Mayor's Office of Recovery & Resiliency

PRELIMINARY

CLIMATE RESILIENCY DESIGN GUIDELINES

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Version 1.0

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CONTENTS

KEY TERMS[1]

100-year flood (1% annual chance flood)	A flood that has a 1% probability of occurring in any given year. The 100-year floodplain is the extent of the area of a flood that has a 1% chance of occurring or being exceeded in any given year.
500-year flood (0.2% annual chance flood)	A flood that has a 0.2% probability of occurring in any given year. The 500-year floodplain is the extent of the area of a flood that has a 0.2% chance of occurring or being exceeded in any given year.
Adaptation	Adjustment in natural or human systems to a new or changing environment that seeks to maximize beneficial opportunities or moderate negative effects.
Base flood elevation (BFE)	The elevation of surface water resulting from a flood that has a 1% annual chance of occurring or being exceeded in any given year. The BFE is shown on the Flood Insurance Rate Map (FIRM).[2]
Climate change	Changes in average weather conditions that persist over multiple decades or longer. Climate change encompasses both increases and decreases in temperature, as well as shifts in precipitation, changing risk of certain types of severe weather events and changes to other variables of the climate system.
Climate risk	The chance that investments can be affected by the physical impacts of climate change.[3] Risks are evaluated as a product of the likelihood of occurrence (probability) and the damages that would result if they did occur (consequences).
Design life	The life expectancy of an asset or product as determined during design.[4] As opposed to *useful life* (see below).
Extreme event	A weather event that has a low probability of occurring at a particular place and time of year, including, for example, heat waves, cold waves, heavy rains, periods of drought and flooding and severe storms.
Flexible adaptation pathway	Resilience-building strategies that can evolve over time as climate risk assessments, evaluations of adaptation strategies and monitoring continue.[5]
Flood Insurance Rate Maps (FIRM)	Official flood map of a community on which FEMA has delineated the 1% annual chance floodplain and the base flood elevations (BFEs) applicable to the community.[6]
Freeboard	An additional amount of height above the base flood elevation used as a factor of safety (e.g., 2 feet above the base flood) in determining the level at which a structure's lowest floor must be elevated or floodproofed to be in accordance with state or community floodplain management regulations.[7]

[1] All terms are from the U.S. Global Change Research Program (USGCRP) glossary unless otherwise noted. The USGCRP glossary is available at: http://www.globalchange.gov/climate-change/glossary
[2] "Definitions," FEMA, last modified March 1, 2017. https://www.fema.gov/national-flood-insurance-program/definitions
[3] "Account for Climate Risk," International Finance Corporation
[4] Sustainable Infrastructure Management Program Learning Environment. http://simple.werf.org/
[5] Rosenzweig, C. et al. *Climate Change Adaptation in New York City: Building a Risk Management Response*.
[6] "Definitions," FEMA.
[7] Ibid.

Heat wave	A period of three consecutive days where temperatures rise above 90°F[8]
New York City Panel on Climate Change (NPCC)	A body of leading climate and social scientists charged with making climate projections for the city.[9]
Open-grid pavement system	Pavements that consist of loose substrates supported by a grid of a more structurally sound grid or webbing. Unbounded, loose substrates in these systems transfer and store less heat than bound and compacted pavements.[10]
Preliminary Flood Insurance Rate Map (PFIRM)	Flood map developed by FEMA that provides an initial look at flood hazards.[11]
Resiliency	The ability to bounce back after change or adversity. The capability of preparing for, responding to and recovering from difficult conditions.[12]
Sea level rise-adjusted design flood elevation	As defined in these guidelines, the height of the base flood elevation, plus freeboard depending on the criticality of the facility, plus a sea level rise adjustment depending on the useful life of the facility.
Storm surge	The water height during storms such as hurricanes that is above the normal level expected at that time and place based on the tides alone.
Substantial improvement	Any repair, reconstruction, rehabilitation, addition, or improvement of a building or structure, the cost which equals or exceeds 50% of the market value of the structure before the improvement or repairs started. *For more information, see Appendix G of the NYC Building Code and 1 RCNY §3606-01.*[13]
Tidal inundation	Flooding which occurs at high tides due to climate-related sea level rise, land subsidence and/or the loss of natural barriers.[14]
Urban Heat Island (UHI) effect	The tendency for higher air temperatures to persist in urban areas as a result of heat absorbed and emitted by buildings and asphalt, tending to make cities warmer than the surrounding countryside.
Useful life	The period over which an asset or component is expected to be available for use by an entity. This period of time typically exceeds the *design life* (see above).[15]

[8] Horton, R. et al. *New York City Panel on Climate Change 2015 Report*: Chapter 1: Climate Observations and Projections. Ann. N.Y. Acad. Sci. ISSN 0077-8923. (New York, 2015) 25.
[9] *A Stronger, More Resilient New York*, PlaNYC. (The City of New York, 2013).
[10] "Glossary," US Green Building Council (2017). Available at: http://www.usgbc.org/glossary/term/5525
[11] "Preliminary FEMA Map Products," FEMA Map Service Center. Available at: https://hazards.fema.gov/femaportal/prelimdownload/
[12] *A Stronger, More Resilient New York* (2013), 1.
[13] "Flood Resistant Construction," Appendix G, New York City Building Code (2008), and 1 RCNY §3606-01 available at https://www1.nyc.gov/assets/buildings/rules/1_RCNY_3606-01.pdf
[14] "Ocean Facts," National Ocean Service. NOAA. Available at: http://oceanservice.noaa.gov/facts/nuisance-flooding.html.
[15] "Glossary," International Infrastructure Management Manual (2011). Available at: http://www.ipwea.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=ba2a9420-363c-4229-a240-df5239ec6d29

INTRODUCTION

In the coming years and throughout the 21st century, New York City (NYC) will face new challenges from a rapidly changing climate. Many physical infrastructure and building projects ("facilities") will face new or more severe risks from extreme flooding, precipitation and heat events.[16] At the same time, environmental conditions are also projected to change, posing chronic hazards as some coastal areas are regularly inundated by high tide and average yearly temperatures rise. Through the 80 x 50 plan, the City is committed to reducing emissions of greenhouse gases.[17] However, the impacts from climate change are already occurring, and these Guidelines establish how the City can increase its resilience through design.

Codes and standards that regulate the design of infrastructure and buildings incorporate historic weather data to determine how to build for the future. However, historic conditions do not accurately represent the projected severity and frequency of future storms, heat waves and precipitation. The climate is already changing and will continue to change in significant ways over the entire useful life of assets designed today, threatening to undermine capital investments and impede critical services. To protect the facilities New Yorkers depend upon, the City will design them using the best available data for future conditions.

These preliminary Climate Resiliency Design Guidelines ("Guidelines") provide step-by-step instructions on how to supplement historic climate data with specific, regional, forward-looking climate data in the design of infrastructure and buildings. These Guidelines apply to all City capital projects except coastal protection projects (e.g. sea walls and levees), for which the City will develop separate guidance. Implementing the Guidelines will result in protection standards that will make the City's built environment more resilient to climate change and promote the health, safety and prosperity of New Yorkers.

The Guidelines are an initial step towards integrating resiliency as a core principle in the design of buildings and infrastructure in NYC. Throughout 2017, this preliminary version of the guidelines will be refined through ongoing pilot testing, with a final version anticipated being released by the end of the year.

GOALS

The primary goal of the Guidelines is to incorporate forward-looking climate data into the design of all City of New York capital projects. The Guidelines provide a consistent methodology for engineers, architects and planners to design facilities that are resilient to changing climate conditions. The Guidelines are to be used throughout the design process—as a reference in RFPs through to the conceptual or study phase, to final design—for all new construction and substantial improvements of City buildings and infrastructure.

These Guidelines were developed by the Mayor's Office of Recovery and Resiliency in close collaboration with City agencies that are involved in design of capital projects. A Design Guidelines Working Group was convened to consult on the development of the Guidelines,

[16] Though the intensity and frequency of storms is expected to increase, firm projections on future wind conditions have not yet been developed. NYC will commence a study in 2017 to assess projected changes to extreme wind hazards and identify risks to the city's built environment.

[17] To learn more about 80 x 50, visit: http://www1.nyc.gov/site/sustainability/codes/80x50.page.

which included more than 15 City agencies.[18] These Guidelines do not encompass all City resiliency policies. To learn more about how the City of New York plans for a resilient future, see the latest OneNYC plan and the 2013 report *A Stronger, More Resilient New York.*[19]

CLIMATE CHANGE PROJECTIONS FOR NEW YORK CITY

The New York City Panel on Climate Change (NPCC) provides regional climate projections that inform City resiliency policy. Composed of leading scientists, the NPCC prepares projections for the City and metropolitan region which have shown that extreme weather will increase in frequency and severity, and that the climate will become more variable. Climate projections encompass a wide range of possible outcomes, for example:

- Mean annual temperature is projected to increase between 4.1 and 6.6°F by the 2050s and between 5.3 and 10.3°F by the 2080s.[20]
- Frequency of heat waves is projected to triple by the 2050s to 5 to 7 heat waves per year. [21]
- Mean annual precipitation is projected to increase between 4 to 13% by the 2050s and between 5 to 19% by the 2080s.[22]
- Sea level is expected to continue rising by 11 to 21 inches by the 2050s and by 18 to 39 inches by the 2080s.[23]

This document provides guidance on how to use the range of climate projections in design. For more information on climate projections for NYC, see Appendix 1. The NPCC continues to study and refine climate projections for the metropolitan region, and these Guidelines will be updated as new reports are released by the NPCC.

PLANNING ACROSS THE USEFUL LIFE

A resilient facility is one built to withstand or recovery quickly from natural hazards. Climate impacts continue to change over time, which makes considering the full useful life important for choosing the right level of protection.[24] The full *useful life* of a facility is typically a longer period than the *design life*, and more accurately represents the extended service life of most types of building or infrastructure. For example, an administration building may have a design life of 30 years, but in practice such buildings remain in use for 50 years or more. When siting more permanent structures, such as catch basins or outfalls, additional evaluation is needed. Using professional knowledge and examples from the built environment, estimate the full useful life of the facility in design. The facility's useful life will determine the necessary design adjustments below that increase its resilience.

[18] Representatives from the following City departments and agencies contributed to the creation of this document: Environmental Protection, Transportation, City Planning, Buildings, Design and Construction, Parks and Recreation, Emergency Management, School Construction Authority, City Administrative Services, Health and Hospitals, Information Technology and Telecommunications, Economic Development Corporation, Housing Authority, Public Design Commission, Mayor's Office of Sustainability, Housing Preservation and Development, Office of Management and Budget, Sanitation and Law.

[19] The latest OneNYC report is available at http://www1.nyc.gov/html/onenyc/index.html. The 2013 resiliency report is available at http://www.nyc.gov/html/sirr/html/report/report.shtml.

[20] Ranges for heat reflect the middle and high range estimates from the NPCC. See Appendix 1 for more information.

[21] Ibid.

[22] Ranges for precipitation reflect the middle and high range estimates from the NPCC. See Appendix 1 for more information.

[23] Ranges for sea level rise reflect the middle range estimates. See Appendix 1 for more information.

[24] NIST, *Community Resilience Planning Guide for Buildings and Infrastructure Systems, Vol. 1* .NIST Special Publication 1190: US Department of Commerce, 2016.

MANAGING UNCERTAINTY

The NYC climate projections from the NPCC are the product of state-of-the-art modeling and analysis. However as with all projections, there is uncertainty embedded within them.[25] The NPCC continues to develop, review and synthesize the latest climate data for the NYC metropolitan region, and future findings will be incorporated into later versions of the Guidelines.

Flexible adaptation pathways provide a useful, iterative approach for managing uncertainty and designing resilient facilities, particularly those with a useful life that extends beyond 50 years (beyond which the uncertainty of climate projections increases).[26] Adaptation pathways provide a way to balance uncertainty with cost, as well as manage operational and maintenance constraints. A facility can be engineered with an adaptable protection level which reduces the hazard risk to acceptable levels for part of its useful life which can be re-evaluated as risk levels change. For example, when designing a flood wall at a facility with an estimated useful life of 100 years, incorporate a sea level rise adjustment that accounts for part of the facility's useful life and design the barrier to be increased in the height.

Adaptation pathways may not apply equally to all types of projects or climate projections. Facility flood defenses, for example, may be more easily developed iteratively than heat-vulnerable materials or below grade drainage systems. For these reasons, use the middle of the 25th to 75th percentile range projections for sea level rise and the high-end 90th percentile projections for heat and precipitation.

Some facilities, such as those that are critical or cost more than $100 million for design and construction, will benefit from a full climate risk assessment.[27] This assessment will evaluate protecting the facility to a potentially higher level of sea level rise than the recommended height in these Guidelines. If engaging in a climate risk assessment process, please contact the NYC Mayor's Office of Recovery and Resiliency at ResilientDesign@cityhall.nyc.gov.

PROJECT-SPECIFIC CONSIDERATIONS

Existing information and requirements specific to different kinds of projects will be reviewed on a case-by-case basis. Discuss these considerations as a project team to determine which ones apply.

- **Financing requirements:** if the project is federally-funded or receives post-Sandy recovery funding, discuss with the funding agency if certain protection standards are required. For example, FEMA requires specific flood protection standards for critical facilities and non-critical facilities.
- **Ongoing hazard mitigation projects:** evaluate any system-wide or perimeter protection projects that may affect how the facility is influenced by a climate hazard. A map that catalogues NYC resiliency projects is located here: https://maps.nyc.gov/resiliency/.

[25] *PlaNYC, A Stronger More Resilient New York,* report of the NYC Special Initiative for Rebuilding and Resiliency. Report. June 11, 2013, page 28. From that report: "Like all projections, the NPCC climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system and limited understanding of some physical processes. The NPCC characterizes levels of uncertainty using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations and recent peer-reviewed literature. Even so, the projections are not true probabilities, and the potential for error should be acknowledged."

[26] To learn more, see Chapter 2 in the NPCC 2010 report, *Climate Change Adaptation in New York City*, available at http://onlinelibrary.wiley.com/doi/10.1111/nyas.2010.1196.issue-1/issuetoc

[27] A full climate risk assessment involves a detailed, project-specific analysis that includes a vulnerability and risk assessment, often followed by cost-benefit analysis, to assess and select investments in climate risk mitigation.

- **Interdependencies**: consider how hazards impact interdependencies across sectors, as well as the risks from coincident events (e.g. major precipitation occurring during a coastal storm) to specific projects.
- **Existing projects and risk studies:** evaluate if nearby or associated projects have already been assessed for climate risks. Identify if any studies have been conducted that could inform design (e.g. local flood modeling with sea level rise). This may inform the climate risk assessment or provide insights into site specific conditions and projections.
- **Further questions?** Contact the Mayor's Office of Recovery and Resiliency at ResilientDesign@cityhall.nyc.gov.

RESILIENT DESIGN ADJUSTMENTS

All City of New York buildings and infrastructure should be designed to withstand increasing heat and precipitation based on the useful life of the asset, while design interventions for storm surge and sea level rise depend on the project's proximity to the floodplain, useful life and criticality. The Guidelines provide climate projections and recommend design adjustments or interventions in response to increasing heat, increasing precipitation and sea level rise.

INCREASING HEAT

Use this section to determine how to adjust a facility's design to account for increasing temperatures and to reduce the facility's contribution to the Urban Heat Island effect. Heat reduction levels will be determined by the function, location and useful life of the asset.

Background

The impacts of heat on NYC are well established. High temperatures kill over 100 New Yorkers every summer on average and exacerbate health problems.[28] The region has recently broken numerous temperature records, and temperatures are projected to keep rising, worsening heat-related mortality. By the 2050s the number of days above 90°F is expected to double, and the frequency and length of heat waves will triple to an average 6 heat waves per year.[29] In OneNYC, the City has prioritized developing strategies to study the Urban Heat Island effect and make targeted investments that benefit communities most vulnerable to heat.[30]

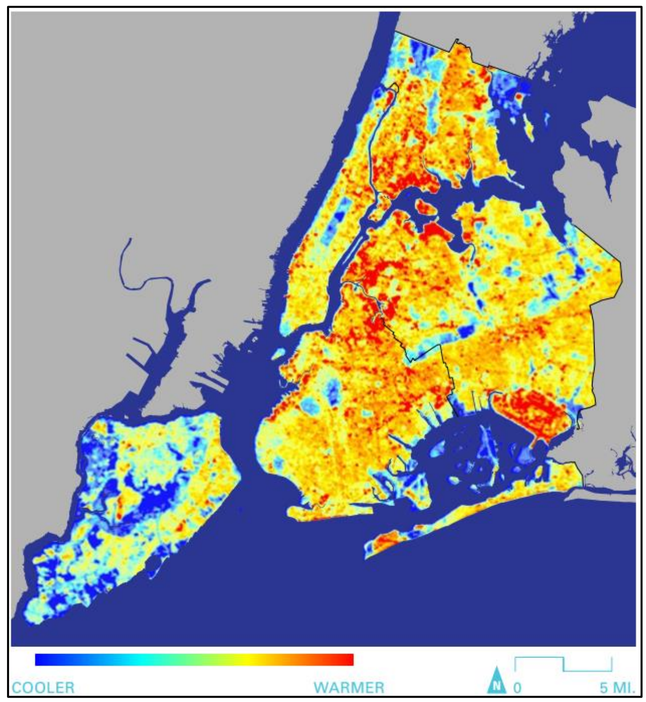

Figure 1 - Thermal imagery of New York City, based on LANDSAT Thermal Data from 8/18/2009[1]

[28] *OneNYC: The Plan for a Strong and Just City*. (The City of New York, 2015) 228. See also: Madrigano J, Ito K, Johnson S, Kinney PL, Matte T. 2015. A case-only study of vulnerability to heat wave–related mortality in New York City (2000–2011). Environmental Health Perspectives 123:672–678; http://dx.doi.org/10.1289/ehp.1408178

[29] Horton et al. *New York City Panel on Climate Change 2015 Report Chapter 1: Climate Observations and Projections*. Ann. N.Y. Acad. Sci. ISSN 0077-8923: New York, 2015.

[30] *OneNYC,* 228.

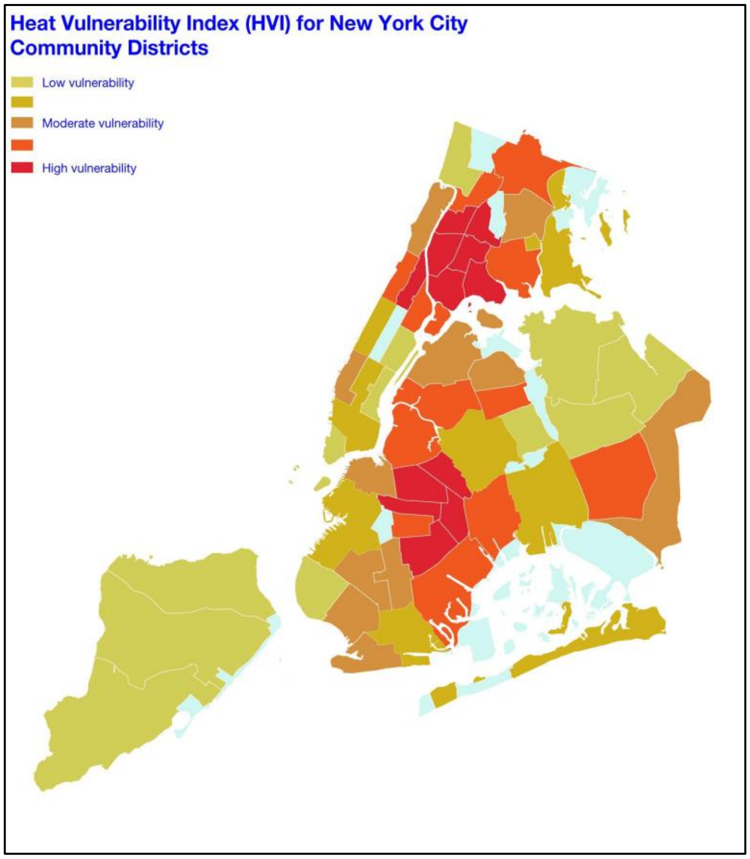

Figure 2 - Heat Vulnerability Index (HVI) for New York City Community Districts (Source: NYC DOHMH 2015). This analysis identifies physical, social and economic factors associated with increased risk of heat-related morbidity and mortality.[32]

Certain areas of NYC already experience higher temperatures relative to other parts of the city, and these hot spots will be exacerbated by climate change (see Figure 1). Heat can be lethal, but its impact on New Yorkers is not equal. New Yorkers are more or less vulnerable to heat largely based upon socio-economic factors, including age and income. The NYC Department of Health and Mental Hygiene developed a Heat Vulnerability Index (HVI) which highlights parts of the city where more residents face an increased risk of heat-related mortality (see Figure 2).[31] While all new capital projects should address heat impacts, those sited in moderate to high vulnerable HVI areas should implement multiple strategies to reduce the Urban Heat Island.

The Guidelines highlight two approaches for project designers to address increasing heat in the built environment:

- **Urban Heat Island reduction:** the materials in our built environment absorb the sun's heat throughout the hottest portions of the day and reradiate it back into the atmosphere, driving the localized temperatures even higher and increasing demands on cooling systems. Air conditioning and ventilation equipment also push extra heat into the air, contributing to a feedback loop that increases localized ambient temperatures and impacts the health of heat-vulnerable New Yorkers. This section provides guidance on how new capital construction can limit its contribution to ambient heat in the city.
- **Minimize impact from increasing heat:** increasing heat will physically impact components of buildings and infrastructure, damaging or stressing materials, electrical systems and mechanical systems at a facility. Rising temperatures will also stress energy and communications networks facilities rely upon.[33] This section provides climate data to be used to adjust and adapt heat-vulnerable components of assets.

[31] To learn more about Heat Vulnerability Index, see page 229 of OneNYC at http://www.nyc.gov/html/onenyc/downloads/pdf/publications/OneNYC.pdf.
[32] See page 229 in the OneNYC plan to learn more about HVI, available at http://www.nyc.gov/html/onenyc/downloads/pdf/publications/OneNYC.pdf.
[33] Damiano, H. et al. *NYC's Risk Landscape: A Guide to Hazard Mitigation.* (NYC Emergency Management, 2014), 103.

1. Urban Heat Island reduction

New capital construction should minimize its contribution to the Urban Heat Island effect. The design interventions provided below can also provide direct benefits to the facility through reduced heat loading, reduced energy costs and/or improved occupant health and thermal comfort. The appropriate combination of design interventions will vary dependent on the project scope.

a) **Cool and shade facility lots:** Lighter, reflective surfaces help reduce the Urban Heat Island effect, reduce heat loading, reduce internal building temperatures and extend the lifespan of rooftops and heating, ventilation and air conditioning (HVAC) equipment. The City has taken steps towards reducing ambient temperatures, such as implementing the NYC Cool Roofs program.[34] This program reduces a building's contribution to Urban Heat Island effect and provides energy savings by coating the normally dark, asphalt roof surface with white paint, allowing the roof to reflect solar radiation. Increase the shading and solar reflectance of surfaces by utilizing light-colored pavement, trees, or plantings on 50% of the non-structure areas of facility sites.[35]

b) **Improve efficiency of building envelopes:** NYC already requires that residential building envelopes are designed to meet higher insulation and fenestration requirements to improve energy efficiency.[36] All City capital projects, including non-residential structures, meet Climate Zone 6 standards for fenestration and insulation (See Table R402.1.2 in Chapter 4 of the 2016 NYC Energy Code).

c) **Utilize green roofs and landscape elements:** The City already encourages the use of green roofs on buildings to reduce the Urban Heat Island effect[37] and provide stormwater management. Besides replacing dark roof surfaces with vegetation, green roofs and vegetation also provide shade and keep the air cool through evapotranspiration by releasing moisture into the atmosphere. Some of these designs support the shading and solar reflectance goal in Step a) above. Additionally, City capital projects are subject to Leadership in Energy and Environmental Design (LEED) certification; as such, green roofs can earn LEED credits.[38] Work with landscape architectures to select appropriate landscape elements that maximize cooling. Projects should integrate cooling strategies listed below:
   - Green roofs on a broader range of facilities (including industrial buildings, storage, garages, administration buildings, etc.).
   - Green walls/structures (to reduce heat loading on vertical surfaces).
   - Shade trees, planters and vegetated structures.
   - Bioswales, rain gardens and bioretention cells.[39]
   - Permeable surfaces (used for stormwater management, these retain moisture that evaporates as surface temperatures rise).[40]
   - Open-grid pavement system (at least 50% unbound).[41]
   - Evaluate site planning and building massing with regard to solar gain.

[34] Local Law No. 21 (2011) amended Chapter 12 of the NYC Building Code to update roof coating standards. Also, see *Cool and Green Roofing Manual* (DDC) 2007 for more information on NYC standards for cool and green roofs: http://www.nyc.gov/html/ddc/downloads/pdf/cool_green_roof_man.pdf.
[35] Urban Green Council (2010). *Green Codes Task Force*. Proposed code "EF 12: Reduce Summer Heat with Cool, Shady Building Lots".
[36] Read more about the code here https://www1.nyc.gov/site/buildings/codes/2016-energy-conservation-code.page.
[37] See *Cool and Green Roofing Manual* (DDC) 2007 for more information on NYC standards for cool and green roofs: http://www.nyc.gov/html/ddc/downloads/pdf/cool_green_roof_man.pdf.
[38] See Local Law No. 32 (2016) for more information.
[39] When siting bioswales, consider groundwater levels. A high water table may prohibit some applications.
[40] Urban Green Council (2010). *Green Codes Task Force*. Proposed code "SW 1: REDUCE EXCESSIVE PAVING OF SITES"
[41] LEED Neighborhood Development v4 "Heat island reduction" credit.

2. Minimize impact from increasing heat

This section provides information to support making design adjustments to capital projects to reduce impacts from rising temperatures and increasing extreme heat events on the built environment.

a) **Review forward-looking climate data** provided in Table 1. These figures provide design criteria for average temperatures and incidents of extreme heat events projected to different time periods across the 21st century. Utilize the heat projections specific for useful life of the facility and of the heat-vulnerable components to evaluate and reduce impacts in the steps below.

Table 1 – Baseline and projected extreme heat events[42]

End of useful life	# heat waves per year *(3 or more consecutive days with max temperatures at or above 90°F)*	# days above 90°F	Annual average temperature
Baseline *(1971-2000)*	2	18	54°F
Through to 2039	4	33	57.2°F
2040-2069	7	57	60.6°F
2070-2099	9	87	64.3°F

b) **Evaluate potential impacts on systems and materials**. A decrease in the useful life or operational capacity of a facility, or components of a facility, may occur due to rising temperatures. However, heat impacts on a facility are highly contingent on the facility type and should be reviewed on a case-by-case basis.[43] Interventions will also vary depending on whether the project is a new capital investment or a substantial improvement to an existing facility. Factors to evaluate, as applicable to project scope, include but are not limited to:
   - Thermal expansion, warping, softening, or other forms of material change or degradation of structural integrity occurring at an accelerated rate by excessive heat;
   - Health and safety impacts on occupants vulnerable to heat;
   - Increased failure or reduced efficiency of electrical or mechanical systems; and
   - Prioritization of critical loads for systems and components at the facility.

   The results of this evaluation will inform steps taken in ***c) Reduce heat impacts*** below.

c) **Reduce heat impacts.** Review and implement specific changes to the facility design based on the project team discussion. Develop a strategy based on the specific type of facility, its operational profile and its useful life. Specific areas of focus are:
   - **Electricity outages:** High temperatures drive demand for air conditioning and can increase the risk of equipment failure or brownouts.[44,45] To manage this risk, design City facilities to withstand periods without electricity using the following approaches:

[42] Projected estimates are based upon 90th percentile estimates from New York City Panel on Climate Change (2015).
[43] Sector- and facility-specific impacts vary greatly. For examples of sector-specific impacts and design responses, see *Flooded Bus Barns and Buckled Rails* (FTA 2011) and *Ready to Respond: Strategies for Multifamily Building Resilience* (Enterprise Green Communities 2015)
[44] McGregor et al. (2013) *Two Degrees: The Built Environment and Our Changing Climate*. Routledge Press.
[45] High temperatures also increase energy demand, which can increase fossil fuel based greenhouse gas emissions.

    - Identify and assess how much of the facility's load is critical (e.g., "critical load"), including the necessary duration of the backup power supply (e.g., is backup power needed for 8 hours or multiple days?). Critical load includes a facility's essential operations and what the role of the facility will be in the event of an emergency situation.[46]
    - Depending on the size of the critical load and budget, different options could range from backup generators to hybrid systems (e.g., solar + storage + appropriately sized generator). For shorter duration needs, buildings with existing solar systems should consider adding storage to provide a resiliency benefit. In some cases, cogeneration systems may make sense from an economic and resiliency perspective, especially if there is a significant heating and/or cooling load in addition to an electricity demand. [47]
    - Depending on the option, assess need to invest in internal electricity rewiring (e.g., switches) and/or need for external hookups for temporary generators and boilers.[48]
- **Failure in facility ventilation, electrical and air conditioning systems:** Some systems designed to meet the requirements of past climate may overheat and fail during extreme events. Some design interventions include: [49]
    - Selecting systems with higher heat tolerance.
    - Providing additional or redundant ventilation systems, either mechanical or natural, to cool electrical equipment.
- **Passive solar cooling and ventilation:** There are numerous design features that provide passive solar cooling for buildings to help maintain lower internal ambient temperatures with less air conditioning. Some design features include:[50]
    - Appropriate east-west orientation.
    - Passive ventilation design.
    - Vertically stacked double skin facades.
    - Exterior window shades.
    - Shaded arcades.
    - Thermally massive materials.
    - High performance glazing.
    - Operable windows.

[46] The key roles of the facility that need to be identified are operational hours, number of occupants and electrical loads needed for the desired operations. Electrical equipment and appliances for the desired operations may include–but are not limited to--safety lighting, life-supporting systems, fire protection systems, mechanical systems to mitigate extreme temperatures and computing equipment. Every facility is unique. Operational characteristics and load profiles need to be established prior to sizing the equipment required to keep the facility in operational mode.
[47] To learn more, see the Building Resiliency Task Force report from Urban Green Council (2013).
[48] Ibid.
[49] *Flooded Bus Barns and Buckled Rails.* FTA Office of Budget and Policy, 2011.
[50] These and other examples are found in McGregor et al. (2013) *Two Degrees: The Built Environment and Our Changing Climate*. Routledge Press. Also see, *Flooded Bus Barns and Buckled Rails.* FTA Office of Budget and Policy, 2011.

INCREASING PRECIPITATION

The intensity and frequency of precipitation events are projected to increase with climate change, creating new challenges for stormwater management and impacts to the built environment, such as:

- The potential for greater frequency of stormwater management systems being overwhelmed; [51]
- More frequent and severe flooding of facilities sited in low-lying, impervious areas; and
- Greater variability in rainfall events, including the chance of drought.

The data provided in this section should inform drainage planning and stormwater management, with design solutions ultimately chosen based on a sensitivity analysis.

Background

NYC's drainage infrastructure is composed of many different systems that convey or store stormwater during precipitation events of different magnitudes. Figure 3 below demonstrates the capacity of different types of stormwater drainage systems.

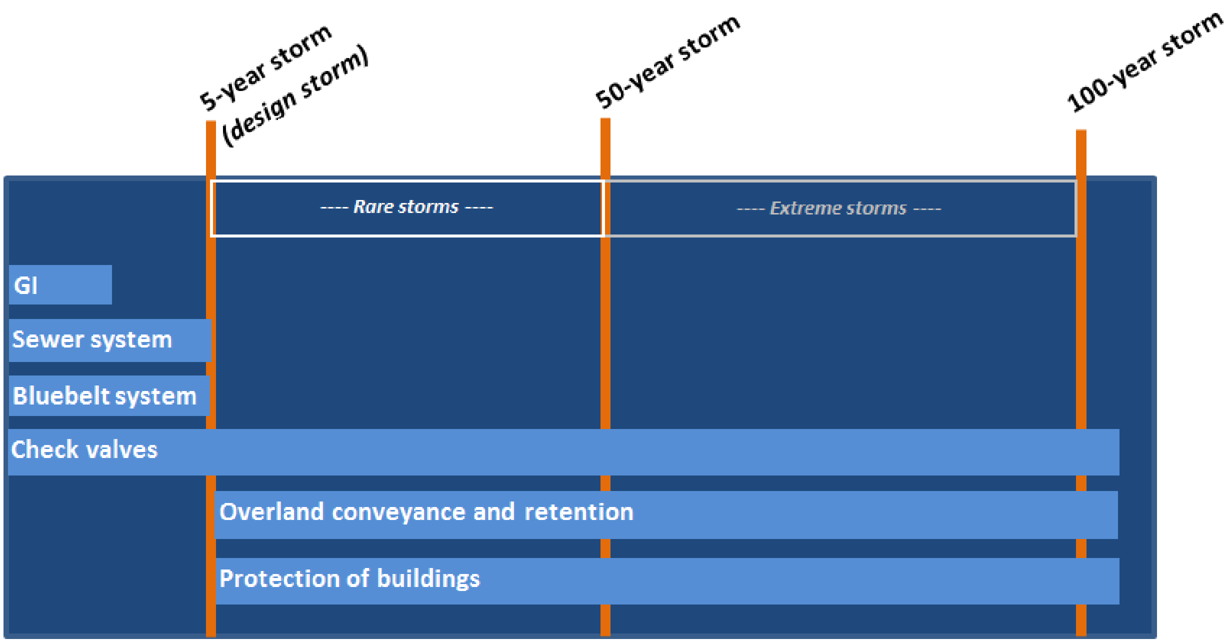

Figure 3 – Schematic elements of the NYC drainage system (illustrative), GI = green infrastructure[52]

NYC's drainage systems are designed to handle a 3-year intensity-duration-frequency (IDF) event in most areas of the city where sewers were built prior to 1970. In locations with sewers built after 1970, the capacity was built to handle the 5-year event. NYC's network of drainage systems can experience flooding above those thresholds due to larger precipitation events and by short, intense storms (sometimes called "cloudbursts"), causing flooding and backups. Climate projections indicate that these flooding events will increase in frequency. This increasing probability is forecast for all types of precipitation events in NYC although there is uncertainty particularly for short duration events.

[51] NYC is already taking steps to address this problem, which will worsen with climate change. To learn more about how NYC is using green and grey infrastructure to manage stormwater, visit http://www.nyc.gov/html/dep/html/stormwater/index.shtml.

[52] Adapted from figure in Krieger, K. *Pluvial Flood Protection – Adaption of German Regulations and Practical Examples from Hamburg*, Amsterdam International Water Week, 2015.

Relying on sewers alone to manage extreme precipitation events will not be sufficient in a changing climate. The City will reduce impervious areas and provide additional storage capacity to reduce flood damage. For managing stormwater from larger storms such as at the 50- and 100-year recurrence intervals, the Department of Environmental Protection (DEP) is increasingly considering the role of streets and open space in managing flow; this is referred to as a dual drainage design approach.

Another set of interventions include bluebelt best management practices (BMPs) and green infrastructure, which in NYC have generally been designed to reduce flooding and combined sewer overflow, respectively, and are not typically sized to manage precipitation events of the same magnitude as sewers, which serve as primary drainage conveyance. However, bluebelt BMPs, green infrastructure and other stormwater management tools may provide an additional buffer by temporarily storing and/or infiltrating runoff that would otherwise be directed into the sewer system if appropriately designed to retain or infiltrate larger storm events. These approaches will help reduce chronic pollution issues related to increasing rainfall and can reduce the amount of stormwater entering the existing drainage system, particularly when scaled over a large land area. The City is piloting projects to test this dual drainage approach. Adjusting for these changes protects communities, increases the resiliency of NYC and safeguards City investments in critical infrastructure. However, this will need to be evaluated for the entire sewershed to understand the integrated stormwater planning approach and feasibility.

The City, led by DEP, continues to develop its understanding of precipitation projections and how to utilize that data in design. DEP is developing approaches to evaluate sea level rise and rainfall intensity for drainage planning. These efforts will integrate forward-looking climate data into the design of these capital assets. Another resource to be developed includes projected sub-hourly rainfall intensities, which will be a primary tool in drainage planning. While considerable uncertainty exists regarding projections at this timescale, the City is seeking guidance from its academic partners to determine reasonable estimates of sub-hourly future rainfall intensity. A methodology is also under development that will establish a consistent citywide process for addressing legal grade.

1. Precipitation design adjustment

Based upon the useful life of the facility and the design storm required, follow the steps below to determine the climate-adjusted depths of the design storm and review recommended design interventions to manage the increasing severity.

a) **Identify the duration of the design event required**. NYC building code uses different sizes of design storms for infrastructure and buildings.[53] Refer to relevant codes and standards to determine the required design storm size for the project, and then proceed to Step b). Typically drainage systems are designed based on the sub-hourly or hourly duration, on the assumption that a storm will be short-lived, but retention and detention systems should consider longer durations up to 24 hours.
b) **Use Table 2 below to determine which forward-looking climate data to use** based upon the relevant design storm, duration and useful life of the project. Additional values for NYC[54] are provided in Intensity-Duration-Frequency (IDF) curves in Appendix 2. Note that values are representative and can be

[53] For example, NYC Plumbing Code Chapter 11, and Title 15 of the Rules of the City of New York Chapter 31.
[54] Locations outside NYC, such as the NYC watershed, should refer to the local observations and projections from NOAA Atlas 14 and the Northeast Regional Climate Center, respectively.

used for sensitivity analyses, although projects are often dependent on sub-hourly data, which are in development.

Table 2 – Baseline and projected design storm events for the 1-hour and 24-hour duration			
1-hour duration rainfall depths			
End of useful life	**5-year design storm** (inches)	**50-year design storm** (inches)	**100-year design storm** (inches)
Baseline[55,56]	1.61	2.57	2.87
Through to 2039[57]	1.83	3.02	3.41
2040-2069	1.97	3.33	3.93
2070-2099	2.12	3.74	4.34
24-hour duration rainfall depths			
End of useful life	**5-year design storm** (inches)	**50-year design storm** (inches)	**100-year design storm** (inches)
Baseline[58,59]	4.70	7.83	8.79
Through to 2039[60]	5.41	9.21	10.55
2040-2069	5.88	10.13	12.31
2070-2099	6.35	11.28	13.40

c) **Conduct sensitivity analysis.** Major projects (e.g. projects which cost more than $100 million design and construction) should perform sensitivity analysis using data from Table 2 to determine whether there is flooding risk that may warrant additional conveyance or storage of flow volumes under conditions of increasing storm intensity.
   - The simplest mitigation measures are source controls such as green infrastructure, bluebelt BMPs and other potential stormwater management practices (see Step d) below). Alternatively, surface conveyance options such as swales can be explored.
   - If neither of these mitigation measures can meet the additional flow capacity requirement, consider revising the design of the sewer pipe to provide additional capacity.
   - Both options above should be considered in the sensitivity analysis along with any potential negative impacts on downstream segments. However, the City will make every effort to not impact upstream or downstream homeowners or infrastructure. For instance, if bending weirs, regulators, pump stations, or interceptors are not sized to handle the increase in flows, then the receiving system cannot handle increased flows.

d) **Identify design interventions** for managing increased precipitation.[61] There are different ways to better manage stormwater and avoid urban flooding after intense rain. Choose the right combination of

[55] From NOAA Atlas 14 for Central Park (based on observed precipitation data through 2014).
[56] NYCDEP uses a slightly different 5-year, 1-hour rainfall of 1.67 inches, as calculated by I=125/(T+15), a simple approximation to estimate intensity based on time of concentration.
[57] All projections based on 90th percentile of RCP 8.5 projections from the Northeast Regional Climate Center, as corrected with baseline data from NOAA Atlas 14.
[58] From NOAA Atlas 14 for Central Park (based on observed precipitation data through 2014).
[59] NYC DEP uses a slightly different 5-year, 24-hour rainfall of 4.5 inches, as derived from TP-40 (US Weather Bureau 1961).
[60] All projections based on 90th percentile of RCP 8.5 projections from the Northeast Regional Climate Center, as corrected with baseline data from NOAA Atlas 14.
[61] Additional resources include DEP Guide to Rain Event Preparedness http://www.nyc.gov/html/dep/pdf/brochures/flood-preparedness-flyer.pdf and Ready to Respond: Strategies for Multifamily Building Resilience http://www.enterprisecommunity.org/resources/ready-respond-strategies-multifamily-building-resilience-13356

interventions after considering the site location, operational requirements, cost and useful life. Some examples of design interventions are:

- Retain and infiltrate, evaporate, or re-use the rainwater that falls on a site (e.g. using permeable paving materials, increased green spaces, cisterns).
- Install check valves and other backwater flow prevention where applicable.
- Install stormwater detention and storage (e.g. bioswales,[62] green roofs, blue roofs, blue belts and other blue or green infrastructure; storage basins or tanks).
- Protect areas below grade from flooding.
- Keep catch basin grates clear.

[62] When siting bioswales, consider groundwater levels. A high water table may prohibit some applications.

SEA LEVEL RISE

This section provides tools to 1) determine if the project will be subject to tidal inundation during its useful life due to sea level rise and 2) incorporate sea level rise into flood protections of capital projects. For projects in the current and future 1% annual chance floodplains, sea level rise-adjusted design flood elevations are provided and reflect the criticality of the asset and its useful life.

Background

NYC has experienced the devastation of coastal storms, most recently during Hurricane Sandy as well as tidal flooding in low-lying areas during high tides, especially nor'easters. Sea level rise is projected to increase the depth, extent and frequency of flooding from storm surge.[63] Sea level rise will also regularly inundate some low-lying areas during high tides. Current flood protection heights are determined by using the base flood elevation established by the FEMA Preliminary Flood Insurance Rate Map (PFIRM) 2015[64] and the standard of protection for buildings in the floodplain in Appendix G of the NYC Building Code. These Guidelines will augment existing requirements for two primary purposes: ensuring City facilities built today are incorporating sea level rise and that critical assets (Table 3) are protected to a higher level.

Designers should differentiate between critical and non-critical components within a larger facility or campus (e.g. an airport or maintenance yard). Critical components essential to the structure's functionality should be protected to the higher standard for criticality even if the facility itself may be non-critical. These components include but are not limited to electrical distribution and switching areas, motor-control centers, chemical feed equipment, boilers, communications systems, monitoring and safety equipment, HVAC units, fire alarms and suppression equipment, furnaces, elevators, emergency fuel supplies, emergency generators and hazardous material storage. Component protection should also evaluate if a facility is expected to be fully operational during a flood event, or if it is expected to resume full operations after an event.

For facilities with a long useful life, it is not always cost effective or operationally feasible to design a facility to be resilient to hazards it may only face at the end of its useful life. In these cases, the most resilient design will be one that provides extra protection against hazards in the initial decades while also leaving open design alternatives for updating resiliency measures as new data is provided or new risk assessments are completed. This Flexible Adaptation Pathways approach builds in options to protect assets later in life. For large scale projects with a design and construction cost above $100 million, a climate risk assessment should be used to evaluate protecting the facility to a different level of sea level rise than the recommended height in these Guidelines.

These Guidelines apply to all City capital projects with one exception. Coastal flood protection systems are designed to different standards than those provided here for buildings and other physical infrastructure. Many of NYC's coastal protection systems are currently being developed to comply with FEMA accreditation for levee systems.[65] The City plans to develop guidance for designing resilient coastal protection projects. Projects that require discretionary approval are required to incorporate sea level rise projections as part of the NYC Waterfront Revitalization Program.[66]

[63] New York City Panel on Climate Change Report Chapter 2: Sea Level Rise and Coastal Storms (2015).
[64] However, NYC Building code G102.2.2 requires that designers review both the PFIRMs and the effective FIRMs and use the more restrictive of the two.
[65] To read more, please visit: www.fema.gov/fema-levee-resources-library
[66] For more information, visit www.nyc.gov/wrp.

1. Preparing for tidal inundation due to sea level rise

Tidal flooding currently affects parts of NYC and is projected to worsen as sea levels rise and inundate low-lying coastal sites during high tides. Some facilities, such as wastewater treatment plants and harbor facilities, need to be near the coast for operational purposes. When determining a site location or establishing scope of substantial improvements for other types of coastal facilities, the project team will consider alternative sites outside of zones threatened with regular inundation.

a) **Determine inundation risk from sea level rise**, separate from coastal flood events. Use the Flood Hazard Mapper (nyc.gov/floodhazardmapper)[67] to see if your site is in an area inundated from high tide plus sea level rise within the project's useful life (e.g., if the useful life ends between 2040 and 2069, choose the 2050s High Tide map). Determine risk only from high tide and sea level rise, separate from flood events. Follow the instructions in Figure 4 and refer to the example in Figure 5 to review inundation at the end of an asset's useful life.

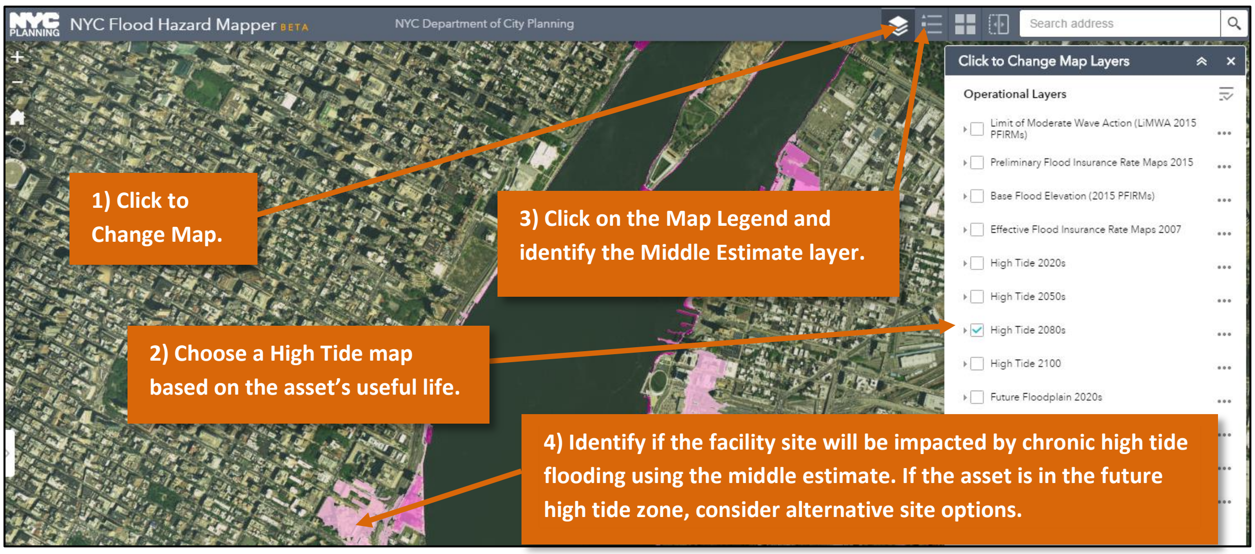

Figure 4 – Flood Hazard Mapper with High Tide + sea level rise at nyc.gov/floodhazardmapper

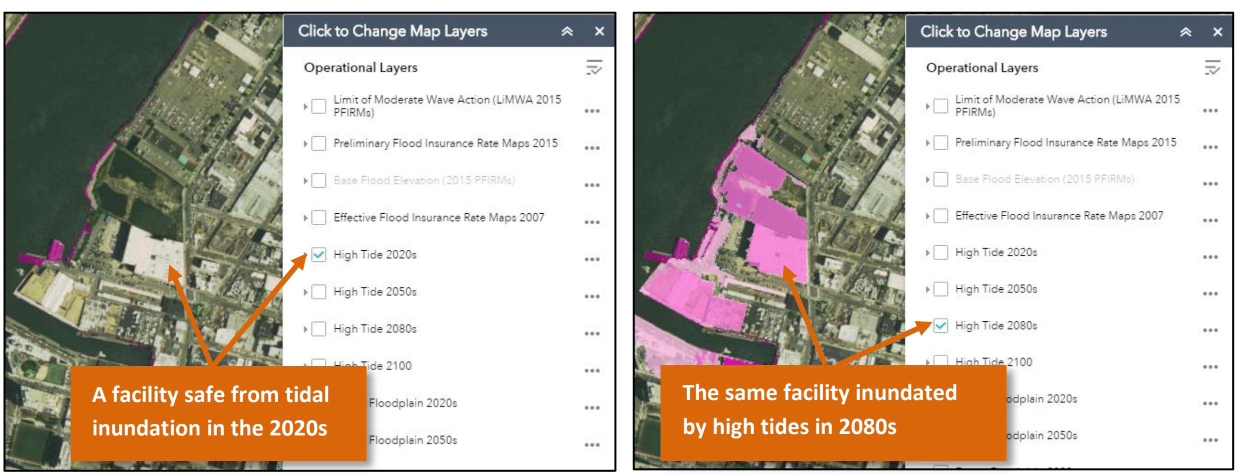

Figure 5 – Flood Hazard Mapper with high tide in the 2020s (left) and in the 2080s (right) at nyc.gov/floodhazardmapper

[67] The Flood Hazard Mapper relies on publicly available data to present these map resources. Users should also refer to FEMA and the NPCC for official information.

b) If the Flood Hazard Mapper shows that the facility is **expected to be inundated by high tides within its useful life** or if primary access roads are at risk of inundation, consider alternative site options.

c) If the site is not expected to be regularly inundated by tides, proceed to the next section.

2. Addressing Risks in the Current Floodplain[68]

A facility located in the current 1% annual chance floodplain (PFIRMs 2015)[69] will face increasing risk of flooding during its useful life due to sea level rise increasing the depth of coastal storms. This section provides a process for adjusting the design flood elevation required by code to account for sea level rise.

a) **Find the location of the facility using the Flood Hazard Mapper** (nyc.gov/floodhazardmapper)**.** Follow the instructions in Figure 6.
   - Choose to view the layer "FEMA Preliminary FIRM 2015".
   - Click on the facility site in the 1% floodplain to determine the base flood elevation.

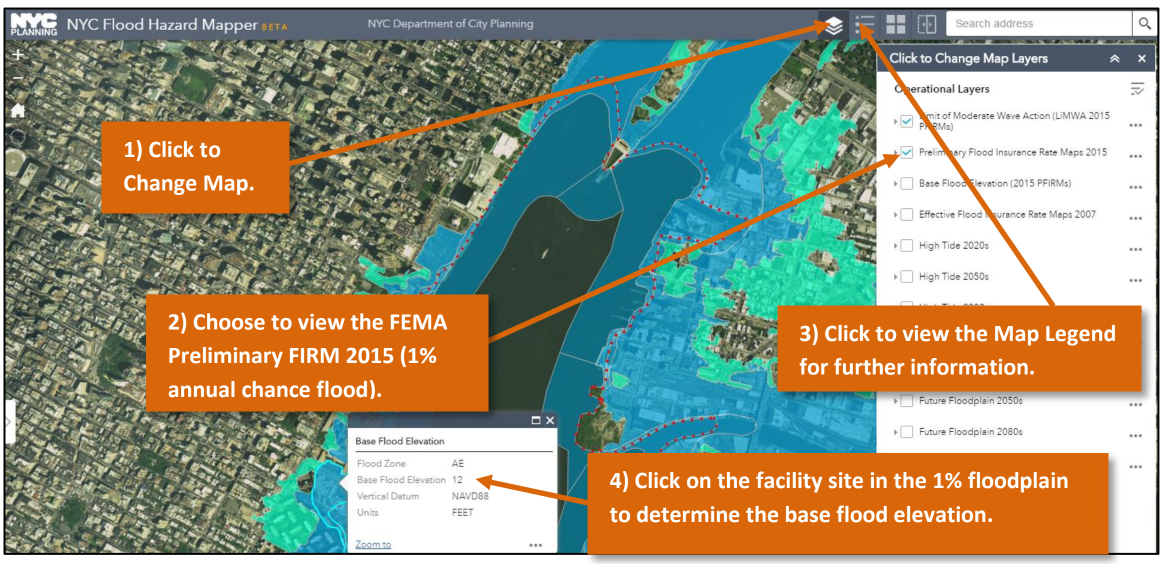

Figure 6 – Flood Hazard Mapper with FEMA PFIRM (2015) at nyc.gov/floodhazardmapper

b) **If the facility is <u>not in the current</u> 1% annual chance floodplain (PFIRMs 2015),** proceed to the next section: **"*3. Addressing Risks in the Future Floodplain*".**

-- OR --

If the facility <u>is in the current</u> 1% annual chance floodplain (PFIRMs 2015), note the base flood elevation and proceed to Step c).

c) Use the current base flood elevation at your site, the facility's useful life and its criticality level to determine the design flood elevation. Use the **design flood elevation identified in Table 3 as a basis of design.**

[68] This process for adjusting the design flood elevation to account for sea level rise satisfies the criteria of the Climate-Informed Science Approach (CISA), the preferred approach outlined by (2015) FEMA's Federal Flood Risk Management Standard (FFRMS).

[69] FEMA updates its flood maps periodically. As of January 2017, the most recent maps are the Preliminary Flood Insurance Rate Maps (PFIRMs) available at DCP's Flood Hazard Mapper (www.nyc.gov/floodhazardmapper).Please note that the DCP maps are not official and all site locations should be confirmed with the official FEMA PFIRMs. NYC will provide information on the latest flood maps here as they are updated. Also note that NYC Building Code requires developers to use the PFIRMs (2015) or the FIRMs (2007), whichever is higher. For more information on these requirements please refer to Appendix G of the NYC Building Code.

Table 3 - Determine the sea level rise-adjusted design flood elevation for critical and non-critical facilities[70]

Critical* facilities				
End of useful life	**Base Flood Elevation (BFE)[71]**	**+ Freeboard[72]**	**+ Sea Level Rise Adjustment[73]**	**= Design Flood Elevation (DFE)**
Through 2039	FEMA 1% (PFIRMs)	24"	6"	**= FEMA 1% + 30"**
2040-2069	FEMA 1% (PFIRMs)	24"	16"	**= FEMA 1% + 40"**
2070-2099	FEMA 1% (PFIRMs)	24"	28"	**= FEMA 1% + 52"**
2100+	FEMA 1% (PFIRMs)	24"	36"	**= FEMA 1% + 60"**

Non-critical facilities				
End of useful life	**Base Flood Elevation (BFE)**	**+ Freeboard**	**+ Sea Level Rise Adjustment**	**= Design Flood Elevation (DFE)**
Through 2039	FEMA 1% (PFIRMs)	12"	6"	**= FEMA 1% + 18"**
2040-2069	FEMA 1% (PFIRMs)	12"	16"	**= FEMA 1% + 28"**
2070-2099	FEMA 1% (PFIRMs)	12"	28"	**= FEMA 1% + 40"**
2100+	FEMA 1% (PFIRMs)	12"	36"	**= FEMA 1% + 48"**

***Definition of critical buildings and infrastructure**

The criticality definitions below are for use in the application of the Guidelines only. All items identified as critical in NYC Building Code Appendix G are critical in these guidelines; however, this list includes additional facilities that are not listed in Appendix G. If a facility is not listed here, it is considered non-critical for the purposes of determining freeboard.

- Hospitals and health care facilities;
- Fire, rescue, ambulance and police stations and emergency vehicle garages;
- Jails, correctional facilities and detention facilities;
- Facilities used in emergency response, including emergency shelters, emergency preparedness, communication, operation centers, communication towers, electrical substations, back-up generators, fuel or water storage tanks, power generating stations and other public utility facilities;
- Critical aviation facilities such as control towers, air traffic control centers and hangars for aircraft used in emergency response;
- Major food distribution centers (with an annual expected volume of greater than 170,000,000 pounds);[74]
- Buildings and other structures that manufacture, process, handle, store, dispose, or use toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released;[75]
- Infrastructure in transportation, telecommunications, or power networks including bridges, tunnels (vehicular and rail), traffic signals, (and other right of way elements including street lights and utilities), power transmission facilities, substations, circuit breaker houses, city gate stations, arterial roadways, telecommunications central offices, switching facilities, etc.;
- Ventilation buildings and fan plants;
- Operations centers;
- Pumping stations (sanitary and stormwater);
- Train and transit maintenance yards and shops;
- Wastewater treatment plants;
- Fueling stations;
- Waste transfer stations; and
- Facilities where residents have limited mobility or ability, including care facilities and nursing homes.

[70] If an industry standard does not include freeboard in its flood protection standards for particular infrastructure assets, then only consider the sea level rise adjustment when determining flood protection levels.
[71] Note that NYC Building Code requires developers to use the PFIRMs (2015) or the FIRMs (2007), whichever is higher. For more information on these requirements please refer to Appendix G of the NYC Building Code.
[72] These freeboard values reflect NYC Building Code Appendix G Table 2-1, which establishes the minimum elevation of the top of lowest floor. Appendix G requires other freeboard values for other parts of structures and in different parts of the floodplain. Refer to Appendix G for the appropriate freeboard and use that value in Table 3.
[73] The sea level rise figures provided are for the middle of the 25th-75th percentile range projections from the NPCC.
[74] This threshold represents the median volume of main food distributors in NYC according to statistics collected by the Mayor's Office.
[75] The threshold quantity for hazardous materials is established by Chapter 7 of Title 24 of the NYC Administration Code.

3. Addressing Risks in the Future Floodplain

If the facility is *not* in the current 1% annual chance floodplain (PFIRMs 2015), it may still be at risk in the future from flooding with sea level rise. Follow the steps and refer to Figure 7 to determine if your facility is located in the future floodplain, and if so what sea level rise-adjusted design flood elevation to use.

a) **Use the Flood Hazard Mapper** (nyc.gov/floodhazardmapper) **to determine if the facility site will be in the future 1% annual chance floodplain** during its useful life (e.g., if the useful life ends between 2040 and 2069, choose the 2050s floodplain map). Follow the steps in Figure 7 below:

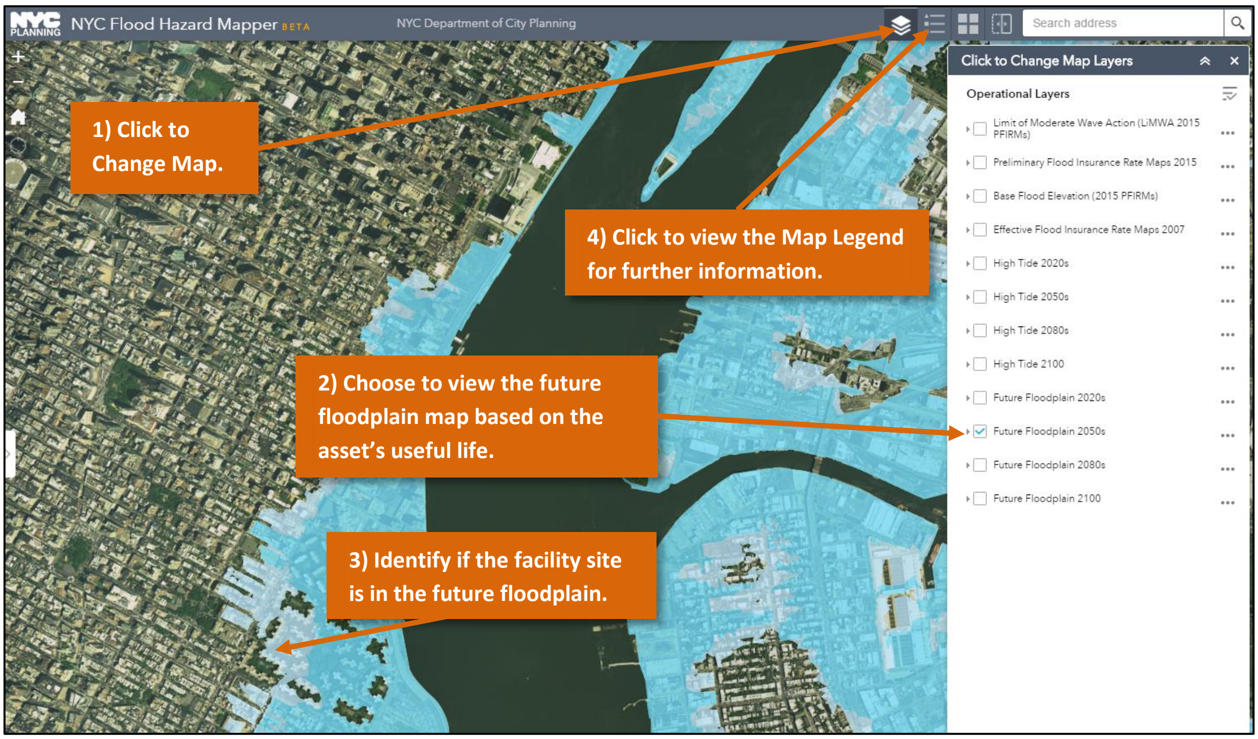

Figure7 – Flood Hazard Mapper with future 1% annual chance floodplain (adjusted for sea level rise) at nyc.gov/floodhazardmapper

b) **If the site is not in the future floodplain**, no further action is necessary regarding flood protection for this facility.

-- OR --

If the site is in the future floodplain, identify the nearest adjacent base flood elevation at the project site in the current 1% annual chance floodplain (PFIRM 2015) using the Flood Hazard Mapper.[76]

c) **Use Table 3 (see page 22)** to determine a design flood elevation, adding freeboard and SLR-adjustment to the *nearest adjacent base flood elevation* on the current 1% annual chance floodplain (PFIRMs 2015).

d) **Apply the design flood elevation from Table 3** to the protected facility. See Figure 8 for an illustration.

[76] Maps of future floodplains show the impacts of sea level rise alone, and do not consider how changes in storms' climatology might also affect the floodplain.

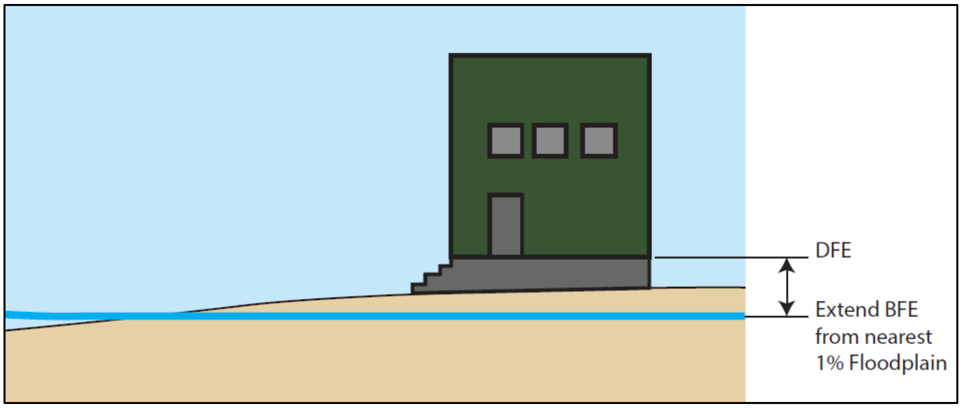

Figure 8 – This schematic demonstrates how to determine the design flood elevation outside of a facility outside of the current 1% floodplain.

4. **Identify design interventions**. For all projects at risk of current or future flooding, design protections that meet the project's design flood elevation. Consider project-specific factors including the site location, operational requirements and cost.[77] Some examples of design alternatives are:
   - Site-specific permanent barriers (e.g. floodwalls, levees).
   - Deployable flood barriers (e.g. stop logs, flood doors/gates, inflatable barriers).
   - Nature-based approaches (e.g. living shorelines, restored wetlands).[78]
   - Prioritized protection of electrical, mechanical and other critical or costly to replace equipment above the design flood elevation (e.g. motors and controller, boilers and furnaces, fuel storage tanks, duct work, alarm systems and suppression equipment, electrical panels, electrical distribution and switching areas, gas and electric meters, telecommunications equipment, chemical feed equipment, HVAC units and emergency generators).[79]
   - Dry floodproofing: design a facility to prevent water from entering.
   - Wet floodproofing: design a facility to permit floodwaters to flow in and out of the structure without causing significant damage (e.g. elevate or protect critical equipment, use water-resistant building materials below the design flood elevation, include flood vents, pumps).
   - Design redundant telecommunications conduit entrances and for multiple telecommunication carrier entry.
   - Installation of backwater valves and sump pumps, particularly behind flood barriers that allow some water to penetrate, for all facilities in the floodplain.
   - Backflow preventers.
   - Shoreline improvements that reduce the height of waves or attenuate waves.
   - Site relocation. Where feasible, conduct alternative site analysis.

[77] Additional Resources: *Urban Waterfront Adaptive Strategies* (NYC Department of City Planning https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/sustainable-communities/climate-resilience/urban_waterfront.pdf; *Floodproofing Non-Residential Buildings* (FEMA) https://www.fema.gov/media-library-data/9a50c534fc5895799321dcdd4b6083e7/P-936_8-20-13_508r.pdf; *Ready to Respond: Strategies for Multifamily Building Resilience* (Enterprise Green Community) http://www.enterprisecommunity.org/resources/ready-respond-strategies-multifamily-building-resilience-13356.

[78] While nature-based approaches ameliorate flooding, their use for storm surge or wave mitigation would need to be quantified before contributing towards the design flood elevation.

[79] For more information, see FEMA's Floodproofing Non-Residential Buildings at https://www.fema.gov/media-library/assets/documents/34270.

APPENDIX 1 - CLIMATE PROJECTIONS

Climate projections are provided by the New York City Panel on Climate Change (NPCC). The full NPCC report is available from the New York Academy of Science, with selected tables reproduced below.[80]

Table 4 – NYC sea level rise projections.[81]

Baseline (2000-2004) 0 in	Low estimate (10th percentile)	Middle range (25th to 75th percentile)	High estimate (90th percentile)
2020s	2 in	4-8 in	10 in
2050s	8 in	11-21 in	30 in
2080s	13 in	18-39 in	58 in
2100	15 in	22-50 in	75 in

Note: Projections are based on six-component approach that incorporates both local and global factors. The model-based components are from 24 global climate models and two representative concentration pathways. Projections are relative to the 2000-2004 base period.

Table 5 – Mean annual changes[82]

a. Temperature Baseline (1971-2000) 54°F	Low estimate (10th percentile)	Middle range (25th to 75th percentile)	High estimate (90th percentile)
2020s	+ 1.5°F	+2.0-2.9°F	+3.2°F
2050s	+3.1°F	+4.1-5.7°F	+6.6°F
2080s	+3.8°F	+5.3-8.8°F	+10.3°F
2100	+4.2°F	+5.8-10.4°F	+12.1F
b. Precipitation Baseline (1971-2000) 50.1 in	**Low estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High estimate (90th percentile)**
2020s	-1 percent	+1-8%	+10%
2050s	+1 percent	+4-11%	+13%
2080s	+2 percent	+5-13%	+19%
2100	-6 percent	-1% to +19%	+25%

Note: Based on 35 GCMs and two RCPs. Baseline data cover the 1971–2000 base period and are from the NOAA National Climatic Data Center (NCDC). Shown are the low estimate (10th percentile), middle range (25th percentile to 75th percentile), and high estimate (90th percentile). These estimates are based on a ranking (from most to least) of the 70 (35 GCMs times 2 RCPs) projections. The 90th percentile is defined as the value that 90 percent of the outcomes (or 63 of the 70 values) are the same or lower than. Like all projections, the NPCC climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system and limited understanding of some physical processes. The NPCC characterizes levels of uncertainty using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations and recent peer-reviewed literature. Even so, the projections are not true probabilities and the potential for error should be acknowledged.

[80] The NPCC 2015 report is available at: http://onlinelibrary.wiley.com/doi/10.1111/nyas.2015.1336.issue-1/issuetoc.
[81] From *New York City Panel on Climate Change 2015 Report, Chapter 1: Climate Observations and Projections*, page 41.
[82] From *New York City Panel on Climate Change 2015 Report, Chapter 1: Climate Observations and Projections*, page 30.

Table 6 –Extreme events[83]				
2020s	**Baseline (1971-2000)**	**Low estimate (10^{th} percentile)**	**Middle range (25^{th} to 75^{th} percentile)**	**High estimate (90^{th} percentile)**
Numbers of heat waves per year	2	3	3-4	4
Average heat wave duration (days)	4	5	5	5
Number of days per year with				
Maximum temperature at or above 90°F	18	24	26-31	33
Maximum temperature at or above 100°F	0.4	0.7	1-2	2
Minimum temperature at or below 32°F	71	50	52-58	60
Rainfall at or above 1 inch	13	13	14-15	16
Rainfall at or above 2 inches	3	3	3-4	5
Rainfall at or above 4 inches	0.3	0.2	0.3–0.4	0.5
2050s	**Baseline (1971-2000)**	**Low estimate (10^{th} percentile)**	**Middle range (25^{th} to 75^{th} percentile)**	**High estimate (90^{th} percentile)**
Numbers of heat waves per year	2	4	5-7	7
Average heat wave duration (days)	4	5	5-6	6
Number of days per year with				
Maximum temperature at or above 90°F	18	32	39-52	57
Maximum temperature at or above 100°F	0.4	2	3-5	7
Minimum temperature at or below 32°F	71	37	42-48	52
Rainfall at or above 1 inch	13	13	14-16	17
Rainfall at or above 2 inches	3	3	4-4	5
Rainfall at or above 4 inches	0.3	0.3	0.3-0.4	0.5
2080s	**Baseline (1971-2000)**	**Low estimate (10^{th} percentile)**	**Middle range (25^{th} to 75^{th} percentile)**	**High estimate (90^{th} percentile)**
Numbers of heat waves per year	2	5	6-9	9
Average heat wave duration (days)	4	5	5-7	8
Number of days per year with				
Maximum temperature at or above 90°F	18	38	44-76	87
Maximum temperature at or above 100°F	0.4	2	4-14	20
Minimum temperature at or below 32°F	71	25	30-42	49
Rainfall at or above 1 inch	13	14	15-17	18
Rainfall at or above 2 inches	3	3	4-5	5
Rainfall at or above 4 inches	0.3	0.2	0.3-0.5	0.7

Note: Projections for temperature and precipitation are based on 35 GCMs and 2 RCPs. Baseline data are for the 1971 to 2000 base period and are from the NOAA National Climatic Data Center (NCDC). Shown are the low estimate (10th percentile), middle range (25th to 75th percentile) and high estimate (90th percentile) 30-year mean values from model-based outcomes. Decimal places are shown for values less than one, although this does not indicate higher precision/certainty. Heat waves are defined as three or more consecutive days with maximum temperatures at or above 90°F. Like all projections, the NPCC climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system and limited understanding of some physical processes. The NPCC characterizes levels of uncertainty using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations and recent peer-reviewed literature. Even so, the projections are not true probabilities and the potential for error should be acknowledged.

[83] From *New York City Panel on Climate Change 2015 Report, Chapter 1: Climate Observations and Projections*, page 31.

APPENDIX 2 - IDF CURVES

The intensity-duration-frequency (IDF) curves in this appendix are the source of the values provided in Table 2 in the section on Increasing Precipitation, and are provided here for further reference. IDF curves are a common tool used in sewer design. The standard criterion when designing New York City sewers is to use the intensity-duration values for a storm with a 5-year return frequency (i.e., a precipitation event with a 20% chance of occurrence in any given year) to calculate how large the sewer pipes need to be sized to appropriately manage stormwater. The peak sewer design flow for a drainage area can be estimated using a runoff coefficient based on land use and imperviousness, the rainfall intensity value taken from the IDF curves and the size of the contributing drainage area. The design of combined sewers also accounts for sanitary flows.

With climate change, precipitation in NYC is projected to increase in terms of total accumulations and intensity. These IDF curves below update existing data to include forward-looking climate data in Central Park for the 5-year, 50-year and the 100-year events. An area for further research is developing sub-hourly projected IDF curves.

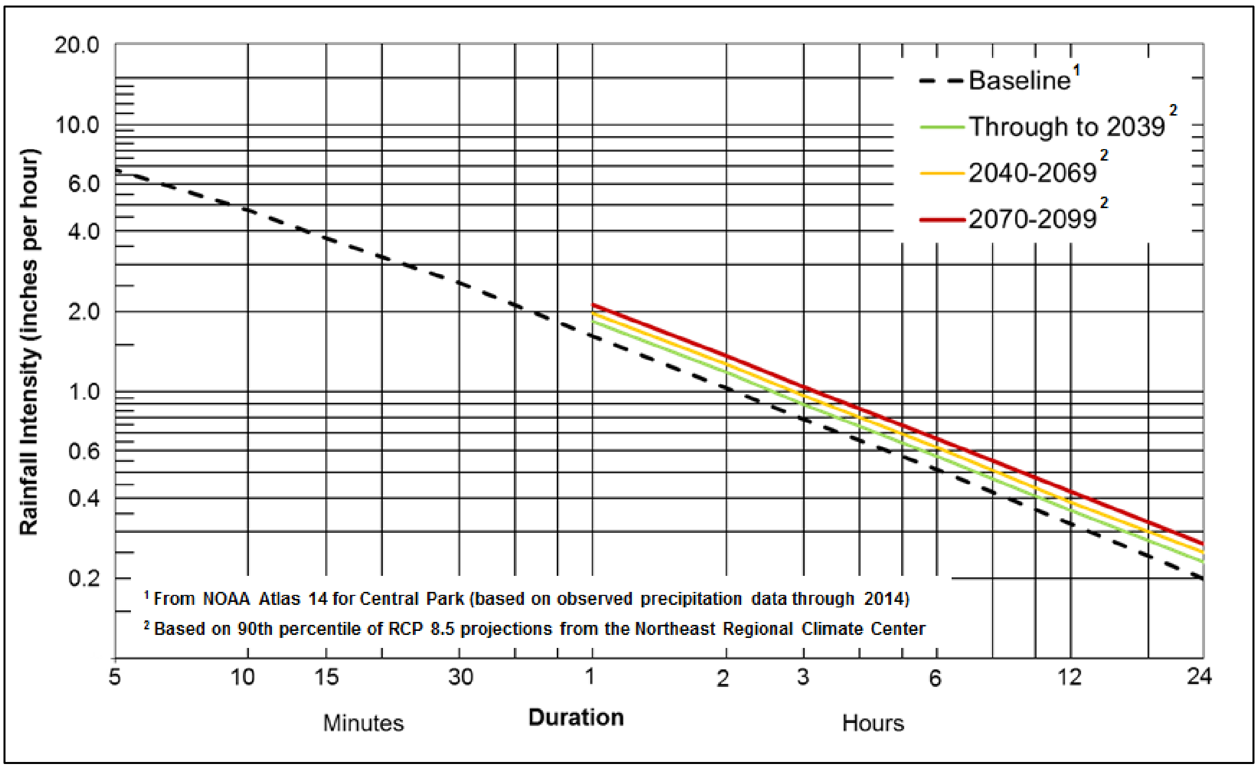

Figure 9 - Projected and Baseline Intensity-Duration-Frequency (IDF) Curves for the 5-year Storm Event in Central Park, NYC.

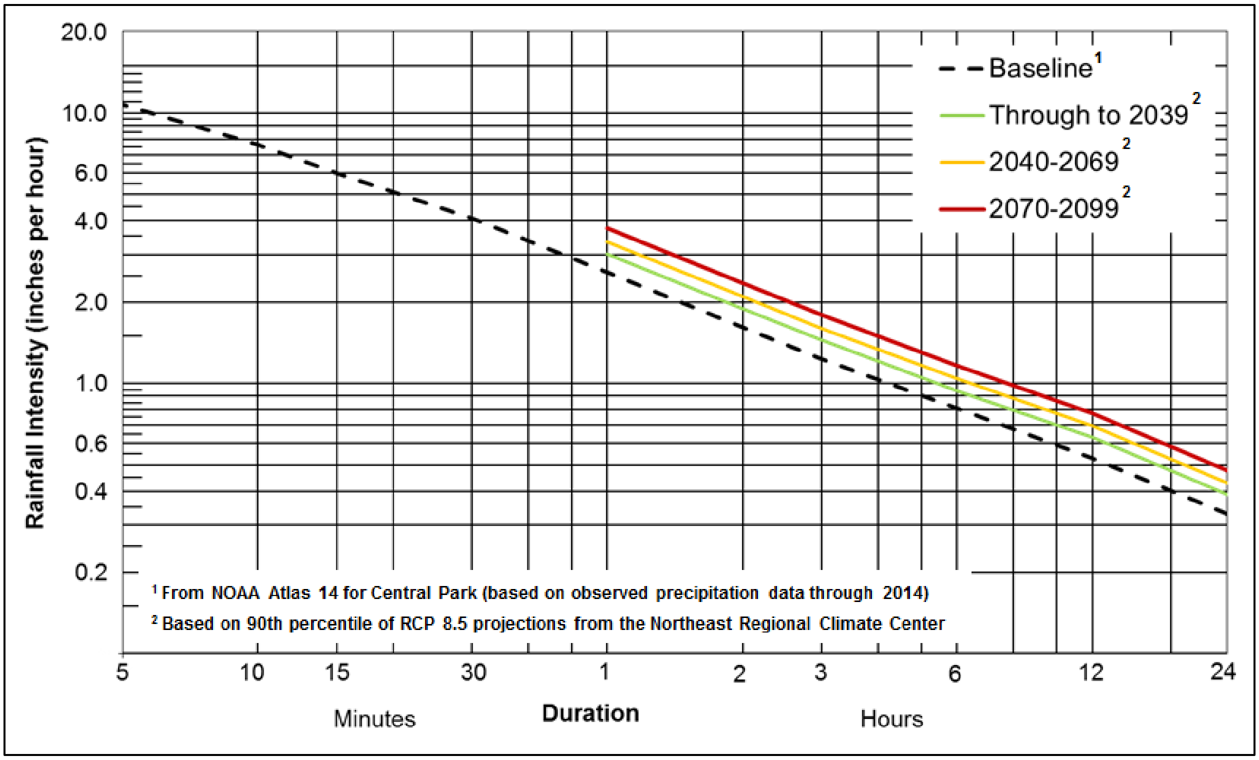

Figure 9 - Projected and Baseline Intensity-Duration-Frequency Curves for the 50-year Storm Event in Central Park, NYC

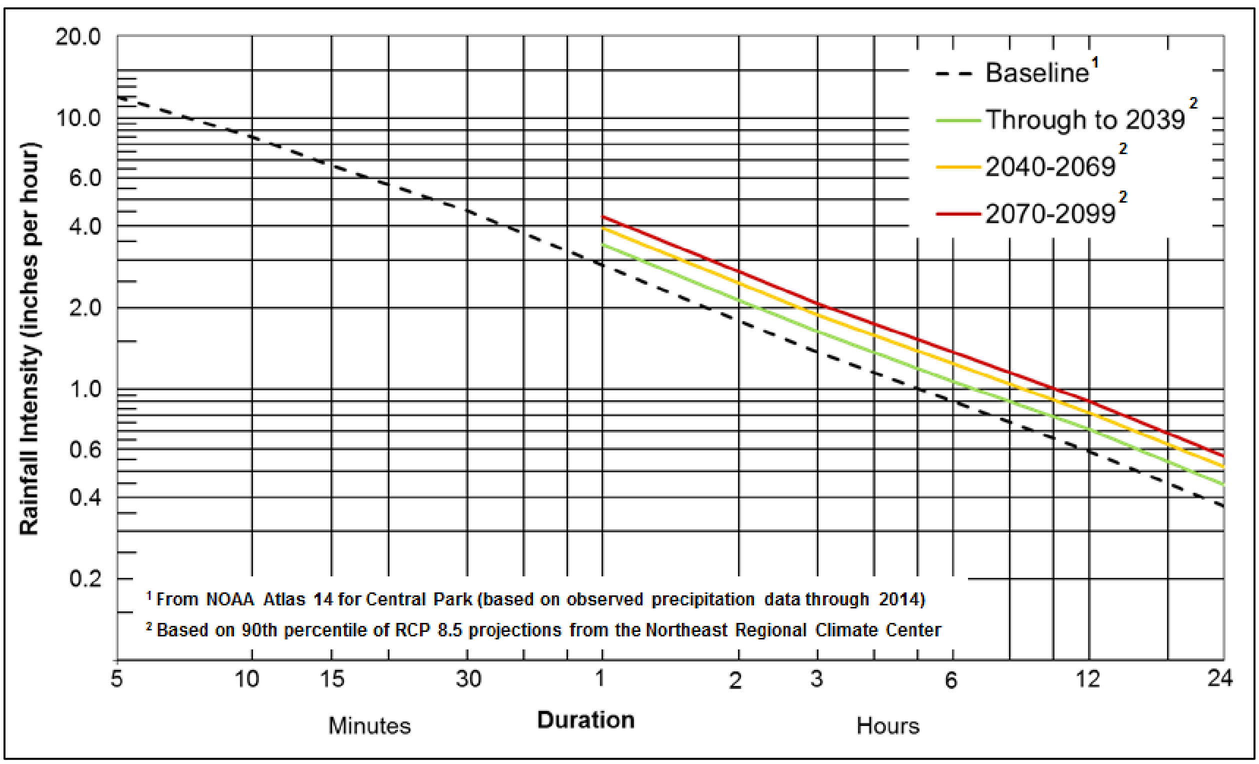

Figure 10 - Projected and Baseline Intensity-Duration-Frequency Curves for the 100-year Storm Event in Central Park, NYC

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