city – for example, extreme heat is experienced differently and disproportionately. As shown in the NPCC4, Climate Science 2024 report (Braneon et al., 2024), indoor extreme heat exposure is a critical driver of heat related mortality and hospitalization, and yet there is limited work dedicated to monitoring and projecting indoor thermal environments that exacerbate outdoor heat in the present day, let alone to estimate such potential impacts in the future under warmer conditions (Braneon et al., 2024). In this section, we assess the current knowledge about the socio-demographic, built environment, health, and nature-based futures of the city.

5.1 Demographic Futures

Because of the work of the DCP, we know a good deal about the population distribution and composition, change in the recent past and projections a few decades into the future. This section begins with a short discussion of that but then transitions into uses the SSP framework to project population mid-century and beyond.

5.1.1 The population of New York City is getting older and more diverse

The population of NYC in 2020 was over 8.8 million persons, with more than half of the population residing in Brooklyn and Queens. Aging is a national trend, and NYC is no exception. Between 2010 and 2020, the median age increased from 35.5 to 37.3 (38.1) years (5-year estimate. 1-year estimate in parentheses) (Matte et al., 2024; United States Census Bureau, 2021). In 2013, NYC DCP (2013) projected the population in 2040 to reach 9 million persons[1]. According to the 2013 DCP projections, the share of population over age 65 was 12.2% in 2010 and is projected to rise to 15.6% by 2040. Placing this in historical perspective, 7.7% of the city's population was over age 65 in 1950.

Growth in the population of NYC comes largely from natural increase, that is births minus deaths, as the city has a long-standing pattern of migration losses – more people move out of the city than move in – consistent from the mid-twentieth century onward (City of New York Department of City Planning, 2013, 2022). "The net outflow from the city in the past decade totaled just 51,000, but it was a result of a remarkable population churn, with 2.57 million people moving to NYC and 2.62 million people leaving" (City of New York Department of City Planning, 2023b). Population growth is not uniform by race and ethnic composition: "NYC's Hispanic population growth reflected the citywide pattern, with natural increase outstripping net outflows. Asian population growth bucked the trend, with both natural increase and net inflows, resulting in dramatic increases across the boroughs. There were population declines among the White and Black populations as natural increase only partially offset net outflows" (City of New York Department of City Planning, 2023b).

Figure 4 shows the long-standing and increasing diversity of NYC. In the past decade, the Asian population grew by nearly 350,000, accounting for 55 percent of the city's growth, and the Hispanic population, which increased by about 150,000, accounted for about one-quarter of the city's growth over the decade. The White population remained relatively unchanged (declining slightly) whereas the Black population decreased by 84,000. The remainder of the population growth is accounted for by those identifying as two or more races or some other race.

[1] There is inherent uncertainty in projecting the future: DCP's 2013 projection of the 2020 population to be 8.55 million – somewhat lower than the actual 2020 population – and it projected the 2030 population to be around the current-day population, but given the current estimate of the 2022 population of around 8.4 million (City of New York, 2023a) these estimates may turn out to be on target.

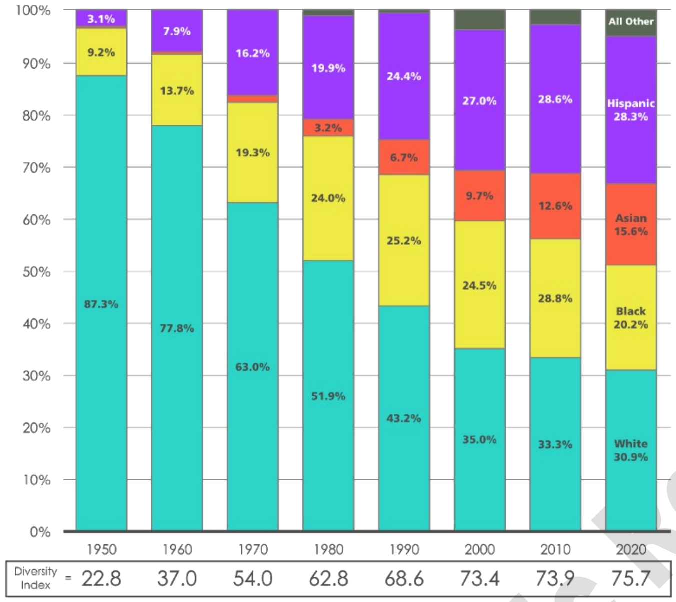


Figure 4: Share of Population by Race/Hispanic Origin, New York City, 1950-2020. Source: NYC DCP (City of New York Department of City Planning, 2023b)

Population aging, migration, and diversity result from larger social processes. Population aging is expected to continue with high certainty into the future and while NYC has long been home to migrants from places throughout the US and abroad, forecasting future migration streams is much harder than projecting future age structure. The NYMTC Socioeconomic and Demographic (SED) projections for 2055 "show both employment and population growing regionwide from 2017 to the 2055 forecast year. Employment, although lagged in the near term to acknowledge the economic slowdown caused by the pandemic, will exceed that projected in earlier forecasts" (New York Metropolitan Transportation Council, 2020b). Growth rates in the region also slow later in the period, due to population aging.

Additional socioeconomic characteristics are important from a climate vulnerability perspective – such as levels and trends in change in income (and wealth) distribution, new, available, and affordable housing units, and job growth. New York University's Furman Center has produced city-wide indicators (2023) (as well as neighborhood level) of housing characteristics, median income and inequality metrics from 2000-2021. In these two decades, they find increases in homeowners (from 30.2 to 33.3%) concomitant with even larger increases in the proportion of households that are rent-burdened (from 23.7 to 30.1%), with substantial increases outside Manhattan since 1980 (Balk et al., 2022). While recent trends are a good indicator of conditions in the near term, apart from using new building permits in the NYMTC forecasts, such socioeconomic factors have not typically been forecast in the medium or long-term.

5.1.2 The spatial distribution of population in New York City

DCP's projections for NYC are for the total population for each borough by age and sex. Projections are not done by race or ethnic composition but are available for the total population down to the transportation analysis zone (TAZ) level, which are akin to census tracts and can be reaggregated in spatial units useful to particular user groups. Apart from their projections, in their recent neighborhood analysis, DCP (2023b) finds that 'Roughly half of neighborhoods experienced net outflows [from 2010-2020]. The vast majority of these still experienced population growth through natural increase, reflecting the citywide pattern of population growth despite net migration losses." DCP also undertakes periodic analysis of the dynamics of racial and ethnic composition of NYC neighborhoods (City of New York Department of City Planning, 2021a). NYC's remarkably diverse population is not evenly dispersed (nor has it ever been) across boroughs or neighborhoods. To understand neighborhood change, DCP also examines decadal change in new construction at the neighborhood level and places these in the context of the change in the racial and ethnic composition of neighborhoods (City of New York Department of City Planning, 2021b), information essential for understanding climate impacts with a racial justice lens despite the short-term nature of the change analysis.

5.1.3 Demographic futures consistent with different SSPs

In thinking about the future climate of NYC, and the ability to adapt to it, it is also important to understand the population futures that are consistent with those different climate futures, and the pathways that jointly lead to them.

Thus, this assessment makes use of new population projections consistent with three SSPs (Jiang et al., 2020) – SSP2, SSP3 and SSP5 – and which were downscaled to 1km spatial resolution (Zoraghein & O'Neill, 2020a, 2020b) for the United States. To project the future, and as an important improvement on global applications, US-state-specific inputs on fertility, mortality and migration are used to project future population and a set of state-specific modelling parameters for urban and rural spatial distributions in downscaling the projections to 1km grid. Adapting these three SSPs to the US states, SSP2 is characterized by medium population growth including medium levels of fertility, mortality, and international migration; SSP3 evolves with low population growth due to low fertility and international migration but higher mortality; and SSP5 sees higher population growth due to high fertility and international migration along with low mortality (Jiang et al., 2020) (See BOX 1 for additional narratives describing these three scenarios).

Table 1 displays the results of those new data for NYC and State. The three scenarios not only produce different expected population totals and age distributions (Figure 5) as well as much different spatial distributions (Figure 6). One of the three scenarios, SSP2 – a "middle of the road" scenario (in terms of the assumptions it makes about demographic futures, and one that resembles recent (2000-2010) historical trends that remain constant over time), envisions that by mid-century the population of NYC will be about the same as present day and modest increases to the end of the century. Another, SSP3, envisions a less populous city, whereas SSP5 envisions an increase of over an additional million New Yorkers. This pattern continues to 2100 where SSP3 produces a much less populous and SSP5 produces a much more populous NYC. Table 1 places these changes in the context of projections for the state as whole. The population of NYC in the present day is under 45% of the state population, and while that doesn't change much by 2050 irrespective of the SSP, by 2100, the relative size of the city's population to the state's varies considerably. According to Zoraghein and O'Neill (2020b, p. 22) paraphrasing their results, SSP3 results in lower relative populations in suburban areas with higher population concentrated city centers; that is, SSP3 parameters result in population loss everywhere but more so outside the city. In contrast, suburban population growth is consistent with SSP5 and sprawling development – where the positive suburban population difference is limited to the surroundings of NYC, emphasizing NYC as the dominant socioeconomic hub of the state. "These effects are accentuated in 2100, where population decline under SSP3 is especially prominent … and in SSP5 the rapid suburban population growth around NYC is noticeable (…which in contrast to the suburbs, show lower populations than SSP2 in the city center)." Uncertainty is inherent in predicting the future: Given the post-World War II growth of NYC's suburbs, as well as recent out-migration related to the COVID-19 pandemic and uptake in remote employment, it is necessary to envision a range of plausible futures such as those from SSP3 and SSP5 scenarios.

Table 1: Projected Population in NYC according to three Shared Socioeconomic Pathway Scenarios in 2050 and 2100 by Borough

	2050			2100		
	SSP2	**SSP3**	**SSP5**	**SSP2**	**SSP3**	**SSP5**
BOROUGH						
Bronx	1,572,273	1,398,464	1,772,284	1,578,596	1,289,855	1,859,701
Staten Island	483,968	442,586	506,137	484,869	307,826	613,835
Brooklyn	2,736,109	2,457,513	3,038,038	2,746,352	2,275,813	3,167,712
Queens	2,444,575	2,202,263	2,700,211	2,450,862	1,925,237	2,893,837
Manhattan	1,713,796	1,535,215	1,922,651	1,720,296	1,468,880	1,972,750
New York City	**8,950,722**	**8,036,041**	**9,939,320**	**8,980,976**	**7,267,610**	**10,507,834**
New York State	**19,376,000**	**17,210,000**	**20,492,000**	**18,685,000**	**10,952,000**	**26,174,000**
NYC as % of State	**46.2%**	**46.7%**	**48.5%**	**48.1%**	**66.4%**	**40.1%**

Table derived from data used in Zoraghein and O'Neill (2020b). Estimates are based on US-national, state-level projections; modification of approach for NYC was underway at the time of publication as part of the City's Climate Vulnerability, Impact, and Adaptation (VIA) analysis.

The different predicted changes are reflected in the proportion over age 65 and expected contributions of fertility, migration, and mortality across the three SSPs (Figure 5 for all NY State). SSP3 projects much higher proportions of those over 65 (and consequently much lower fertility and population totals) and lower proportions in SSP5 (shown Figure 5, panel C). Similarly, in terms of migration (based largely on historical patterns), New York States's growth is due to the continued flows of international migration streams, rather than net internal migration; this largely accounts for the population decline seen in SSP3, even though that future also has low fertility and high mortality trends (Jiang et al., 2020). Note that net internal migration is negative in all three SSPs – that is, the state is assumed to lose internal migrants, on average – but only SSP3 has declining international migration, as well.

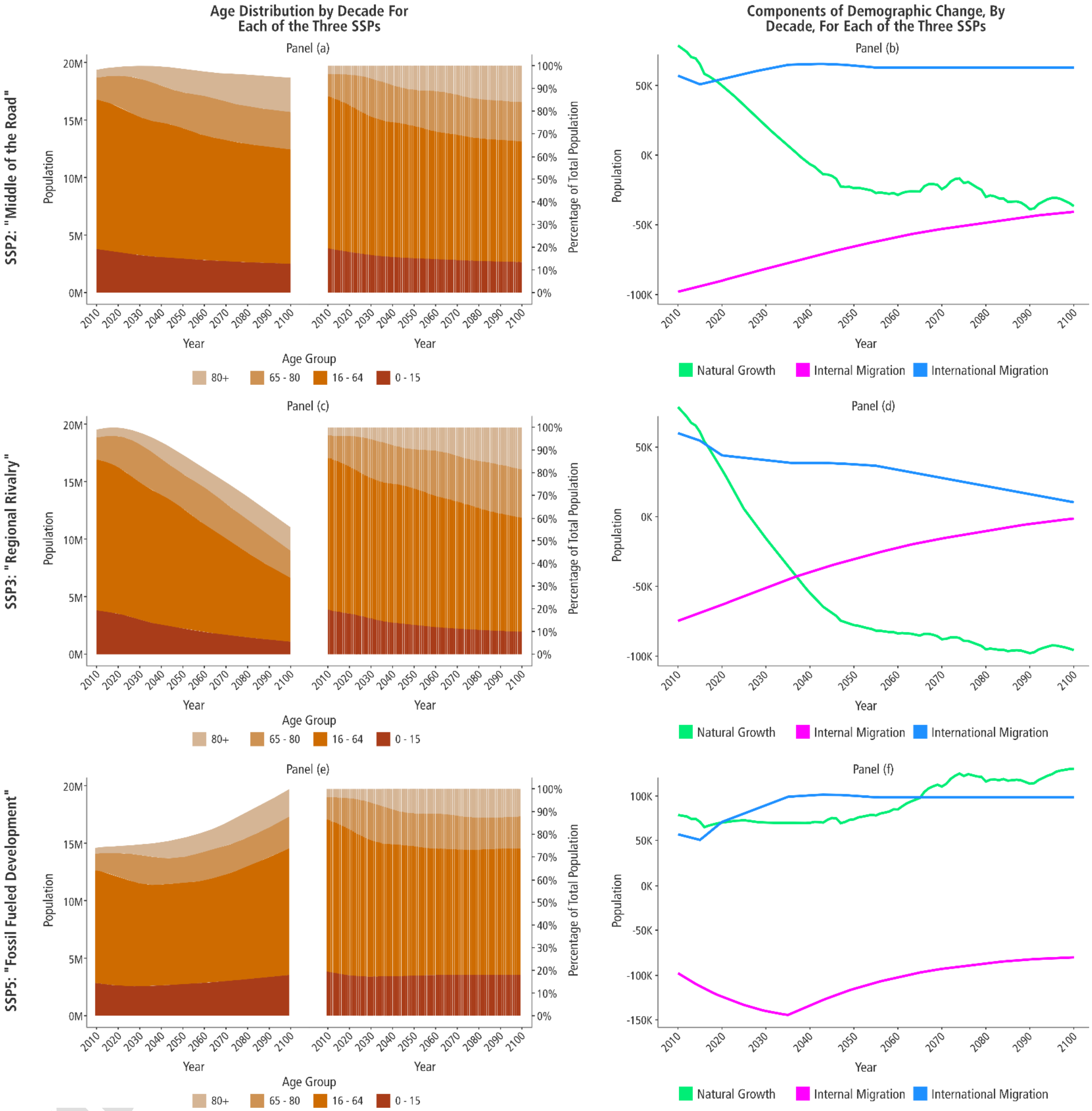
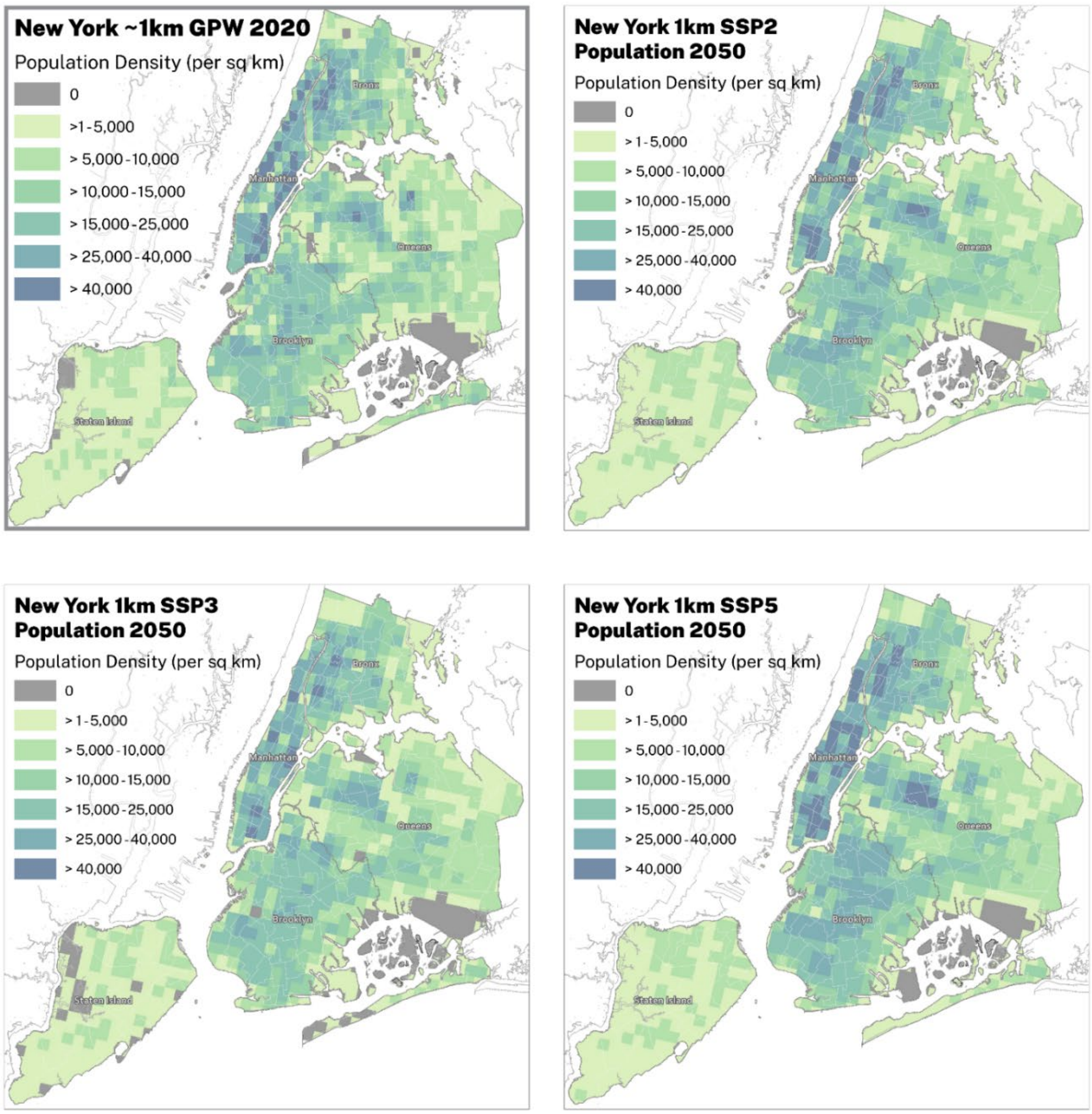


Figure 5: NYS Age distribution by decade and Components of Demographic Change by Decade. Source: Jiang & Zoraghein (Jiang & Zoraghein, 2023)

Differences in spatial distributions of the population are shown in Figure 6. There are many more low-density grid cells (shaded lighter hues) in SSP3 than in either SSP2 or especially SSP5. Population density increases in all boroughs in the SSP5 scenario, with increases in density especially notably in the Elmhurst neighborhood of Queens, while falling in all areas in SSP3 (especially in Staten Island). The patterns to 2100 look quite similar to 2050. These maps are a first look at the spatial distribution of population but drawing on this application of the SSPs to the US, the approach of Jiang and colleagues (2020) and (Zoraghein & O'Neill, 2020a, 2020b) is being adapted to NYC, to include migration flows as well as inputs that are suitable to the diversity of NYC's population as part of the ongoing VIA analysis. The VIA research will produce population projections for NYC that that go out to the end of the century and include race and ethnicity as well as age and gender among its outputs, which will be downscaled to address climate impacts assessments at a fine scale.



Note:
Due to the underlying resolution of the data, population in these diagrams is indicated in NYC's parks (Central Park, Prospect Park)

Figure 6: Population Distribution in 2050 according to three future development scenarios (of the Shared Socioeconomic Pathways, SSPs) New York City and Long Island regions (Zoraghein & O'Neill, 2020b) and compared to 2020 Gridded Population of the World (Center For International Earth Science Information Network-CIESIN-Columbia University, 2018)

5.2 Built Futures

NPCC3 inventoried multiple NYC critical infrastructure domains and infrastructure resilience strategies to address climate risks (Zimmerman et al., 2019). In this assessment, we consider other aspects of NYC's built infrastructure that were not fully considered in NPCC3 but have become especially salient due to the recent crises of COVID-19 and Hurricane Ida. We examine the role of buildings, especially residential structures, and their connection to the energy sector in NPCC4: Energy and Energy Insecurity, and below we consider surface transportation and, more broadly, the public right of way (ROW) to examine opportunities in the ROW for resilient NYC futures. In the case of the public ROW, it is an understudied topic and therefore our assessment concentrates on understanding its historical and current features and the wide range of near and medium-term plans that address aspects of future planning processes.

5.2.1 Historical transformations of New York City's built environment

NYC's current built environment has been shaped over the past 200 years by urban design, economic transitions, population growth and migration, public health challenges, technological innovation that enabled infrastructure improvements, and interactions among these forces. Many changes involved transformation of heavily developed places to new uses. Some of these changes were adapted to the climate and other circumstances of the day but have become maladaptive over time. Others were harmful and/or inequitable when and as implemented. For example, in the early 1800s rapid population growth came before knowledge about communicable disease transmission and control, the construction of water and sanitation infrastructure, and adequate healthy housing resulted in overcrowded neighborhoods and recurrent lethal outbreaks from cholera, yellow fever, typhoid, and other infectious diseases. Notably, residents of basement apartments were observed to be at highest risk. Over time, communicable disease risks abated with the construction of the Croton reservoir, housing codes, and other public health measures (Plunz & Álvarez-Dávila, 2020).

The early 20th century saw rapid, dense, transit-oriented development along new subway lines and the beginning of repurposing waterfront land from piers, warehouses, and industrial use to housing developments. While these publicly and privately financed developments were intended to provide decent affordable housing, they often reinforced *de jure* and *de facto* racial segregation (Rothstein, 2012). More recently, transit-oriented "upzoning" to develop underutilized waterfront and other neighborhoods has often resulted in luxury developments out of reach of households that could most benefit from transit access. Inequities in NYC-area land use policies is considered in more depth in NPCC4, Foster et al. (Foster et al., 2024).

In the early and mid-20th century, bridge and highway construction afforded some NYC residents, those with cars, access to amenities (such as beaches and parks) outside the city. While the motivation behind parkway construction that excluded transit buses is disputed (Kessler, 2021), access was more difficult for those who could not afford cars. Over time, the same car-centric road building promoted suburban land development, including communities segregated by racially restrictive covenants (Sheidlower, 2020), brought traffic congestion caused by car commuters, and highways that bisected neighborhoods and afflicted them with air pollution and noise that impacts the city today. This history demonstrates the potential for built infrastructure, housing, and transportation systems to remake already developed land and the need for foresight and an equity lens to envision futures that avoid unhealthy and maladaptive pathways, as discussed further in the next section.

5.2.2 Streets and the public right-of-way

NPCC3 considered, as part of a broader look at resilience strategies for critical infrastructure, NYC's rail public transportation and its surface transportation assets for moving vehicles and freight (Zimmerman et al., 2019). Plans and progress reports for addressing some of these risks are available (Metropolitan Transportation Authority Climate Adaptation Task Force, 2019). This section extends that assessment by focusing on the public right-of-way (ROW) – mainly streets and sidewalks – (Freudenberg et al., 2021) and how potential future uses can shape either greater resilience or greater vulnerability to climate risks. Realizing a more climate-adapted ROW would require prioritizing the most efficient, essential, accessible, safe, active, healthy, and sustainable transportation modes for moving people – bus transit, walking, and cycling – over the least efficient uses – parking and driving private motor vehicles (Figure 7. We have selected the ROW as a topic of interest because like other topics in this chapter, it requires substantial interdisciplinarity drawing on concepts from multiple sectors to be brought to bear.

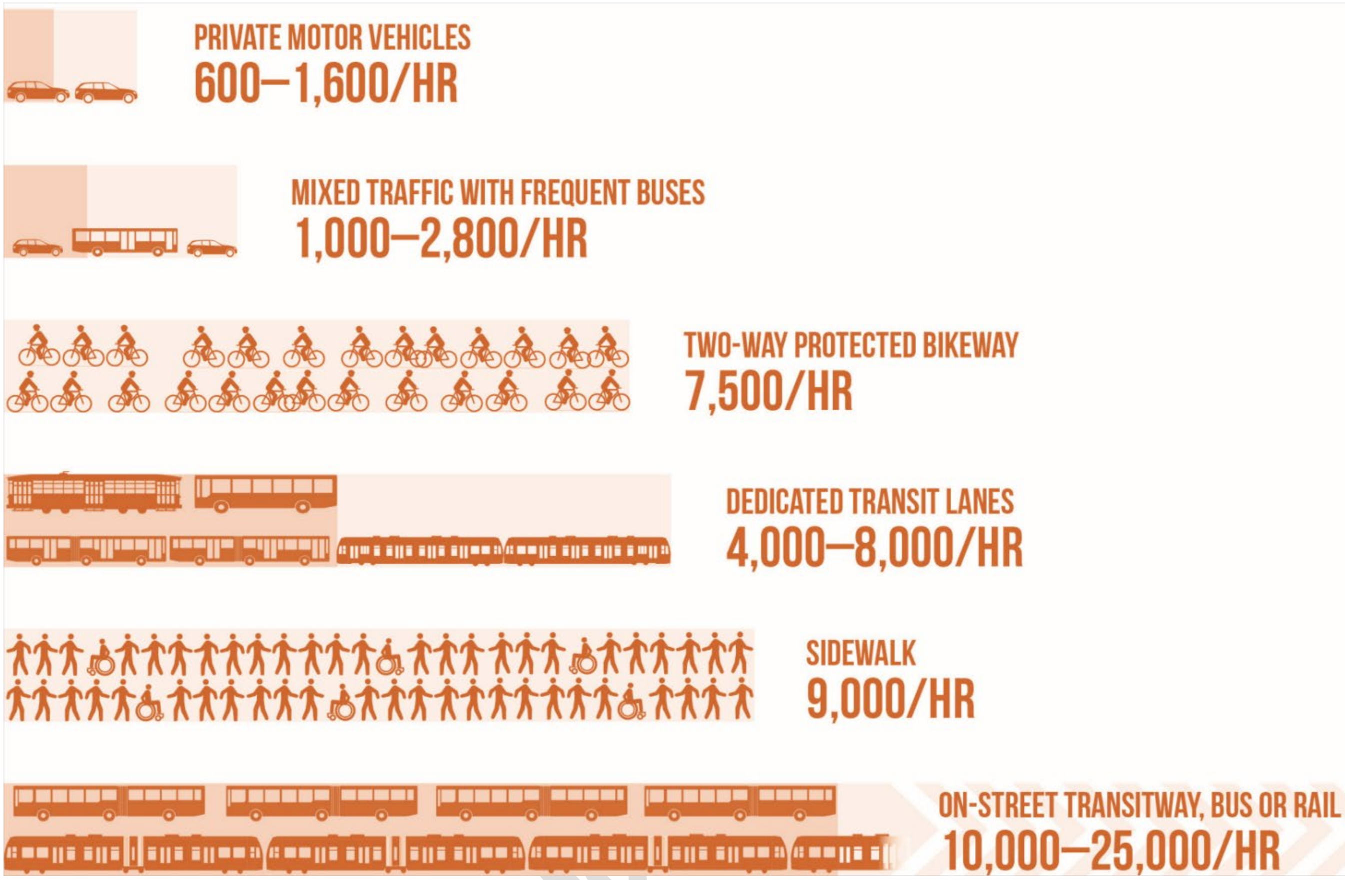


Figure 7: The Capacity of a Single 10-Foot Lane (or equivalent width) by Mode at Peak Conditions with Normal Operations (National Association of City Transportation Officials, 2016)

The urgent need and possibility of much faster and more ambitious repurposing of the ROW was made clear by the recent climate and health crises of flooding from Hurricane Ida (City of New York Office of the Deputy Mayor for Administration, 2021) and the urgent need for safe outdoor spaces for socially distanced gathering, dining, and exercising created by the COVID-19 pandemic.

In a densely developed city like New York, the ROW is a critical asset, comprising approximately 16.5% of the land area of the city (32,000 of 193,700 acres) (Freudenberg et al., 2021) that can be used in ways that are either adaptive and equitable or in ways that are maladaptive and inequitable. Past decisions, beginning a century ago, have shaped the ROW in maladaptive ways to prioritize the movement and parking of private motor vehicles; according to one estimate, NYC devotes enough curb space to park 3 million vehicles (Czebotar, 2021; Freudenberg et al., 2021). Now there is abundant evidence of how built and natural features in the public ROW influence climate risks and how the future of NYC's ROWs can be shaped to reduce climate risks from heat, flooding, and air pollution while providing co-benefits of improved health, greater equity, sustainability, and economic development. Several existing NYC policies, investments, and plans are already beginning to shape a more climate adapted ROW. Other more ambitious plans have been proposed and are supported by successful transformations of other global cities.

Asphalt contributes to climate risks from hot weather and flooding. When exposed to sun, asphalt is a major contributor to the urban heat island (Mohajerani et al., 2017) and higher surface temperatures in turn increase the vulnerability to illness and death during hot weather in NYC (Madrigano et al., 2015). Asphalt and other impervious surfaces in the ROW speed the movement of stormwater as it seeks low points, increasing the risk of dangerous flash flooding for residents of basement apartments, subway users, and even drivers. For a detailed discussion of pluvial flooding, see NPCC4, Rosenzweig et al (B. Rosenzweig et al., 2024). Reducing the amount of ROW devoted to impervious asphalt and replacing it with trees, vegetated bioswales, and materials that are less heat absorbing and more pervious can reduce both risks.

Traffic-related air pollution (TRAP), including $PM^{2.5}$ and nitrogen dioxide (NO_2), exacerbates multiple chronic health conditions, contributes to preventable morbidity and mortality (Bosson et al., 2019; Khreis et al., 2017; Yang et al., 2018). In NYC, TRAP disproportionately impacts communities with higher populations of people who are low-income, Black or Hispanic, and living in places disproportionately impacted by emissions from heavy-duty diesel vehicles (Kheirbek et al., 2016a). Concentrations of TRAP, of which ambient NO_2 is a useful indicator, is highest close to busy roadways and declines rapidly with distance (Brugge et al., 2015). Exposures to TRAP in cities can be greatly reduced by limiting traffic on streets with large numbers of pedestrians and cyclists or by creating low-emission zones in densely populated areas. (Aaron, 2011; Brugge et al., 2015; Pestel & Wozny, 2019; Zhai & Wolff, 2021).

Because NYC's public right of ways are vital conduits for movement of people and goods, freeing space for climate adapted uses requires prioritizing transportation modes that make the most of available street space. Dedicated busways, bus lanes, sidewalks and pedestrian plazas can move roughly 5-6 times more people per hour than a lane devoted to moving private motor vehicles (Figure 7). Parking private motor vehicles occupies valuable space in curb lanes, while enabling the movement of relatively few people. The present allocation of space to private motor vehicles is one reason why traffic congestion has rebounded to pre-pandemic levels (Hinsdale, 2022). Progress reducing traffic deaths has stalled (City of New York, 2013), bus speeds remain slow (Metropolitan Transportation Authority, 2023) and ridership fell in each of the several years prior to the pandemic (Metropolitan Transportation Authority, 2020), while NYC GHG emissions from transportation were little changed from 2010 through 2019, the last pre-pandemic year for which data is available (City of New York Mayor's Office of Climate & Environmental Justice, 2022b).

In addition to freeing ROW space to help cool it, manage stormwater, and provide cleaner air, prioritizing efficient transportation modes would provide multiple health co-benefits (Figure 8). Regular trips using transit, walking, cycling, or combinations of these increase physical activity that provides multiple physical and mental health benefits (Besser & Dannenberg, 2005a; Edwards, 2008a; Gaesser & Angadi, 2021; Heath et al., 2012a; Saint-Maurice et al., 2022; The Community Guide, 2017), helping to shape a future population with a lower burden of health conditions that make people more vulnerable to heat, flooding, and power outages (see NPCC4, Matte et al. (Matte et al., 2024)). Narrower and fewer traffic lanes help calm and slow traffic, reducing injury and death risk of vehicle collisions with pedestrians and cyclists (Lubbe et al., 2022; Smart Growth America, 2022). Dedicated safe space for pedestrians and cyclists could also help support safe routes to school programs for children, with proven health benefits (Centers for Disease Control and Prevention, 2023; Muennig et al., 2014; Stewart et al., 2014). Finally, busways and bus lanes to speed trips and increase ridership will provide a greater return of passenger service for the existing transit bus fleet. Expansion of the battery electric bus service will help reduce TRAP, and it can be facilitated by reducing range losses from congestion and the energy needed for winter heating (Sustainable Bus, 2022; Zhou et al., 2016). In addition to these transportation-related health benefits, increasing greenery that people will encounter every day in the ROW has multiple positive effects on mental and physical health (Keeler et al., 2019). The potential health and environmental benefits of natural features in urban communities is an area of active research.

Other important climate, equity, and development benefits can flow from a re-envisioned ROW in NYC. These include improved access to jobs and services, curbside space to scale up composting and reduce GHG emissions from solid waste management as well as the improvement of waste staging in NYC (see Clean Curbs (City of New York Department of Sanitation, 2016)), reducing combined-sewer overflows (CSO) and non-point stormwater pollution (City of New York Department of Environmental Protection, 2023a), and expanding space for economic, social, recreational, and cultural activity (Freudenberg et al., 2021).

The spatial and temporal scale of changes to the ROW vary from very local and rapid (e.g., street closures and repurposed space during the COVID pandemic) to medium term, such as bus lanes that require community consultation but minimal new construction, to longer term such as removing an urban highway. What history and other cities have made clear is that some rapid near-term change is possible, but that forward-looking, multi-sectoral planning is needed to avoid lock-in of maladaptive uses and enable future transformations.

Several city policies, investments, and plans are already beginning to transform the public right-of-way for climate adaptation. These include: NYC Streets Plan, Green Wave cycling plan, Better Buses Action Plan, NYC Plaza Program, Open Streets, and Pedestrian Mobility Plan (City of New York, 2019; City of New York Department of Transportation, 2023c, 2023b, 2023a). A reimagined public right of way can also support broader visions and goals for NYC's post pandemic future, such as those in Making New York Work for Everyone: reimagining business districts, making it easier to get to work, and generating inclusive, future focused growth (NYCEDC, 2022).

Successful implementations of these approaches in NYC include the 14th Street busway, which improved bus speeds and ridership, reduced traffic crashes and pedestrian injuries, and increased Citi Bike use (City of New York Department of Transportation, 2022; Sam Swartz, 2019) and the pedestrian plaza that revitalized Times Square while reducing exposure to traffic pollution (Aaron, 2011). Other global cities have implemented approaches that could be adapted to the varied local contexts of NYC neighborhoods, such as Barcelona's superblock initiative that limits, shares, or closes some neighborhood streets to through traffic to enhance pedestrian, retail, and commercial activity.

This and other strategies for transforming and capturing greater benefits from the public right of way in NYC have been proposed (Freudenberg et al., 2021; Transportation Alternatives, 2021).

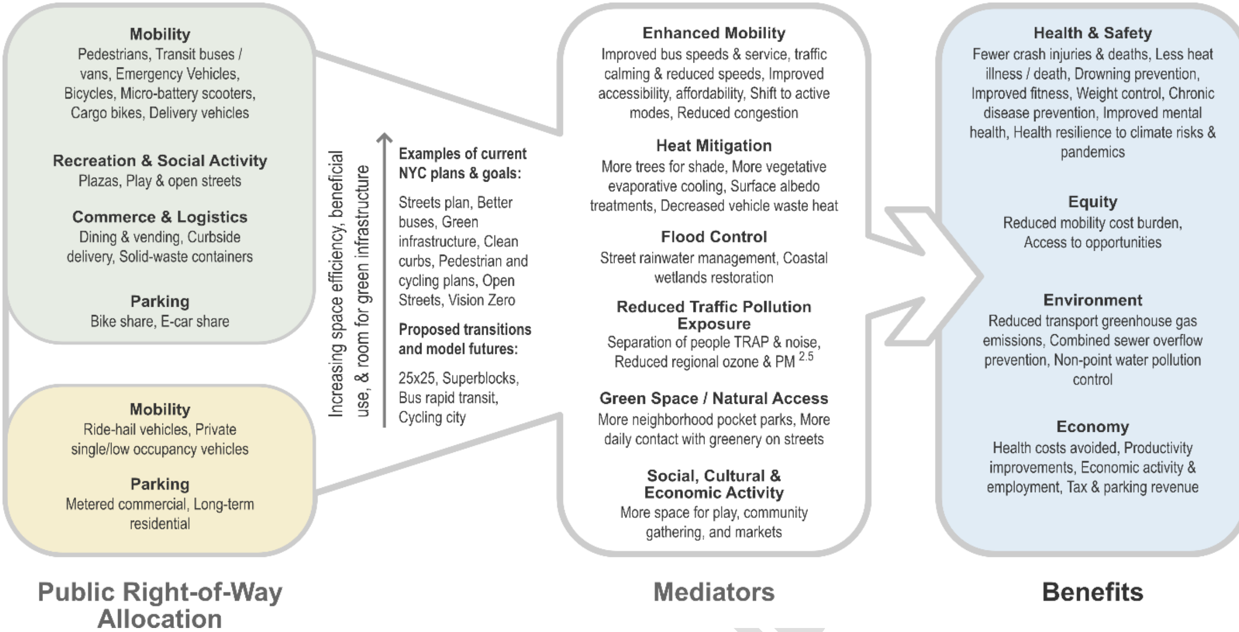


Figure 8: Street space allocation influences how much space is available for beneficial, climate-adapted uses as well as the health, safety, equity, and efficiency effects of our surface transportation system.

5.3 Health Futures

Shaping an urban environment that supports human health and wellbeing, as well as social and economic opportunity and equity should be a central aim of the City's climate planning (Capon, 2017). Pathways to achieve this aim can be informed by methods and tools that quantitatively and qualitatively assess local health impacts, both beneficial and harmful, and their distribution under different policy alternatives and future scenarios (Castillo et al., 2021; Foster et al., 2019; Sohn et al., 2018). Health impacts may be considered "co-benefits" (or co-harms) when other sectors are the primary goal or focus of a policy or planning scenario, such as climate change mitigation, transportation improvements, or ecosystem conservation. Alternatively, policies that primarily have public health and welfare goals can have co-benefits of enhancing climate change adaptation and resilience. Health co-benefits of reallocating space in the public right-of-way are discussed in the preceding section. Other examples of health co-benefits of climate action, and tools to assessment, follow.

5.3.1 Health impact assessment and co-benefits: greenhouse gas mitigation, air pollution, and active mobility

Reducing local air pollution emissions and concentrations provides important health co-benefits from reducing local greenhouse gas emissions. Measures of air pollution can be estimated using the US EPA's Benefits Mapping and Analysis Program Community Edition (BenMAP) tool (Sacks et al., 2018) in conjunction with local and regional air pollution emissions and atmospheric modeling. For example, fully implementing NYC's 2014 strategy of reducing greenhouse gas (GHG) emissions 80% by 2050, was estimated to annually avoid between 160 and 390 premature deaths, relative to a 2012-2014 annual average, and health-related costs valued at $3.4 billion (Johnson et al., 2020). Similar methods can also be used to estimate potential health co-benefits of sector-specific actions, such as phasing out the most polluting heating fuels either prospectively or retrospectively using ambient monitoring data (Kheirbek et al., 2014; Zhang et al., 2021). Clean air scenarios can also be evaluated to estimate health benefits of idealized, hypothetical futures, such as sustaining air pollution improvements observed during COVID-19 restrictions or eliminating traffic related PM2.5 emissions. By analyzing both air quality change and health data at neighborhood scale, these analyses also show that the most vulnerable and disadvantaged communities are most harmed by current emission levels and their spatial distribution and have the most to gain from cleaner air (Figure 9) (Johnson et al., 2020; Kheirbek et al., 2014, 2016b; Perera et al., 2021).

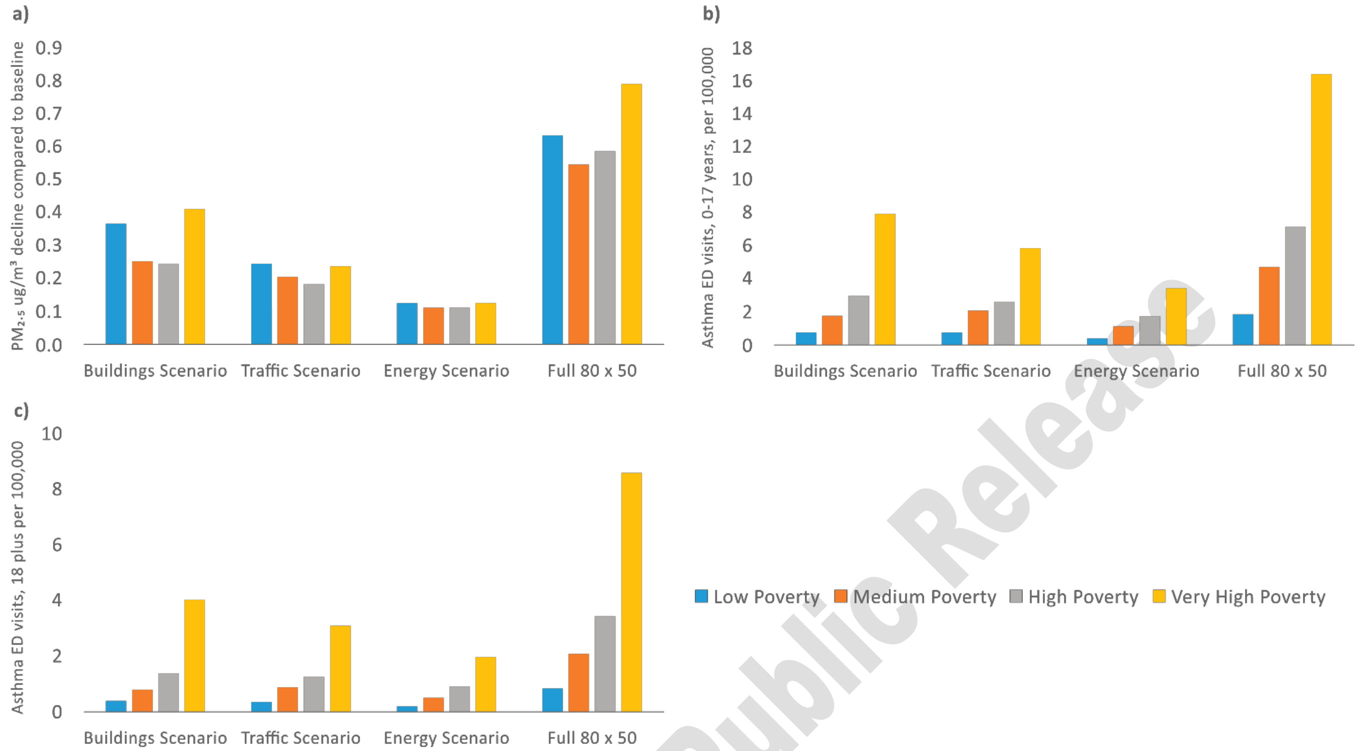


Figure 9: Median decline in zip code tabulation areas (ZCTA) average ambient annual average PM2.5 (a) and avoided asthma ED visits, age 0-17 years (b) and age 18 plus (c) under the sector=specific 80x50 strategies, alone and in combination stratified by neighborhood poverty. Adapted from Johnson et al., Figure 3 (Johnson et al., 2020).

Health impact assessment is a tool that can engage community stakeholders in ways that enhance procedural equity and shed light on distributive equity of proposed actions (Foster et al., 2019; Sohn et al., 2018). Often overlooked in health impact assessments focused on clean air benefits of climate action are the health benefits that transportation, land use, and urban planning strategies can provide through shifting from driving to more active modes of getting around such as walking and cycling (Mueller et al., 2015). Benefits of regular physical activity during trips to access jobs, school, services, and other essential needs include improved self-reported health, greater fitness, weight loss or less weight gain, reduced risk of chronic physical and mental health conditions, and reduced death rates (Gaesser & Angadi, 2021; Heath et al., 2012b; Saint-Maurice et al., 2022; The Community Guide, 2017, 2023). Active mobility need not involve cycling or walking alone; transit trips almost always involve physical activity beneficial to health, like walking (Besser & Dannenberg, 2005b; Edwards, 2008b) or cycling (Dutch Cycling Embassy (DCE), 2023; Nello-Deakin & Brömmelstroet, 2021) to and from stations and stops, with a shared motorized segment in the middle. Physical activity benefits of shifting trips from driving to transit and other active modes can provide health benefits far surpassing those from strategies focused on air quality improvements alone, such as electrifying cars to reduce tailpipe emissions. While health benefit pathways depend on local context, this importance of physical activity benefits has been shown in health impact assessments conducted in the Northeast, (Harvard T.H. Chan School of Public Health, 2021; James et al., 2014) in London, and Delhi (Woodcock et al., 2009).

NYC has long had many walkable neighborhoods (City of New York Department of Environmental Health, 2023) and has expanded its cycling infrastructure (City of New York Department of Transportation, 2019). However, faster, more comprehensive implementation of safe street designs is needed to reduce fatal pedestrian and cyclist crashes (New York Police Department, 2023) and to make adjustments in shared walkways and bike paths for an increasingly older population. Reducing private vehicle trips in favor of transit, cycling, and walking could also make more efficient use of the public right-of-way to move people, (Global Designing Cities Initiative, 2016, p. 14) freeing up space for additional trees, bioswales, and other green infrastructure, reducing local urban heat island effects, and better managing stormwater runoff, all of which may make investments in ROW even more compelling.

5.3.2 Heat, mechanical cooling, and health: applying maladaptation criteria to the local context

In NYC during the latter part of the 20th century, there was a substantial decline in excess mortality associated with higher temperature during the warm season (Petkova et al., 2014). This trend occurred nationally in association with increasing access to residential air conditioning (Barreca et al., 2013). Globally increased air conditioning prevalence from 1972-2009 was associated with reduced heat-related mortality in a comparison among several high-income countries, but the findings suggest that other adaptive strategies such as investments in green infrastructure and social connectedness may have played a more important role (Sera et al., 2020).

Without air conditioning, indoor temperatures can be much higher than outdoors, a difference that persists for up to 3 days after the temperatures have cooled off outside (Vant-Hull et al., 2018) due to thermal inertia of the building, highlighting the importance of understanding the interplay of the built and demographic character of cities. This may play a role in the delayed effects of up to 3 days documented in studies of NYC heat-exacerbated deaths (Matte et al., 2016; Metzger et al., 2010). Elevated indoor temperatures may also play a role in deaths and illnesses that occur when the outdoor temperature is moderately hot but not extreme (City of New York Department of Health and Mental Hygiene, 2022a). Those who die of heat stress in NYC are most often overcome by heat in dangerously hot homes without a working air conditioner (City of New York Department of Health and Mental Hygiene, 2022a, 2022d). Vulnerable New Yorkers most often stay at home during hot weather, even if unable to stay cool because of a lack of air conditioning (Lane et al., 2014). Other health benefits of mechanical cooling are discussed in NPCC4, Matte et al.,(2024).

Air conditioning already accounts for a substantial share of residential and commercial energy use in the US (17%, 12%) (Biardeau et al., 2020). By contrast, among energy uses in NYC's multifamily buildings, space cooling accounted for just 4% of greenhouse gas emissions in 2014 compared to 15% in commercial buildings. Across all NYC buildings, energy consumption for space heating (42%) and domestic hot water (15%) accounted for more GHG emissions that space cooling (8%) (City of New York, 2016). The need for heating and cooling will likely shift with increased climate impacts requiring increased cooling (and likely decreased heating) as well driven by population and demographic change. Air conditioning use increases peak electric demand during hot weather, and potentially outages, which are associated with health risks. The NPCC3 noted the potential for heat waves to severely stress the electric grid (Zimmerman et al., 2019). As recently as June 2021, it was reported that the major electricity outage threat during a heat wave was narrowly averted, but many neighborhoods were affected by localized outages and voltage reductions (Noor, 2021). Waste heat from building air conditioning may contribute substantially to the urban heat island, especially in dense cities (Gamarro et al., 2020; Ohashi et al., 2007) potentially adding to the risk of outages. More information on the health risks of power outages is provided in NPCC4, Yoon et al.(2024).

Substantial lock-in risks and vulnerabilities that accompanied the health benefits of mechanical cooling have already occurred over several decades in NYC, but the benefits and risks are inequitably distributed. Nearly all commercial and institutional buildings are mechanically cooled and roughly 90% of households have at least one air conditioner, but the proportions without access vary more than four-fold across neighborhoods. Households in low-income communities, and non-Hispanic Black people are more likely to lack air conditioning or report being unable to pay the added electricity cost (City of New York Department of Health and Mental Hygiene, 2022c; Lane et al., 2014; Madrigano et al., 2018). In a warming climate, the increased energy cost burden will fall hardest on these populations (City of New York Department of Health and Mental Hygiene, 2022b; Ortiz et al., 2022). The health and equity effects of energy cost burden and insecurity are addressed in more detail in NPCC4, Yoon et al. (Yoon et al., 2024).

Mechanical cooling in many large NYC buildings has been accompanied by maladaptive building design changes. During a warm weather power outage, glass façade high-rise buildings gain heat faster than comparable brick buildings (Urban Green Council, 2014). Limited operable window area and potential for passive ventilation may lock in the need for more mechanical cooling. Even when opening windows can maintain thermal comfort, a lack of screens in many modern buildings provides access for mosquitos that can transmit diseases like West Nile virus (see Section 3.5 in NPCC4, Matte et al.) (Matte et al., 2024). Raising air conditioning set points to avoid wasteful over-cooling while maintaining safe indoor temperatures can substantially reduce cooling energy use (Ortiz et al., 2022).

Other co-benefits (or costs) can be considered in building design. For example, energy efficient building design can also be bird-friendly design because increased glass on building facades increases both heating and cooling energy requirements and fatal bird strikes (Klem et al., 2009; Morris & Barges, 2023; Sheppard & Phillips, 2015). With Local law 15 (Local Law 15, 2020), NYC is already a leader in this space requiring new construction, and significantly altered buildings to use bird-friendly materials. Additionally, shade trees, green roofs, and other nature-based features can provide cooling through shading and evapotranspiration serving as key sources of heat adaptation through cooling that has potential to support reduced health-related impacts of heat exposure (Crown et al., 2023), and thus reduce the need for potentially maladaptive responses in the short-term.

5.4 Nature and Nature-based Futures

NYC is a complex social-ecological-technological system in which the ecological dimension is a fundamental driver of human health and well-being and a critical component of climate adaptation and mitigation strategies (Keeler et al., 2019; R. McDonald & Beatley, 2021; R. I. McDonald et al., 2023; McPhearson et al., 2022b). Nature and nature-based solutions have potential to provide many climate adaptation services in cities (stormwater management, urban heat island relief, flood, and erosion protection) and simultaneously provide health, social, economic, and ecological co-benefits that improve the well-being of people and support biodiversity and the function of ecosystems. In this section, we provide a brief assessment of how nature and nature-based solutions can contribute to a healthier, more resilient, equitable, and sustainable future for NYC.

As NYC prepares for increased climate change impacts, nature and nature-based solutions (NBS) can play an important role in addressing the twin crises of climate change and biodiversity loss, connecting people to nature where they live, and increasing the resilience of both people and nature. The International Union for Conservation of Nature (IUCN) defines NBS as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2020). NBS encompasses both natural ecosystems and engineered solutions that incorporate or mimic characteristics of nature to achieve the services needed by the city. Cities around the world are using NBS in innovative ways to address some of urban planning's biggest challenges (Keeler et al., 2019). One advantage to NBS over traditional engineered solutions is that they can be multi-disciplinary efforts designed to address more than just one issue and create feedbacks among urban social, ecological, and technological systems providing multiple co-benefits (McPhearson et al., 2023; Treglia et al., 2022). Because urban NBS exist in a developed urban area where the natural processes on which they depend have been disrupted, natural areas require strategic long-term management to maintain desired benefits for people and ecosystem function (Pregitzer et al., 2018; Swadek et al., 2021) and engineered NBS require a dedicated workforce trained to design, install, and maintain them (Just Nature NYC, 2021).

Natural habitats (forests, wetlands, grasslands, streams) within NYC have intrinsic value, provide valuable ecosystem services that benefit people, and support local, regional, and global biodiversity (Cullman et al., 2023). Nature-based solutions of the engineered variety are diverse and can include parks and other green spaces, street trees, green roofs, community gardens, living shorelines, rain gardens, and bioswales. In addition to the measurable benefits of heat reduction, stormwater management, and carbon sequestration provided by green and blue infrastructure in the city, some of the most important services provided by nature are those that support human health and well-being that cannot be replicated by engineered solutions (e.g. Keeler et al., 2019). Streets and ROWs that are shaded by dense tree canopy create opportunities for active mobility and recreation. Engagement in urban environmental stewardship such as tending to green spaces like building a bioswale or working in a community garden can build community identity and social resilience (Campbell, Svendsen, et al., 2021; McMillen et al., 2019).

While the utility and efficiency of NBS for climate adaptation and social and ecological co-benefits has been widely documented (Bridges et al., 2015, 2018; IUCN, 2020), operationalizing them to achieve holistic resilience benefits in an equitable way is still a developing practice (Andersson et al., 2021; Wickenberg et al., 2021; Wijsman et al., 2021). Meeting our current challenges will require planning where and how to implement these strategies in a complex city system (Hoover et al., 2023; McPhearson et al., 2022a). Inclusive engagement of communities who will experience the benefits and burdens of decisions highlights their values and explicitly centers equity and justice to avoid unintended consequences that could exacerbate inequity (Grabowski et al., 2023).

One example of an ongoing effort to address NYC's needs for equitable application of NBS is the Forest for All NYC coalition working to advance the Urban Forest Agenda (NYC Urban Forest Task Force, 2021). The coalition is composed of over 126 diverse organizations including environmental justice and community groups, City agencies, NGOs and other groups working to support and equitably expand the urban forest to benefit all New Yorkers. Coalition goals include equitably expanding tree canopy cover citywide to 30% by 2035, advocating authentic engagement with local communities, and elevating local needs and leadership. Equitable expansion of NBS in NYC has tremendous potential to transform the function of NYC systems and the well-being of its inhabitants. Just as it takes time for a newly planted tree to expand its canopy and provide heat-reducing shade, authentic community engagement to identify the right solution for the right place takes time. Investment in solutions that integrate social, ecological, and economic attributes will be instrumental in transitioning NYC into a more healthy, resilient, sustainable, and equitable city.

5.5 Benefit-Cost Analysis

Benefit-cost analysis (BCA) is a planning tool used by federal, state, and local governments, including NYC (City of New York Mayor's Office of Climate & Environmental Justice, 2022a), to evaluate whether a proposed policy, project, or regulation should be pursued. The deciding criterion is whether benefits are greater than costs. The big question in applying BCA in practice, especially with an eye toward equity considerations: benefits and costs for whom? This question must be considered across generations, with discount rate assumptions front and center, as well as equity considerations within generations. Key in the application of BCA is for all assumptions to be fully transparent. BOX 4 lays out a set of best practices and guidance for applying BCA to climate mitigation and adaptation projects (for related discussions, see NPCC4, Foster et al. (Foster et al., 2024) and NPCC4, Rosenzweig et al. (B. Rosenzweig et al., 2024)).

Challenges to monetizing benefits and costs in applying BCAs have led to the development of many other alternative decision mechanisms, including 'multi-criteria analysis', 'robust decision making', 'socially tolerable risk', 'maxi-min' to maximize the lot of those worst off, 'mini-max' to minimize the maximum downside risk, and related methods. Multi-criteria analysis, for example, is just that, adding criteria other than maximizing (monetized and monetizable) net benefits as decision tools. 'Robust decision making' comes close to recommendation #1 in BOX 4 below: focus on risks and uncertainties, in a BCA framework. While some of these analyses, like those focusing on 'fat tails' and extreme risks (i.e., predicting the probability of extreme outcomes and being "fatter" making those outcomes more likely), pose fundamental challenges to standard BCA analysis. Strictly speaking, fat-tailed distributions make BCAs literally impossible (Weitzman, 2009) yet no other decision criterion comes close to the overall rigor and internal consistency of BCAs when *properly* applied. One downside is that unquantified and perhaps even unquantifiable risks and uncertainties might indeed dominate, which requires developing proper frameworks to deal with true 'unknown unknowns'. Practically, it might mean treating the outcome of a BCA as the 'lower bound' of large potential range of outcomes.

BOX 4: BCA guidance and best practices.

Be explicit about risks, uncertainties, and biases

BCA, in the broadest sense, is merely an attempt to compare like with like, typically by translating benefits and costs of any (policy) action — or the lack thereof — into dollars and cents. Therein begin the problems: calculating 'cents' would immediately imply false precision, false accuracy, or worse — leading to a fundamental confusion of precision with rationality (Brookes & Wagner, 2021). Users of this tool must be careful not to fall into that trap.

Every BCA is biased. The question is which way these biases go. For individual public works projects such as local adaptation measures, benefits are sometimes overestimated while costs are often underestimated. The latter is due to the inherent delays and cost overruns. For example, costs are based on third-party bids, which are incentivized to lower their costs. Delays, inflation, additional regulatory burdens, and other reasons, meanwhile, lead to increased costs. Adaptation benefits, too, might be underestimated largely due to missing quantifications of 'indirect' benefits. Underestimates of both benefits and costs now leads to the need to trading off the relative biases, a task made more difficult because even the signs of biases might change with the type of projects analyzed (Flyvbjerg & Bester, 2021).

For climate mitigation BCAs, the biases often go the other way — with costs of cutting emissions often overestimated (sometimes, substantially so) while societal benefits are underestimated. The latter is largely due to difficulties and delays in quantifying expected climate benefits and other risks and uncertainties. The former might be even more important: Biased cost estimates are due to the rapid nature of technological change and improvements in mitigation technologies and processes. The overall result is a bias toward inaction (Wagner et al., 2021).

Any BCA tools developed need to allow for presenting risks, uncertainties, and biases — at the very least by presenting 'high' and 'low' estimates in addition to 'best'/'average' results. Ideally, BCAs would span full-fledged uncertainty analysis, relying on probability density functions rather than point estimates. That process, too, might introduce false precision by forcing guesstimates of uncertainty ranges that are unmeasurable. Sometimes then, these biases necessitate moving (well) beyond BCA as a decision-tool. When examining risks and uncertainties, and the appropriate step could be to look toward direct 'risk-risk tradeoffs' (Zeckhauser & Wagner, 2019) a BCA emphasizing the probability of extreme impact risks (sometimes called tail risk).

Efficacy, cost-effectiveness, and equity

One danger of applying BCAs is elevating narrow interpretations of (economic) efficiency above all else, including important distributional considerations. That would be a mistake and misapplication of the concept — and also presents an important stumbling block in socializing and getting broader buy-in for BCAs. A SETS approach could also benefit BCA. Though BCA do well in terms of efficacy and cost-effectiveness, they could more explicitly include equity and co-benefits (such as in health and nature outcomes) as part of the BCA calculations.

A first step to avoid this fallacy is to explicitly split efficiency into efficacy and cost-effectiveness, and to add equity as an explicit additional criterion, at least in any narrative describing the analysis. Enlightened BCAs can span all three, with 'equity weights' explicitly incorporating effects of inequality (Anthoff et al., 2009). City-level applications might pose additional challenges, but that does not excuse their absence in BCAs. If anything, it calls for a shared understanding of the need to incorporating equity considerations into BCAs and standardized approaches across city agencies to do so.

Applying equity weights and putting distributional impacts front and center are important in lending BCAs much-needed legitimacy. Case in point is the U.S. Interagency Working Group on the Social Cost of Greenhouse Gases, which ended in U.S. government agencies agreeing to disagree, and for U.S. EPA to go it alone with its own SCC (U.S. Environmental Protection Agency, 2022). The separation of efficacy and cost-effectiveness, meanwhile, might be less important in the final analysis. BCA clearly spans both.

Train, engage NYC agency staff to help conduct BCA analyses

Some agencies like DOT already conduct their own BCAs. Other agencies outsource theirs. Since many agencies are now considering how to mitigate and especially adapt to climate change, thus establishing capacity and consistency across agencies' effort may be an important city-wide objective. BCAs, and the framing they provide, could be one important parts of this process.

6 Limitations of Future Scenarios and Approaches

Despite the variety of scenarios and current approaches for envisioning the future of NYC and its many transitions, they also have recognized limitations. Among these limitations are shortcomings in the degree of understanding about who and where future New Yorkers will be living and working; lack of a longer-term perspective on lessons from relevant policies in the recent past with place-based implications; lack of comprehensive comparisons between approaches; and the need to consider these projected futures in an integrated way across the multiple sectors and dimensions of NYC's urban systems. While it is a sizeable challenge to describe integrated, multi-sectoral, plausible pathways to positive futures for NYC, providing details of how future events might unfold can limit anxiety toward worrisome future events and reduce the perceived likelihood of negative outcomes (Jing et al., 2016).

Discussing uncertainty allows us to better understand the range and parameters around different futures. Low probability events (such as catastrophic flood expected to occur once in a 1000 years) with high magnitude and potential for damage cannot be predicted but can be projected recognizing that such projections come with high uncertainty due to the low probability nature of such events. Another challenge inherent in projecting or envisioning the future is that it may include events or disturbances that we have yet to experience, or even imagine. The COVID-19 pandemic and Hurricane Ida (in which the City for the first time issued a flash flood warning), are other examples of events that in the past many planners would have considered unlikely, but nonetheless have now occurred. Lastly, unforeseen and unintended consequences of plans add another layer to uncertainty and while the magnitude of such consequences can often not be forecasted, narratives around such consequences can often be articulated.

6.1 Climate Actions and Plans Can Be Adaptive or Maladaptive

Plans and actions to enable resilient futures can be adaptive or maladaptive. Maladaptation describes actions that lead to increased vulnerability or risk to climate impacts or diminish welfare. The IPCC describes responses to climate change that unintentionally "create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change and exacerbate existing inequalities" as maladaptive. Understanding the processes leading to maladaptation can help prevent it. Whether an action is maladapted or not can depend on social or environmental context, scale, or time. In some cases, maladaptive responses to hazards have exacerbated inequality in the distribution of impacts, for example shifting risk from one community or group to another.

There are a variety of causes of maladaptation, including lack of knowledge. For example, early in the 20th Century, health officials recommended substituting the new automobile technologies to replace horses. Horses created excrement and often died on city streets, creating safety and health hazards. Health officials argued the automobiles were a good, healthy solution to urban horse use (McShane, 1994; Melosi, 2000; Tarr, 1971), only to see rising injuries, deaths, traffic congestion, and other problems caused by the flooding of cars into cities. Similarly, unintended consequences of segregated land use zoning, which was originally put forth to keep residents away from industrial locations, included it becoming a tool for creating segregated suburban communities (Jackson, 1985). Alternatively, maladaptation can also occur through plans, policies, or investments that consider sectors and climate risks in isolation or that ignore climate risks for what are seen as more urgent planning priorities. In the local context, this has involved, for example, policies that subsidize and encourage driving, parking, and car ownership, removing electric streetcars, widening surface streets and building urban highways without considering implications for health, safety and equity and, more recently climate risks, equity, and mitigation goals. Maladaptation can also result if climate risks are not considered in "non-climate" policies that influence climate risks, such as those governing zoning, building codes, and affordable housing.

For example, building walls to keep floodwaters out of low-lying areas can be a critical source of coastal flood protection but may also be maladaptive over longer time frames because sea walls can give a false sense of security, encourage additional development in flood-prone areas, limit public access to the water, exacerbate erosion, negatively impact coastal habitats, and may be built to design guidelines that become quickly outdated as sea level rise and storm surge projections change over time (Dodman et al., 2022). Structural mitigations like floodwalls can also result in "resilience gentrification" resulting in greater inequality (Gould & Lewis, 2021). Floodwalls and tide gates are generally designed for a single purpose, and as such, may fail to meet the complex needs of a city. Indeed, NYC's flood reduction strategy must address multiple compound flood hazards including storm surge, regular tidal flooding, groundwater flooding, heavy rainfall and compound flooding (see NPCC4, Rosenzweig et al.(B. Rosenzweig et al., 2024)), but it must also balance flood protection with other resiliency needs such as sustainable economic development, social equity and affordable housing, and biodiversity and the protection of nature that together will support resilience of the city long term.

Several evidence-informed criteria can be applied to assess whether actions are adaptive or maladaptive within the local context of NYC and its diverse communities. One example, the use and expansion of mechanical cooling in several types of NYC buildings, was considered in Section 5.3.2 . Elsewhere in this assessment, measures are described to reverse or reduce maladaptation in other sectors, including the public right of way, mechanical cooling in buildings, and flood protection. For most adaptation strategies, recognizing inherent feedbacks among system components (such as between use of air conditioning to reduce heat risks that may also increase energy use and increase carbon emissions) will be critical to ensure intended adaptation approaches do not become or enhance maladaptation in other systems, contexts, or timescales. Similarly, trade-offs are likely to exist for all adaptation strategies, including spatial trade-offs such as where adaptation in one location may increase and thus drive maladaptation in other locations. Whether maladaptation occurs thus depends on whether a particular strategy or climate adaptation action is examined for larger potential trade-offs, cross-sector impacts, and longer-term effects versus short-term outcomes.

6.2 Uncertainty

There are many uncertainties that must be accounted for in estimating and planning for the future. Like weather forecasts, these include temporal and spatial factors and pertain to the social and ecological themes as well as climate-related factors: It is more difficult to predict the future, the farther one goes, and predicting changes that will occur in precise locations (specific neighborhoods) is much less certain than in larger spatial units (all of NYC, or the greater metropolitan area). The IPCC has been a leader in thinking about ways to address uncertainty in the future climate, examples from which are shown in BOX 5.

In addition to understanding climate futures, each sector, and within those particular themes (or variables of interest), produces models that generate futures that quantify or qualify uncertainty in different ways. Typically, there are trade-offs between spatial and temporal uncertainty, which make futuring exercises at a long-term sub-city scale challenging. Furthermore, models used to predict the future have their own uncertainty associated with the data and estimation techniques. While we have identified many of these areas of uncertainty in this chapter, future work on understanding and communicating uncertainty inherent in city scale issues remains to be done.

BOX 5: How the IPCC contextualizes uncertainty

"Impacts at high levels of warming are particularly uncertain, as all methodologies require extrapolation and insufficiently incorporate possible tipping elements in the climate system (from IPCC WGII Ch.16 (O'Neill et al., 2022)).

"Unlike known or identified risks, emergent risks are characterized by the uncertainty of consequences and/or probabilities of occurrence. The International Risk Governance Council (IRGC) suggests three categories of emergent risks: (1) high uncertainty and a lack of knowledge about potential impacts and interactions with risk-absorbing systems; (2) increasing complexity, emergent interactions and systemic dependencies that can lead to nonlinear impacts and surprises; and (3) changes in context (for example, social and behavioural trends, organizational settings, regulations, natural environments) that may alter the nature, probability and magnitude of expected impacts." (O'Neill et al., 2022).

Figure 16.1 illustrates the elements covered by the chapter, which can be summarised as four key questions

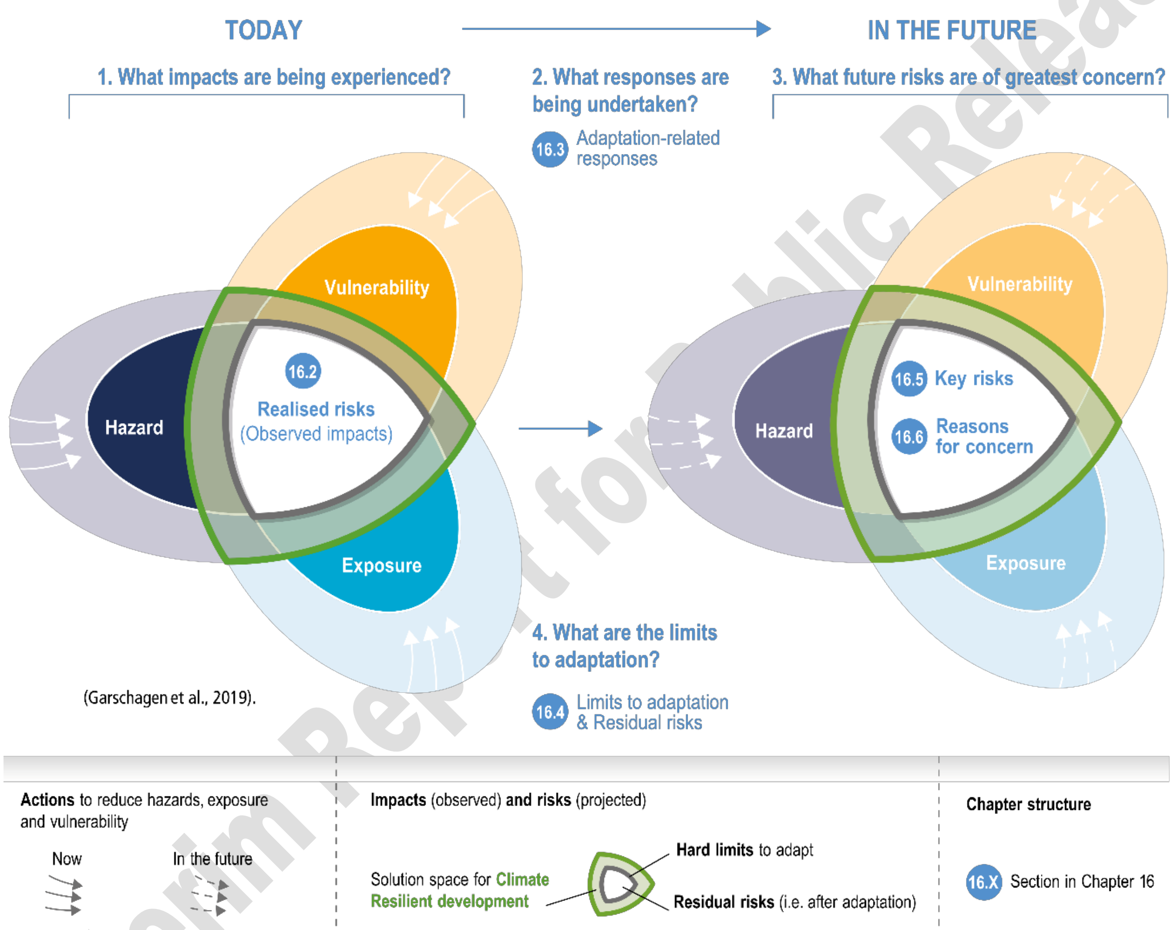


Figure16.1 | Illustrative storyline of the chapter highlighting the central questions addressed in the various sections,from realised risks (observed impacts) to future risks (key risks and reasons for concern), informed by adaptation-related responses and the limits to adaptation. The arrows illustrate actions to reduce hazard, exposure and vulnerability, which shape risks over time. Accordingly, the green areas at the centre of the propeller diagrams indicate the ability for such solutions to reduce risk, up to certain adaptation limits, leaving the white residual risk (or observed impacts) in the centre. The shading of the right-hand-side propeller diagram compared with the non-shaded one on the left reflects some degree of uncertainty about future risks. The figure builds on the conceptual framework of risk–adaptation relationships used in SROCC (Garschagen et al., 2019).

Figure 10. Realized risks (observed impacts), future risks (key risks and reasons for concern), adaptation-related responses, and the limits to adaptation. Chapters identified here refer to IPCC6, WGII. Source: O'Neill et al., (2022, p. 2419)

The challenges of managing these risks are amplified by the complex interactions between climate and urban scenarios, owing to the smaller spatial–temporal scales of urban areas in climate change modelling relative to global climate models (GCM) and shared socioeconomic pathways (SSP); geographical or geomorphological variations in city location; uncertainties arising from incomplete assumptions about socio-economic pathways at urban scales affecting demographic characteristics of cities, etc.

7 Sustained Engagement Through New York City Climate Knowledge Exchange

Sustained engagement is a foundational component of sustained assessment and may contribute to building communities of practice and establishing a public agenda for climate research. Through the sharing of knowledge about ongoing efforts across the City, sustained engagement with city government agencies, community groups, academics, and others can help to foster informed decision-making, build community capacity and empowerment, and inform the development of effective communications tools. Sustained engagement helps to identify current gaps in knowledge and practices and create a process for discourse and knowledge sharing about how to effectively plan for adaptation in the short and medium term.

In 2020, the Mayor's Office of Climate and Environmental Justice (MOCEJ) initiated the Climate Knowledge Exchange (CKE), a sustained engagement process to identify the City's climate research priorities and co-produce a future public climate research agenda for the City. In Year 1, the CKE brought together over 170 participants from city agencies and NGOs in small discussion groups. Using a combination of thematic analysis from the discussions, document review of existing community based and government plans and analysis of survey data, MOCEJ developed an agenda for future climate resiliency and adaptation research: 1) Living with Climate Change, 2) Managing Resiliency, 3) Climate and the Built Environment, and 4) Climate Communication, Education, and Engagement. For more details on each research priority, see the State of Climate Knowledge 2021 Report (City of New York, 2022). Participants also identified future areas of improvement for the climate knowledge exchange process, including create sustained partnerships and build awareness of ongoing efforts, raise funding to support community participation in research initiatives, improve information sharing and knowledge development, recognize multiple ways of knowing, and evaluate outcomes of the CKE process and research.

These improvement areas helped to inform Year 2 of the CKE, which took a step back from Year 1 to refine the design of the engagement process to achieve the CKE's broader objectives using the Theory of Change (TOC) framework. A TOC is a tool for planning, implementing, and evaluating an initiative, and typically includes a statement of the problem being addressed, an overarching end goal, and short, medium, and long-term pathways to achieve the end goal. Through a series of three workshops in 2022, participants co-produced a TOC for the CKE. The five key goals identified, and informed by Year 1 improvement areas, were: Sustained funding is achieved; information is accessible to all; networking and partnerships with stakeholders are created and maintained; multi-way exchanges to empower and elevate communities are established; and Brave spaces for listening and learning are fostered. A full description of the workshops and outcomes is available in the State of Climate Knowledge Exchange 2022 Workshop Summary Report (City of New York, 2022).

The city continues the CKE, currently in Year 3, as a forum for sharing information, research, and initiatives amongst a diverse group of city and state agencies, community organizations, nonprofits, and academic institutions. The CKE is one model of sustained engagement processes, and going forward, others may also be adopted.

8 Conclusion and Future Research Needs

This chapter has illustrated how interacting dimensions of the complex nature of NYC, including intersecting social, ecological, and technological-infrastructure system domains, are essential to address in order to transition to a climate-adapted future that protects all New Yorkers. We reviewed a range of approaches to futures and scenario development processes as part of the emergence of scenario planning to guide decision-making for climate adaptation and mitigation in the city. We also reviewed community-based planning and opportunities to integrate community and stakeholder ideas about what would make NYC more livable, equitable, and resilient. By assessing these current approaches to future visioning and scenarios across community and city level initiatives and examining these diverse dimensions of the NYC system to reduce risk and vulnerability, we find that city as well as a multitude of community organizations are engaged in a wide range of adaptative planning; although these are largely oriented to near-term objectives and strategies and are mostly framed around sectoral concerns.

While long-term visioning has been part of the City's planning efforts in the past, no current plan, let alone a demographic forecast, matches the end of century dates of the climate projections, and represents a gap in long-term planning need to guide NYC decision-making that looks beyond the near term to actions now that will impact the city later this century. The future NYC will be increasingly older, and there is little to suggest that it will not continue to thrive as a diverse city. But whether the NYC of 2100 is more or less populous than today is unknown. Further, whether future New Yorkers increasingly live in flood-prone neighborhoods or heat-prone housing – let alone whether such risks will be born unequally according to race and ethnicity, or socioeconomic or nativity status – remain unknown. Yet these unknowns are modifiable by tools, planning and policy; and planning for a range of possible outcomes is increasingly necessary. Thus, there is need for increased multi-sector, multi-hazard long-term planning initiatives, and future research can help to evaluate, assess, and monitor the progress of these planning initiatives, as well as the capacities and collaboration of community-based organizations and government entities to implement the plans.

Though the are many tools that could drive policymaking and decisions about how to prioritize investments, BCA remain influential in deciding what gets built (or invested in), how, and by whom. BCA of policies and future investments still have not typically included valuation of costs associated with climate-sensitive health conditions. Including health-related costs in these analyses can more fully capture the benefits of avoidable health costs and be more forward-looking by accounting for future population shifts and future climate projections. Additionally, health impact assessment can be a useful tool for estimating health co-benefits of climate actions and assessing their distributional equity. Such tools are already well established, but their application to climate adaptation and mitigation is still new and therefore underutilized.

Many aspects of the built environment (such as infrastructure) have been addressed by prior NPCCs. In this chapter, we took a novel look at NYC's public ROW (streets and sidewalks) and found that this valuable shared resource has the wide potential to be transformed to better support climate adaptation, health, and equity. Near-, medium-, and long-term changes to how streets, sidewalks, and other public spaces that are part of the public ROW are designed, governed, and managed at different spatial scales can begin to reverse maladaptive uses and enable a more sustainable future, yet aspects of the public ROW need to be incorporated in a range of planning and knowledge-gathering initiatives. This chapter did not review issues in the housing sector in any detail, and notes that housing quantity and quality remains an important issue for future NPCCs to address fully.

People and nature co-exist in NYC, but NBS are often siloed despite acknowledgment of their many co-benefits including those on physical and mental health. Furthermore, the benefits of nature are not evenly distributed across the city. Thus, investment in NBS alongside other engineered and social approaches to adapting to increasing climate impacts may have broad potential. Examples of these adaptations can include increase investments and plans for natural area restoration, conservation, and protection alongside new hybrid and green infrastructure installations including expanding tree canopy and installing green roofs and bioswales. As noted above with health impacts assessment and BCA, NBS must include intentional equity dimensions in their implementation in order to ensure that they not do not reinforce or exacerbate historical inequities and that they work to making NYC more sustainable for all.

Systems approaches such as that of the SETS framework are needed to ensure adaptation and mitigation decisions do not occur in siloes; rather they consider a range of futuring options that accommodate feedbacks to other sectors and subsystems. For example, mechanical cooling, while maladaptive in some applications, has helped reduce heat health impacts among vulnerable populations. Yet long-term investments in cooling the city to protect residents from high heat impacts need to consider nature-based and other systemic solutions to cool the city, while recognizing the need for mechanical cooling to reduce heat impacts during high heat events. Overall, maladaptive and wasteful uses in NYC buildings should be reduced to avoid increasing energy use and emissions as access is expanded.

It is increasingly clear that equity and social justice are critical to inclusive climate adaptation goals, implementation efforts, and future planning. Centering equity in climate adaptation and mitigation actions provides an opportunity to decrease impacts on the most vulnerable while creating more inclusive processes that center community voices in climate adaptation and mitigation planning, policymaking, and investments decisions. This means that tools for planning must allow for explicit attention to equity concerns.

Prior NPCCs have noted the need for regular and meaningful indicators of climate impacts in perpetuity. This NPCC finds equal imperative in the City's commitment to regular and meaningful monitoring of adaptation progress. Such meaningful and transparent indicators, and related fora for exchange such as the CKE, are important so that the agencies of city government, and other civil actors, as well as the public can observe and engage in the city's progress toward a more sustainable and equitable future.

As part of the first NPCC Futures and Transitions Working Group, this chapter has contributed to imagining, visioning, and planning the future of NYC. It introduced frameworks that would allow for longer demographic projections consistent with socioeconomic futures that are plausible given a range of climate futures and social-ecological-technological systems (SETS) that model complex urban dynamics with a range of cascading influences and feedbacks. These new frameworks offer longer-term scenarios to guide the decision-making today and, with continued use, in the future. Going forward, much work remains to be done to assess the alternative projections, visions and scenarios, and their inherent uncertainties, but so doing will build the necessary tools for a climate adapted, sustainable, and equitable future NYC.

9 Traceable Accounts

Key Message 1	NYC is projected to be hotter, wetter, and more flood prone, with multiple types of tropical and winter storms that are likely to increase in frequency, intensity, and severity. At the same time, the population of the city is expected to age. Long traditions of in- and out-migration have shaped the city and are expected to continue to be an important part of its future, anchoring it in the region and the nation. The built environment will largely remain in place, yet changes in land use and land cover, including in impervious and natural areas are expected. Managing and planning the future NYC to be more adapted and resilient to diverse climate, economic, and social pressures will require understanding these diverse futures that also interact dynamically in real-time.
Description of Evidence	The Climate Science Special Report (Braneon et al., 2024) lays out the future climate conditions for NYC. Projections of population, which describe future aging patterns and the total size of NYC's population in the short and medium term, are produced by NYC's Department of City Planning (2013) to 2040 and New York Metropolitan Transportation Council (NYMTC) (New York Metropolitan Transportation Council, 2020b) to 2055. Historical evidence shows that NYC has become increasingly diverse in terms of its racial and ethnic composition since 1950 (City of New York Department of City Planning, 2023b). See KM8 for evidence on changes to the natural environment.
New Information and Remaining Uncertainties	Population futures that match the temporal scale of the climate projections, out to 2100, do not yet exist, and therefore those uncertainties remain hard to describe (Balk et al., 2022). Evidence from work done for US States (Zoraghein & O'Neill, 2020a, 2020b) indicates that the total population of NYC at mid- and end of the century could be larger, smaller or about the same size as it is now, depending in part upon which climate future is used to inform that future population trajectory. Such projections for NYC, that will include spatial downscaling in order to assess future impacts of climate hazards, are underway as part of Task 4 of the NYC Vulnerability, Impacts and Adaptation Assessment (VIA) project; these will project the population by race/ethnicity and age out to 2100.
Assessment of Confidence based on the Evidence	The evidence that NYC will remain diverse, continue to be a home to migrants (both domestic and international), and that its population will become older (as will the rest of the country) is very high with strong evidence. Levels of each of these compositional characteristics is less certain, as is the spatial distribution.
Key Message 2	Future complexity and uncertainty due to climate change demands new ways to plan our cities. Scenario-based planning can incorporate important urban dynamics and complexities and uncertainties common to the non-anecdotal challenges of the Anthropocene that other planning tools cannot, partly by addressing uncertainty over the mid-to-long term. By incorporating scenario planning into NYC futuring exercises, a range of new opportunities for envisioning and shaping health, social, environmental, economic, and population change outcomes can be applied to meet broad or sectoral adaptation and mitigation planning.
Description of Evidence	Scenarios, as future tools, have consistent internal logic and coherent narratives useful in addressing complexity and uncertainty (Díaz et al., 2019; Iwaniec et al., 2014; Moss et al., 2010; Reid et al., 2005). While these tools have been deployed at the global scale, less work has been done at regional or city scales (Reimann et al., 2021; Rohat et al., 2021). Historically, localities have focused on predictive scenarios or forecasts, that extrapolate future conditions based upon predefined models of historic and existing trends (City of New York Department of City Planning, 2013, 2023b) and are relatively short-term projections (Balk et al., 2022). Moreover, most of these plans focus on land use zoning needs based upon economic and population growth (see review in Balk et al.(Balk et al., 2022)).
New Information and Remaining Uncertainties	Planners have started employing scenarios in local development analyses (Finn & Miller, 2022). While scenarios promise to provide new insight, issues to watch out for include adequate consideration of uncertainties, an overemphasis on "picking" a preferred future (Chakraborty et al., 2011), and a lack of effective public involvement (Bartholomew, 2007).
Assessment of Confidence based on the Evidence	Localities could use scenario planning in a variety of development plans (High Confidence). Questions remain, however, about how best to move forward and incorporate scenario approaches in both private and public planning exercises.

Key Message 3	Equity and social justice should be explicitly centered in future climate adaptation goals, implementation efforts, and future planning. Planning without centering equity will likely result in unintended negative consequences, such as gentrification or displacement, which exacerbate inequity. Centering equity in climate adaptation and mitigation actions provides an opportunity to decrease impacts on the most vulnerable.
Description of Evidence	Historical evidence shows that NYC has become increasingly diverse in terms of its racial and ethnic composition since 1950 (City of New York Department of City Planning, 2023a). Persons of color are more likely to lack air conditioning or report being unable to pay the added electricity cost amplifying the burden of future heat in communities of color (City of New York Department of Health and Mental Hygiene, 2022d; Lane et al., 2014; Madrigano et al., 2015). For example, gentrification, or the displacement of populations from neighborhoods due to rising property values, increasing rents, upzoning, and other core gentrification drivers are an increasing concern among vulnerable communities in NYC (Foster et al., 2024). Additional evidence is reviewed in the NPCC4, Foster et al (Foster et al., 2024).
New Information and Remaining Uncertainties	Health impact assessment can be a useful tool for engaging community stakeholders in ways that enhance procedural equity and shed light on distributive equity of proposed actions (Foster et al., 2019; Sohn et al., 2018). Future population projections by race/ethnicity and that are spatially specific would also help the city guide response with an equity lens (Balk et al., 2022).
Assessment of Confidence based on the Evidence	Counterfactuals (that is, the ability to show the results had a given plan not been implemented) is hard to observe at a city scale, yet evidence from a variety of plans and programs with equity goals is a helpful precondition for equity goals to be met. Very high confidence and strong evidence.
Key Message 4	NYC is dynamic, and the scale and complexity of NYC requires managing interacting socio-economic, ecological-biophysical, and technological-infrastructure components. However, there is often a lack of understanding by planners of the fundamental drivers of behaviors and patterns that are important for planning and designing more resilient, equitable, and adapted NYC and metropolitan region. Inherent in these interdependencies are trade-offs between temporal and spatial scales in planning activities, as well as between sectors; identifying these trade-offs is integral to transparency in planning and adaptation. Incorporating approaches that acknowledge interdependencies in future planning will prevent a siloed understanding of trade-offs and uncertainties.
Description of Evidence	Cities have many interacting and interdependent social-economic, ecological-biophysical, and technological-infrastructure systems and NYC is at risk from climate change precisely because of its dense concentration of people, infrastructure, and economies. Transforming NYC to be flexible, adaptive, and resilient requires the capacity to build, design, and plan for complexity (Chester et al., 2023; McPhearson, 2020). To ensure that climate solutions don't create unintended trade-offs, or maladaptation, it is important to account for the interdependencies among social, ecological, and technological infrastructure components of urban systems (E. M. Cook & McPhearson, 2020; Grabowski et al., 2017; Grimm et al., 2016, 2017; McPhearson, 2020; McPhearson et al., 2021, 2022b; McPhearson, Iwaniec, et al., 2016).
New Information and Remaining Uncertainties	Recent extreme events demonstrated failures or inadequacies not just in the built infrastructure but also in resources, institutions, information, and governance systems—components of the urban SETS—to prepare for, and respond to, events of this magnitude (Eakin et al., 2018). There also remaining uncertainties in best practices for identifying and comprehensively assessing trade-offs across sectors and spatial and temporal scales to inform future decision-making (Zeckhauser & Wagner, 2019) . More research is needed on approaches that focus on identifying trends and uncertainties that would allow decision makers to overcome siloed or short-term planning as needed (Balk et al., 2022; Schoemaker, 1995).
Assessment of Confidence based on the Evidence	To advance governance for resilience means also advancing our ability to understand such complex urban dynamics and develop near and longer-term scenarios to guide decision-making. There is high confidence that without significant investment in transparency and cross-sectoral collaboration, there will continue to be siloed planning initiatives and unintended tradeoffs that will hinder future resilience and adaptation. There is high confidence and moderate evidence through a quickly emerging body of literature that a social-ecological-technological systems (SETS) approach can improve ability to examine

	complexity of cities and examine trade-offs across sectors and scales. This body of literature is expanding globally, as well as for NYC empirical case studies.
Key Message 5	In the context of climate change risks in NYC and the metropolitan region, changes in key sectors and deployment of technologies have included some which are adaptive and beneficial and others that are unintentionally maladaptive, causing risks and inequities that are costly to reverse. The adaptive or maladaptive potential of such changes have depended on the extent to which their costs, benefits, and risks are balanced and equitably distributed. Local examples considered in this chapter include mechanical cooling, flood protection measures, and spatial allocation of the public right of way (ROW, mainly streets and sidewalks). Maladaptation can be caused by ignoring climate risks and equity considerations and by siloed planning, within and among sectors, levels of government, government agencies, non-governmental institutions, and the private sector. Potential for maladaptive and inequitable effects of climate adaptation strategies and other sectoral actions influencing climate risks should be weighed to ensure that near-term actions are not maladaptive in the long term.
Description of Evidence	Abundant and robust evidence shows that key technologies in NYC have been deployed in ways that have been both adaptive and maladaptive and inequitable; evidence-informed approaches can inform potential for adaptive and equitable sectoral transitions. Mechanical cooling of residences has greatly reduced deaths caused by hot weather in NYC and nationally (Petkova et al., 2014) (Barreca et al., 2013) and provides other health benefits (Matte et al., 2024). Widespread but inequitable access contributes to greater heat vulnerability in low-income and non-Hispanic Black populations (City of New York Department of Health and Mental Hygiene, 2022c; Lane et al., 2014; Madrigano et al., 2018). Much larger sources of building energy consumption include space heating, provision of hot water, and space cooling in commercial buildings (City of New York, 2016). Building designs vary in their adaptation to hot weather (Urban Green Council, 2014)). Evidence concerning maladaptive and adaptive uses of the ROW is considered in KM 7. Evidence concerning maladaptive and adaptive flood protection measures is considered in NPCC4, Rosenzweig et al (B. Rosenzweig et al., 2024).
New Information and Remaining Uncertainties	Emerging and future developments in mechanical cooling technologies, the potential efficacy of scaling urban heat island mitigation measures, future energy transition challenges (Yoon et al., 2024), and proposed new policies (City of New York Office of the Mayor, 2023) add uncertainty to forecasting future benefits, costs, and inequities that mechanical cooling might create. Uncertainties concerning the public right of way are considered in KM 7. Uncertainties concerning flood protection measures is considered in NPCC4, Rosenzweig et al (B. Rosenzweig et al., 2024).
Assessment of Confidence based on the Evidence	There is high confidence that mechanical cooling, use of the ROW, and flood protection have been deployed locally in ways both adaptive and maladaptive and that it is feasible to begin transitions to more adaptive uses.
Key Message 6	Without shared positive visions for the future, it is unlikely that plans made now will achieve the equity, justice, sustainability, and resilience goals desired for the future of NYC and its communities. Participatory processes are critical in co-developing shared visions that bring together diverse perspectives and forms of knowledge, and a sustained engagement process is critically needed to identify the City's climate research priorities and co-produce a future public climate research agenda for the city. Co-produced visions, goals, and strategies can involve perspectives across multiple sectors, scales, and communities to gather the full range of ideas, innovations, and possible actions to address trade-offs and inform transitions toward a climate-adapted future for NYC. However, tools for longer-term (beyond 2050) transitions and pathways to achieve future plans for NYC are currently missing and needed to guide efforts to secure an inclusive climate resilient future for all New Yorkers. In order to track progress towards these goals, periodic and systematic monitoring and evaluation are necessary.
Description of Evidence	Shared positive visions of the future can help to address the barriers to action of dystopian or negative framings of the future (Iwaniec et al., 2020; McPhearson, Iwaniec, et al., 2016). Co-production processes that bring together a range of perspectives and stakeholders have already been employed in NYC (City of New York, 2022; E. Cook et al., 2022). An analysis of government and community-based plans in this chapter indicated that most plans have short or mid-term timelines, and very few focus on the long-term (Figure 3).

New Information and Remaining Uncertainties	There are remaining uncertainties as to how to effectively engage community members and community-based organizations and more meaningfully learn from and integrate their expertise into planning initiatives while addressing redundancies in community engagement across sectors or agencies (E. Cook et al., 2022). More research is needed on effective methods to evaluate progress on co-production and community engagement in planning.
Assessment of Confidence based on the Evidence	Without improved processes such as those that are co-produced or others that are integrated into resilience planning, there is high confidence that we will continue to replicate historic trends and mistakes in resilience planning without the multiple perspectives and innovations that co-production processes generate.
Key Message 7	Transitioning the built environment to be more climate resilient while addressing fundamental challenges to equity and sustainability requires policies and investments to retrofit, rebuild, and improve the built infrastructure to support population health. Prioritizing active and sustainable modes, including transit, walking, and cycling can provide multiple, equitable health benefits through increased physical activity, reduced air pollution exposure, more affordable transportation options, and reduced risk of conditions that increase vulnerability to climate change. At the same time, reducing miles driven by private motor vehicles within, into, and out of the city will reduce greenhouse gas remissions and expand space available on streets and sidewalks for uses that provide climate resilience and social and equity benefits.
Description of Evidence	Extensive evidence shows that active transportation modes, including public transit, promotes regular physical activity that confers multiple health benefits (Besser & Dannenberg, 2005a; Edwards, 2008a; Gaesser & Angadi, 2021; Heath et al., 2012a; Saint-Maurice et al., 2022; The Community Guide, 2017) (Besser & Dannenberg, 2005b; Edwards, 2008b) (Dutch Cycling Embassy (DCE), 2023; Nello-Deakin & Brömmelstroet, 2021). Studies also show that policies promoting motor vehicle traffic cause congestion in densely populated areas, increase exposure to air pollution (Bosson et al., 2019; Khreis et al., 2017; Yang et al., 2018) and increase crash risks for pedestrians; these risks are inequitably distributed (Kheirbek et al., 2016a; Lubbe et al., 2022; Smart Growth America, 2022). Such policies also limit space available for safe, healthy, active modes. Spatial allocation of NYC's public right of way (ROW, mostly streets and sidewalks), has prioritized the movement and parking of private motor vehicles (Czebotar, 2021; Freudenberg et al., 2021) over more spatially efficient modes (National Association of City Transportation Officials, 2016). The amount of paved impervious surface required contributes to climate risks from heat and flooding (Mohajerani et al., 2017) (Madrigano et al., 2015; B. Rosenzweig et al., 2024). Potential strategies and examples of adaptive transition of the ROW have been described and demonstrated in NYC and elsewhere (Freudenberg et al., 2021) (Aaron, 2011; Brugge et al., 2015; Pestel & Wozny, 2019; Zhai & Wolff, 2021) (City of New York, 2019; City of New York Department of Transportation, 2023c, 2023b, 2023a) (City of New York Department of Transportation, 2022; Sam Swartz, 2019).
New Information and Remaining Uncertainties	Emerging changes in the transportation sector within and around NYC create opportunities, implementation challenges, and some uncertainty about the potential for transitions that provide health and environmental co-benefits. These include the advent and implementation of congestion pricing (Slevin, 2019), electrification of buses (Sustainable Bus, 2022; Zhou et al., 2016), state and national subsidies promoting battery electric private vehicles, which share most maladaptive features of fossil fueled vehicles (Kelly & Zhu, 2016; Requia et al., 2018), and the expanded use of delivery apps and motorized two wheeled vehicles (Cohen, 2023; DiMaggio et al., 2020).
Assessment of Confidence based on the Evidence	Despite challenges and uncertainties, there is high confidence that sustainable and active transportation investments and policies, including reallocation of space on streets and sidewalks can advance NYC health, equity, and environmental goals.
Key Message 8	Nature-based solutions are critical for addressing climate adaptation needs in the city and can simultaneously provide co-benefits for public health, society, and natural systems that help create a resilient city. Planning, implementation, and management of nature-based solutions to achieve equitable distribution and holistic resilience in a complex city system is still a developing practice.
Description of Evidence	Nature-based solutions have the potential to provide many climate adaptation services in cities and when strategically designed to do so, have the potential to simultaneously provide health, social, economic, and ecological co-benefits that improve the well-being of people and support biodiversity and the function of

	ecosystems (Campbell, Cheng, et al., 2021; Keeler et al., 2019; R. McDonald & Beatley, 2021; R. I. McDonald et al., 2023; McPhearson et al., 2022b).
New Information and Remaining Uncertainties	Measuring the delivery of social-cultural benefits and the avoidance of disservices is still a developing and evolving practice that needs to be more fully developed to measure whether NBS deliver promised co-benefits and avoid unintentional disservices (Andersson et al., 2021; Campbell, Cheng, et al., 2021; Hoover et al., 2023; Wickenberg et al., 2021; Wijsman et al., 2021). The Forest for All NYC coalition is an ongoing collaborative effort with great potential that incorporates procedural and distributional equity in an effort to advance equitable expansion of the Urban Forest in NYC so that it can benefit all New Yorkers (NYC Urban Forest Task Force, 2021).
Assessment of Confidence based on the Evidence	Because measuring effectiveness is a developing field, with some early evidence (e.g. Campbell et al. (Campbell, Cheng, et al., 2021)) there is medium confidence that if NBS are designed and implemented with social-cultural benefits and avoidance of disservices like green gentrification as central to their project goals, that they can be successful and contribute to holistic resilience for the city. The Forest for All NYC coalition, established in 2021, is new enough that there are not yet measurable outcomes of the anticipated social and cultural benefits.

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Abstract

This chapter provides an overview of the major themes, findings, and recommendations from NPCC4. It presents summary statements from each chapter of the assessment which identify salient and pressing issues raised and provides recommendations for future research and for enhancement of climate resiliency. The chapter also outlines a set of broader recommendations for future NPCC work and identifies some key topics for the next assessment.

Recommended Citation

Towers, J., Leichenko, R., Braneon, C., Balk, D., Yoon, L., Wagner, G., Ventrella, J., Tchen, J., Rosenzweig, B., Orton, P., Ortiz, L., Moss, R., Montalto, F., McPhearson, T., McComas, K., Marcotullio, P., Matte, T., Maher, N., Knowlton, K., Horton, R., Foster, S., Bader, D., Baptista, A. (2024). Climate Risk and Equity: Advancing Knowledge Toward a Sustainable Future – Conclusion. New York City Panel on Climate Change. https://climateassessment.nyc

Table of Contents

1 Introduction

The New York City Panel on Climate Change (NPCC) was established to help the city “prepare for and mitigate the expected impact of climate change on New York City's communities, vulnerable populations, public health, natural systems, critical infrastructure, buildings and the economy” (LL42). As an assessment, the NPCC reviews recent advances in biophysical climate science and social science to provide policy-relevant guidance to the city. NPCC4 builds on the prior three NPCC assessments, providing climate projections while deepening areas of prior reports on flooding, health, and equity. It crafts two new areas of emphasis – on energy and energy insecurity, and tools for future visioning and planning – that further understanding of the impacts of climate risks on the human and ecological systems of New York City (NYC).

Navigating present and future climate risks and related socio-economic challenges facing the city will require tradeoffs and compromises forged through constructive and scientifically informed public dialogue. To plan and act, community-based organizations, businesses, city government, and other stakeholders will need to continue to integrate scientific and technical information with community values and knowledge. Scientific and technical information are critical to addressing the challenges the city faces and to understanding the technologies and measures that are available to meet them. Scientific and technical information can provide insights and guidance that inform, for example: how to update codes and standards (e.g. Climate Resiliency Design Guidelines) so that new and renovated structures are resilient and efficient; how to identify where, and what kind of flood protection should be prioritized; how to estimate the service loads public infrastructure for stormwater management, sanitation, electric power, and water supply will need to bear; and how to plan public health strategies to manage cascading and compounding extreme events (e.g. co-occurrence of storms, power failures, and heat waves). Community perspectives and local knowledge[1] provide an essential compass to help navigate issues such as growing economic opportunities, improving social welfare, planning transportation systems, and improving access to nature-based solutions that contribute to multiple dimensions of well-being. Local knowledge offers complementary information and expertise to bio-physical and social science, ensuring that, as the city prepares for the future, it does so in a way that increases civic participation, social cohesion, and community stewardship, all indicators of resiliency. Evidence suggests the integration of different forms of local knowledge (e.g. NOAA’s Urban Heat Island mapping program) can

[1] Local knowledge (LK) refers to the understandings and skills developed by individuals and populations, specific to the place where they live. It can contribute to effective land management, predictions of natural disasters, and identification of longer-term climate changes, and LK can be particularly useful where formal data collection on environmental conditions may be sparse (IPCC).

improve decision-making associated with climate risk management and community stewardship of, and commitment to, climate resiliency initiatives (Anthony, 2023; Carmona et al., 2023; Hurlbert et al., 2019).

2 Chapter Summary

This chapter provides an overview of the major themes, findings, and recommendations from NPCC4. It presents summary statements from each chapter of the assessment which identify salient and pressing issues raised and provides recommendations for future research and for enhancement of climate resiliency. The chapter also outlines a set of broader recommendations for future NPCC work and identifies some key topics for the next assessment.

2.1 Climate Science

New York City faces many challenges due to climate change and its interactions with social vulnerabilities and uneven urban development patterns and processes. In its assessment, NPCC4 confirms new sea level rise, temperature, precipitation, and extreme events projections of record for use by NYC, and presents a new methodology related to climate extremes.

Sea level is projected to rise for centuries and remain elevated for thousands of years. Glaciers and ice sheets combined are now the dominant contributors to global mean sea level rise. Coastal locations in the NYC metropolitan region continue to experience higher rates of relative sea level rise as compared to the global mean.

Surface and air temperature varies throughout NYC as a function of time of day, season, and the underlying characteristics of the built environment. The number of days with minimum temperatures below freezing has been steadily declining since 1900. The total number of hot days in the city and the frequency and duration of heat waves are expected to increase as this century progresses. Although the increase in total annual precipitation is projected to be relatively small, global climate models project somewhat larger increases in the frequency of extreme precipitation events.

2.1.1 Recommendations for Future Research

- Indoor heat exposure is the most common cause of both heat-related and heat-exacerbated deaths in NYC. In order to better understand indoor heat exposure and address its impacts (e.g., morbidity, mortality), there is a need for research to quantify the climate and infrastructure drivers of indoor temperature extremes.

- More research is needed on the meteorological factors that contributed to extreme precipitation events like the remnants of Hurricane Ida that adversely impacted the NYC metropolitan region.

- Projected sea level rise for NYC will exacerbate the destructive hazards posed by storm surges and cause more frequent high-tide flooding. More research is needed on both the baseline storm surge hazard (e.g., extreme wave heights, expected damages) as well as its potential future changes (e.g., inundation area and extent).

- The compound effect of climate hazards and stressors (e.g., pluvial flooding, high wind speeds, and storm surge) can play an important role in exacerbating climate impacts. More research is needed on compound extreme events (e.g., tropical cyclone-blackout-heatwave events).

2.1.2 Recommendations for Climate Resiliency

- Although many improvements have been made to protect neighborhoods and secure critical infrastructure in future floods, many neighborhoods remain vulnerable to coastal flooding. Long-term planning needs to examine plausible scenarios at the upper tail of the projected sea level rise distribution, and meaningfully engage communities in planning processes.

- In order to better understand indoor temperature change and address its impacts, there is a need for (1) operational monitoring of indoor temperatures to map the spatial distribution of indoor hazardous heat as well as (2) better communication and warning systems when hazardous indoor conditions can be expected.

- Consideration of water management under drought currently relies on estimates of imbalances between annual supply and evaporative losses, but droughts are a manifestation of the non-linear interaction between supply and demand as the climate risks faced by water users vary over time and by sector of use. There is a need for more comprehensive assessment of drought vulnerability that accounts for projected changes in cross-sectoral demand as well as projected climate impacts.

2.2 Flooding

NYC faces risk from four types of flooding: pluvial, fluvial, coastal, and groundwater, which can occur individually or in combination. In the absence of adaptation projects supporting comprehensive Flood Risk Management (FRM), the risks associated with all four of these types of flooding will increase due to sea level rise and the intensification of precipitation expected with climate change. Incremental flood adaptation measures scaled to singular conceptualizations of future conditions can lead to maladaptation. Comprehensive FRM must include neighborhood-specific combinations of structural (e.g., grey) and non-structural (e.g., green) approaches for living with water. These approaches must be implemented across multiple systems and scales, selected through collaborative processes, and be synergistic with the needs and goals of communities. To contribute to a comprehensive flood strategy, natural and nature-based solutions (NNBS) would need to be integrated extensively, and in novel new ways, to an urban ecosystem that has been modified profoundly over centuries of development. Progress is being made, but more information is needed regarding the extent and magnitude of flood hazards, exposure, and vulnerability, accompanied by greater cross sector, cross scale collaboration and decision-making.

2.2.1 Recommendations for Future Research

- Additional research is necessary to develop hazard maps that represent a broader range of flooding hazards and their increase in magnitude in response to anthropogenic climate change. This includes the continued development and integration of high-resolution models that can be used to simulate coastal hydrodynamics, sewer, surface, and groundwater flows in the same modeling platform.

- A denser network of gauges that record subhourly rainfall, water level, and flow in local streams, creeks, and sewers, and groundwater monitoring wells instrumented with water level loggers and salinity/conductivity probes are needed to calibrate and validate numerical models and in order to understand how climate is changing the city's hydrology at the spatial scales relevant for flood resilience.

- Collect and share -- with relevant agencies, researchers, and communities -- additional data on flood-prone buildings, including location and the vertical distribution of people and utilities to prioritize adaptation investments.

- Qualitative and quantitative social science research is needed to comprehensively assess the costs of flooding when it occurs in NYC to respond to climate events and to allocate resources equitably to mitigate harm.

- Research into how NNBS are impacted by flood/storm surge events, hydroperiod[2] changes, rising water tables and salinization, complimented by applied research into if and how NNBS can be enhanced, restored, or created at the spatial scales that would be needed to mitigate the impacts of various flood hazards.

2.2.2 Recommendations for Climate Resiliency

- While traditional floodplain management can be an effective strategy for reducing exposure to fluvial floods, pluvial flood hazards affect a much larger percentage of the city. A landscape-scale approach is needed that integrates strategic and safe stormwater conveyance, retention, and storage appropriately into the built environment. This approach would include design redundancies that are needed to plan for the uncertainty associated with future conditions.

- To advance equity, community stakeholders must have agency in decisions regarding FRM, and especially those strategies that seek to advance the long term social and ecological transformations needed to promote resilience.

2.3 Equity

Since the release of NPCC3 (2019), the City's climate-related equity work has become more explicitly focused on redressing environmental injustice and racial disparities. This includes the adoption of various laws and policies, internal institutional reforms, the formation of an Environmental Justice Advisory Board, and the incorporation of equity into risk assessments and resilience planning. There is, however, limited understanding of climate change impacts and adaptation needs at the community or neighborhood level and limited systematic data exists on city-sponsored adaptation projects and resilience investments. Going forward, the City's climate-related equity work would benefit from more comprehensive data on disaggregated climate risks at the local level and tracking of city-sponsored

[2] A hydroperiod can be defined as the number of days per year that an area of land is wet or the length of time that there is standing water at a location.

climate adaptation projects and resilience investments in different communities. Climate adaptation and resilience planning should also consider the ways that climate change challenges that NYC faces are inextricably linked to the bioregion's early history and how climate risks for the most socially vulnerable populations are connected to both past and present land use decisions and their underlying inequities (See Foster et al., Section 3 (Foster et al., 2024)). Understanding the impacts of this history is vital for formulating effective policies and strategies to mitigate and adapt to climate change. Without the creation and implementation of climate policies and practices that promote racially equitable procedures and outcomes, the City will risk perpetuating these inequities in new forms.

For example, climate displacement is an important dimension of social vulnerability to climate change and should be measured by the City. The City's ability to measure the risks of climate displacement at an appropriate scale, such as at the neighborhood level, could help determine whether and how new climate-resilient infrastructure or infrastructure investments might risk displacement. Without anti-displacement strategies in place, resilience-promoting investments can have inequitable outcomes. These strategies most often require prioritizing community-driven climate resilience approaches that mitigate the risk of displacement.

2.3.1 Recommendations for Future Research

- Collect and analyze more disaggregated climate risk data and systematic tracking of city-sponsored climate investments at the neighborhood level.
- Examine the relationship between the region's history and development patterns, including the legacy of land dispossession, rezoning, discriminatory policies such as redlining, and climate risks for socially vulnerable communities.
- Further develop combined climate displacement and social vulnerability (CDSV) metrics that integrate socio-economic, climate risk, and evictions and housing data to improve information and planning concerning the risks of climate displacement at a fine scale (such as the census tract).

2.3.2 Recommendations for Climate Resiliency

- Promote anti-displacement adaptation and resilience approaches that incorporate an understanding of neighborhood history, take a holistic approach to reducing racialized vulnerability to climate shocks, include inseparable issues like housing and transit access, and recognize that the cost burdens of climate adaptation (e.g., higher energy costs, insurance premiums, relocation) disproportionately result in increased displacement risk to the most socially marginalized communities.
- Understand and seek to scale up the work of community-based organizations that have implemented climate adaptation initiatives attentive to the intersecting nature of climate risks, social vulnerability, and displacement. These initiatives provide multiple benefits including equitable access to renewable energy, affordable and efficient housing, and economic development strategies that promote equitable green, adaptation economies.
- Investigate and incorporate best practices from around the country and that promote integrated, affirmatively anti-racist, equitable, and just approaches to tackling climate (and related) risks. These include those that advance just transitions, community-led planning processes, and collaborative relationships between communities, civic organizations, and state and local government offices and programs.

2.4 Health

Climate change-related health risks are a threat to all New Yorkers, but especially those most vulnerable because of age, poor health, racial and social inequities, and social isolation. Inequities in household and neighborhood physical environments also mediate vulnerability to health impacts of climate change. Most important among climate health risks are those from hot weather and flooding. A changing climate could also increase exposures to air pollution, pollen and mold, mosquito and tick vectors of human illness, and water contaminants. Addressing key environmental and social drivers of vulnerability is an essential adaptation strategy. Many current City policies and strategies, (e.g., improving access to residential air conditioning, tree planting), aim to accomplish this. These efforts can be informed and evaluated using data on climate-health vulnerabilities, such as components of the Heat Vulnerability Index (HVI) and the Flood Vulnerability Index (FVI).

2.4.1 Recommendations for Future Research

- While it is known that housing condition, construction, and location influence vulnerability to climate risks, key knowledge gaps should be addressed in future research. These include indoor temperatures and health risks in different types of structures and the spatial distribution of social and housing vulnerability to flooding, including the location of basement dwellings.

- While temperature and humidity both influence heat stress and health risks, to better design climate adapted buildings and outdoor environments, a better understanding is needed of the relationships between heat and humidity under a changing climate.

- Social isolation has been clearly established as a strong, independent risk factor for poor health and has a plausible influence on vulnerability to a variety of climate hazards. However, evidence of the role of social isolation in climate vulnerability is inconsistent, in part because it is difficult to measure, and standardized measures are not collected through census or other health surveys. Future research should assess how different dimensions of social isolation are best measured, study how these influence climate vulnerability, and develop and evaluate effective interventions.

2.4.2 Recommendations for Climate Resiliency

Because the built and natural environment shapes vulnerability to health impacts from climate change, creating more climate-adapted and resilient environments for vulnerable people and communities must be a priority. Climate actions and investments and policies in sectors that shape climate vulnerability must reduce longstanding racial, social, and economic inequities, especially in key sectors such as housing, energy, and transportation.

- Sectoral policies and investments that can advance climate resilience in vulnerable communities include expanded residential cooling access, flood-protected residential building mechanical systems, improved energy affordability, reliability, and backup systems, mandating window screens, and expanding the supply of affordable, healthy, safe housing to provide alternatives to flood-prone basement dwellings.

- Social factors also mediate vulnerability to climate health risks. Thus, investments and programs that strengthen community cohesion and social infrastructure are also needed.

- Vulnerable and marginalized communities should also be the focus of efforts to improve and evaluate communication strategies intended to promote awareness, preparedness, and timely response to warnings.

2.5 Energy & Energy Insecurity

The urgent need to reduce energy use and GHG emissions in NYC, in alignment with NY State's ambitious climate goals, brings to light significant challenges and opportunities. Key among these challenges is the management of energy insecurity (EI), which poses direct and indirect threats to public health and well-being, especially among vulnerable populations such as low-income groups, communities affected by systemic racism, individuals with health conditions and renters. The transition to renewable energy and the electrification of infrastructure, while offering prospects for local economic investment and improved air quality, must be navigated carefully to ensure energy affordability and reliability, particularly during extreme weather events. This transition exacerbates existing vulnerabilities and introduces new risks, particularly for those already facing EI.

2.5.1 Recommendations for Future Research

- Investigate the long-term health impacts of energy transitions on vulnerable populations, including those experiencing EI.

- Explore the effectiveness of existing policies and interventions aimed at reducing EI and their impacts on health outcomes.

- Examine the relationship between renewable energy adoption, energy infrastructure resilience, and community health, with a focus on environmental justice communities.

- Assess the health and safety implications of new energy technologies, such as battery storage, especially in dense urban environments like NYC.

- Expand available data on household energy use and outage data to assess with an equity lens.

2.5.2 Recommendations for Climate Resiliency

- Develop and implement policies to ensure that the benefits of energy transitions, such as improved air quality and reduced GHG emissions, are equitable and accessible to all communities, especially those historically affected by environmental injustice.

- Enhance the resilience of the energy infrastructure to withstand extreme weather events, prioritizing investments in areas with high vulnerability to power outages and EI.
- Foster community-led renewable energy initiatives and expand access to renewable energy sources and energy efficiency programs in low-income and minority communities, reducing both energy costs and health risks.
- Strengthen regulations and safety standards for new energy technologies, such as e-mobility devices, to mitigate risks and ensure public safety.

2.6 Futures and Transitions

NYC is dynamic, and the scale and complexity of the city requires managing interacting socio-economic, ecological-biophysical, and technological-infrastructure components of the urban system. Managing and planning the future NYC to be more adapted and resilient to diverse climate, economic, and social pressures will require understanding diverse futures that also interact in real-time. As climate change unfolds, the future NYC will be increasingly older, and there is little to suggest that it will not continue to thrive as a diverse city. But whether the NYC of 2100 is more or less populous than today is unknown. Long traditions of in- and out-migration, which shaped the city historically, are expected to continue to be an important part of its future, anchoring it in the region and the nation While long-term visioning has been part of the City's planning efforts in the past, no current plan, let alone a demographic forecast, matches the end of century dates of the climate projections, and represents a gap in long-term planning need to guide NYC decision-making that looks beyond the near term to actions now that will impact the city later this century.

The City's built environment will largely remain in place, yet changes in land use and land cover, including conversions in impervious and natural areas, are expected. While NYC planning has often focused on immediate, short-term land use decisions and includes some community participation, planning for the future requires the use of tools for addressing the complexities and uncertainties inherent in climate change and need to include medium- to long-term time-horizons and attention to local variation in physical and socioeconomic characteristics. Incorporating approaches that acknowledge sectoral interdependencies in future planning can prevent a siloed understanding of trade-offs and uncertainties.

Natural and nature-based solutions (NNBS) are critical for addressing climate adaptation needs in the city and can simultaneously provide co-benefits for public health, climate mitigation, flood risk management, and habitat for biodiversity. Yet, planning, implementation, and management of NNBS to achieve equitable distribution and holistic resilience in a complex city system is still a developing practice. Recognizing that the benefits of nature are not evenly distributed across the city, investment in NNBS to address this inequity alongside other engineered and social approaches to adapting to increasing climate impacts may have broad potential. Examples of these adaptations can include increase investments and plans for natural area restoration, conservation, and protection alongside new hybrid and green infrastructure installations including expanding tree canopy, installing green roofs and bioswales.

2.6.1 Recommendations for Future Research

This first NPCC Futures and Transitions Working Group contributed to imagining, visioning, and planning the future of NYC. It introduced frameworks that would allow for longer demographic projections consistent with socioeconomic futures that are plausible given a range of climate futures and social-ecological-technological systems (SETS) that model complex urban dynamics with a range of cascading influences and feedbacks. Such frameworks – those that acknowledge inherent complexities in New York City -- are needed to ensure adaptation and mitigation decisions do not occur in siloes; rather they consider a range of futuring options that accommodate feedbacks to other sectors and subsystems. These new frameworks offer longer-term scenarios to guide the decision-making today and, with continued use, in the future. Developing and making meaningful use of such frameworks at the scale of NYC will require new research:

- Much work remains to be done to assess alternative visions and scenarios, and their inherent uncertainties, but so doing will build the necessary tools for a climate adapted, sustainable, and equitable future NYC.
- Future research needs to examine housing futures, nature futures, and the intersectionality of the built, social, and ecological futures and ways to minimized trade-offs that may emerge through short-term decisions underlining the need for long-term visions and plans.
- Prior NPCCs have noted the need for regular and meaningful indicators of climate impacts in perpetuity and the equity and flood chapters advance these in this assessment, but the role of indicators within the context of planning tools for the future is a gap that requires future research and assessment.

2.6.2 Recommendations for Climate Resiliency

Tools for longer-term (beyond 2050) transitions and pathways to achieve future plans for NYC are currently missing and needed to guide efforts to secure an inclusive climate resilient future for all New Yorkers. Participatory processes are critical in co-developing shared visions that bring together diverse perspectives and forms of knowledge, and a sustained engagement process is also critically needed to identify the City's climate research priorities and co-produce a future public climate research agenda for the city. Without such shared positive visions for the future, it is unlikely that plans made now will achieve the equity, justice, sustainability, and resilience goals of a future NYC and its communities.

- It is increasingly clear that equity and social justice are critical to inclusive climate adaptation goals, implementation efforts, and future planning. Centering equity in climate adaptation and mitigation actions provides an opportunity to decrease impacts on the most vulnerable while creating more inclusive processes that center community voices in climate adaptation and mitigation planning, policymaking, and investments decisions. This means that tools for planning must allow for explicit attention to equity concerns as well to resiliency in a multi-hazard world.

- Climate resiliency will need to adapt to future unknowns. Long-term planning that incorporates flexible adaptation pathways and uncertainty across many spatial scales, as determined by sectoral or community need, is imperative.

3 Looking forward to NPCC 5

NPCC4 confirms, with a high degree of certainty, that NYC's future will be warmer -- including more extreme heat events that may lead to increased morbidity and mortality in summers, and wetter -- with specific risk from intense rainfall and inland flooding. Compound and cascading events are also very likely to expose the city to increased climate risk. Addressing the risks presented by climate change will require multiple levels of investment, innovation, and transformation across sectors including (but not limited to) housing, transportation, land use, ecosystems, and critical infrastructure. All of these efforts will require innovative urban climate action, planning, and investments. For NYC to achieve a more resilient, equitable, and adaptable future, intersectoral and multisectoral climate-forward planning will be necessary. These efforts need ongoing and urgent consideration now, as well as a continued commitment throughout the coming years. In this section, we offer suggestions and recommendations to help support the city and the next NPCC panel in these efforts.

3.1 Harness holistic, multi-disciplinary approaches that blend climate and related socio-demographic risks in the planning process

Whether future New Yorkers increasingly live in flood-prone neighborhoods or heat-prone housing – let alone whether such risks will be born unequally according to race and ethnicity, or socioeconomic or nativity status (or many other socioeconomic characteristics) – depends on policy and a broader commitment to a just transition. These possible futures are modifiable by tools, planning and policy; and planning for a range of possible outcomes is increasingly necessary. Thus, there is need for increased multi-sector, multi-hazard long-term planning initiatives. There is also a need to evaluate, assess, and monitor the progress of these planning initiatives including attention to capacities and collaboration with community-based organizations and government entities to implement the plans.

Future NPCC panels will, therefore, benefit from an interdisciplinary composition. While the exact composition of any panel will need to be determined by future priorities, the experience of NPCC4 is that those panels will need expertise from Earth, social, and health sciences as well as researchers from other allied academic fields including, but not limited to planning, architecture, law, business, humanities, and the arts.

3.2 Center equity in adaptation planning and decision making

Equity and social justice should continue to be explicitly centered in future climate adaptation goals, implementation efforts, and future planning. Planning without centering equity will likely result in unintended negative consequences, such as green gentrification or displacement. Centering equity in climate adaptation and mitigation actions provides an opportunity to decrease impacts on the most vulnerable. The potential for maladaptive and inequitable effects of climate adaptation strategies and other sectoral actions influencing climate risks should be considered to ensure that near-term actions are not maladaptive in the long term.

In addition to centering equity in the content of future assessments, it is important to also strive for representational equity in the composition of future panels and their working groups. One way of accomplishing this is to include early career scholars and researchers that draw from a wide range of public and private New York area educational institutions and are diversified by rank, age, and experience, as well as by race, ethnicity, and economic status.

3.3 Evaluate and assess adaptation projects and initiatives

Adaptation efforts require their own assessments, and that will start with stewardship from the City and its communities to undergo periodic self-evaluation. In order to meaningfully assess the value, efficacy and success of adaptation planning efforts in New York, the City's adaptation actions must be monitored and evaluated over time (Blake et al., 2019; C40 Cities et al., 2019; Olazabal & Ruiz De Gopegui, 2021). It is especially important for New York City decisionmakers and stakeholders to understand which approaches to adaptation, including short-, medium- and long-term investments, are most effective in terms of reducing climate risk and enhancing resilience to the effects of climate change locally (Dinshaw et al., 2014) (New York City Panel on Climate Change, 2019). It will also be critical for the City to design adaption measures and strategies with evaluation and monitoring in mind (e.g. in situ measurements; indicators of climate exposure, vulnerability, risk or resilience; context-specific indicators of adaptation interventions) from the ideation stage (Boulanger, 2023).

Monitoring and measuring the efficacy of adaptation measures has received only limited research attention and remains an important area for ongoing research. For example, the evaluation of the effectiveness of ecosystem-based adaptation and nature-based solutions (NBS) is still mainly based on modelling, and data from monitoring and in situ measurements remain fragmentary (Donatti et al., 2020; Sauvé et al., 2023). If properly designed and used, adaptation metrics, indicators and monitoring can enhance local understanding of which types of adaptation measure are effective and why, as suggested by previous NPCC assessment reports (Blake et al., 2019; Leiter et al., 2019).

3.4 Improve the efficacy of climate risk communications

To meet the myriad challenges posed by climate change, New York City will benefit from a concerted risk communication strategy that clearly outlines goals, objectives, and tactics for the many sectors of the City and customizes messages for the many different audiences. Climate risk communication in the context of municipal policy and planning decision-making operates at many levels, which makes such coordination challenging. Because climate change is deeply intersectional with impacts that are often unevenly distributed across race and economic status, no single report or communication strategy will suffice. Risk communication is also not a one-way, one-time process but instead is multi-directional and ongoing. Effective risk communication requires understanding different audiences' needs and tailoring risk message content to meet those needs.

Local Law 42 charges NPCC with the assessment of the most recent science and data regarding climate risk in New York City and providing advice on its communication to City residents. The wide range of this ambition suggests that the cycle of NPCC reports generates information that is valuable to share with groups as diverse as biophysical and social scientists, policy makers, planners, architects, engineers, community groups, and individuals at every level of educational attainment. Meeting these diverse needs can be challenging, especially given the practical constraints on the NPCC and the importance of ensuring the reliability and clarity of the information. Further, simply making this information available does not mean that audiences will seek it out or find it useful. NPCC4 has sought to balance these demands by delivering peer reviewed, subject specific assessments, a new web-based archive, and a series of summaries intended for a wide range of audiences. Future NPCC panels and New York City offices and agencies will benefit from continuing to innovate and evaluate the effectiveness and efficacy of their climate risk communications. Engaging with community organizations and other stakeholders to provide input and feedback on proposed messages is one way to increase the value of risk communication and decrease the potential for unintended negative consequences. The more diverse audiences have access to this information the more inclusive and equitable the process of climate adaptation and mitigation will be. The science is clear that the City and its residents will need to change to meet the challenges of a climate altered present and future. Effective climate risk communication will be critical to ensuring that people understand why such change is necessary and how they can engage in meeting those challenges.

3.5 Learn from processes that make other Assessments run efficiently

NPCC is designed by local law to ensure that those involved do not have conflicts of interest, and as such has been undertaken by researchers and academics who volunteer their time to the multi-year commitment required to conduct each assessment. This follows the model for service on the National Climate Assessment (NCA) and the Intergovernmental Panel on Climate Change (IPCC) but not the recent New York State Climate Impacts Assessment (NYSCIA), which provided small stipends for contributors. Importantly, all three of these other Assessment bodies have strong, financed support systems.

Ensuring that NPCC is effective and inclusive of researchers from a variety of academic and research venues may require revisiting the Local Law 42 of 2012 requirement that NPCC panel members serve in a voluntary capacity.

Researchers from the non-profit sector, private sector, and those in grant-funded academic positions can make vital contributions to future NPCC efforts, but typically require some form of compensation in order to devote the substantial time required to serve on the NPCC.

The NPCC also provides an invaluable opportunity for the training of students and new researchers. The NPCC4 student internship program allowed student interns to participate in many of the work groups, but in contrast to the panel members, student members could not participate in a volunteer capacity. Thus, identifying resources to support and sustain a robust student internship/fellowship program is also an important part of the NPCC success as well as training the future workforce of adaptation professionals for the City.

Support for the organization and production of the Assessment is also vital to the success and sustainability of future NPCC efforts. This includes administrative support for the organization of the panel's work and report production, as well as resources for a robust co-production process, which engages city officials, agency representatives, as well as non-city entities such as non-profits and community groups. For example, NPCC4 had the good fortune of working with Climate Adaptation Partners to co-produce these structures for its Assessment for the first time. These structures will benefit from being strengthened for future assessments.

3.6 Key Topics for NPCC5

Each NPCC report covers a limited set of topics that are relevant to the adaptation goals and planning of the city. All reports cover climate factors but the breadth of allied topics cycles through pressing needs and evolving sustained assessment frameworks. Below is a list of thematic areas that NPCC4 recommends receive attention in the next Assessment.

- Ecological Impacts and Natural and Nature-based Solutions: NNBS are critical for addressing climate adaptation needs in the city and can simultaneously provide co-benefits for well-being and public health, climate mitigation, flood risk management, and habitat for biodiversity. Yet, planning, implementation, and management of NNBS to achieve equitable distribution and holistic resilience in a complex city system is still a developing practice. Greater attention to the role and integration of NNBS in the City's climate adaptation and mitigation plans is warranted.

- Housing risk and resiliency: Climate change threatens housing in many ways, both direct and indirect. While many chapters in this report touched on the housing sector, there is a need for more explicit attention to impacts of climate change on the housing sector including attention to the unhoused and precariously housed, housing affordability, housing shortages, and the conditions and resiliencies of the city's housing stocks.

- Spatial and temporal scale dependencies: Climate risk is experienced over a range of spatial scales from the individual person to regional systems (e.g., drought). NYC residents and ecology are impacted at every scale from the street-level to the region, and, therefore, future NPCC assessments will need to work across a range of social and spatial geographies to support climate adaptation and mitigation in the city. This Assessment brought in a wide range of new temporal scales – from hourly flooding to long-term scenario planning – and points to the need to continue to expand on these scales as necessary (such as subhourly flooding, daily climate warnings or communications, end-of-century demographic futures).

- Infrastructure and built environment: While many aspects of climate risks associated with aspects of the city's built environment and infrastructure systems have been addressed by prior NPCCs, there is a continued need for attention to the impacts of climate change on the city's vital infrastructure systems (water, transportation, communication, energy, etc.), There is also a need to consider governance and management of these systems and to identify ways to enhance adaptation, health, and equity, and to align with mitigation efforts. For example, near-, medium-, and long-term changes to how streets, sidewalks, and other public spaces that are part of the public right-of-way are designed, governed, and managed at different spatial scales can begin to reverse maladaptive uses and enable a more sustainable future.

4 Conclusion

Local Law 42 created the NPCC to help "prepare for, [adapt to], and mitigate the expected impact of climate change on New York City's communities, vulnerable populations, public health, natural systems, critical infrastructure, buildings and the economy." This fourth report of the NPCC validates the critical role that science informed policy making plays in the creation of an equitable, resilient, and sustainable future for NYC.

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We also acknowledge the NPCC4 panel members for their helpful comments on this chapter, and our home institutions (noted in our affiliation) for supporting our work on this assessment in myriad ways.

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NYC NPCC4

New York City Panel on Climate Change 4th Assessment

Climate Change, Energy, and Energy Insecurity in New York City - ANNEXES

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The first author (L.Y.) is grateful for the guidance and mentorship of Prof. Diana Hernández, PhD, on her pioneering work on energy insecurity.

Annex A: Energy Insecurity - Global, National, and Historical Context

Energy or fuel poverty are terms that have been used internationally to describe a lack of access or means to afford modern energy services and products needed for health and development. In developing countries, a lack of clean household energy for cooking and heating[1] is a major cause of preventable illness and death. While energy access is improving in many developing economies, by one estimate 733 million people without access to reliable electricity and 2.4 billion people using dangerous and inefficient cooking systems.[2] Among this population, those that lack access to energy include those that simply cannot afford it. Access to electricity in the US is virtually universal, while in Malawi, for example, only about 11% of the population has electricity access[3] and more than 95% of people depend on solid household fuels. Globally, household air pollution from use of solid fuels for cooking and other needs caused an estimated 2.3 million deaths in 2019, from causes including childhood pneumonia, COPD, heart disease and strokes, diabetes, low birth weight and preterm birth.[4,5] Improving clean household energy access is a UN sustainable development goal (number 7).

A lack of energy access and excessive cost burden also exists in developed economies.[6] "Fuel poverty" was first studied intensively in the United Kingdom.[7] As with energy insecurity, fuel poverty considers all essential energy services (not just heating), what is needed (not only what is used), and housing energy inefficiency as a major cause.

In the United States, electricity came first to cities more than 100 years ago, and the need to expand access was recognized. The rural electrification program beginning in the 1930s improved electricity access in rural areas from less than 10% to near-universal. Among other benefits, a decline in infant mortality has been attributed to this program.[8] With modern energy connections becoming near universal in the US, excessive energy cost burden emerged as a major hardship for both urban and rural households. This concept has been the focus of many U.S. researchers who study the relative costs of energy to households. The energy burden focuses on the household energy bill as a percentage of the household's annual income.

For New York State, the energy burden is defined as households that spend more than 6% of their annual income on energy.[9,10] According to the US DOE's Low-Income Energy Affordability Data (LEAD) Tool the national average energy burden for low-income households is 8.6%, three times higher than for non-low-income households which is estimated at 3%. In some areas, depending on location and income, the energy burden can be as high as 30%.[11] Nevertheless, the extent of the energy household burden has been a persistent if underappreciated problem in the United States.[12] For example, urban and rural low-income households (defined as 80% of area median income or 150% federal poverty level) spend roughly three times as much of their income on energy cost as compared to non-low-income households (7.2% and 9% versus 2.3% and 3.1%, respectively.[13,14] Moreover, low-income, African American, Latinx, multifamily and renter households are disproportionately impacted by high energy burdens.[13] Out of a total of 118.2 million US households, in 2015, the US Energy Information Administration (EIA) estimated that 17 million households received an energy disconnect/delivery stop notice and 25 million households had to forgo food and medicine to pay energy bills.[15]

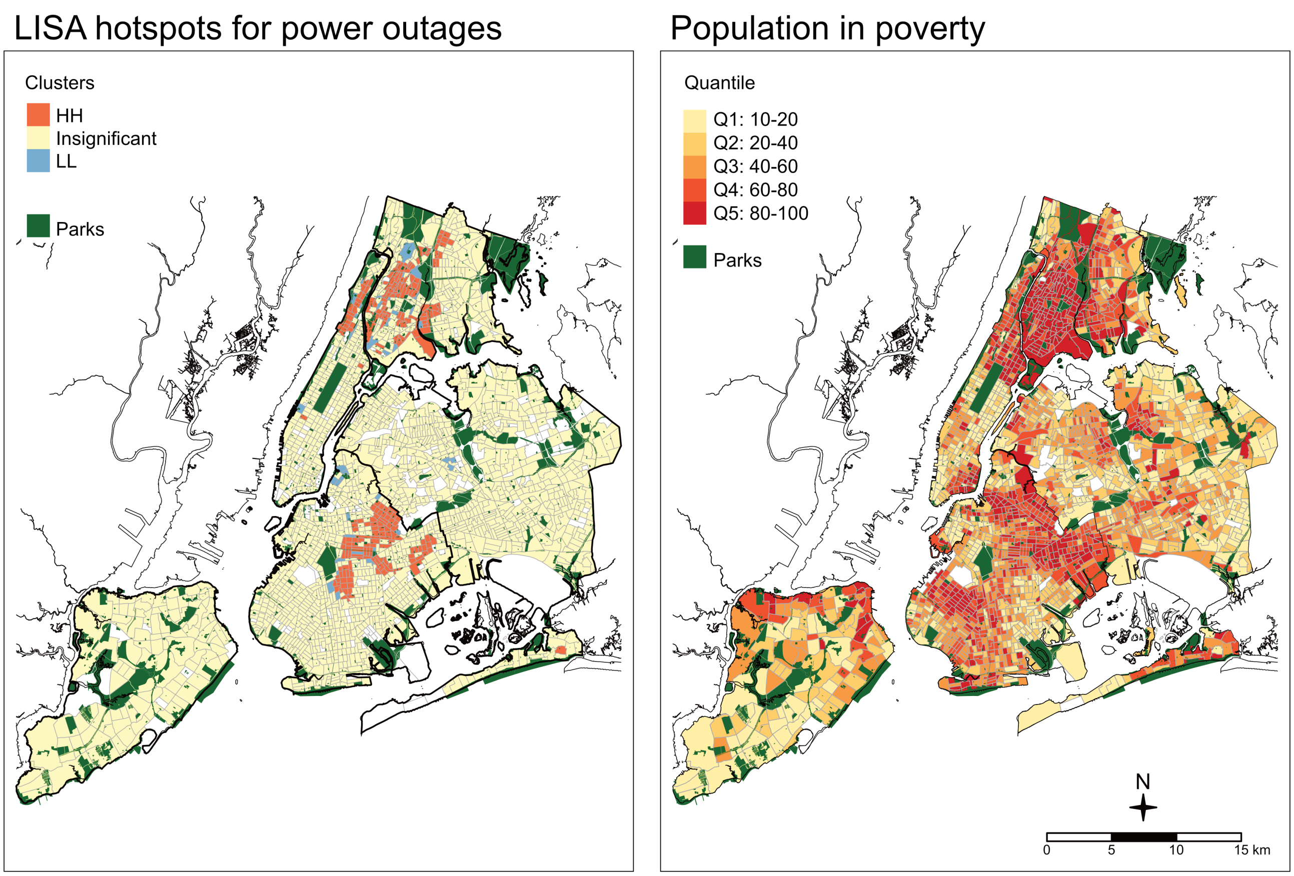
The results of the energy burden have been identified as energy insecurity, or the state in which households cannot meet their energy needs.[16] This term refers to the uncertainty that a household faces in being able to make utility bill payments.[17] The point emphasized from this concept is that the stress from insecurity creates significant health issues.[18] For example, the results of energy insecurity include extreme home temperatures, hazardous heating alternatives, and the constant threat of utility shut-offs or mounting arrears in utility bills because of nonpayment. This problem is especially acute for low-income residents such as single parents, the elderly, the disabled, and others with low or fixed incomes.[19,20] Those facing energy insecurity may be homeowners unable to invest in efficiency upgrades or may be renters living in housing units where landlords do not pay for the utilities and consequently have very little incentive to create more energy efficient units.[21] Energy insecurity is an important issue in the US. The DOE EIA Residential Energy Consumption Survey (RECS) data for 2015 suggest that 31% of U.S. households experienced some form of energy insecurity. That year, nearly seven million households had their access to heat interrupted at least once, and six million lost access to air conditioning at least once.[22] Adequate housing and income are central to energy justice. Energy justice is a branch of environmental justice[23,24] focused on the notion that all individuals should have access to energy that is affordable, safe, sustainable and able to sustain a decent lifestyle, as well as the opportunity to participate in and lead energy decision-making processes with the authority to make change.[25–27] Energy justice scholarship stresses that neither the adaptation to climate change nor the renewable energy transition is inherently just nor democratizing in terms of the distribution of technologies and benefits.[28] Energy justice is based upon disparities within energy systems closely associated with housing including, inter alia, notions concerning energy poverty, fuel poverty, energy burden and energy insecurity.

Annex B: 311 Calls for Summer Power Outages - Methods

Researchers tested whether the 311 calls were clustered, dispersed or randomly distributed throughout the city.[29] Using spatial statistical test, the research found that there is a clustering of high numbers of 311-calls made between 2013 and 2022. That is, high numbers of calls were spatially clustered together as were low numbers of calls. A specific test, called the Local Indicator of Spatial Autocorrelation (LISA) demonstrated the location of these different levels of calls. The results of this analysis are presented in Annex Figure B-1 (left panel). Across most of the census tracts in the city, there is no clustering of calls amounts, but high numbers of calls are clustered in Northern Manhattan, parts of the Bronx, central Brooklyn, and Southeastern Queens. Areas designated as High-High (HH) signal locations of high absolute numbers of 311-calls for power outages (i.e., above the mean level of 311-calls for power outages per census tract) and where the adjacent census tracts also had High absolute number of 311-calls for power outages. The HH designation indicates areas of spatially clustered high levels of 311-calls for loss of power. Alternatively, areas designated as Low-Low (LL) are areas of low absolute numbers of 311-calls for power outages (i.e., below the citywide mean for 311-calls for power outages per census tract) and the adjacent cells are also areas of low absolute numbers of 311-calls for power outages.

Selected socio-economic characteristics of the census tracts with different levels of 311 calls were also examined. The research identified that there is an association between the levels of calls and the level of poverty within the different clusters. The distribution of those in poverty is presented in Annex Figure B-1 (right panel). A statistical test (student's t-test) of the means of the percent poverty in census tracts in high call cluster areas and the percent of poverty in census tract of low call cluster areas is significant ($t = 3.5806$, $df = 84.929$, $p\text{-value} = 0.0006$).

The results suggest that there is a significantly higher percentage of the population in poverty within census tracts with high numbers of calls compared to the percentage of population in poverty in census tracts with low numbers of calls. The mean percent in poverty in census tracts with high cluster calls is 26.0% and the mean percent of poverty in the census tracts with low cluster calls is 19.3%.



Annex Figure B 1. Local Indicator of Spatial Autocorrelation (LISA) results for 311 calls for power outages by census tract from January 1, 2014-January 1, 2023 (left). The distribution of percent population in poverty by quantile and census tract in New York City 2020 (right)

Annex C: Energy Transition Plans, Reliability, and Affordability - Challenges for NYC

As NYC addresses consistency with the Climate Leadership and Community Protection Act (CLCPA) and the commitment to carbon neutrality, there will be a growing need for technology and infrastructure that can improve efficiency and reliability. Over the course of the next few decades, New York State has committed to an energy transition. The transition is slated to occur through a decrease in use of fossil fuels to generate electrical power, while electrifying transportation and building energy services including heating, hot water, and cooking. Plans call for replacing fossil fuels with renewables including solar, wind, and hydropower.[30] The role of nuclear power remains an open question.

NYC will play a significant role in the energy transition, as the city's energy use is a major share of state energy use (30%) and the city produces 40% of the state's GHG emissions. The City also has committed to carbon neutrality by 2050.[31] At the same time, the City faces significant challenges in reducing the use of fossil fuels, acquiring renewables and electrifying sectors. The City's commitment to carbon neutrality is envisioned through the use of increased renewable energy generation, battery storage, and renewable energy transmission from up-State and beyond. All transportation and building energy demand are slated to be met by renewable electricity, meaning that electricity demand will increase dramatically. In order to meet low carbon fuel goals and reduce emissions, the City plans three important strategies:

1. Transform the electricity system to deliver 100% zero-emission electricity to buildings and the capacity to provide the same for more than a million zero emission vehicles (ZEVs);
2. Transform the current natural gas system to deliver low carbon gas (e.g., such as hydrogen or renewable natural gas) for end uses too costly and complex to fully electrify; and
3. Provide low carbon steam system for heating and cooling to some of the largest and most difficult buildings to decarbonize.[32]

According to New York Independent System Operator (NYISO), given current trends and conditions, annual baseline energy use will increase from 49,230 GWh in 2023 to 68,810 GWh in 2050 (40% increase) and baseline peak demand is projected to increase from 11,023 MW to 13,200 MW over the same period.[33] Energy storage to allow for renewable energy use is currently 22 MW and is projected to increase to 704 MW by 2050, and this storage will increase energy provision from 3 GWh in 2023 to 686 GWh in 2050[33] (about 10% of annual electricity demand during that 2050 period). Two transmission lines will deliver renewable energy to NYC; the Champlain-Hudson Power Express (CHPE) project that will deliver hydropower from Canada directly to Queens, and the New York Power Authority (NYPA)-led proposal, known as Clean Path NY, which proposes to deliver renewable energy from upstate New York directly to NYC.

There are at least four concerns to meeting carbon neutrality given current plans. The first is that many of the technologies to meet carbon neutrality goals are not yet commercially available. As a NYC study states, additional innovation is needed as battery storage technology is untested and undeveloped at the scale required to decarbonize NYC.[32] For example, Fekete et al.[34] points out that current battery storage technologies have limited capacity that may not meet the need for base load given seasonal variation in renewable energy generation. Current research suggests that studies of net-zero decarbonization include carbon capture and sequestration (CCS).[35] In fact, many studies suggest that CO2 emission reductions of great than 50% will not be possible without CCS.[36] CSS was not considered in the City's plans, suggesting contrary to research that the City's transition could indeed reduce carbon emissions without it. New York State is currently in the process of defining what constitutes 'zero emissions' that meet CLCPA targets,[37] to which there have been environmental, equity and justice-related concerns about the implications of fuels and technologies that may be included (e.g., nuclear, biofuels, hydrogen).[38]

Second, there are reliability concerns with the transition to a larger role of the electricity grid. Recently, the New York Independent System Operator (NYISO) finds that thinning reliability margins over the next decade present increased challenges to reliability for NYC.[39] NYISO quarterly assessment of reliability of the bulk electric system found a deficit in reliability margins for the NYC area beginning in summer 2025. The deficit is as large as 446 MW, driven primarily by the combination of a forecasted increase in peak demand (through the electrification of the transportation and building sectors, continued economic growth following the pandemic) and the unavailability of certain generators (Peaker plants).

Third, the electricity costs and affordability are important concerns. New York State is among the top 10 states with the highest electricity costs in the country. In 2023, cost of residential electricity was 21.92 cents/KWh compared to 15.92 cents/KWh for the country.[40] Costs will be increasing, as in June 2023, Con Ed requested another increase in electricity rates resulting in a roughly 12% increase for customers over the next three years.[41] These increases will go towards financing upgrades to the company's electricity delivery system, funding renewable energy plans and improving overall infrastructure. Continual rate increases can be critical for some NYC residents as approximately 610,000 families (representing 18% of total families in the city) pay greater than 6 percent of their household income and are therefore considered energy cost burdened.[9] Moreover, as there are large areas in the city that have low hosting capacity there will be a need to further upgrade the electricity grid in these locations so as to provide equitable renewable energy access.

Finally, there is concern whether Con Edison will be able to provide enough electricity distribution necessary to meet the increased demand for heating and transportation during the transition and if this increase can be accomplished while keeping affordability in check.

Annex D: Overview of City and State-Level Energy Policy

Table D1:Overview of City and State-level Energy Policy

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
STATE				
Climate Leadership and Community Protection Act (CLCPA)	New York State Public Service Commission (PSC), New York State Energy Research and Development Authority (NYSERDA), New York State Department of Environmental Conservation (DEC), Climate Action Council (CAC)	6,000 MW of distributed solar installed by 2025, 185 trillion BTU reduction in total energy consumption, including electrification to reduce fossil fuel use in buildings by 2025, 3,000 MW of storage installed by 2030, 70% of load supplied by renewable resources by 2030, 9,000 MW of offshore wind installed by 2035, 100% of load supplied by zero emissions resources by 2040.	Transformation of the power grid, necessitating changes in market structures, planning processes, flexible load, and investment in bulk power system infrastructure.	The Climate Act mandates that no less than 35% with a goal of at least 40% of our climate action benefits will go toward New York's disadvantaged communities. The aim is to address the challenges and barriers these communities are facing.
Tier 4	New York State, New York City, New York State Public Service Commission (PSC)	TIer 4 is an innovative approach to supporting the development of transmission infrastructure at the state level while also providing clean energy to the state's most challenging load center.	Tier 4 addresses the imbalance of renewable energy access within the state grid. Administered by the New York State Energy Research and Development Authority (NYSERDA), the program procures renewable energy attributes in the form of Tier 4 Renewable Energy Certificates (RECs), which are tied to the delivery of renewable generation in New York City.	After a thorough project evaluation and negotiation process, two contract awards were recommended for projects: Clean Path NY (CPNY), and Champlain Hudson Power Express (CHPE). This renewable energy will help increase grid reliability and provide clean energy to New York City.
"Peaker Rule" Ozone Season Oxides of Nitrogen (NOx) Emissions Limits for Simple Cycle and Regenerative Combustion Turbines	NYS DEC	Reduce ozone-contributing pollutants associated with New York State-based peaking unit generation. Compliance obligations phased in between 2023 and 2025.	Reduction of fossil fuel use.	The Peaker Rule was issued to remove the legacy environmental harms in environmental justice communities and has resulted in the pursuit of deactivation by some of the city's oldest and dirtiest Peaker plants, allowing these sites to be redeveloped for energy storage and renewable energy infrastructure.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
STATE				
NYS Accelerated Renewable Energy Growth and Community Benefit Act (AREA)	Office of Renewable Energy Siting (ORES) within the NYS Department of State, NYPSC, NYSERDA	Provides for an accelerated path for the permitting and construction of renewable energy projects other than the Article 10 power plant siting law, calls for a comprehensive study to identify cost-effective distribution, local and bulk electric system upgrades to support the state's climate goals, and to file the study with the New York State Public Service Commission. Calls for use of NYISO's competitive Public Policy Process to meet transmission needs to meet CLCPA goals.	Intended to help accelerate siting of eligible renewable resources and establish new transmission investment priorities to facilitate the achievement of state climate and energy policies.	This legislation aims at improving the siting and construction of large-scale renewable energy projects in an environmentally responsible and cost-effective manner. Communities have input on reviews and potentially can receive compensation benefits for hosting major renewable facilities. All project approvals include provision for host community benefits.
Indian Point Deactivation	Agreement between New York State and Entergy	Deactivate Indian Point units 2 and 3 by 2020 and 2021, respectively.	Remove this nuclear power plant from the grid. NYISO Deactivation Assessment found no reliability need with loss of 2,311 MW. Three gas powered plants were subsequently used to make up baseload.	Deactivation resulted in the replacement of energy by natural gas. The closure of Indian Point has resulted in higher electricity prices.
Regional Greenhouse Gas Initiative (RGGI)	New York and other RGGI states	Reduce carbon dioxide emissions cap by 30% from 2020 to 2030 and expand applicability to currently exempt "peaking units" below current 25 MW threshold.	The NYS DEC proposed to expand applicability in NYS to generators of 15 MW or greater, whereas currently rules do not apply to generators less than 25 MW.	Power sector carbon mitigation policies' focusing on aggregate emissions reductions have largely benefitted non-environmental justice communities and have not redressed the fundamental problem of disparities in pollutant burdens between EJ and non-EJ communities.
Offshore Wind development	New York State Public Service Commission (PSC) / New York State Energy Research and Development Authority (NYSERDA)	NYSERDA currently has five offshore wind projects in active development, totaling more than 4,300 megawatts – nearly half of the State's goal for 9,000 megawatts by 2030. In July 2022, NYSERDA launched a third offshore wind solicitation to procure at least 2,000 additional megawatts of offshore wind energy for New Yorkers.	In addition to greening the grid, the offshore wind industry can bring thousands of new jobs to NYC and help revitalize our working waterfronts–like the efforts currently underway to transform the South Brooklyn Marine Terminal into an offshore wind staging site.	New York has entered into agreements to provide new jobs to EJ communities. The New York City Public Design Commission (PDC) has approved Equinor's design for the offshore wind operations and maintenance building to be constructed at the South Brooklyn Marine Terminal (SBMT). The approval from the PDC allows for advancement of New York's first-ever, purpose-built offshore wind operations and maintenance facility, marking an important step in revitalizing a working waterfront at this historic port. Jobs from this operation can help residents from disadvantaged communities.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
CITY				
Local Law 43 (2010) and Local Law 32 (2023)	New York City	Eliminate combustion of fuel oil numbers 6 and 4 in NYC.	Removal of "dirty" oil fuel use in residential and commercial buildings.	The Clean Heat program, related to this effort, reduced air pollution emissions in both high and low-income neighborhoods.
Local Law 97 (2019)	New York City	Requires reduced building greenhouse gas emissions by 40% by 2030, with compliance starting in 2024, and 100% by 2050.	Mandate applies to any building in NYC 25,000 square feet or larger; the law was updated in 2020 to include buildings in which up to 35% of units are rent regulated, starting in 2026. Officials estimate the law would apply to roughly 50,000 of the city's more than one million buildings.	Local Law 97 focuses on NYC's large buildings, both residential and commercial. Large residential buildings, where about two thirds of the city's population live, are already more efficient than single and two-family homes. Moreover, measurement of efficiency is based upon square footage, and it would be more effective to focus on per capita or household level emissions. To address this NYC launched the ElectrifyNYC (Electrify New York City), a free program that helps NYC homeowners in 1-4 unit buildings with green and efficient home upgrades so they can save money, make their homes more comfortable, and clean the air.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
CITY				
Local Law 24 (2016)	New York City	To enhance public awareness of the city's efforts to install 100 MW of solar by 2025. The city is required to assess the solar PV potential of all City-owned buildings over 10,000 gross square feet once every two years. Special focus is given to identifying and quantifying potential capacity at solar-ready buildings, which are defined as buildings that have roofs that are no more than 10 years old and in fair or good condition. The City has initiated the "Solar 100" project goal to install 100 megawatts (MW) of solar photovoltaic (PV) electricity generation capacity across municipal buildings by 2025. The Department of Education (DOE) partners with Solar One (a 501(c)(3) organization fostering sustainability education, training and technical assistance), on programs that support climate education and climate-related workforce development opportunities for public schools.	Increase in renewable solar energy generation within NYC.	There is a difference in hosting capacity across NYC neighborhoods which brings up questions of whether this will affect solar installation and energy storage capacity in EJ communities.
Local Law 92 and Local Law 94 (2019)	New York City	These laws require all buildings undergoing roof decking replacement and any newly constructed buildings to have a sustainable roofing zone—a solar PV system, a green roof, or a combination of both.	Enhance the development and implementation of solar energy in NYC.	NYC Accelerator program provides resources, training, and one-on-one expert guidance to help building owners and industry professionals improve energy efficiency and reduce carbon emissions from buildings in NYC.
Local Law 2 (2022)	New York City	Requires the creation of a demonstration program for geothermal exchange systems, pending results of the ongoing feasibility study.	Geothermal heat pumps provide clean and efficient heating and cooling, while using less electricity than other types of heat pumps. The project can realize further efficiencies and maximize environmental benefits through balanced loads and a diversity of thermal sources and sinks.	Geothermal power can potentially provide EJ communities with clean and efficient heating and cooling.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
CITY				
Local Law 99 (2019)	New York City	Assessing the feasibility of replacing in-city gas fired power plants with battery storage powered by renewables, and assessing the readiness of NYC's electric grid to accommodate anticipated increases in customer electricity demand due to building electrification.	Providing background on replacing fossil fuel power plants with clean energy and battery storage.	Background material can be used to provide information one energy storage access in EJ communities.
Local Law 248 (2017)	New York City	A law that requires NYC to create a long-term energy plan in 2019, every four years after and also establishes a City energy policy advisory subcommittee.	Provides a plan for energy use, a review of the current energy supply and capacity; a summary of the current citywide energy demand and a projection of the future citywide energy demand over the next four years, or such longer period as the advisory subcommittee may deem appropriate, including (i) an identification of factors that may affect demand; (ii) specific recommendations regarding the capacity that could be added to the current energy supply to meet such projected demand after consideration of such factors; and (iii) actions the City could take in connection with such recommendations.	Background material can be used to provide information on availability of wind generation in EJ communities.
Local Law 104 (2018)	New York City	A Local Law to amend the administrative code of the City of New York, in relation to the creation of wind maps demonstrating wind energy generation potential within the city.	Promote wind generation in NYC.	Background material can be used to provide information on removing highly polluting plants from EJ communities.
Local Law 181 (2019)	New York City	Studying the feasibility of installing utility-scale energy storage on private buildings throughout the city.	Provision of utility scale storage systems to allow for use of renewable energy.	Background material can be used to provide information on energy storage availability to EJ communities and what is feasible to use in lieu of Peaker plants.
Local Law 17	New York City	To direct the mayor’s office of long-term planning and sustainability to study the feasibility of different types of renewable energy sources combined with battery storage on Rikers Island.	Provide background on renewable energy to Riker's Island.	Provide renewable energy to officers, staff and inmates at Riker’s Island facility.

Local Policy Initiative	Policy Entities	Policy Mandates	Energy Implications	Justice Implications
CITY				
Local Law 154	New York City	To amend the administrative code of the City of New York, in relation to the use of substances with certain emissions profiles.	No person shall permit the combustion of any substance that emits 25 kilograms or more of carbon dioxide per million British thermal units of energy, as determined by the United States energy information administration, within such building.	Reduction of carbon dioxide emissions and electrification of EJ community buildings.
Local Laws 60 and 64	New York City	Assess the environmental equity issues in NYC and develop a plan to incorporate environmental justice into the fabric of City decision making. The law covers Power plants, Substations, distribution, and transmission Citygate stations, High-pressure regulators stations over 300psi; any boilers burning fuel oil #4 or #6 with or without waivers from City agencies; renewable energy systems, including solar PV, wind, microgrids, and energy storage, Generators required to be registered with DEP.	A report, an online EJ portal, and a plan are available. This legislatively mandated work, known as Environmental Justice New York City (EJNYC), represents a historic investment from the City of New York to study environmental inequities affecting how and where low-income communities and communities of color live, and to provide all residents the tools to advocate for the best outcomes for their communities.	The report on future investment decisions includes energy infrastructure in and affecting EJ communities.

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