Appendix C

CLIMATE PROTECTION LEVELS

Incorporating Climate Change into Design and Performance Standards

New York City Panel on Climate Change

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CLIMATE PROTECTION LEVELS

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William Solecki, Lesley Patrick, and Michael Brady were primarily responsible for the preparation and writing of the Climate Protection Levels document. William Solecki led the Climate Protection Levels group in developing the conceptual framework and methodology of the process described in this workbook. Kristen Grady authored each of the maps with contributions from Andrew Maroko, Lesley Patrick, William Solecki, and Michael Brady.

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The information in this document reflects the views and opinions of the New York City Panel on Climate Change and not the City of New York.

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EXECUTIVE SUMMARY

Climate change poses a range of hazards to New York City and its infrastructure. These changes suggest a need for the City to rethink the way it operates and adapts to its evolving environment. To respond to these changes and accomplish the goals outlined in PlaNYC, the City's comprehensive sustainability plan, Mayor Michael Bloomberg, with funding from the Rockefeller Foundation, convened the New York City Panel on Climate Change (NPCC) in August 2008. The NPCC, which consists of leading climate change and impact scientists, academics, and private sector practitioners, was charged with advising the Mayor and the New York City Climate Change Adaptation Task Force (the "Task Force") on issues related to climate change and adaptation as it relates to infrastructure. This document, one of three in a series of workbooks produced for the Task Force, assesses the extent to which climate change could alter the effectiveness and robustness of selected design standards for critical infrastructure in New York City and highlights areas that should be reviewed to determine if new climate protection levels are needed to account for climate change.

Infrastructure in New York City is governed by a complex set of city, state, and federal regulations and design standards. As the City's environmental baseline changes; however, these regulations, which are often based on historic climate trends, may be compromised and fail to provide the level of protection and service they were designed to ensure. As a result, key regulations should be reviewed through the lens of climate change to determine whether they will remain effective in the future and provide an adequate level of climate protection.

This workbook highlights the need to develop design standards that incorporate climate change projections, a concept referred to as *Climate Protection Levels* (CPLs), to ensure that infrastructure built today can operate in the future. In many cases, CPLs may be adjustments to existing codes and standards that maintain the City's critical infrastructure to at least the current level of risk exposure given climate change. The NPCC identified several areas where CPLs may be needed to take into account climate change; however, recommendations for specific CPLs are not included in this workbook as the work required to determine the cost-benefit, feasibility, or environmental impact of potential CPLs was beyond of the scope of this work.

Existing standards and potential climate protection levels were reviewed by the NPCC within the context of four of the most important climate risks in New York City as noted in the NPCC's Climate Risk Information workbook and by NYC Climate Change Adaptation Task Force. The risks include coastal flooding and storm surge, inland flooding, heat waves, and extreme wind events. In the document, example standards are discussed with respect to each hazard to illustrate the impacts that climate change could have on design standards and specifications. It should be noted that the list of standards examined is not exhaustive and the potential climate protection levels offered are to be considered as points of discussion rather than normative statements. To develop complete CPLs economic, engineering, and environmental analyses outside the range of this study would need to be conducted.

One of the most important standards that will be affected by climate change is the 1-in-100 year (or 1%) flood map. Developed by the Federal Emergency Management Agency (FEMA), Flood Insurance Rate Maps delineate the horizontal extent of the 1-in-100 year flood zone and are used to dictate the location and design of certain infrastructure and buildings through the City's building and zoning codes. To better understand the impact that sea level rise may have on New York, the NPCC developed a set of maps reflecting the possible increase of flooding area associated with the 100-year flood zone in New York City under varying scenarios of sea level rise. These maps are purely illustrative and give a directional sense of how the current floodplains could change over time. They should not be used to determine site-specific risks and contain a number of data errors and uncertainties embedded in their creation. City-wide flood maps are featured in Chapter 4 while higher resolution case study maps are presented in Chapter 8. A detailed mapping methodology including caveats, errors, and interpretation is presented in the Annex of this document.

POLICY & OPERATIONAL ISSUES

The NPCC via this document also identified a series of additional research needs to help the city adapt to climate change, including formal reviews, engineering-based studies, and gap assessments of current policies. Emerging research needs include examination of the built environment and risk exposure, administrative connectivity, economic impacts and equity considerations.

About the New York City Panel on Climate Change (NPCC)

Convened by Mayor Michael Bloomberg, the New York City Panel on Climate Change advises the Mayor and City on issues related to climate change and adaptation. Made up of climate change and impacts scientists, and legal, insurance and risk management experts, the NPCC is modeled on the Intergovernmental Panel on Climate Change (IPCC). Among its ongoing activities, the NPCC developed climate change projections for New York City; created this set of workbooks (Appendices A, B, and C) to assist the City's Climate Change Adaptation Task Force and drafted this report on the effects of climate change on New York City—similar to the IPCC reports on global climate change. The NPCC is chaired by Dr. Cynthia Rosenzweig of NASA Goddard Institute for Space Studies and Columbia University's Center for Climate Systems Research, and Dr. William Solecki of the CUNY Institute for Sustainable Cities at Hunter. The NPCC is funded through a generous grant from the Rockefeller Foundation.

About the Rockefeller Foundation

The Rockefeller Foundation fosters innovative solutions to many of the world's most pressing challenges, affirming its mission, since 1913, to "promote the well-being" of humanity. Today, the Foundation works to ensure that more people can tap into the benefits of globalization while strengthening resilience to its risks. Foundation initiatives include efforts to mobilize an agricultural revolution in Sub-Saharan Africa, bolster economic security for American workers, inform equitable, sustainable transportation policies in the United States, ensure access to affordable and high-quality health systems in developing countries, and develop strategies and services that help vulnerable communities cope with the impacts of climate change. For more information, please visit www.rockfound.org.

1. CLIMATE CHANGE AND NEW YORK CITY

Global mean temperatures and sea levels have been increasing for the last century, accompanied by other changes in the earth's climate. As these trends continue, climate change is increasingly being recognized as a major global concern. An international panel of leading climate scientists, the Intergovernmental Panel on Climate Change (IPCC), was formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to provide objective and up-to-date information regarding the changing climate. In its 2007 Fourth Assessment Report (AR4), the IPCC stated that there is a greater than 90% chance that warming temperatures since 1750 are primarily due to human activities. As described by the IPCC and as had been predicted in the 19th century, the principal driver of climate change over the past century has been increasing levels of atmospheric greenhouse gases associated with fossil-fuel combustion, changing land-use practices, and other human activities. Atmospheric concentrations of the major greenhouse gas carbon dioxide (CO_2) are now more than one-third higher than in pre-industrial times. Concentrations of other important greenhouse gases, including methane (CH_4), ozone (O_3) and nitrous oxide (N_2O) have increased as well. Largely as a result of work done by the IPCC and the United Nations Framework Convention on Climate Change (UNFCCC), efforts to mitigate the severity of climate change by limiting levels of greenhouse gas emissions are underway globally.

Climate Change and New York City

Climate change is extremely likely to bring warmer temperatures to New York City and the surrounding region. Heat waves are very likely to become more frequent, intense, and longer in duration. Total annual precipitation will more likely than not increase and brief, intense rainstorms are likely to increase. Towards the end of the 21st century, it is more likely than not that droughts will become more severe. Additionally, rising sea levels are extremely likely, and are very likely to lead to more frequent and damaging flooding during coastal storm events in the future.

Because of greenhouse gas forcing mechanisms already in the climate and the long timeframe of some climate system processes, awareness is growing that some impacts from climate change are inevitable. Responses to climate change have grown beyond a focus on mitigation to include adaptation measures in an effort to minimize the impacts of climate change already underway and to prepare for unavoidable future impacts.

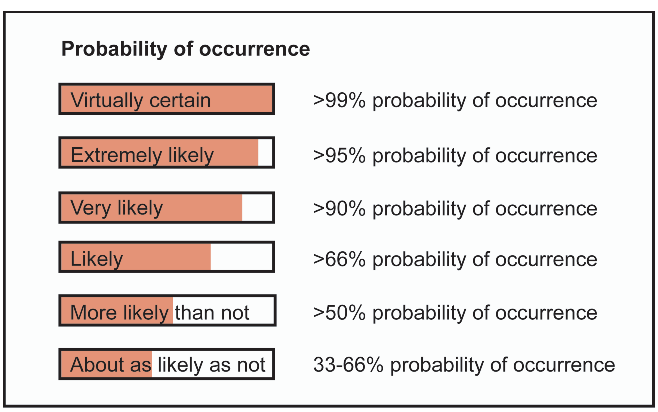
To respond to climate changes in New York City and accomplish the goals outlined in PlaNYC, the City's comprehensive plan to create a greener, more sustainable city, Mayor Michael Bloomberg, in partnership with the Rockefeller Foundation, convened the New York City Panel on Climate Change (NPCC) in August 2008. The NPCC, which consists of climate change and impacts scientists, and legal, insurance and risk management experts, serves as the technical advisory body for the Mayor and the New York City Climate Change Adaptation Task Force (the "Task Force") on issues related to climate change, impacts and adaptation.

The Task Force was also launched in August 2008 to identify climate change risks and opportunities for the City's critical infrastructure and to develop coordinated adaptation strategies. The Task Force consists of 40 city, state and federal agencies, regional public authorities, and private companies that operate, maintain or regulate critical infrastructure in the region. In the Task Force's work, critical infrastructure is defined as systems and assets (excluding residential and commercial buildings, handled by other city efforts) that support activities that are so vital to the city that the diminished function or destruction of such systems and assets would have a debilitating impact on public safety and/or economic security.

The NPCC was charged with creating three workbooks to guide Task Force members through the process of identifying climate risks to their critical infrastructure, creating adaptation plans, and considering the regulatory environment as it pertains to climate change adaptation. The Climate Risk Information (CRI) workbook provides a summary of climate data and projections for New York City and identifies potential risks to the City's critical infrastructure posed by climate change. The Adaptation Assessment Guidebook (AAG) provides stakeholders with a framework in which to incorporate climate change projections with their planning processes. The Climate Protection Levels (CPL) workbook evaluates some of the policies, rules and regulations that govern infrastructure to determine how they could be affected by climate change.

In February 2009, the NPCC released the Climate Risk Information workbook, which outlined climate change projections for New York City for the 2020s, 2050s, and 2080s. The workbook presents climate change projections in quantitative form wherever possible and qualitatively for climate variables characterized by higher uncertainty. Directional statements about climate projections are expressed in terms of their likelihood or probability of occurrence. The treatment of likelihood in the CRI is similar to that developed and used by the IPCC (Figure 1). The six likelihood categories used here are as defined in the IPCC Working Group (WG) I Technical Summary (2007). The assignment of climate hazards to these categories is based on global climate simulations, published literature, and expert judgment.

FIGURE 1. Probability of Occurrence



The treatment of likelihood in the CRI is similar to that developed and used by the IPCC. The six likelihood categories used here are as defined in the IPCC Working Group I Technical Summary (2007). The assignment of climate hazards to these categories is based on global climate simulations, published literature and expert judgment. Source: IPCC WG1, 2007

The following tables from the CRI workbook summarize the key climate findings. Warmer temperatures and rising sea levels are extremely likely with total annual precipitation in New York City more likely than not to increase. The projected mean annual changes of these variables are detailed in Table 1.

TABLE 1. Baseline Climate and Mean Annual Changes[1]

	Baseline 1971-2000	**2020s**	**2050s**	**2080s**
Air temperature Central range[2]	55° F	+ 1.5 to 3.0° F	+ 3.0 to 5.0° F	+ 4.0 to 7.5° F
Precipitation Central range[2]	46.5 in[3]	+ 0 to 5 %	+ 0 to 10 %	+ 5 to 10 %
Sea level rise[3] Central range[2]	NA	+ 2 to 5 in	+ 7 to 12 in	+ 12 to 23 in
Rapid ice-melt scenario[4]	NA	~ 5 to 10 in	~ 19 to 29 in	~ 41 to 55 in

Source: Columbia University Center for Climate Systems Research

[1] Based on 16 GCMs (7 GCMs for sea level rise) and 3 emissions scenarios. Baseline is 1971-2000 for temperature and precipitation and 2000-2004 for sea level rise. Data from National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA). Temperature data are from Central Park; precipitation data are the mean of the Central Park and La Guardia Airport values; and sea level data are from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available).
[2] Central range = middle 67% of values from model-based probabilities; temperatures ranges are rounded to the nearest half-degree, precipitation to the nearest 5%, and sea level rise to the nearest inch.
[3] The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections. For more information, see the "sea level rise" paragraph in the "mean annual changes" section.
[4] "Rapid ice-melt scenario" is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic Ice sheets and paleoclimate studies.

Table 2 summarizes the projected quantitative changes in extreme events, including heat wave durations, days of excessive rainfall, and flood heights and recurrence intervals associated with the 1-in-10, 1-in-100 and 1-in-500 year flood. Detailed methods of extreme event projections are offered in Annex B of the CRI workbook.

TABLE 2. Quantitative Changes in Extreme Events

Note: Extreme events are characterized by higher uncertainty than mean annual changes. The central range (middle 67% of values from model-based probabilities) across the GCMs and greenhouse gas emissions scenarios is shown. See the CRI workbook for the full range of values.

	Extreme Event	*Baseline (1971- 2000)*	2020s	2050s	2080s
Heat waves & Cold Events	# of days/year with maximum temperature exceeding:				
	90°F	*14*	23 to 29	29 to 45	37 to 64
	100°F	*0.4*[1]	0.6 to 1	1 to 4	2 to 9
	# of heat waves/year[2]	2	3 to 4	4 to 6	5 to 8
	Average duration (in days)	*4*	4 to 5	5	5 to 7
	# of days/year with minimum temperature at or below 32°F	*72*	53 to 61	45 to 54	36 to 49
Intense Precipitation & Droughts	# of days per year with rainfall exceeding:				
	1 inch	*13*	13 to 14	13 to 15	14 to 16
	2 inches	*3*	3 to 4	3 to 4	4
	4 inches	*0.3*	0.2 to 0.4	0.3 to 0.4	0.3 to 0.5
	Drought to occur, on average[3]	*~once every 100 yrs*	~once every 100 yrs	~once every 50 to 100 yrs	~once every 8 to 100 yrs
Coastal Floods & Storms[4]	1-in-10 yr flood to recur, on average	*~once every 10 yrs*	~once every 8 to 10 yrs	~once every 3 to 6 yrs	~once every 1 to 3 yrs
	Flood heights (in ft) associated with 1-in-10 yr flood	*6.3*	6.5 to 6.8	7.0 to 7.3	7.4 to 8.2
	1-in-100 yr flood to recur, on average	*~once every 100 yrs*	~once every 65 to 80 yrs	~once every 35 to 55 yrs	~once every 15 to 35 yrs
	Flood heights (in ft) associated with 1-in-100 yr flood	*8.6*	8.8 to 9.0	9.2 to 9.6	9.6 to 10.5
	1-in-500 yr flood to recur, on average	*~once every 500 yrs*	~once every 380 to 450 yrs	~once every 250 to 330 yrs	~once every 120 to 250 yrs
	Flood heights (in ft) associated with 1-in-500 yr flood	*10.7*	10.9 to 11.2	11.4 to 11.7	11.8 to 12.6

Source: Columbia University Center for Climate Systems Research

[1] Decimal places shown for values less than 1 (and for all flood heights), although this does not indicate higher accuracy/certainty. More generally, the high precision and narrow range shown here are due to the fact that these results are model-based. Due to multiple uncertainties, actual values and range are not known to the level of precision shown in this table.

[2] Defined as 3 or more consecutive days with maximum temperature exceeding 90°F.

[3] Based on minima of the Palmer Drought Severity Index (PDSI) over any 12 consecutive months. More information on the PDSI and the drought methods can be found in Annex B of the CRI workbook.

[4] Does not include the rapid ice-melt scenario.

Broad directional statements about a larger range of extreme events are captured in Table 3. Among these extreme events, heat waves are very likely to become more frequent, intense, and longer in duration; brief, intense precipitation events that can cause inland flooding are also likely to increase; storm-related coastal flooding due to sea level rise is very likely to increase; and it is more likely than not that droughts will become more severe.

TABLE 3. Qualitative Changes in Extreme Events

Extreme Event	Probable Direction Throughout 21st Century	Likelihood[1]
Heat index[2]	⇧	Very likely
Ice storms/ Freezing rain	⇧	About as likely as not
Snowfall frequency & amount	⇩	Likely
Downpours (precipitation rate/hour)	⇧	Likely
Lightning	*Unknown*	
Intense hurricanes	⇧	More likely than not
Nor'easters	*Unknown*	
Extreme winds	⇧	More likely than not

This table shows the probable direction of change over the 21st century, as well as the likelihood associated with the qualitative projection. For these variables, which can have large impacts on infrastructure, quantitative projections are not possible due to insufficient information.

Source: Columbia University Center for Climate Systems Research

[1] Likelihood definitions found in Figure 1.

[2] The National Weather Service uses a heat index related to tempreature and humidity to define the likelihood of harm after "prolonged exposure or strenuous activity" (http://www.weather.gov/om/heat/index.shtml).

2. DEFINITIONS AND FRAMEWORK

The New York City Panel on Climate Change assessed the extent to which climate change could alter the effectiveness and robustness of selected design standards for critical infrastructure in New York City, and highlighted areas that should be reviewed to determine if new climate protection levels (CPLs) are needed to account for climate change. This document creates a framework for incorporating climate change into the regulatory environment for critical infrastructure, reviews and assesses selected standards, and recommends areas that could require more robust or new standards. This review was based on climate change projections for the 2020s, 2050s and 2080s as outlined in the NPCC's Climate Risk Information workbook.

The design and construction of critical infrastructure in New York City is guided by building and construction codes and regulations, design standards, and best practices as adopted by the professional engineering community and various government entities. Design standards are regulations that dictate how or where an asset is built and can take the form of engineering or administrative regulations, policies, and practices. They are typically intended to protect life, improve safety, and reduce or avoid physical damage and related direct costs (i.e., repair and replacement costs) or secondary economic losses. In the context of this document, we focused on design standards specifically developed in response to emerging climate change information to maintain an acceptable level of climate risk.

Design standards are one metric used to achieve performance standards. Performance standards, in the context of risk management, are rules or codes that quantify the manner in which an asset, system, piece of equipment, person, or procedure must operate to achieve a goal or minimal level of service. In relation to climate, performance standards can be considered as principles which can inform decision-making and planning to ensure the continued functionality of infrastructure during and/or soon after an extreme weather event, such as a heat wave or a coastal storm.

While climate protection levels are introduced as a new term in this document, they – under other headings - have been developed and used in several major cities worldwide. Climate protection levels are climate-based, expert-determined benchmarks that are achieved through the implementation of design and performance standards with the express purpose of limiting the climate change risk exposure of critical infrastructure. The development of CPLs is guided by emerging climate risk information, projections of climate hazards, and socially acceptable levels of risk. The goal is to ensure that critical assets remain viable and operational through time under projected climate conditions and are therefore vital to the development of future climate risk management strategies. An essential feature of CPLs is that they provide benchmarks to which asset managers can plan incremental adaptations of their facilities, according to up-to-date climate risk information.

New York City's critical infrastructure is currently not equipped with climate protection levels specifically tailored to climate change. Existing design and performance standards in some cases do reflect contemporary or historical information on climate extremes and climate variability, but do not consider climate change already underway or projected for the future.

In this workbook, the potential impacts of climate change for four climate-related hazards on selected regulations and design standards were evaluated to illustrate the need to incorporate climate change projections into regulations governing and planning long-lasting infrastructure. The four hazards are associated with major cross-cutting risks to the region and include:

- Coastal flooding and storm surge
- Inland flooding
- Heat waves
- Extreme wind events

Many other climate change-related hazards could affect New York City's infrastructure, such as drought, ice storms and blizzards, lightning, and tornadoes. Establishing climate protection levels for these and other hazards could be considered in future assessments.

The process of developing CPLs contributes to the larger natural hazard mitigation strategy framework for the region. Natural hazard mitigation is defined as any cost-effective and continuous action taken to reduce or eliminate the long-term risk to human life or property from natural hazards (HMP, 2009). These actions relate to locational characteristics of hazards, structural and material resistance, operational guidance, usage and other behavioral modifications. An example of existing natural hazard mitigation related to climate is the requirement of properties situated within the 1-in-100 year flood zone,[1] as determined by the Federal Emergency Management Agency (FEMA), to adopt measures that reduce or avoid the risk of flooding and/or its consequences. Such flood zone regulations mandate how to reduce these risks through design standards, which are embodied in building codes and are considered in Environmental Impact Statements (EIS) for new development and redevelopment projects.

Several efforts are currently underway in New York City to mitigate the risks posed by current climate hazards. The 2009 *New York City Natural Hazard Mitigation Plan* (HMP) provides an inventory of hazard mitigation actions that exist in New York City, listed by stakeholder. The plan was developed by the New York City Office of Emergency Management (OEM) in accordance with FEMA guidelines and has since been adopted by both agencies. The OEM identified one-hundred forty-five existing and proposed hazard mitigation actions.

The potential for CPLs developed for this document interface with current climate risk management strategies such as the natural hazard mitigation efforts already underway. However, they are not simply outgrowths or extensions of present natural hazard mitigation guidelines. This is because climate change is now on-going, and because climate-related risks are projected to increase over time and result in dynamic hazard-exposure levels. As a result, CPLs need to be devised and/or applied to a broader range of areas, infrastructure types, and hazards than current efforts allow, in order to address the threat of increased risk in geographic scope, scale, and frequency. The goal of climate protection levels is to provide continued safe operation of the region's infrastructure without undue disruption

[1] Also presented as 1% flood in this document.

under conditions of a changing climate. They may be implemented by a variety of means such as the inclusion of appropriate requirements for new construction or incremental retrofits of existing infrastructure.

Overall, the CPL workbook is designed to provide illustrative examples of current standards and recommendations for areas where climate protection levels may be needed to account for climate change. The CPL workbook does not include specific recommendations for CPLs as this was beyond the scope and capacity of the NPCC at this time. Nor does the workbook discuss specific determinants of capacity to adapt to CPLs or take a position with respect to what are appropriate future levels of acceptable risk. However, it does assume that acceptable levels of risk will remain constant over time. The report also does not include a discussion of future adaptation strategies and their potential impact on the level of risk from or exposure to climate change on New York City. The CPL should not be viewed as a comprehensive review of all of the rules and regulations governing infrastructure, but a sample of some of the standards that could be impacted.

3. METHODOLOGY

A general process for identifying areas in need of CPLs is summarized in the following steps:

1. Develop regional/local-specific climate change projections
2. Select climate hazards of focus (i.e., coastal flooding and storm surge, inland flooding, heat waves, and extreme wind events)
3. Solicit feedback from operators and regulators of infrastructure through questionnaires to identify potential impacts of climate change hazards on infrastructure
4. Identify key existing design and/or performance standards relevant to critical infrastructure
5. Review and reassess these standards in light of the climate change projections
6. Highlight those standards that may be compromised by climate change or need further study to determine whether climate protection levels are necessary to facilitate climate resiliency

The NPCC's review of design and performance standards focused on selected primary or baseline standards. A description of these standards and the institutional entity that utilizes them to operate or manage critical infrastructure was developed for each of the four selected hazards (coastal flooding and storm surge, inland flooding, heat waves, and extreme wind events). The selected design and performance standards were either explicitly climate-based, or guided the formation of critical infrastructure at risk to climate-related hazards without direct reference to climate information.

Where example potential CPL recommendations are offered, they were derived through the use of a set of definitional criteria (i.e., whether the standard could be defined as a CPL), discussion and consensus among NPCC members, and contributions from external reviewers. Recommendations were not subject to environmental, engineering, or economic analysis and should be further evaluated and analyzed before considered final. To be considered for recommendation, a CPL, a regulation, policy, or practice must:

- Guide the formation or maintenance of critical infrastructure at-risk to climate-related hazards
- Dictate action with respect to climate-related hazards and maintenance of acceptable risk levels with respect to climate-related hazards
- Allow for adjustments that will enable a stable level of risk protection in response to a changing climate

Discussion among NPCC members focused on identifying any hindrances that a prospective CPL might have in meeting these three requirements. Preliminary analysis by the NPCC leads its members to suggest that stakeholders could use the 90th percentile of projections for the 2080s as a baseline to determine if climate change is likely to impact their assets and operations by the end of the century (either on existing or planned infrastructure), the potential extent of that impact, the acceptable level of risk, and the feasibility and/or the need for an adaptation strategy. Strategies could be tied to the location and lifespan of the asset, cost-benefit analysis of impacts, and magnitude of consequences should the impact occur. This metric does not reflect the position that current actions be taken to achieve the 90% metric in the short-term, but instead promotes the idea that actions taken in the short-term (i.e., next 5 to 10 years) would not preclude or hamper achieving this metric goal in the medium- and long-term. The 90% level was considered to be an appropriate measure for evaluation that resulted from statistically based measures within the Climate Risk Information workbook and expert judgment.

Given the state of information available to the NPCC and the scope of its current work, the development of specific recommendations for CPLs was not feasible. The NPCC was able to make broad-based suggestions of areas to review to determine the impacts of climate change. These suggestions take five forms:

- *Quantitative statements*. Statements that emerge from the interplay between quantitative design and performance standards and quantitative climate risk information.
- *General statements*. Narrative comments on the relevance of climate risk information to existing design standards.
- *Infrastructure analysis*. Recommendations for further analysis of the critical parts of the infrastructure for which more information is needed to create CPLs. For example, more specific information on the existing design standards of street catch basins for inland street level flooding is required to determine if a CPL is needed to address this issue.
- *Engineering-based studies*. Suggestions for engineering studies such as hydrologic studies that need to be performed in order to determine if and/or how current standards need to be changed. These are necessary in situations where there are limitations in the climate change projections or knowledge of the system/material-level response to climate change and variability (e.g., responses of materials to increased heat).
- *Key policy and planning issues*. Evaluation of system-wide issues such as the distribution of impervious surfaces, land use changes, and human health issues.

4. COASTAL FLOODING AND STORM SURGE

INTRODUCTION

Coastal flooding and storm surge are coincident hazards that occur during extreme weather events such as tropical storms, hurricanes, and nor'easters. The high winds and low barometric pressure of these intense storm systems act to push ocean water inland, resulting in coastal flooding. The water that is pushed ashore, referred to as the storm surge, can often be several meters above mean water level. New York City is especially vulnerable to the storm surge of hurricanes and nor'easters because of its dense population and unique position at the hinge of the New York Bight – a right angle configuration of the New York and New Jersey coastlines that can act to funnel and hold storm surge in the Lower New York Harbor.

As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. Any increase in the frequency or intensity of storms themselves would result in even more frequent future flood occurrences relative to the current 1-in-10 and 1-in-100 year coastal flood events. Storms of a given magnitude will result in higher coastal flood elevations that inundate a larger geographic area. The heavy precipitation associated with these storm systems can cause increased surface runoff, particularly in urban areas dominated by impervious surfaces, and river surges that can intensify the effects of storm surges coming in from the sea.

PRIMARY STANDARD FOR NEW YORK CITY: THE 1-IN-100 YEAR FLOOD STANDARD

The primary design and performance standard for coastal flooding and storm surge in the United States is the Federal Emergency Management Agency (FEMA) defined 1-in-100 year flood, also known as the 1% flood. The 1-in-100 yr flood is defined as a flood that has a 1% chance of being equaled or exceeded in any given year. For nearly 40 years, the 1-in-100 year flood zone has been considered a high risk flooding area and subject to special building codes and insurance and environmental regulations.

In 1968, the National Flood Insurance Act established the National Flood Insurance Program (NFIP), a program to protect property owners in flood-prone areas from potential losses and to reduce future flood damage. Through this program, communities in flood hazard areas can adopt floodplain management ordinances and become eligible for flood insurance. The Act also directed the U.S. Department of Housing and Urban Development (HUD) to identify areas of flood hazard and develop floodplain management strategies. Given this task, HUD partnered with experts at the University of Chicago and convened the Chicago Seminar, a conference of experts in flood-plain management who developed the 1-in-100 year flood standard—a standard for identifying flood hazard areas and regulations. In 1971, the NFIP tied the regulatory requirements of their program to the recently developed 1-in-100 year flood standard. The FEMA is now responsible for creating and maintaining Flood Insurance Rate Maps (FIRMs) that delineate the 1-in-100 year floodplain for all communities that participate in the National Flood Insurance Program.

FIRMs are developed from various sources of information including historic flood, meteorological, and hydrologic data. The 1-in-100 year flood zone, also known as the Special Flood Hazard Area (SFHA), is identified on these maps as well as site-specific base flood elevations (BFEs), also known as the 100-year flood elevation. These maps are used by federal agencies to determine if flood insurance is required when banks provide federally insured loans or grants towards new construction.

In New York State, compliance with the National Flood Insurance Program is mandatory for all jurisdictions and the existence of flood insurance plans at the community level is a condition for any given property to obtain flood insurance. Development activity within the FEMA 1-in-100 year flood zone is subject to special permitting procedures due to the high flood risk. Many of the flood-resistant construction codes of New York City are required to meet the state and federal requirements, which have been standardized through the International Building Code (IBC).

SUMMARY OF CLIMATE RISK INFORMATION

The NPCC developed quantitative and qualitative projections about future coastal flooding, including projections of sea level rise based on global climate models and rapid ice melt scenarios, and flood frequency and elevation projections based on global climate models (Table 4). The sea level rise projections are characterized by a degree of uncertainty in large part due to the potential for rapid ice melt in the Polar Regions. To account for this, the NPCC developed rapid ice melt scenarios to reflect additional sea level rise due to ice melt from the Greenland and West Antarctic ice sheets (Appendix A, p. 175).

TABLE 4. Summary of Quantitative Climate Risk Information Data for Sea Level Rise and Flooding

Time slice	Sea Level Rise (in) (central range*)	Rapid Ice-Melt Sea Level Rise (in)	Flood recurrence intervals (years)**			Flood heights(ft)**		
			1-in-10 Yr to occur once every	1-in-100 Yr to occur once every	1-in-500 Yr to occur once every	1-in-10 Yr	1-in-100 Yr	1-in-500 Yr
Baseline (1971-2000)	n/a	n/a	10	100	500	6.3	8.6	10.7
2020s	2 to 5	5 to 10	8 to10	65 to 80	380 to 450	6.5 to 6.8	8.8 to 9.0	10.9 to 11.2
2050s	7 to 12	19 to 29	3 to 6	35 to 55	250 to 330	7.0 to 7.3	9.2 to 9.6	11.4 to 11.7
2080s	12 to 23	41 to 55	1 to 3	15 to 35	120 to 250	7.4 to 8.2	9.6 to 10.5	11.8 to 12.6

*The central range is the middle 67% of values from model-based probabilities
** Does not include the rapid ice-melt scenario.
Source: NPCC's Climate Risk Information workbook

The NPCC also developed qualitative projections that stated that intense hurricanes will more likely than not become more frequent throughout the 21st century (Table 3. See Appendix A for details). The future frequency of nor'easters is uncertain. Additional data are needed to better understand the dynamics of ice sheets, and to allow for more accurate estimates of hurricane and nor'easter frequency.

EXISTING STANDARDS AND POTENTIAL CLIMATE PROTECTION LEVELS: COASTAL FLOODING AND STORM SURGE EXAMPLES

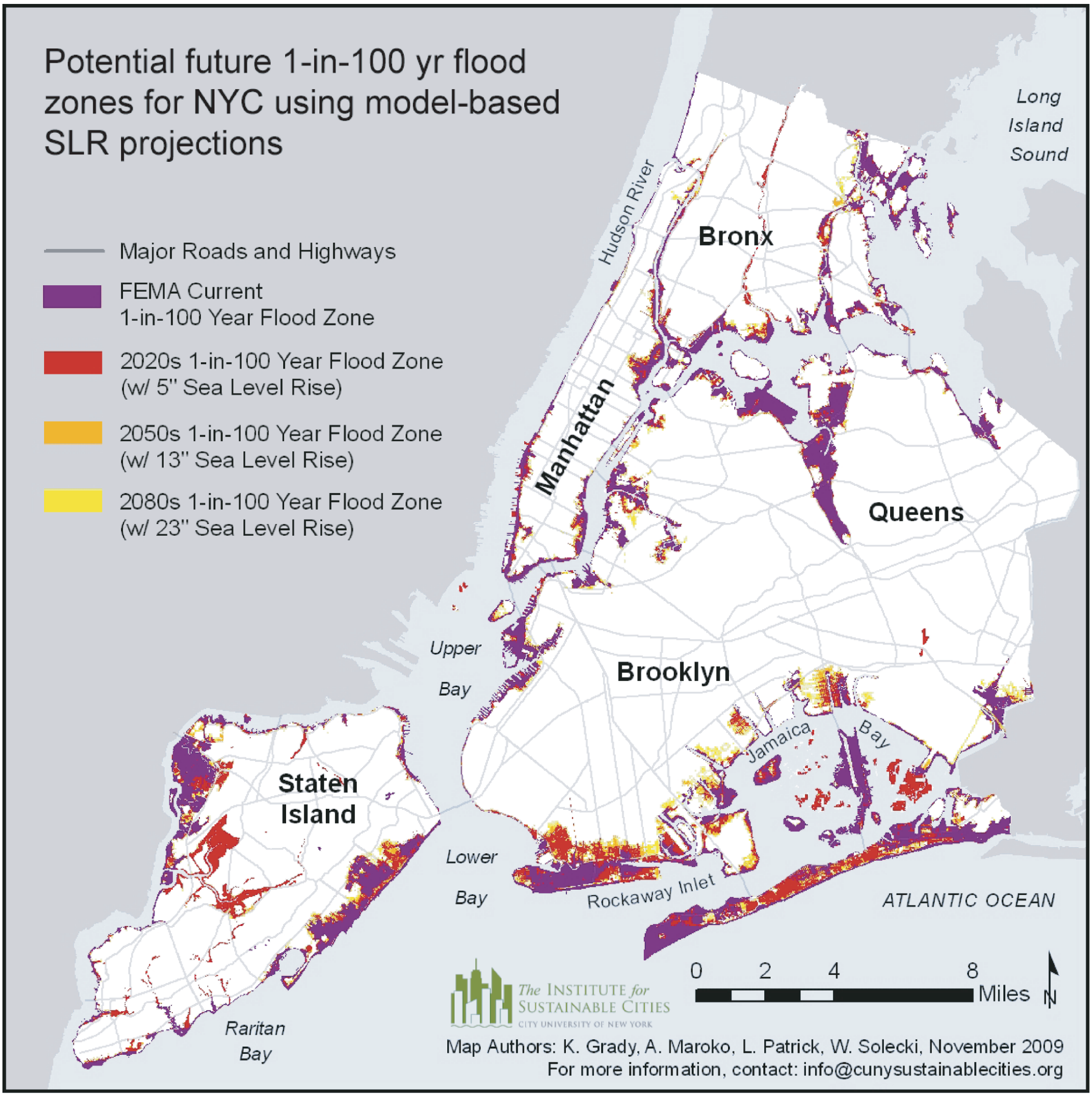
- Incorporate sea level rise projections into regulatory maps of coastal areas, including FEMA Flood Insurance Rate Maps (FIRMs), A- and V-zones, and the SLOSH Model

The single most significant CPL recommendation for coastal flooding and sea level rise is to update the current 1-in-100 year flood zone to incorporate projections of sea level rise. It is important to recognize that projected sea level rise will increase the frequency of extreme flooding events. To estimate the potential impact of sea level rise on the spatial extent of the current 1-in-100 year flood zone, the NPCC developed a series of maps to illustrate the areas in the city that are currently at risk, those that may be in the future, and those that likely will not. These maps are purely illustrative and contain numerous inaccuracies and errors that are discussed further in this section and in the annex of this workbook. Figures 2 and 3 illustrate the potential impact of sea level rise on the scope of areas in New York City that could be subject to a 1-in-100 year flood risk in the 2020s, 2050s, and 2080s, as calculated with and without rapid ice melt. The 90th percentile applies to the model-based uncertainty terms. For the rapid ice melt scenario meltwater term, the average of the meltwater estimate based on the paleoclimatic record is 43 inches per century. This was used to set the 90th percent level of sea level rise as opposed to the meltwater range provided in the CRI (39 to 47 inches per century. See CRI Table 3 for more information about the rapid ice melt scenario meltwater estimate).

To estimate the scope and direction of the impact of sea level rise on FEMA FIRMS, the NPCC added its sea level rise projections to the FEMA 1-in-100 year base flood elevations. These projections add 23” of SLR and 53” of rapid ice melt SLR in the 2080s to the existing 1-in-100 year FEMA base flood elevations. The maps illustrate ever increasing areas of flooding due to sea level rise; however the maps include several levels of error and needed caveats resulting from data and information limitations, including limitations in scope and error inherent in the 1983 FEMA coastal modeling, the climate modeling, and GIS methodology, as well as the broad accuracy range of topographic elevation data. The maps should not be used to judge site-specific risks; however, they do illustrate the directional trends of areas currently not within the 1-in-100 year flood zone that may become so in the future.

Using the 90th percentile of the model-based component of the rapid ice melt scenario in the 2080s provides a very high probability that sea level rise will not exceed the protection level before that time. Should sea level rise prove lower by the 2080s, a CPL based on the 90th percentile of rapid ice melt would provide a buffer for larger storm surges than those defined by the 1-in-100 year flood. Should sea level rise be lower than the CPL, and the 1-in-100 year flood prove lower than NPCC’s projected flood levels, the CPL can be thought of as providing: 1) protection for sea level rise beyond the 2080s, and 2) protection against rarer storms up until the time when sea level rise exceeds the CPL. Figure 3 in particular highlights the potentially dramatic landward progression of the 1-in-100 year flood zone, specifically in the Greater Jamaica Bay area of Brooklyn and Queens, under a rapid ice melt regime in the 2080s.

FIGURE 2. Areas potentially at-risk to the 1-in-100 year floods in NYC due to sea level rise projections derived from global climate models.



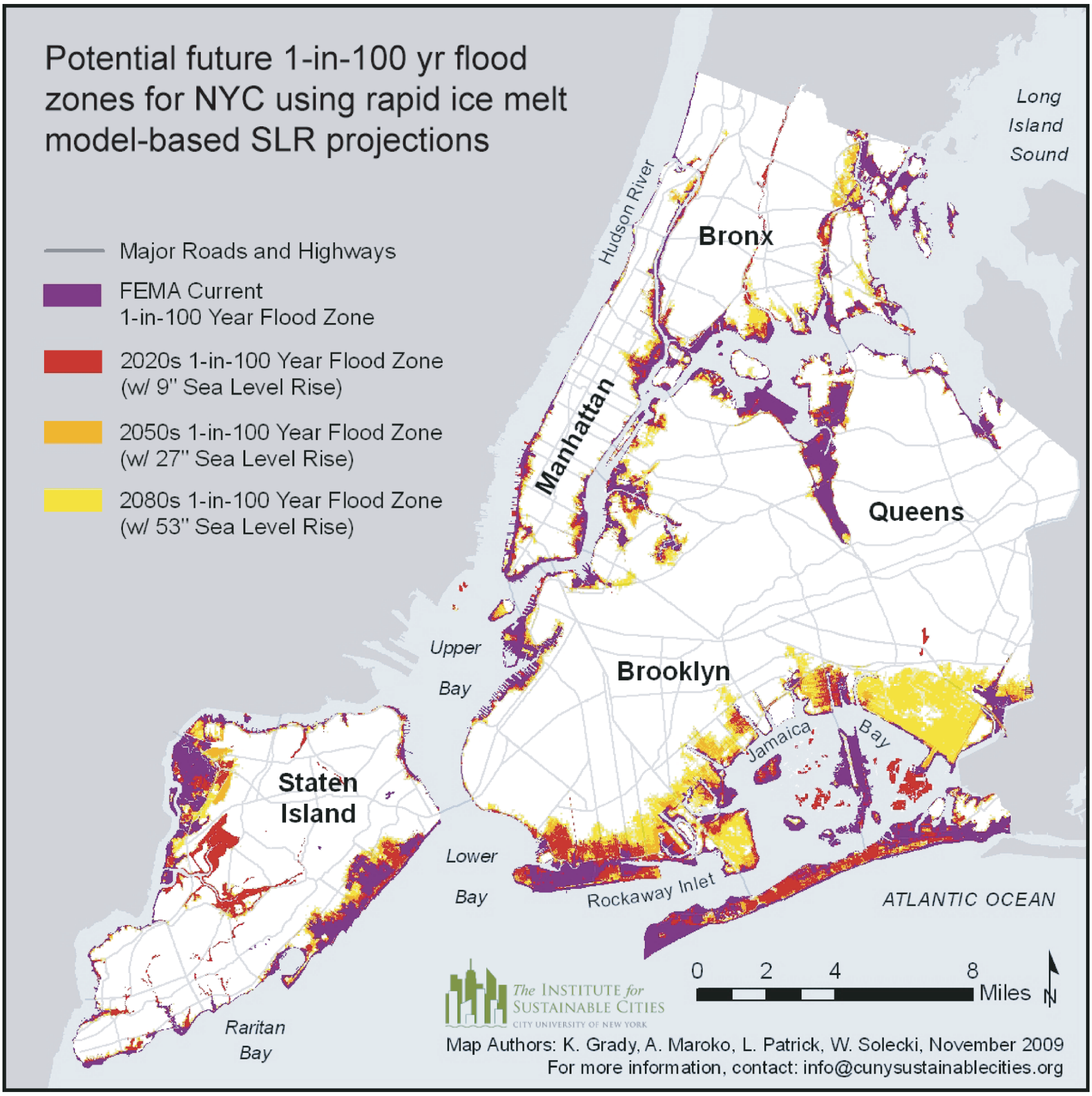
Note. This map is subject to limitations in accuracy as a result of the quantitative models, datasets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

Interpretation. The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios used in this research (end of the current century).

Figure 2 shows the current FEMA 1-in-100 year flood zone and potential areas that could be impacted by a 1-in-100 year flood in the 2020s, 2050s, and 2080s based on the 90th percentile model-based projections of sea level rise.

Source: CUNY Institute for Sustainable Cities

FIGURE 3. Areas potentially at-risk to the 1-in-100 year floods in NYC due to rapid ice melt sea level rise projections derived from global climate models.



Note. This map is subject to limitations in accuracy as a result of the quantitative models, datasets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

Interpretation. The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios used in this research (end of the current century).

Figure 3 shows the current FEMA 1-in-100 year flood zone and potential areas that could be impacted by a 1-in-100 year flood in the 2020s, 2050s, and 2080s based on projections of the 90th percentile model-based "rapid ice melt" sea level rise scenario. This estimate is based on the average meltwater rate of 43 inches per century in paleoclimatic times (see CRI Table 3 for more information).

Source: CUNY Institute for Sustainable Cities

The following climate protection level recommendations are founded upon and in response to the primary recommendation of updating 1-in-100 year flood zone to reflect rapid ice melt sea level rise. In the meantime, a significant action would be for FEMA to update its FIRMs for New York City to account for changes in sea levels and mapping technology over the past 30 years. Going forward, periodic updates to the maps should be made to reflect improvements in our understanding or climate change, climate change science, hydrodynamic modeling, and mapping.

Any updates to the 1-in-100 year flood maps, whether reflecting current or future risks, must include updates to the 1-in-100 year flood A- and V-zones, which delineate zones of wave action and/or high velocity water (V-zones) and areas without wave action (A-zones). The New York City Building Code currently details flood-specific regulations in the coastal zones, such as the required elevation of lowest floor, utilities and equipment, and dry and wet flood-proofing, as well as the elevation at which flood-damage-resistant materials must be used.[2] However, as the higher energy associated with wave action can result in greater damage, structures in A-zones and structures in V-zones are subject to different construction codes. To allow construction codes to continue to effectively protect structures in high risk flood areas, the 1-in-100 year flood zone and the A- and V-zones need to be revised in tandem.

In addition to the FIRMs, the National Oceanic and Atmospheric Administration (NOAA) should incorporate sea level rise projections into its SLOSH model (Sea, Lake and Overland Surges from Hurricanes), which estimates the area that will be inundated by the storm surge of different category hurricanes.[3] This information is used to design the NYC Coastal Storm Plan, a city-wide preparedness plan for hurricanes that features "…strategies for storm tracking, public information, evacuation procedures, people with special needs, recovery, and restoration."[4]

In order to prepare for more frequent intense hurricanes, greater storm surge and higher storm tide, and a larger inundation area, the City should work with NOAA to develop hurricane storm surge calculations generated by the SLOSH model that incorporate projections of rapid ice melt sea level rise for the 2080s. These new storm projections will provide stakeholders with a maximum flooding scenario, one associated with a major hurricane (category 3 or 4) making landfall just south of the city. New York City will be able to anticipate revisions to their Coastal Storm Plan that incorporate a wider inundation area, resulting in a larger affected population and changes to evacuation routes and procedures.

INCORPORATE SEA LEVEL RISE PROJECTIONS AND POTENTIAL FOR MORE FREQUENT EXTREME STORM EVENTS IN DESIGN STANDARDS AND REGULATIONS GOVERNING BRIDGES

- As flood frequency and flood intensity potentially increase in response to sea level rise, the criteria through which bridges are inspected for scour may need to be adjusted. For example, it

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[2] New York City Department of Buildings (NYC DOB). New York City Construction Codes-LL-33 / Appendix G: Flood-Resistant Construction. July 2008. 20 Dec 2008 <http://www.nyc.gov/html/dob/downloads/pdf/cc_appendix_g.pdf>

[3] New York City Office of Emergency Management (NYC OEM). New York City Hazard Mitigation Plan, Section 3f: Coastal Storm Hazard Analysis. 2009. <http://www.nyc.gov/html/oem/downloads/pdf/hazard_mitigation/section_3f_coastal_storm_hazard_analysis.pdf>

[4] New York City Office of Emergency Management. Planning for Emergencies: Coastal Storm Plan. 2006. <http://www.nyc.gov/html/oem/html/about/planning_coastal_storm.shtml>

could be considered that in order to allow for the projected elevations of the 1-in-100 year flood for the 2080s, the Federal Highway Administration alters its requirement that bridge owners check for scour associated with the 1-in-100 and 1-in-500 year event.

- Similarly, NYSDOT could consider adjusting requirements of substructure openings to account for the increase in flood elevation and flood extent expected with the projected elevations of the 1-in-100 year flood for the 2080s.

Scour is the hole left behind when sediment (sand and rocks) is washed away from the bottom of a river (USGS, 2007). It affects bridges by removing sediment from around bridge piers or abutments, and is exacerbated by an increase in speed of the water as it moves through a bridge opening that is narrower than the natural river channel. Ultimately, bridge scour can compromise the structural integrity of the structure leading to failure or collapse. “The majority of bridge failures in the United States are the result of scour …in that the flow of water currents at the column base can erode the stability of the column foundation. [The Federal Highway Administration] FHWA requires that bridge owners evaluate bridges for potential scour associated with the 100-year event … and to check scour effects for the 500-year event …” (Meyer, 2008).

The New York State Department of Transportation (NYSDOT) sets requirements to limit the effects of bridge scouring associated with extreme flooding events.[5] For example, inadequate substructure openings that restrict water conveyance under a bridge and between piers increase water flow velocities, accelerating scour during extreme flooding. The NYSDOT requires bridges to be designed with a substructure opening adequate to accommodate the 1-in-100 year flood volume for in-state bridges and the 1-in-500 year flood volume for interstate bridges.

- Evaluate the need to include sea level rise projections into the NYSDOT mandated two-foot freeboard clearance for bridges.

Bridge structures often serve as a collection point for debris caused by flooding. Debris collection increases potential scour by reducing the bridge design opening and increasing water flow velocities.[6] To reduce the risk of increased scour due to debris collection, the NYSDOT requires structures built over non-navigable waterways provide a minimum two-foot *freeboard clearance*, the required clearance between the lower limit of bridge or other structure and the high water surface elevation, for the 1-in-50 year flood to allow ice and debris to pass.[7] Design guidance also recommends appropriate design configurations to limit debris collection.

Sea level rise and more intense, longer-lasting, and frequent precipitation events will alter the regimes under which many bridges have been designed. The current 1-in-50 year flood will become more frequent and future 1-in-50 year flood scenarios will have a greater flood extent thereby posing a challenge to the maintenance of the two-foot freeboard clearance. Linking bridge construction and inspection criteria with climate change projections will provide a more accurate understanding of bridge vulnerability to extreme flooding events in the future.

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5 New York Department of Transportation. Bridge Safety Assurance: Hydraulic Vulnerability Manual. 2003. <https://www.nysdot.gov/divisions/engineering/structures/repository/manuals/bridge_safety/bsa_hyd_vuln_manual.pdf>

6 Ibid.

7 New York State Department of Transportation (NYSDOT). Bridge Manual, Section 2: Geometric Design Policy for Bridges, 2.4.3. 2008. <https://www.nysdot.gov/divisions/engineering/structures/repository/manuals/brman-usc/Section_2_US_2008_1st.pdf>

COASTAL ZONES: WATERFRONT REVITALIZATION PROGRAM

- Incorporate sea level rise projections into the delineation of New York City Coastal Zone Boundary.

The New York City Waterfront Revitalization Program (WRP) is considered the City's principle coastal zone management tool.[8] New York City's Coastal Zone Boundary, as originally mapped and adopted in 1982, defines the geographic scope of the WRP. Development within the New York City Coastal Zone Boundary is guided by the WRP through the implementation of a consistency program coordinated by the NYSDOS. The purpose of the program is to ensure that all coastal development is consistent with regulations set by every stakeholder within the jurisdiction of development, and participation is mandatory. The only exception is federal lands and facilities which are excluded from the consistency program and subject to federal legislation. The NYC Coastal Zone Boundary is delineated by select coastal features such as wetlands, maritime and industrial areas, historic sites, and coastal floodplains and flood hazard areas.[9] However, portions of the 1-in-100 year flood plain are not captured in the coastal zone, therefore development within the 1-in-100 year flood plain is not consistently subject to the regulations of the permit consistency program.

The City could redefine the coastal zone boundary to incorporate sea level rise. As the 1-in-100 year flood zone encroaches landward, New York City will become more vulnerable to coastal flooding and storm surge hazards if development within the flood zone is not subject to consistent regulations.

Many stakeholder permit programs in New York City that are subject to WRP review actually help to limit natural hazard risk. For example, the NYSDEC Coastal Erosion Control Permit Program[10] regulates the construction, procedures, and other activities that may contribute to increased coastal land erosion in the state legislature designated Coastal Erosion Hazard Areas (CEHA). Erosion contributes to storm surge hazards by increasing the vulnerability of coastal structures through shoreline retreat (FEMA, 1991) and through larger wave heights, increased wave power, and increased destructive force associated with deeper near shore waters (NRC, 1987). It is likely that protocol for granting development permits in the coastal zone are based on dated climate information that does not reflect future levels of natural hazard risk assessments (e.g., the rate and nature of erosion at a proposed development site). All permit programs subject to the WRP that protect New York City from climate-related hazards should be inventoried and assessed in light of up-to-date climate change risk information to ensure that they incorporate climate change projections.

The following table summarizes the recommended areas to evaluate the need for and development of climate protection levels for coastal flooding and storm surge.

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[8] New York City Department of City Planning (NYC DCP). Waterfront Revitalization Program. 2009. <http://www.nyc.gov/html/dcp/html/wrp/wrp.shtml>

[9] New York City Department of City Planning (NYC DCP). New York City Coastal Zone Boundary Maps. 2009. <http://www.nyc.gov/html/dcp/html/wrp/wrpcoastalmaps.shtml>

[10] New York State Department of Environmental Conservation (NYSDEC). Coastal Erosion Control Permit Program. 2009. <http://www.dec.ny.gov/permits/6064.html>

TABLE 5. Examples of Standards and Possible CPLs
Coastal Flooding and Storm Surge

Current Standard	CPL Recommendations	Stakeholder
FEMA 1-in-100 year flood zone	Incorporate sea level rise projections into regulatory maps of coastal areas, including FEMA Flood Insurance Rate Maps (FIRMs), A- and V-zones, and the SLOSH model.	Federal Emergency Management Agency
NYSDOT requires that bridges be designed with a substructure opening adequate to accommodate the 1-in-100 year flood volume for in-state bridges and the 1-in-500 year flood volume for interstate bridges.[1]	Consider adjusting requirements of substructure openings to account for the increase in flood elevation and flood extent expected with the projected elevations of the 1-in-100 year flood for the 2080s.	New York State Department of Transportation
NYSDOT requires non-navigable waterway bridges to have a 2 ft freeboard clearance above the 1-in-50 year flood level.[2]	Evaluate the need to include sea level rise projections into the NYSDOT mandated two-foot freeboard clearance for bridges.	New York State Department of Transportation
FHWA requires bridge owners to inspect bridges for potential scour associated with the 1-in-100 and 1-in-500 year floods.[3]	Incorporate SLR projections for the elevations of the 1-in-100 year flood into FHWA's requirement that bridge owners check for scour associated with the 1-in-100 and 1-in-500 year event.	Federal Highway Administration
The Waterfront Revitalization Program[4] establishes policies for the development and use of New York City's Coastal Boundary lands.[5]	Incorporate sea level rise projections into the New York City Coastal Zone Boundary.	New York City Department of City Planning, NYS Department of State

[1] New York Department of Transportation. Bridge Safety Assurance: Hydraulic Vulnerability Manual. 2003. <https://www.nysdot.gov/divisions/engineering/structures/repository/manuals/bridge_safety/bsa_hyd_vuln_manual.pdf>

[2] New York State Department of Transportation, (NYSDOT) Bridge Manual, Section 2: Geometric Design Policy for Bridges, 2.4.3. 2008

[3] Meyer, Michael D., 2008. Design Standards for U.S. Transportation Infrastructure: The Implications of Climate Change. National Academy of Sciences. <http://onlinepubs.trb.org/onlinepubs/sr/sr290Meyer.pdf>

[4] The New York City Waterfront Revitalization Program (WRP) is the city's principal coastal zone management tool. As originally adopted in 1982 and revised in 1999, it establishes the city's policies for development and use of the waterfront and provides the framework for evaluating the consistency of all discretionary actions in the coastal zone with those policies. When a proposed project is located within the coastal zone and it requires a local, state, or federal discretionary action, a determination of the project's consistency with the policies and intent of the WRP must be made before the project can move forward."
New York City Department of City Planning (NYCDEP). Waterfront Revitalization Program. 2009. <http://www.nyc.gov/html/dcp/html/wrp/wrp.shtml>

[5] The coastal boundary encompasses all land and water of direct and significant impact on coastal waters. The zone extends landward to include geographic features that are vulnerable to coastal flooding. "In developed areas devoid of these features, the coastal zone boundary is generally defined as the nearest legally mapped street at least 300 feet landward of the Mean High Tide Line. In undeveloped areas devoid of these features, the landward boundary is delineated at the legally mapped street nearest to the first major man-made physical barrier. Exceptions to these guidelines include City Island, Broad Channel Island, and the Rockaway Peninsula which are included within the coastal zone in their entirety. Federal lands and facilities are excluded from the coastal zone and consistency review in accordance with federal legislation. However, should the federal government dispose of any coastal property it would be included in the coastal zone."
New York City Department of City Planning. New York City Coastal Zone Boundary Maps. 2009. <http://www.nyc.gov/html/dcp/html/wrp/wrpcoastalmaps.shtml>

5. INLAND FLOODING

INTRODUCTION

Inland flooding refers to riverine and urban street flooding caused by high-intensity precipitation events. Riverine flooding is typically associated with large precipitation events of extended duration. The potential for such flooding is especially great during late winter/early spring snow melt-affected runoff events or when the soil is saturated from previous rains. However the water levels of New York City's rivers are largely controlled by tidal conditions at the mouth of the river with little influence from the upstream flow volume. Therefore riverine flooding only affects small portions of the city, primarily in the Bronx and Staten Island (FEMA, 2007). Street-level flooding is more typically associated with intense, more time-constricted downpour events, during which more than an inch of rain, for example, might fall within a few hours. Urbanization in general, specifically the increase in population density and development of extensive impervious surfaces, has dramatically elevated the potential for urban street flooding. The NYC Natural Hazard Mitigation Plan cites over 55 major urban flooding events since 1993.

PRIMARY DESIGN AND PERFORMANCE STANDARDS

Primary design and performance standards for extreme inland flooding in New York City are the FEMA-designated 1-in-100 year flood zone and the New York State Department of Environmental Conservation (NYSDEC) 100-Year Flood Control Requirement. As previously discussed, development within the 1-in-100 year flood zone, or Special Flood Hazard Area (SFHA), is subject to special floodplain regulations that aim to offset flood risk to an acceptable level. Development requirements applied within A-zones, or zones without high velocity wave action, of the SFHA are most relevant for inland flooding hazards.

The NYSDEC 100 Year Flood Control Requirement is a cross-cutting design and performance standard that applies widely to NYC stormwater control infrastructure. "The intent of the extreme flood criteria is to (a) prevent the increased risk of flood damage from large storm events, (b) maintain the boundaries of the predevelopment 100-year floodplain, and (c) protect the physical integrity of stormwater management practices" (NYSDEC, 2008b). These intents pose wide-reaching implications for NYC stormwater infrastructure. For example, to maintain the boundaries of the predevelopment 1-in-100 year floodplain means that stormwater infrastructure design must allow New York City to safely pass the 1-in-100 year storm notwithstanding urban development, which continuously changes the NYC stormwater management regime.

The 100 Year Flood Control Requirements refer to Technical Paper Number 40 (Hershfield, 1961) to determine flowrates associated with the 1-in-100 year storm event of 24-hour duration. Technical Paper Number 40 provides Rainfall Intensity-Duration-Frequency (IDF) curves for multiple temporal scales of rain intensity durations and return frequencies based on historical climate information. These values vary throughout NYC, as climate is not spatially uniform. Government agencies in New York City involved with managing critical infrastructure affected by flooding use these IDF curves to determine designs for flood management. Stormwater infrastructure designs vary due to different type and level of risk in each location and the purpose of a given component within a stormwater management system. The flowrates developed by FEMA for the NFIP differ from those used in New York State stormwater management, as FEMA's flowrates do not have storm duration associated with them.

Climate change raises many questions about the adequacy of existing flood management efforts. Will future rainfall rates routinely exceed the current maximum sewer designed rainfall intensity value of 5.95 inches per hour? If so, then street flooding could be a major problem in the future, particularly since it is extremely costly and difficult to retrofit existing sewers. Unfortunately, this question cannot be answered quantitatively, since there is little consistency among GCMs in predicting regional rainfall rates. Although the percentage increase in annual precipitation is expected to be relatively small, large percentage increases are expected in the frequency, intensity, and duration of extreme precipitation (defined as more than 1, 2, and 4 inches) at daily timescales. This projection is consistent both with theory and observed trends nationally over the 20th century. It is, therefore, also possible that the peak storm water flow rates that NYCDEP currently uses to design the City's sewers could be more frequently exceeded.

SUMMARY OF CLIMATE RISK INFORMATION

The NPCC developed both quantitative and/or qualitative information about annual precipitation, downpours, snowfall, drought, and days of excessive rainfall. While the central range of projections of precipitation show increases for the region for future decades, these projections have a higher level of uncertainty than the temperature rise projections due to difficulties in simulating regional hydrology.

TABLE 6. Summary of Quantitative CRI data for Inland Flooding

Time slice	Mean annual changes in percent precipitation relative to baseline years (1971-2000) Central Range*	Number of days per year with excessive rainfall > 1"	> 2"	> 4"	Very dry years to occur
Baseline (1971-2000)	46.5 in	13	3	0.3	once every 100 years
2020s	+0.0 to 5.0%	13 to 14	3 to 4	0.2 to 0.4	once every 100 to 100 years
2050s	+0.0 to 10.0%	13 to 15	3 to 4	0.3 to 0.4	once every 50 to 100 years
2080s	+5.0 to 10.0%	14 to 16	4 to 4	0.3 to 0.5	once every 8 to 100 years

*The central range is the middle 67% of values from model-based probabilities
Source: NPCC's Climate Risk Information workbook

Quantitative information is summarized in Table 6. Mean annual precipitation and the number of days per year with rainfall exceeding 1, 2, and 4 inches will increase. The NPCC projects that downpours are likely to increase in frequency and intensity throughout the 21st century, increased total precipitation is likely and rainstorms will become more extreme, while snowfall is likely to become less frequent.

The future frequency and intensity of projected storms is important for the region's infrastructure. Additional research is needed to more fully understand how storm intensity and frequency may shift with climate change. The current scientific consensus is that the overall number of storms will not increase, but that the storms will become more intense and destructive. Climate normals are required for a full climatological assessment of current inland flooding risks. Climate normals for the period 1971 to 2000 are currently available. Updated NOAA climate normals encompassing the years 1981 to 2010 are scheduled to be released in 2012 and should be referenced for updates (NCDC, 2003).

EXISTING STANDARDS AND POTENTIAL CLIMATE PROTECTION LEVELS: INLAND FLOODING EXAMPLES

Many of the standards that will be affected by coastal flooding and storm surges will also be impacted by inland flooding. Because riverine flooding affects only a small portion of the city, FEMA's Flood Insurance Study for the City of New York conducted riverine hydraulic analyses only in select locations; the Bronx River and the streams of Staten Island. Instead coastal stillwater analysis was performed for the majority of the waterways; the Harlem, Hudson, Hutchinson, and East Rivers, and Arthur and Bronx Kills and Kill Van Kull, suggesting that these rivers are largely influenced by coastal conditions such as tides and coastal storms. As such the primary CPL recommendation in Chapter 4, to incorporate sea level rise projection into FEMA FIRMs and other regulatory maps, is relevant to the majority of the New York City coastline, including rivers and tidal straits. Several actions should also be taken to prepare for changes in precipitation patterns that could exacerbate inland flooding.

- Incorporate climate change projections into Intensity-Duration-Frequency (IDF) curves for precipitation.

Extreme downpours are likely to increase in intensity throughout the 21st century. The NYCDEP currently relies on Technical Paper No. 40 IDF curves that were calculated in the 1950s. While new IDF curves illustrating a 5-10% difference have been calculated, the 1950s curves are still used to provide the standard.

- Evaluate grades and levels of streets to determine impacts of climate change on stormwater conveyance.

City streets are constructed to meet specific design standards with respect to grade angle, level and slope. The NYC Charter requires that site grading be designed and maintained so that it will not cause storm water to flow onto adjacent sidewalks or properties. Due to subsidence, land shifting, road construction, freeze-thaw cycles, usage (including vibration) that exceeds design capacity, and accumulated paving, many streets no longer maintain their originally designed surface conditions. The NYC Charter requires each borough to maintain a topographical bureau with a borough engineer to establish and survey street conditions. Street grades and levels could be inventoried regularly in light of up-to-date climate change risk information and incorporated into respective borough maps to identify areas of heightened flood risk and allow for more informed flood risk decision-making and planning.

- Assess the adequacy and applicability in light of climate change projections of NYC Charter requirements for storm water conveyance from developments proximal to storm drains and the special drainage requirements for developments that increase impervious surfaces.

All developments and lots within 500 feet of a sewer are required to provide storm water conveyance with a maximum capacity not to exceed 25% above what is needed. This requirement may not provide adequate protection from flooding hazards for all locations in the city. For example, different storm water flow rates vary by ground surface type. Detailed hydro-logic and hydraulic studies in light of climate change risk information should be conducted for various environmental conditions that exist in the New York City region to determine if this requirement should be extended to developments located further away from a sewer. Similarly, special drainage requirements apply to newly constructed alterations of impervious surfaces that increase already existing impervious surfaces by 20%. Detailed studies based on local environmental conditions and climate change risk information should be conducted to determine whether or not the applicability for this requirement should be expanded.

- Update the NYSDEC 100 Year Flood Control Requirement to reflect updated IDF curves and climate risk information.

The NYSDEC extreme flood control design criteria requires stormwater management practices for new developments to control the peak 1-in-100 year storm to predevelopment peak 1-in-100 year rates. This requirement provides a base for all design and performance standards that protect New York City from extreme flooding because it provides protocol for defining a common criteria for peak stormwater discharge flow rates throughout the jurisdiction. Updating the NYSDEC 1-in-100 year flood control program involves updating the Intensity-Duration-Frequency (IDF) curve for the 1-in-100 year flood, upon which the requirement and its design criteria are based.

TABLE 7. Examples of Standards and Possible CPLs Inland Flooding

Current Standard	CPL Recommendations	Stakeholders
Currently referring to Technical Paper No. 40 IDF curves calculated in the 1950s.	Incorporate climate change projections into Intensity-Duration-Frequency (IDF) curves for precipitation	New York City Department of Environmental Protection
The NYC Charter requires that site grading be designed and maintained so that it will not cause storm water to flow onto adjacent sidewalks or properties	Evaluate grades and levels of streets to determine impacts of climate change on stormwater conveyance.	New York State Department of Buildings, New York City Department of Environmental Protection, Department of City Planning
All developments and lots within 500 feet of a sewer are required to provide storm water conveyance with a maximum capacity not to exceed 25% above required conveyance.[1]	Assess the adequacy and applicability in light of climate change projections of NYC Charter requirements for storm water conveyance from developments proximal to storm drains and the special drainage requirements for developments that increase impervious surfaces.	New York City Department of Environmental Protection, Department of City Planning
Stormwater management practices for new developments must control the peak 1-in-100 year storm to predevelopment peak 1-in-100 year rates.[2]	Update the NYSDEC 100 Year Flood Control Requirement to reflect updated IDF curves and climate risk information.	New York State Department of Environmental Conservation

[1] New York City Administrative Code. Title 24: Environmental Protection Utilities. Section 24-526: Conveyance of storm water from developments and lots and certain adjacent paved areas to off-site disposal points. <http://24.97.137.100/nyc/adcode/title24_24-526.asp>

[2] New York State Department of Environmental Conservation (NYSDEC). New York State Stormwater Design Manual. 2008. <http://www.dec.ny.gov/chemical/29072.html>

6. HEAT WAVES

INTRODUCTION

The NPCC defines a heat wave as a period of three or more consecutive days with maximum temperatures above 90°F. Heat waves occur when high atmospheric pressures prevent muggy summer air from rising and dissipating, keeping temperatures and humidity high. In New York City, extreme heat events are exacerbated by the urban heat island effect, a phenomenon caused by the surfaces within a city's built environment that tend to trap heat such as asphalt, concrete, and metals.[11] Climate change will increase mean annual temperatures in New York City, which will in turn increase with the number of heat waves per year and their durations. In addition to public health concerns, extreme heat events burden local energy sources and stress infrastructure materials. In addition, higher temperatures can disrupt the normal operation of critical infrastructure by limiting population activity (e.g., the work force), causing operator errors, and necessitating service stops to respond to ailing individuals (e.g., passengers taken ill on a subway platform result in train service disruptions).

SUMMARY OF CLIMATE RISK INFORMATION

The NPCC developed both quantitative and qualitative information for projected changes in air temperature and heat waves. Quantitative information is summarized in Table 8. Quantitative and qualitative information from the CRI projects more frequent and intense heat waves, fewer and less extreme cold air outbreaks, and hotter summers and warmer winters. Total number of days with temps > 90 and >100°F will increase[12] and heat waves are very likely to become more frequent and intense. Extensive information exists on the potential for temperature shifts and increased frequency of heat

TABLE 8. Summary of Quantitative CRI Data for Historical and Projected Heat Waves

Time slice	Mean annual changes in °F of air temperature	Max number of days per year with temperatures exceeding 90 and 100 °F		Number of heat waves** per year and their average duration
	Central Range*	>90 °F	>100 °F	
Baseline (1971-2000)	55	14	0.4	2 heat waves, 4 days long
2020s	1.5 to 3.0	23 to 29	0.6 to 1	3 to 4 heat waves, 4 to 5 days long
2050s	3.0 to 5.0	29 to 45	1 to 4	4 to 6 heat waves, 5 to 5 days long
2080s	4.0 to 7.5	37 to 64	2 to 9	5 to 8 heat waves, 5 to 7 days long

* The central range is the middle 67% of values from model-based probabilities
** Heat waves are defined as 3 or more consecutive days with a maximum temperature exceeding 90 °F.
Source: NPCC's Climate Risk Information workbook

11 New York City Office of Emergency Management (NYC OEM). NYC Hazards: Extreme Heat. 30 April 2009. <http://www.nyc.gov/html/oem/html/hazards/heat.shtml>

12 CRI, p. 20

waves. However limited information is available on the climate change-related shifts in humidity and heat index.

EXISTING STANDARDS AND POTENTIAL CLIMATE PROTECTION LEVELS: HEAT WAVE EXAMPLES

Below are several examples of areas where heat wave–related standards and possible climate protection levels could be explored. Beyond the items provided here, another relevant benchmark will be for the City to review the engineering and maintenance protocols in analogous hotter regions such as the southeastern United States. These locations have extensive experience responding to intense and extensive heat waves.

- Update the maximum interior air cooling capability standard to accommodate the higher outdoor temperatures and more frequent and intense heat waves.

The New York City Department of Buildings maintains an air conditioning standard for interior human-occupied spaces that requires interior air-cooling system designs to be capable of maintaining maximum air conditions of 78°F at 50 percent relative humidity when the outside air temperature is 89°F. As air temperatures and associated heat hazards continue to increase with time, air cooling efficiency for system designs based on 89°F or greater outside temperatures may diminish, increasing New York City vulnerability to extreme heat events. Updating the outside base air temperature for air cooling system designs to reflect climate change risk information could help limit the threat to future extreme heat events.

- Assess the adequacy of current standards for emergency back-up power supply systems to support critical infrastructure functions in light of climate change projections.

The New York City Building Code requires emergency back-up power systems to have a 6-hour full-demand fuel source available in case of a disturbance in general service power sources. Proper ventilation is included as an emergency energy demand. As the intensity, duration, and frequency of extreme heat events increases, power interruptions may become more frequent. As a result the City should explore the need to raise the standard for back-up power supply capacities.

- Evaluate the City's ability to meet New York State Reliability Council (NYSRC) standards under conditions of climate change projected through the 2080s and coordinate local, regional, and national electrical power-supply reliability and protection efforts with climate change risk information.

The NYSRC establishes rules and standards that govern local power supply facilities in the New York City Zone. Regional electricity reliability standards set by the Northeast Power Coordination Council[13] provide regional protection measures designed to support nationwide bulk power system reliability efforts initiated by the North American Electric Reliability Corporation. These measures are not designed specifically to protect against climate-related hazards. NYSRC requires 80 percent of New

[13] The Northeast Power Coordinating Council. Regional Standards Authorization Request ID: PRC -012-NPCC- 01: Special Protection Systems. 30 April 2009 <http://www.npcc.org/regStandards/History.aspx?IDRef=5>

York City's peak energy load demand be met by in-city sources. Since peak electricity loads are likely to occur during conditions of extreme heat when air-cooling appliances are used widely throughout the city, peak load estimates should be based on climate change projections. Similarly, Northeast Power Coordination Council protection standards aim to increase bulk power system reliability by enhancing protocol for responding to service disruptions and overall system management. The standards currently do not emphasize electricity overloads that will come with climate change. Omitting climate change considerations from reliability design and performance standards will diminish their effectiveness and provide inadequate protection to New York City.

- Incorporate the projections of more frequent and intense heat waves into the Office of Emergency Management's Heat Wave Action Plan.

The City's response to extreme heat begins with a meeting of the Heat Emergency Steering Committee. This Committee is convened and chaired by the OEM when meteorological forecasts predict heat indices of 100°F or higher for more than two consecutive days, and/or a heat advisory or heat warning is issued by the National Weather Service. The Steering Committee then formulates recommendations such as the activation of 311 and the OEM's Emergency Management Online Locator System (EMOLS), activation of cooling centers and the Emergency Operation Center (EOC), increase of outreach to at-risk populations, and recommending "no dig" procedures to increase excavation safety for contractors. These responses to extreme heat should be evaluated in light of the potential for more intense, frequent, and prolonged heat events to ensure adequate measures continue to be taken. As the HWAP is updated each year by OEM, this review can happen on an ongoing basis.

- Assess the ability of construction materials to withstand long-term exposure to heightened summer temperatures and extreme heat events.

Materials used in the construction of critical infrastructure are affected by extreme heat. For example, continuous welded rail tracks can become distorted due to heat expansion, potentially resulting in derailment. Bridges and highways are also subject to damaging heat expansion despite the installation of expansion joints. Consideration of heat impacts on materials could also suggest changes in construction materials, such as a shift to more heat-tolerant materials, or affect the way infrastructure is operated so as to reduce strain on materials, such as reducing usage or rotating stock.

TABLE 9. Examples of Standards and Possible CPLs
Heat Waves

Current Standard	CPL Recommendations	Stakeholder
Maximum extended interior air temperature is 78°F at 50% relative humidity when outside air temperature is 89°F.[1]	Update the maximum interior air cooling capability standard to accommodate the higher outdoor temperatures and more frequent and intense heat waves projected from climate change.	New York City Department of Buildings
Emergency power systems must have a 6-hour full-demand fuel source on premises.[2]	Assess the adequacy of standards for emergency back-up power systems to support critical infrastructure functions in light of projections for increased temperature.	New York City Department of Buildings
80% of peak load must be met with in-city resources.[3]	Evaluate the City's ability to meet NYSRC standard under conditions of climate change and coordinate local, regional, and national electric power-supply reliability and protection efforts with climate change risk information.	New York State Reliability Council
None	Assess the ability of construction materials to withstand long-term exposure to heightened summer temperatures and extreme heat events.	All

[1] New York City Department of Buildings (NYC DOB). New York City Construction Codes-LL-33, Chapter 12: Interior Environment, Section 1204.2. July 2008. <http://www2.iccsafe.org/states/newyorkcity/Building/Building-Frameset.html>

[2] New York City Department of Buildings (NYC DOB). New York City Construction Codes-LL-33, Chapter 27: Emergency Power Systems, Section 2702.1. July 2008. <http://www2.iccsafe.org/states/newyorkcity/Building/Building-Frameset.html>

[3] New York State Reliability Council (NYSRC), L.L.C., NYSRC Reliability Rules for Planning and Operating the New York State Power System, Version 21. 2007. <http://www.nysrc.org/pdf/Documents/RRManualVer21%20Final%2012-14-07.pdf>

7. EXTREME WIND EVENTS

INTRODUCTION

With an average yearly wind speed of 12.2 mph New York City has been hailed one of the windiest big cities in the Unites States. The City also experiences extreme wind events, with historical climate records citing peak wind gusts of 78mph in Central Park and 113+ mph at the Battery.[14] These events are most commonly associated with severe thunderstorms, nor'easters and, less frequently, tropical storms and hurricanes. Design and performance standards for buildings, as provided through the New York City Construction Code, reflect that New York City is within a hurricane-prone region.[15] Many buildings throughout New York City house critical city functions that require uninterrupted performance to remain effective, therefore extreme wind events are considered hazardous to critical infrastructure.

The 1968 Building Code of the City of New York established wind-load standards for all new construction. These standards were based on the NYC Building Code Reference Standard 9, Section 9-5: Minimum Design Wind Pressures.[16] The NYC Building Code was revised in 2007 with new standards mandatory for all construction built on or after July 1, 2009. Wind-load standards for structures built after the 2007 code are based on Section 6 of American Society for Civil Engineers (ASCE) Standard no. 7: Minimum Design Loads for Buildings and Other Structures. Although most buildings in New York City are currently built in accordance with the 1968 building standards, future construction is expected to meet the new codes. As a result, design standards for critical infrastructure set by the New York City Department of Buildings will vary depending on construction date.

According to Chapter 16 of the 2007 code, the basic wind speed for design standards in New York City is a 3-second gust at 98 mph measured 33 feet above the ground. "This wind speed is based on local wind climate with annual probability of 0.02 (50-year mean recurrence interval)."[17] However different structures can have different design standards. For example, radio, television, and telecommunication towers and antenna supporting structures must be designed to resist two-times the wind load speed set by Telecommunications Industry Association/Electronics Industry Alliance design standard 222-F-96.[18] Bridges are designed to accommodate wind loads as specified by the American Association of State Highway and Transportation Officials (AASHTO). AASHTO's design specifications are implemented nationwide through the Federal Highway Administration,[19] the principal agency charged with monitoring national bridge safety, and locally through the New York City Department of Transportation (NYCDOT).

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14 NOAA National Climactic Data Center. Weather Extremes, Central Park, New York. 12 Feb 2006. <http://www.erh.noaa.gov/okx/climate/records/extremes.html>

15 New York City Department of Buildings (NYC DOB). 2007. New York City Construction Codes-LL-33, Chapter 16: Structural Design. July 2008. <http://www2.iccsafe.org/states/newyorkcity/Building/Building-Frameset.html>

16 New York City Building Code Reference Standard 9. <http://www.nyc.gov/html/dob/downloads/bldgs_code/bcrs9.pdf>

17 Ibid.

18 New York City Department of Buildings (NYC DOB). New York City Construction Codes-LL-33, Chapter 31: Special Construction. July 2008. <http://www2.iccsafe.org/states/newyorkcity/Building/Building-Frameset.html>

19 Federal Highway Administration. FHWA Directives and Policy Memorandums Related to Bridges. 3 Feb 2009. <http://www.fhwa.dot.gov/bridge/memos.htm>

SUMMARY OF CLIMATE RISK INFORMATION

Overall, climate change risk information is limited with respect to projections of the frequency and intensity of future wind events. Due to lack of robustness of climate model projections, quantitative data concerning extreme wind events has not been provided in the CRI workbook. However qualitative statements about directional probability are provided. Intense hurricanes and associated extreme wind events will more likely than not become more frequent.[20] Uncertainty involves changes in future hurricane trajectories, atmospheric gradients, and patterns of uncertainty (e.g., El Nino Southern Oscillation). Changes in nor'easter frequency are too uncertain to support qualitative statements.

- Evaluate the adequacy of the current design wind speed of 3-second gust at 98 mph measured 33 feet above the ground in light of likelihood of more frequent storms.

According to FEMA, New York City is in a hurricane susceptible region of Wind Zone II, which corresponds to a design wind speed of 160 mph.[21] FEMA's design wind speed measuring criteria are consistent with ASCE 7: 3-second gust, 33 feet above grade, for exposure category C.[22] Exposure categories reflect the ground surface roughness that arises from topography, vegetation, and constructed features. In New York City, exposure categories range from A to C therefore FEMA's sole use of exposure zone C is limiting. Zone C applies only to "open terrain with scattered obstructions…flat open country, grasslands, and shorelines…"; land cover that comprises only a small portion of New York City.

TABLE 10. Action Toward Future Climate Protection Levels
Extreme Wind Events

Current Standard	CPL Recommendations	Stakeholder
Wind load standards from the ASCE, TIA, EIA, and AASHTO.[1]	Review the adequacy of the design wind speed of 3-second gust at 98 mph measured 33 feet above the ground.	FEMA, NYCDOB, TIA, FHWA, NYCDOT, NYS, OEM, and AASHTO.

[1] New York City Department of Buildings (NYC DOB). New York City Construction Codes-LL-33, Chapter 16: Structural Design. July 2008. <http://www.nyc.gov/html/dob/downloads/pdf/cc_chapter16.pdf>

[20] CRI, p. 24

[21] Federal Emergency Management Agency (FEMA). Wind Zones in the United States. 30 April 2009 <http://www.fema.gov/plan/prevent/saferoom/tsfs02_wind_zones.shtm>

[22] Exposure C refers to "Open terrain with scattered obstructions, including surface undulations or other irregularities, having heights generally less than 30 feet (9144 mm) extending more than 1,500 feet (457.2 m) from the building site in any quadrant. This exposure shall also apply to any building located within Exposure B-type terrain where the building is directly adjacent ro open areas of Exposure C-type terrain in any quadrant for a distance of more than 600 feet (182.9 m). This category includes flat open country, grasslands, and shorelines in hurricane-prone regions." New York City Department of Buildings (NYC DOB). New York City Construction Codes-LL-33, Chapter 16: Structural Design. July 2008. <http://www.nyc.gov/html/dob/downloads/pdf/cc_chapter16.pdf>

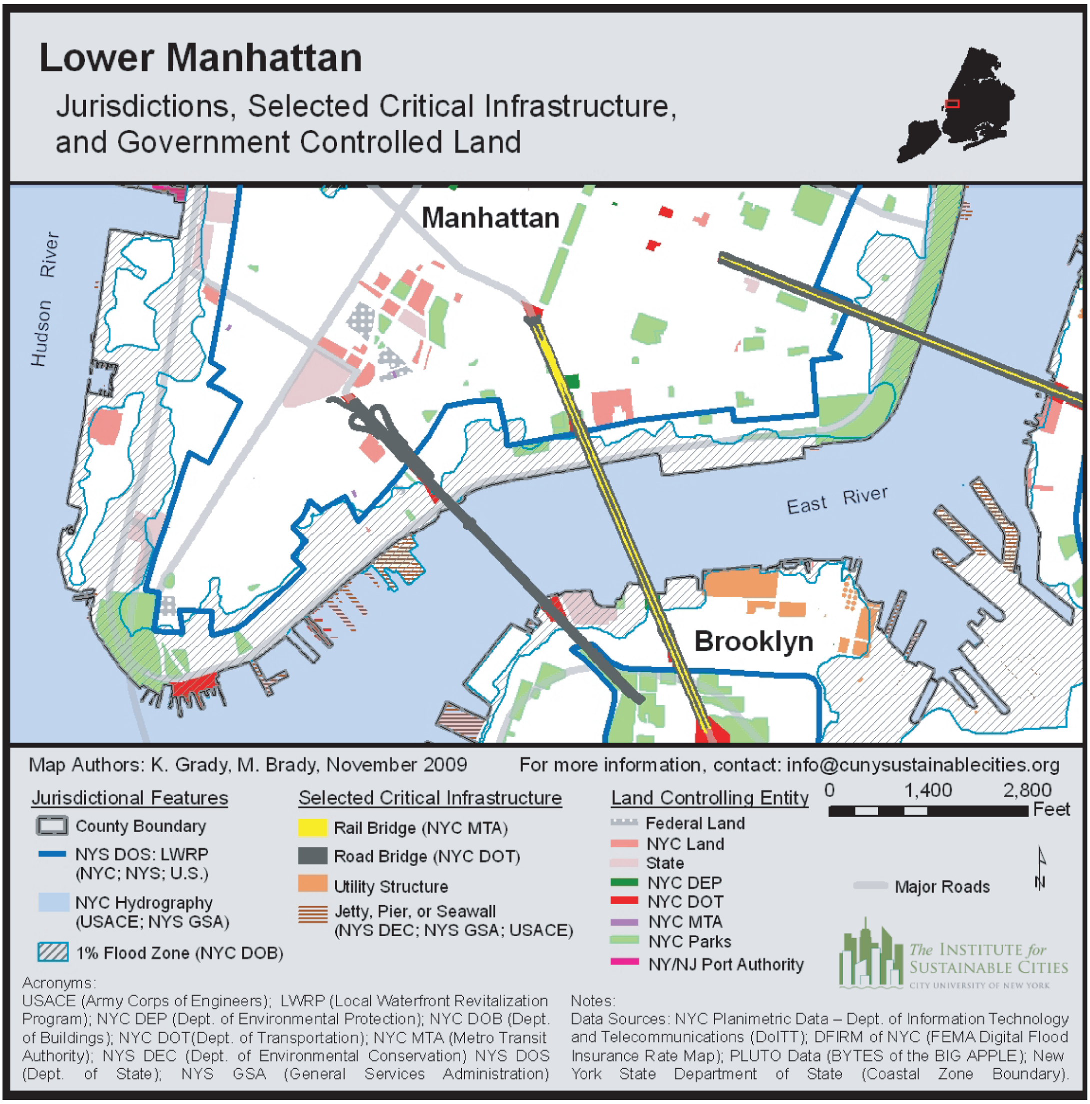
8. POLICY AND OPERATIONAL ISSUES: CONSIDERATIONS AND CASE STUDIES

Climate change expands the time, place, and intensity in which hazards can occur. Climate change-driven sea level rise will increase the spatial extent of the area that could be flooded by an extreme storm event. Infrastructure will be exposed to climate risks over longer periods of time, through more frequent intense precipitation events and longer heat waves. This section looks at the potential impacts of sea level rise on the FEMA designated 1-in-100 year floodplain in lower Manhattan and greater Jamaica Bay. These areas were used to illustrate the need to improve our understanding of future flood risks and incorporate climate change projections into existing design and performance standards. As a result of the potential increase in geographic scope of the flood zones due to sea level rise,[23] the NPCC identified several policy and operational issues to potentially be undertaken by the New York City Climate Change Adaptation Task Force. These follow-up activities are highlighted by the need to consider expansion of the climate hazard zones as a city-wide adaptive strategy and the need for increased interagency and inter-jurisdictional coordination. Detailed examples are presented via case study review of lower Manhattan and greater Jamaica Bay.

The study focuses on critical and at-risk above-ground infrastructure such as roadways, subway and rail lines, and bridges, as well as underground infrastructure such as subway tunnels, telecommunication and electrical lines, and water lines. Lower Manhattan was selected as a low lying area of interest with its extensive high value waterfront development, major bridges and tunnels, waterfront transportation structures including commercial piers and ferry terminals, and underground subway lines. Greater Jamaica Bay was selected as a heavily populated low lying area containing the wetlands of Jamaica Bay, U.S. Army Corps of Engineers beach structures, above-ground subway tracks, bridges, and major roads/highways, the Coney Island and Rockaway Water Pollution Control Plants (WPWC), and parks and recreation spaces.

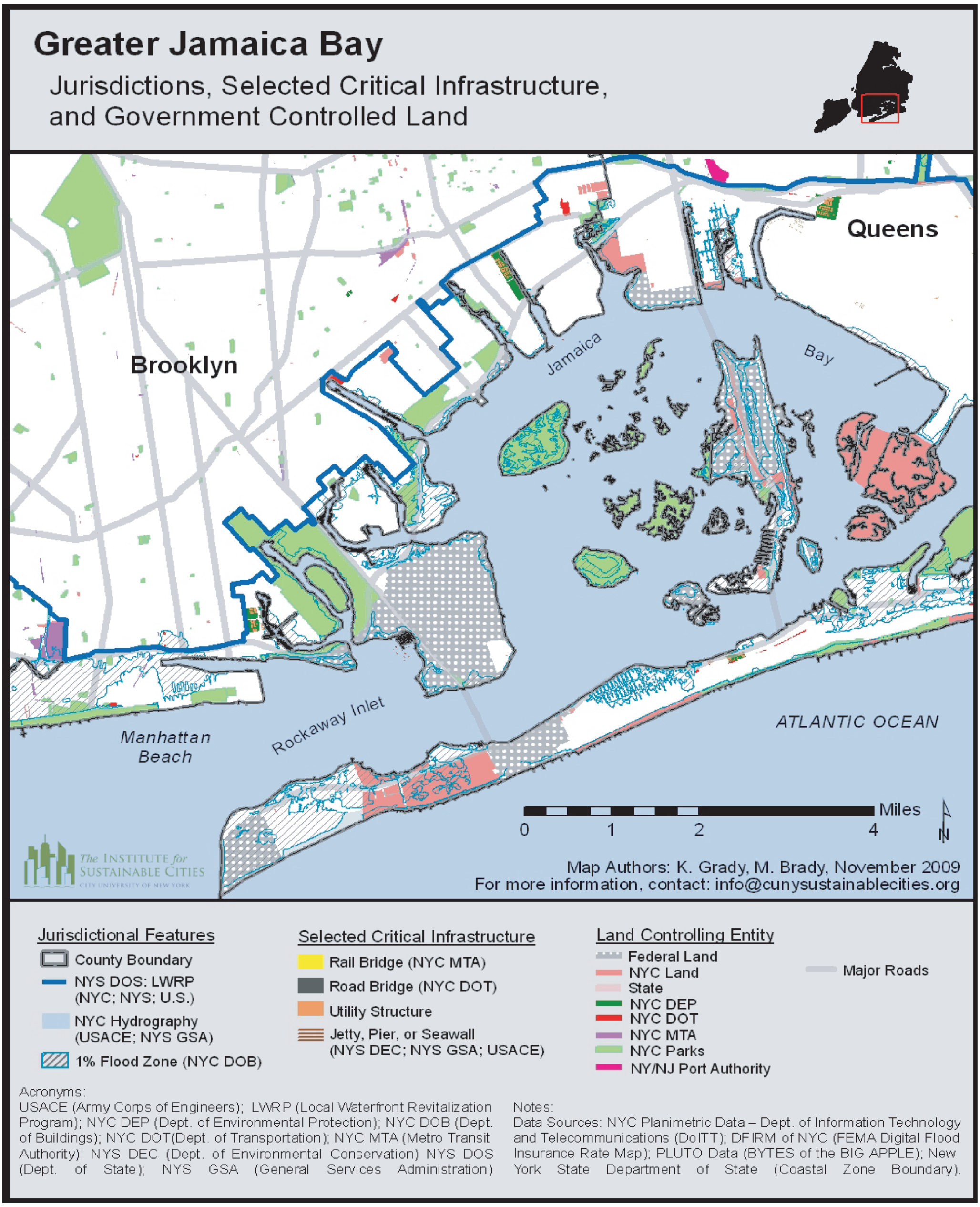
[23] Due to the uncertainty and lack of detailed projections related to changes in storm patterns, the NPCC case studies only reflect the impacts of sea level rise on coastal flooding, not alternations in the intensity, frequency, or movement of coastal storms.

FIGURE 4. Jurisdictional Map of Lower Manhattan



Source: CUNY Institute for Sustainable Cities

FIGURE 5. Jurisdictional Map of Greater Jamaica Bay



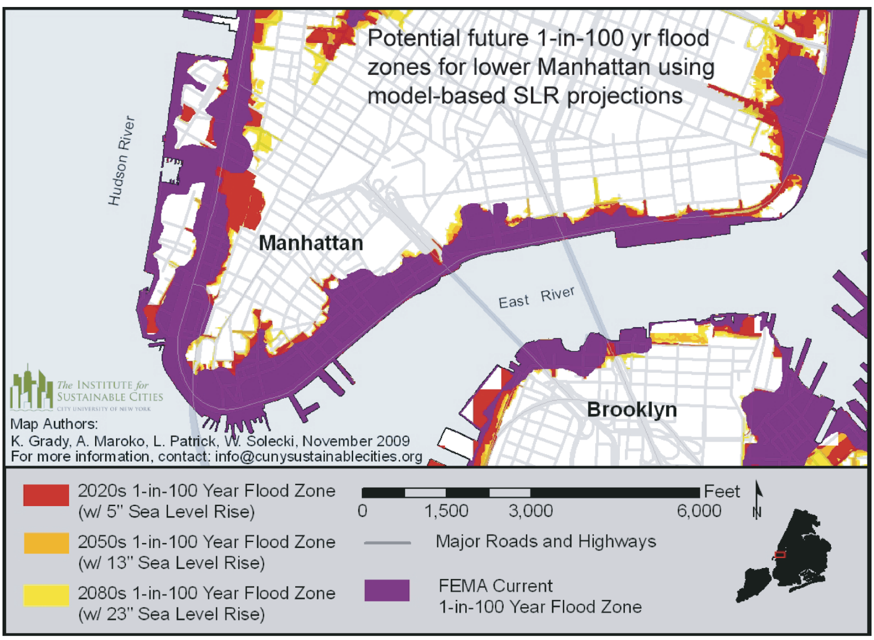
Source: CUNY Institute for Sustainable Cities

Each case study location illustrates the spatial complexity of the varying jurisdictional boundaries of the numerous agencies, offices, and departments that have physical assets or administrative responsibilities in the area. To explore this issue and the related question of how to develop CPLs to manage for future flooding events, a series of maps are presented which illustrate the potential flooding area under different climate change scenarios.

The maps were created using sea level rise projections developed by the NPCC (see Chapter 3 from the CRI workbook). On each map, the current 1-in-100 year flood elevation serves as the baseline upon which mapped projections of SLR are added. The 1-in-100 year flood elevation was estimated by FEMA through their Flood Insurance Studies using complex models of storm surge and wave action and observed historical data. NPCC projections of the 90th percentile sea level rise elevations for the 2020s, 2050s, and 2080s were then added to the FEMA 1-in-100 year flood elevations to show how sea level rise could affect the current horizontal extent of the 1-in-100 year flood. This was done by extracting new flood elevations from a digital elevation model (DEM) of New York City and projecting these new elevations onto a GIS data file (i.e., vector shapefile). The resulting maps illustrate the estimated potential horizontal inundation extent associated with projected SLR elevations. These maps are subject to limitations in accuracy used in their development. They should not be used to assess site-specific risks, insurance rates, or property values. See the annex for a detailed discussion on mapping methodology and the uncertainties associated with these maps.

Case study maps capture the 90th percentile values of sea level rise projections both with and without a rapid ice melt scenario. The 90th percentile values are the elevations to which 90% of the entire set of SLR projections is lesser or equal to. They represent a more extreme flooding scenario by incorporating the high-end values within the dataset (Figures 6 and 7).

FIGURE 6. Areas potentially at-risk to the 1-in-100 year floods in lower Manhattan due to sea level rise projections derived from global climate models.



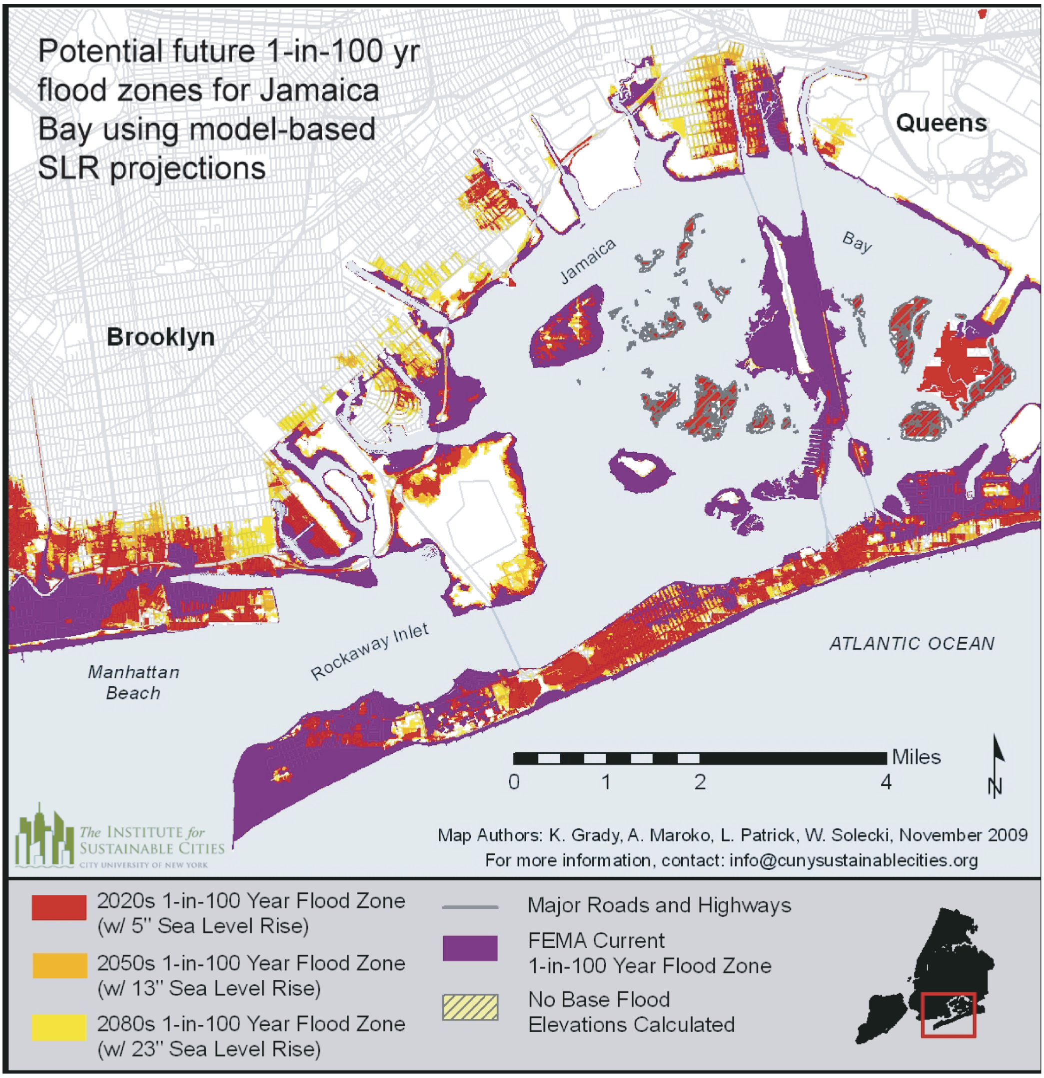
Note. This map is subject to limitations in accuracy as a result of the quantitative models, datasets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

Interpretation. The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios used in this research (end of the current century).

Areas potentially at-risk to the 1-in-100 year floods in lower Manhattan due to sea level rise projections derived from global climate models.

Source: CUNY Institute for Sustainable Cities

FIGURE 7. Areas potentially at-risk to the 1-in-100 year floods in greater Jamaica Bay due to sea level rise projections derived from global climate models.



Note. This map is subject to limitations in accuracy as a result of the quantitative models, datasets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

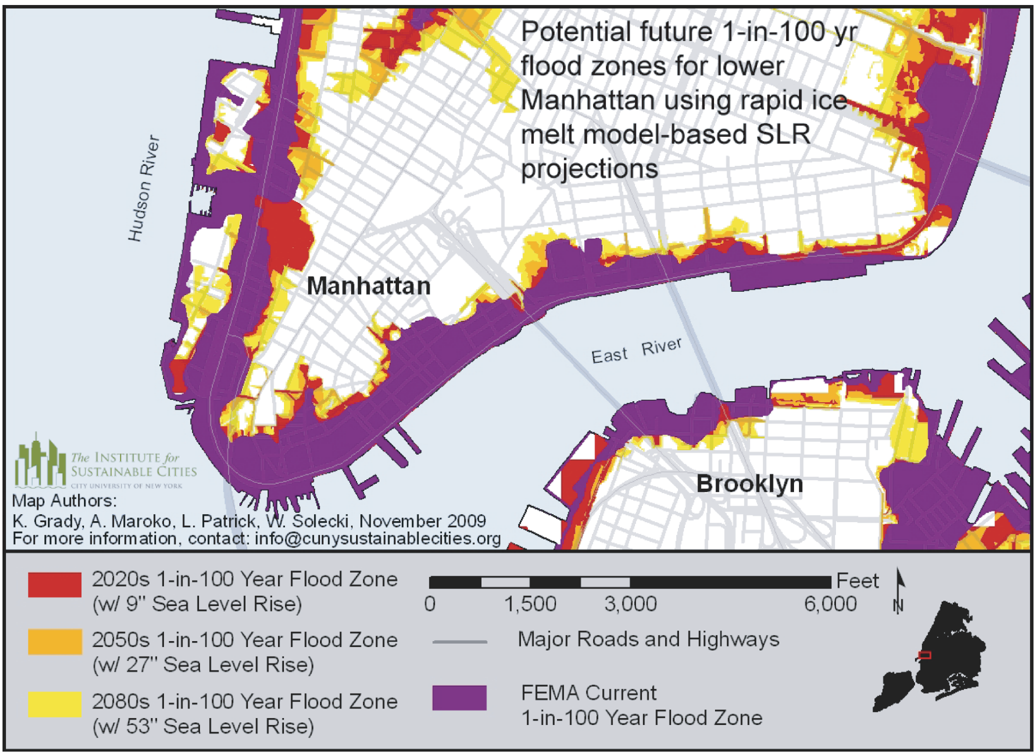
Interpretation. The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios used in this research (end of the current century).

Figure 7 shows the current FEMA 1-in-100 year flood zone and potential areas that could be impacted by a 1-in-100 year flood in the 2020s, 2050s, and 2080s based on the 90th percentile model-based projections of sea level rise.

Source: CUNY Institute for Sustainable Cities

The prospective maps developed for the case studies do not represent precise flood boundaries but rather illustrate three distinct areas of interest: A) areas currently within the 100-year flood zone, B) areas that are not currently in the 100-year flood zone, but will potentially be in the future, and C) areas that are not currently in the 100-year flood zone and are unlikely to be in the timeline of this research. The projected flood extents shown on the maps reflect a "bathtub" methodology whereby a flood elevation is extrapolated landward until it reaches the equivalent contour height on land. This approach does not account for cumulative effects of soils, vegetation, surface permeability, bathymetry, existing structural and non-structural flood protections, friction, and other factors that affect the movement of floodwaters resulting in local variations in flooding extent. In addition, numerous sources of potential error are present in the maps, including limitations of model input and scope (climate and FEMA floodplain models), error inherent in model output, errors in and coarseness of topography, the rounding of base flood elevations to the nearest foot, and in GIS technique. The maps and data should not be used to assess actual coastal hazards, insurance requirements, or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

FIGURE 8. Areas potentially at-risk to the 1-in-100 year floods in lower Manhattan due to rapid ice melt sea level rise projections derived from global climate models.



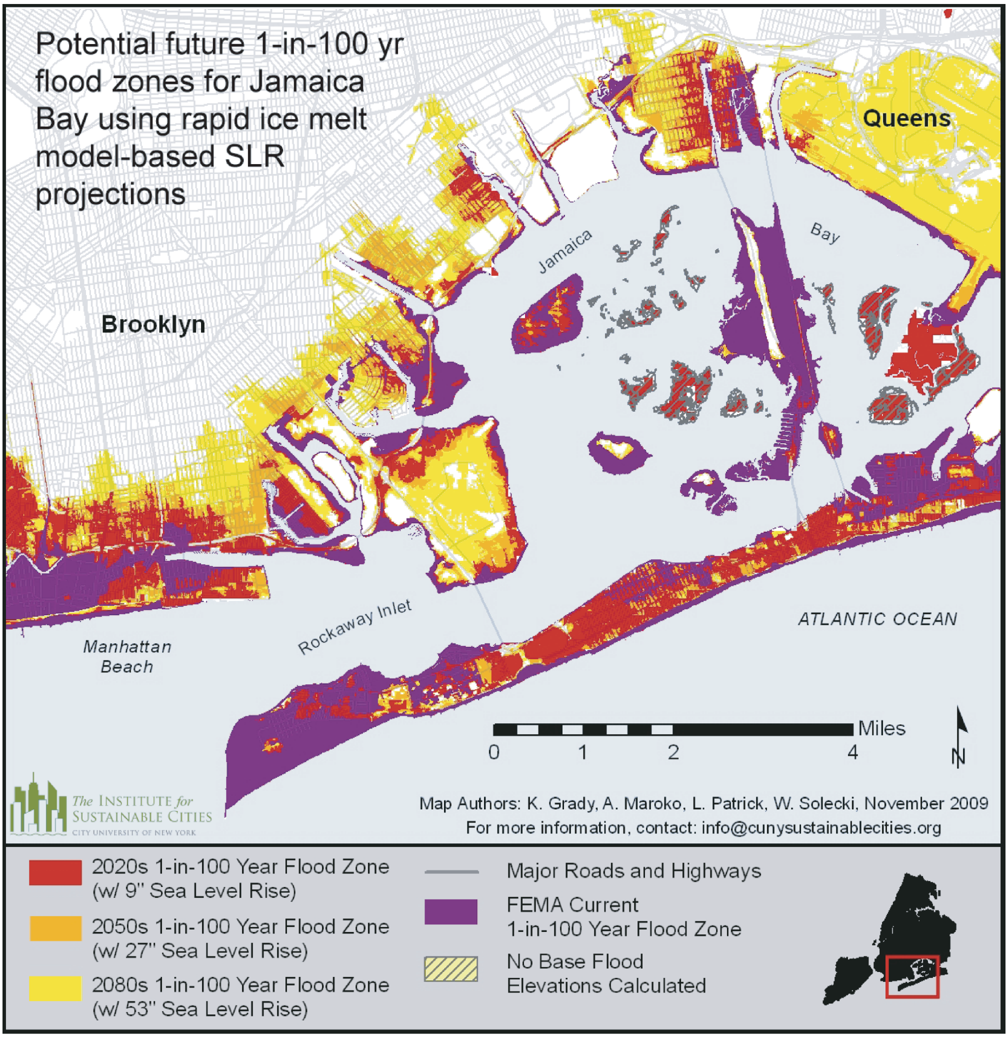
Note. This map is subject to limitations in accuracy as a result of the quantitative models, datasets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

Interpretation. The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios used in this research (end of the current century).

Areas potentially at-risk to the 1-in-100 year floods in lower Manhattan due to rapid ice melt sea level rise projections derived from global climate models.

Source: CUNY Institute for Sustainable Cities

FIGURE 9. Areas potentially at-risk to the 1-in-100 year floods in greater Jamaica Bay due to rapid ice melt sea level rise projections derived from global climate models.



Note. This map is subject to limitations in accuracy as a result of the quantitative models, datasets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

Interpretation. The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios used in this research (end of the current century).

Figure 9 shows the current FEMA 1-in-100 year flood zone and potential areas that could be impacted by a 1-in-100 year flood in the 2020s, 2050s, and 2080s based on projections of the 90th percentile model-based "rapid ice melt" sea level rise scenario. This estimate is based on the average meltwater rate of 43 inches per century in paleoclimatic times (see CRI Table 3 for more information).

Source: CUNY Institute for Sustainable Cities

Figures 8 and 9 illustrate sea level rise projections that incorporate a rapid ice melt scenario. This rapid ice melt scenario is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies. The Base Flood Elevation (BFE) is the elevation that water is expected to rise during a 1-in-100 year flood. For example, if the ground elevation is 8 feet, and the BFE is 10 feet, the water depth in that area (the flood depth) will be 2 feet deep. Coastal BFEs are calculated using detailed hydrologic and hydraulic models that include storm surge and overland wave analysis.

When delineating flood boundaries without using models to determine where flood waters will stop, it is intuitive to think that the flood waters in any given base flood elevation area (or flood hazard area) will stop when the ground elevation meets the height of the BFE. For example, in a 10 foot BFE area, the flow of flood waters - assuming extremely little or no friction or structures/ soils that would inhibit the movement of water - would continue until the ground elevation rises to 10 feet. The FEMA BFE methodology, however, does not adhere exclusively to this logic, but appears to take into account a variety of other factors that affect the flow of floodwaters.

The maps illustrate a marked increase in the geographic spread of potential future floodwaters. The inland movement of the flood prone areas reflects both the climate scenarios presented and the topography of the case study locations. For example, in the greater Jamaica Bay region, the low gentle slope and minimal relief enable floodwaters to move inland significant distances – in some cases several hundred meters. For lower Manhattan, the inland movement of flood waters is arrested slightly by the higher relief in near shore areas. This relief is a remnant vestige of the hilly topography that dominated the island during the pre-19th century era. The maps do not take into account manmade features, including roadways, buildings, sea walls, or other structures.

Overall, the maps illustrate that sea level rise will change the flood hazard zone. If worst case rapid sea level rise were to occur, the consequences for coastal cities such as New York City would be dramatic. In general, the maps delineate three broad zones of interest for operators of critical infrastructure. From the shoreline inward, the first is the existing 1-in-100 year flood zone. This zone certainly will remain at risk to flooding in the future and likely the flooding periodicity will become shorter and flood heights higher. The next zone are those swaths of territory which currently are not managed as flood zones now, but may be considered as flood zones in the future. The exact spatial extent and frequency of flooding still needs to be determined via more in depth engineering-based modeling studies. The third zone includes those parts of the City which, considering the current state-of-the-art scientific understanding, are not likely to be a risk to 1-in-100 year flooding during this century.

EMERGING RESEARCH NEEDS

The future flood maps clearly illustrate the need for more analysis and study. Overall, the development of climate protection levels will require focus on a set of conditions and implications. As with most new policies and programs, CPL related activities imply a demand for heightened understanding of physical processes of the urban environment and connectivity of social benefits and costs. The four following areas require additional research.

1. The built environment's impact on climate risk and exposure profiles, including building construction design influence on micro-meteorological wind dynamics and underground infrastructure serving as a conduit for flooding.
2. Administrative connectivity, including the identification and assessment of administrative mandates of government organizations and agencies, for example, which agencies oversee the travel of a raindrop that hits a New York City street and then falls into a subway grate, or which agencies are engaged in shoreline management in New York City.
3. The relative timing of action will impact the associated short, medium, and long term costs and benefits of any decision. While all CPLs presented in this document could be considered now, decisions to not implement them will be related to differing cost and benefit levels. For example, waiting to implement protection levels later in this century could be associated with higher costs and decreased benefits.
4. Equity considerations, including spatial, temporal, and demographic. Climate protection levels will bring forward a diffuse pattern of cost and benefit distribution. A central objective should be to identify possible inequitable costs and benefit distribution patterns, and provide a spreading of potential negative externalities.

POTENTIAL FOLLOW-ON ACTIVITIES

The CPLs presented in this document reflect the advice and counsel of the NPCC to the City of New York. The objective of this document was to provide as sophisticated statements as possible on potential adjustments to existing codes and standards. The two central goals of the NYC Climate Change Adaptation Task Force moving forward should be to critically consider these recommendations and, where appropriate and feasible, transform current qualitative CPLs into quantitative-based CPLs. To achieve these goals, there are three types of potential follow-on activities that could be considered by the Task Force as part of an analysis of the potential effectiveness of the CPL recommendations:

1. **Formal Reviews**
   Develop and execute a formal review of the quantitatively based potential CPLs as a mechanism to consider their robustness and potential for implementation, e.g., what variant of the 1-in-100 year flood should be used as a new design and performance standard?
2. **Engineering-based Studies**
   Develop and execute specific engineering-based sensitivity studies to generate additional information and knowledge on the increased risk of critical infrastructure affected by climate change, e.g., for increased frequency of more intense winds on cell phone towers.
3. **Current Policy Gap Assessments**
   Assess potential for enhancing existing efforts to further ensure climate protection through studies to determine areas where existing policies and programs can be extended to incorporate climate change considerations or where new policies and programs could be created. One example would be a review and expansion of storm water drain maintenance programs.

9. ANNEX
Mapping Methods and Data Sources

METHODS

Conducting an analysis of the FEMA 1-in-100 Year Flood zones considering future sea level rise projections using only a GIS is limiting. FEMA's methodology for creating flood insurance rate maps (FIRMs) involves using detailed hydrologic and hydraulic modeling that cannot be achieved in a GIS alone. The following list provides important caveats and limitations to keep in mind while examining the results of our flood boundary analysis.

1) **Difference in Vertical Datum (NGVD 29 → NAVD 88)**. All map layers used in a GIS that include elevation data are referenced to a vertical datum. The starting point of the vertical datum used in our analysis begins at mean sea level. The two main data sources used in our analysis, however, are referenced to different vertical datum: The DFIRM (Digital Flood Insurance Rate Map) is referenced to NGVD 29 (National Geodetic Vertical Datum of 1929) and the DEM (Digital Elevation Model) is referenced to NAVD 88 (North American Vertical Datum of 1988). The disparity between the two datum results from the way in which mean sea level was calculated for each. In our analysis of New York City flood zones, the difference between the two datum ranges from 0.8 to 1.1 inches in elevation. This discrepancy was addressed in our methodology by converting the DEM to reference NGVD 29 prior to processing the new projected flood extent.

2) **FEMA's BFEs (Base Flood Elevations) are rounded to the nearest whole number**. BFEs represent the height (referenced to the 1929 vertical datum) that the flood waters will rise above sea level during the 1-in-100 year flood. On the DFIRM they are represented as a single value zone (e.g. "8", "9", or "10" feet), however, they actually represent a range of values. For example, the BFE labeled as 10 feet actually encompasses all values from 9.6 feet to 10.4 feet.

3) **Coarse topographic data**. Higher resolution data, such as LiDAR (Light Detection and Ranging), would produce more accurate results than the 3 meter resolution DEM that we used in our analysis.

4) **Using model output**. This methodology added projections of sea level rise to the 1-in-100 year flood zone created by FEMA in 1983 using storm surge and wave propagation models. The projected flood zones created by the NPCC for the 2020s, 2050s, and 2080s were developed using the output from these models and modifying them in a GIS. A more accurate illustration of projected flood zones would have been achieved by remodeling the coastal zones to generate more up-to-date model output, however that process was beyond the scope and duration of this project.

5) **Various shoreline processes unaccounted for.** Wave setup (and wind-driven effects) is not accounted for on the current New York City FIRM, and this would account for an additional 1-3 feet of flooding. Wave setup is the rise in sea level at the coast caused by breaking waves. Long term beach/shore erosion is also not considered in our approach.

6) **Bathtub approach**. We are using a "bathtub approach," meaning the water level is extrapolated landward until it reaches the equivalent contour height on land, i.e., a BFE of 8 feet extends landward until it terminates at the 8 foot contour interval. The bathtub approach assumes inaccurately that base flood elevations are equivalent to topographic elevations. However the cumulative effects of soils, vegetation, surface permeability, infrastructure (e.g. drainage systems), structures, friction, and other factors can act to limit or increase the extent of flooding at local scales (in most cases these factors will limit the extent of flooding). Therefore the landward extent of the original 1-in-100 year flood zone as developed by FEMA does not follow topographic contours but more often cuts across them.

SOURCES

1) DFIRM of NYC (FEMA Digital Flood Insurance Rate Map)
- Accessed: 11-21-2008
- Horizontal Datum: NAD83
- Vertical Datum: NGVD29
- FEMA ID: 360497
- Date: 5-25-2007

2) FIS of NYC (FEMA Flood Insurance Study)
- Accessed: 12-11-2008
- Original Date: 05-16-1983.
- Revised: 02-15-1991
- Revised: 07-05-1994
- Revised: 05-21-2001
- Revised: 9-5-2007

3) DEM of NYC -DoITT (Digital Elevation Model – NYC Department of Information Technology and Telecommunications)
- Data collected April – June 2006
- Horizontal Datum: NAD83
- Vertical Datum: NAVD88

4) NYC DCP LION Streets (NYC Department of City Planning)
- Date: September 2008

5) NYC DCP Borough Boundaries (NYC Department of City Planning)
- Date: September 2008

10. GLOSSARY AND ABBREVIATIONS

** As defined by, or derived from, definitions used by the IPCC 2007.*

1-in-100 Year Flood
A flood that has a 1% chance of being equaled or exceeded in any given year.

1-in-500 Year Flood
A flood that has a 0.2% chance of being equaled or exceeded in any given year.

A-zones
Flood zones without high velocity wave action.

Adaptation*
Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change impacts. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature shock resistant plants for sensitive ones, etc.

AR4
The Fourth Assessment Report of the IPCC, released in 2007. At the time of publication of this document, AR4 was the most recent IPCC report.

At-Risk Infrastructure
Infrastructure likely to be significantly affected by climate change over its lifetime.

Adaptive Capacity
The ability of a system to adapt to a changing environment by coping with potential damages or consequences and taking advantage of opportunities.

Baseline*
The reference for measurable quantities from which an alternative outcome can be measured, e.g. a non-intervention scenario is used as a reference in the analysis of intervention scenarios.

Base Flood Elevation (BFE)
Also known as the 100-year flood elevation. It is a component of the FIRMs, used by federal agencies to determine if flood insurance is required when banks provide federally insured loans or grants towards new construction.

Carbon Dioxide (CO_2)*
CO_2 is a naturally occurring gas, and a by-product of burning fossil fuels or biomass, of land-use changes and of industrial processes. It is the principal anthropogenic greenhouse gas that affects Earth's radiative balance.

Climate Change*
Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate Forcing*
Any mechanism that alters the global energy balance, causing the climate to change. Examples of climate forcings include variations in greenhouse gas concentrations and solar radiation.

Climate Hazards*
Climate variables which could have particular consequence for New York City and the surrounding region or other specified geographical areas. The main climate hazards discussed in this document are related to temperature, precipitation, sea level rise, and extreme events.

Climate Normals
Defined by the National Oceanic and Atmospheric Administration (NOAA) as the average value of a meteorological element over 30 years.

Climate Risk-Management
The specification of policies, regulations, and practices designed to lessen potential exposure to climate-related conditions and events that can threaten or cause injury to individuals and/or cause property loss.

Climate Protection Levels (CPLs)
Climate-based, expert-determined benchmarks that are achieved through the implementation of design and performance standards with the express purpose of limiting the climate change risk exposure of critical infrastructure.

Critical Infrastructure
For the efforts of the New York City Climate Change Adaptation Task Force, critical infrastructure is defined as systems and assets (excluding residential and commercial buildings, handled by other city efforts) that support other activities which are so vital to the city that the diminished functioning or destruction of such systems and assets would have a debilitating impact on public safety and/or economic security.

Coastal Flooding
Flooding that occurs when intense, offshore low-pressure systems drive ocean water inland.

Coastal Land Erosion
The wearing away and removal of beach sediments by wave action, tidal currents, or wave currents. This process is accelerated by sea level rise.

Design Standards
Regulations that dictate how or where an asset is built and can take the form of engineering or administrative regulations, policies, and practices. They are typically intended to protect life, improve safety, and reduce or avoid physical damage and related direct costs (i.e., repair and replacement costs) or secondary economic losses.

Downpours
Intense precipitation at sub-daily –but in practice often sub-hourly—timescales.

Emissions Scenarios (see SRES)*

Exposure
The measure of people, property, or other interests that would be subject to a given risk.

Freeboard Clearance
The required clearance between the lower limit of a bridge or other structure and the high water surface elevation.

Global Climate Models (GCMs)*
A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity, i.e. for any one component or combination of components a hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or

the level at which the parameters are assessed empirically. Coupled atmosphere/ocean/sea-ice Global Climate Models provide a comprehensive representation of the climate system. There is an evolution towards more complex models with active chemistry and biology.

Greenhouse Gases (GHGs)*
Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine-containing substances, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons.

Heat Index
A measurement of the air temperature in relation to the relative humidity, used as an indicator of the perceived temperature.

Heat Wave
Three or more consecutive days with maximum temperatures above 90°F.

HVAC
Heating Ventilation Air Condition Systems of key importance to many industrial and office buildings. These systems are especially important to maintaining proper temperature of vital system equipment as well as maintaining temperatures suitable for work forces.

Inland Flooding
Riverine and urban street flooding caused by high-intensity precipitation events.

Intergovernmental Panel on Climate Change (IPCC)
The Intergovernmental Panel on Climate Change was formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), and is the international advisory body on climate change.

Likelihood of Occurrence Ranges*
These definitions of likelihood are used by the IPCC to describe potential outcomes.
>99%: Virtually certain
>95% Extremely likely
>90% Very likely
>66% Likely
>50% More likely than not
33 to 66% About as likely as not
<33% Unlikely
<10% Very unlikely
<5% Extremely unlikely
<1% Exceptionally unlikely

Mitigation*
Technological change and substitutions that reduce resource inputs and emissions per unit of output. Several social, economic and technological policies would produce emissions reductions; with respect to climate change analysis, mitigation means implementing policies to reduce GHG emissions and enhance sinks.

Natural Hazard Mitigation
Any cost-effective and sustained action taken to reduce or eliminate the long-term risk to human life or property from natural hazards.

New York City Climate Change Adaptation Task Force (Task Force)
The New York City Climate Change Adaptation Task Force is composed of over 35 stakeholders from city and state agencies, regional authorities, and private sector companies that operate, maintain, or regulate critical infrastructure in the region. The Task Force was launched in August, 2008 by Mayor Michael Bloomberg.

New York City Panel on Climate Change (NPCC)
The New York City Panel on Climate Change is the technical advisory body of the Task Force, and is composed of climate change and impacts scientists, and legal, insurance, and risk-management experts.

Paleoclimate
Paleoclimate research uses the earth's historical climate archives from geophysical, geochemical and sedimentological data analyses to reconstruct various time periods and events in Earth's climate history prior to the modern instrumental record.

Performance Standards
In the context of risk management, are rules or codes that quantify the manner in which an asset, system, piece of equipment, person, or procedure must operate to achieve a goal or minimal level of service.

PlaNYC 2030
A comprehensive sustainability plan for New York City through 2030 and beyond, released by the City's Mayor, Michael R. Bloomberg, on April 22, 2007.

Rainfall Intensity-Duration-Frequency (IDF) Curves
Show the relationship between rainfall or precipitation intensity and duration for different levels of frequency; each curve represents the rainfall intensity-duration which will be equaled or exceeded once in a certain number of years, indicated as the frequency of that curve.

Risk
Risk is the product of the likelihood of an event occurring and the magnitude of consequence should that event occur. For the purposes of this report, likelihood is defined as the probability of occurrence of a climate hazard.

Scenario*
A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are useful to provide a view of the implications of developments and actions.

Scour
The hole left behind when sediment (sand and rocks) is washed away from the bottom of a river.

Special Flood Hazard Area (SFHA)
The land in the flood plain delineated as subject to a one percent or greater chance of flooding in any given year.

SRES*
The IPCC's Special Report on Emissions Scenarios, released in 2000. Each emissions scenario presented in the SRES makes different assumptions about population growth, economic growth, technological change, and land-use change, that lead to greenhouse gas emissions and atmospheric concentration trajectories. While no one single future emissions scenario or global climate model projection will occur exactly as specified, a combination of a suite of global climate model simulations and greenhouse gas emissions profiles provides a range of possible outcomes that can be expressed as a set of projections that reflects the current level of expert knowledge.

Threat
Indication of impending harm.

Timeslice

Projections in the CRI are given in three timeslices, 2020s, 2050s and the 2080s. The projections are a 30-year average, centered around each of the given timeslices (10-year for sea level rise scenarios). Climate models cannot well predict what the specific climate will be in any given year, due in part to the interannual variability of the climate variables, so the given projections are averages of future climate.

Uncertainty*

An expression of the degree to which a value is unknown (e.g., the future state of the climate system). Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or projections of human behavior. Uncertainty can be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

Urban Heat Island Effect

An increase in urban air temperature as compared to surrounding suburban and rural temperature caused by the surfaces within a city's built environment that tend to trap heat such as asphalt, concrete, and metals.

V-zones

Areas of high velocity wave action.

Vulnerability

A system's susceptibility to disruption and/or damage during peak demand conditions.

11. REFERENCES

Brodsky, Richard L., Chairman of the Committee on Corporations, Authorities, and Commissions (2006) Final Report on New York City Emergency Response and Evacuation Plans in the Event of a Weather-Related Emergency, *Report to the New York State Assembly*.

Federal Emergency Management Agency (FEMA) Federal Insurance Administration. Projected Impact of Relative Sea Level Rise on the National Flood Insurance Program. October 1991.

Federal Emergency Management Agency (FEMA). Flood Insurance Study, City of New York, New York. September 5, 2007.

Hershfield, D.M. (1961) Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. U.S. Dep. Commerce, Weather Bur. Tech. Pap. No. 40. Washington, DC. 115 p.

Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Technical Summary, Contribution of Working Group I to the Fourth Assessment Report of the IPCC, Cambridge, UK: Cambridge University Press.

Jacob, K. H., Edelblum, N., and Arnold, J. (2001) Risk Increase to Infrastructure Due to Sea Level Rise, *Metropolitan East Coast Regional Assessment*. Rosenzweig, C. and Solecki, W. eds. New York: Columbia University.

Jacob, K.H., Gornitz, V. and Rosenzweig, C. (2007) Vulnerability of the New York City Metropolitan Area to Coastal Hazards, Including Sea-Level Rise: Inferences for Urban Coastal Risk Management and Adaptation Policies, in *Managing Coastal Vulnerability*, edited by L. McFadden, R.J. Nicholls, and E. Penning-Roswell, Amsterdam: Elsevier, 61-88.

Meyer, Michael D. (2008) Design Standards for U.S. Transportation Infrastructure: The Implications of Climate Change. *Transportation Research Board of the National Academy of Sciences*.

Mileti, Dennis (1999) *Disasters by Design: A Reassessment of Natural Hazards in the United States*, Washington D.C., Joseph Henry Press.

National Academies Disasters Roundtable. Reducing Flood Losses: Is the 1% Chance (100-year) Flood Standard Sufficient, Background reading for the 2004 Assembly of the Gilbert F. White National Flood Policy Forum. 2004.

National Climatic Data Center (NCDC). U.S. Climate Normals 1971-2000, Products. September 2003.

National Oceanic and Atmospheric Administration (NOAA). National Air Quality Forecast Capability. 2008.

National Oceanic and Atmospheric Administration (NOAA). National Weather Service Flash Flood Guidance. 2005.

National Oceanic and Atmospheric Administration (NOAA). NOAA Technical Paper No. 40: Rainfall Frequency Atlas of the Eastern United States for Duration from 30 minutes to 24 hours and Return Periods from 1 to 100 years. 1961.

National Research Council (NRC), Marine Board (1987) *Responding to Changes in Sea Level: Engineering Implications,* Washington, D.C., National Academy Press, 148 pp.

New York City Administrative Code, Title 20: Consumer Affairs, Section 20-716: Legislative Findings. 01 May 2009.

New York City Administrative Code, Title 24: Environmental Protection Utilities, Section 24-526: Conveyance of storm water from developments and lots and certain adjacent paved areas to off-site disposal points. 01 May 2009.

New York City Department of Buildings (NYCDOB). New York City Construction Codes-LL-33 / 2007, Appendix G: Flood-Resistant Construction. July 2008.

New York City Department of Buildings (NYCDOB). New York City Construction Codes-LL-33 / 2007, Chapter 16: Structural Design. July 2008.

New York City Department of Environmental Protection (NYCDEP). New York City's Wastewater Treatment System: Cleaning the Water We Use and Protecting the Environment We Live In. 20 December 2008.

New York City Office of Emergency Management (NYC OEM). Natural Hazard Mitigation Plan. March 2009.

New York City Office of Emergency Management (NYC OEM). NYC Hazards: Heat Emergencies. 2009.

New York City Office of Emergency Management (NYC OEM). NYC Hazards: Tracking a Hurricane. 2009.

New York City Office of Mayor, Sustainability Taskforce – Draft Report on Underground Infrastructure Resilience, *in preparation.*

New York State Department of Environmental Conservation (NYSDEC). Coastal Development Permitting Program. 20 December 2008.

New York State Department of Environmental Conservation (NYSDEC). New York State Stormwater Design Manual. (4-12). 2008b.

New York State Department of Transportation (NYSDOT). Bridge Manual, Section 2: Geometric Design Policy for Bridges, 2.4.3. January 2008.

New York State Reliability Council, L.L.C. NYSRC Reliability Rules for Planning and Operating the New York State Power System, Version 21. 14 December 2007.

United States Department of Commerce (USDOC). Technical Paper No. 49: Two-to Ten Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States. 1964.

United States Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Infectious Diseases and Division of Vector-Borne Infectious Diseases. Epidemic/Epizootic West Nile Virus in the United States: Guidelines for Surveillance, Prevention, and Control, 3rd Revision. 2003.

United States Geological Survey (USGS). Stream Gauging and Flood Forecasting. 20 September 1999.

United States Geological Survey (USGS). Scour at Bridges. 10 Aug 2007.

Yohe, Gary (2009) Characterizing the Value of Reducing Greenhouse Gas Emissions: Creating Benefit Profiles Tracking Diminished Risk, *In Press*.

Zimmerman, R. (1996) Global Warming, Infrastructure, and Land Use in the Metropolitan New York Area: Prevention and Response, in *The Baked Apple? Metropolitan New York in the Greenhouse*, edited by D. Hill. New York, NY: New York Academy of Sciences, pp. 57-83.

Zimmerman, R. (2003) Global Climate Change and Transportation Infrastructure: Lessons from the New York Area, in *The Potential Impacts of Climate Change on Transportation: Workshop Summary and Proceedings*, Washington, DC: U.S. DOT (Center for Climate Change and Environmental Forecasting) in cooperation with the U.S. EPA, U.S. DOE, U.S.GCRP, 2003, pp. 91-101.

Zimmerman, R. and Cusker, M. (2001) Institutional Decision-Making, Chapter 9 and Appendix 10 in *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change*. Metropolitan East Coast Regional Assessment. Rosenzweig, C. and Solecki, W. editors. New York, NY: Columbia Earth Institute and Goddard Institute of Space Studies, 2001, pp. 9-1 to 9-25 and A11-A17.