Reducing the Effects of Urban Flooding in New York City

Hurricane Ida NYC MAT Technical Report 3

June 2023

FEMA

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1. Introduction

Remnants of Hurricane Ida moved through the New York City metropolitan area on September 1, 2021, causing significant urban flooding and damage in many parts of the city. A presidential disaster was declared on September 13, 2021 (FEMA-4615-DR). As part of the response to the disaster, the Federal Emergency Management Agency (FEMA) Building Science Disaster Support program deployed a Mitigation Assessment Team (MAT) to assess the damage. MATs are composed of federal and non-federal experts in building science and other relevant disciplines.

1.1. Report Objective

The primary objectives of the FEMA Building Science Disaster Support program are to improve the resistance of buildings to natural hazards and improve the safety of building occupants. Its work includes evaluating the key causes of building damage and failure, and recommending solutions. The remnants of Hurricane Ida produced widespread urban flooding that overwhelmed the stormwater drainage system in many parts of New York City. As a result, many streets, low-lying areas, underpasses, and some parts of the subway system flooded.

Urban Flooding:

The inundation of property in a built environment, particularly in more densely populated areas.
Urban flooding may be caused by rainfall that runs off large amounts of impervious surfaces and overwhelms the capacity of stormwater drainage systems.

During Hurricane Ida, floodwater entered and damaged many buildings with below-grade and basement areas. The Hurricane Ida NYC MAT Technical Report 1, Building Performance: Basement Buildings and Urban Flooding (FEMA P-2333), notes this type of flood damage has occurred many times in the past. That report also describes the impacts of basement flooding on life safety, buildings, and building utility systems and equipment. It includes a number of recommendations to address the safety of basement occupants and the performance of buildings with floodprone basements. The Hurricane Ida NYC MAT Technical Report 2, Building Performance: Egress from Floodprone Basements (FEMA P-2333), includes brief summaries of New York City's requirements and agency programs and responsibilities related to egress.

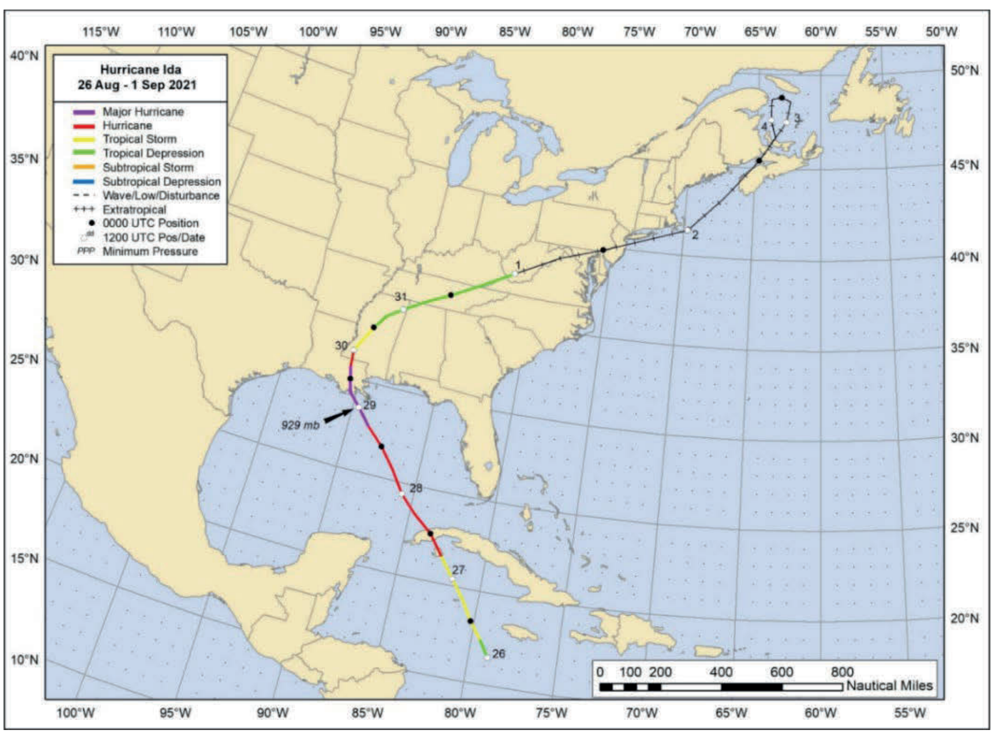
This report briefly explains the basics of rainfall runoff, urban flooding, and urban stormwater drainage systems. It gives a summary of some of New York City's stormwater infrastructure programs and its initiatives to address urban flooding. Applying mitigation measures to stormwater drainage systems and existing buildings can minimize the potential loss of life and injuries, and reduce property damage from future urban flooding events.

After deployment to New York City, the Team produced three technical reports and four fact sheets that relate to the effects of Hurricane Ida on the city. The documents focus on some construction and stormwater issues that were not considered in previous MAT investigations, including:

- Surface runoff and flooding in urbanized areas
- Stormwater collection and drainage systems
- Effects of surface flooding on buildings
- Basement flooding in urbanized areas
- Early warning systems for urban flooding
- Egress (leaving) for occupants of at-risk basements
- Flood warnings and flood risk mapping
- Steps owners and residents can take to reduce risks associated with urban flooding
- Ways to enhance policies and regulations to reduce flood risks

1.2. Hurricane Ida in New York City

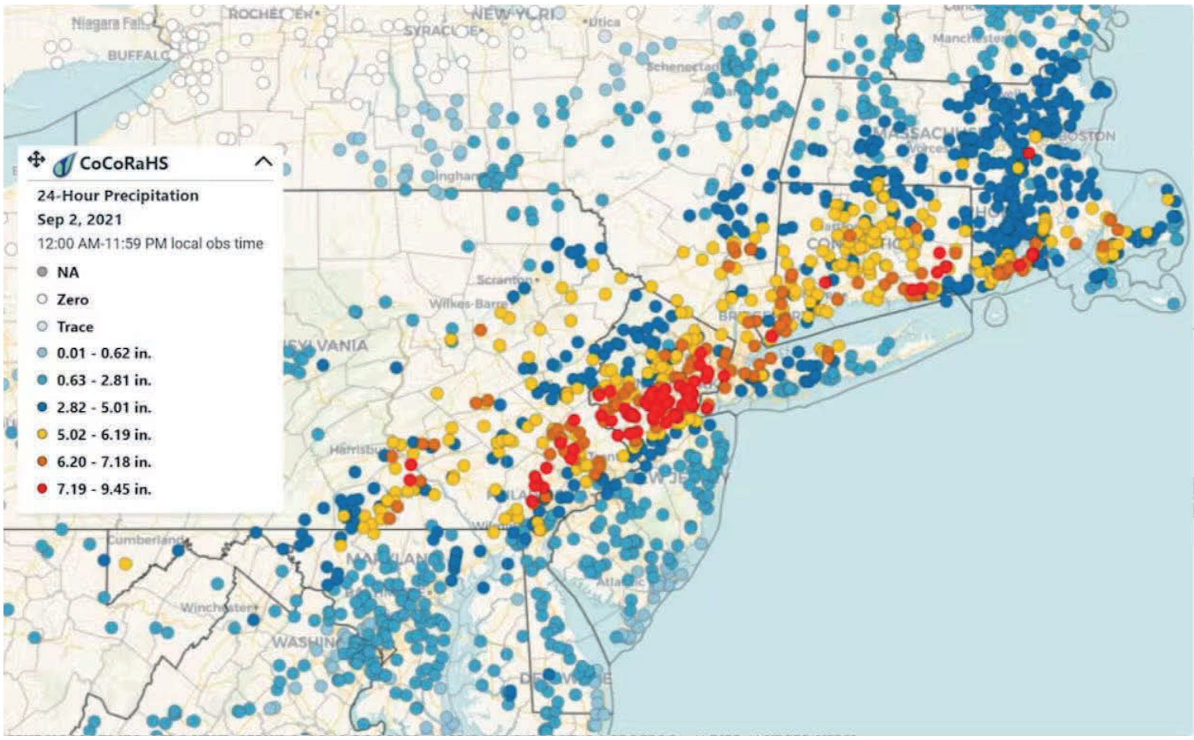
On August 29, 2021, Hurricane Ida made landfall as a Category 4 hurricane in Lafourche Parish, on the Louisiana coastline. This was only 50 miles west of where Hurricane Katrina made landfall on the same day in 2005. The storm generated high winds and storm surge, causing widespread damage to structures and to power and telecommunication infrastructure throughout the state. As Hurricane Ida moved inland, beyond Louisiana (Figure 1), it produced heavy rain and unsettled weather in several states. The National Weather Service reported extreme rainfall (Figure 2) caused flash flooding in New York and neighboring states.



Source: National Hurricane Center

Figure 1. Storm track of Hurricane Ida from August 26 through September 4, 2021

During Hurricane Ida, heavy rainfall overwhelmed the stormwater drainage systems in many parts of New York City. Surface water accumulated, causing significant urban flooding in Queens, Brooklyn, the Bronx, and Staten Island. The peak rainfall intensity in Central Park was 3.15 inches per hour, with a total of 7.13 inches of rain over a 24-hour period. It is important to note that Hurricane Ida was preceded by the remnants of Tropical Storm Fred and Hurricane Henri, which saturated the city with heavy rainfall in August.



Source: CoCoRaHS Mapping

Figure 2. Total precipitation recorded over 24 hours, September 1-2, 2021, in New York and neighboring states

In some areas of the city, the rainfall runoff exceeded the capacity of the stormwater drainage system. Runoff accumulated in streets and low-lying areas (Figure 3). It entered the basements, cellars, and below-grade areas of numerous homes, multi-family buildings, and commercial buildings. Surface water entered through exterior stairways, street-level windows, once it rose above the stair thresholds or windowsills. In multi-story buildings, water typically entered through loading docks, exterior stairwells, access ramps, or through street-level vents and windows.

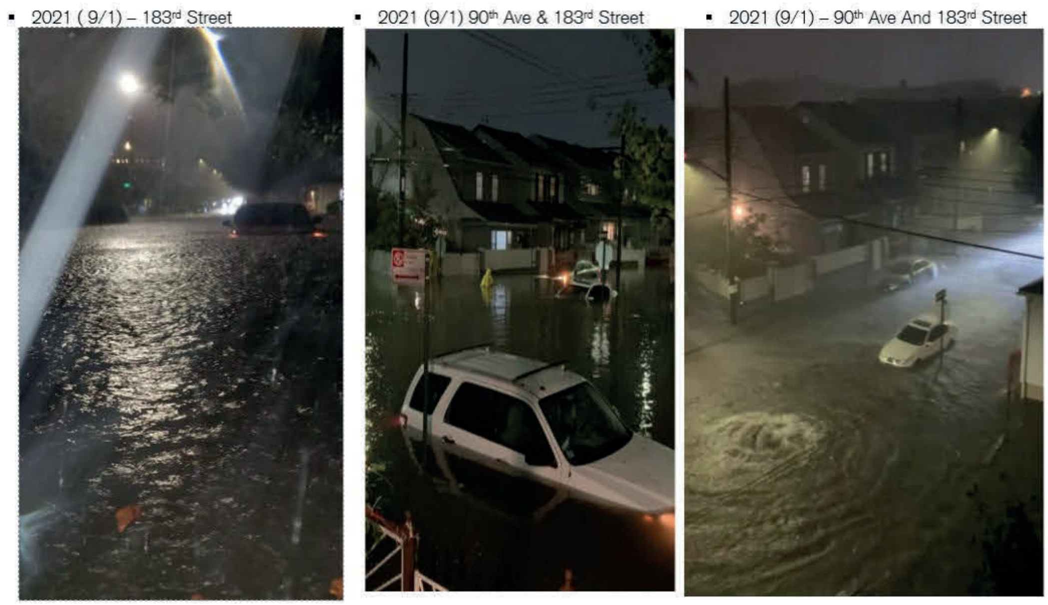


Figure 3. New York City street flooding during Hurricane Ida

2. Rainfall Runoff and Urban Flooding Basics

Cities and highly urbanized areas have many buildings and paved surfaces, including streets, parking lots, and sidewalks. When rain falls on the ground, the water can soak in. But when rain falls on buildings and paved surfaces, it runs off without soaking in. When rainfall runoff does not drain away from low-lying areas, or does not drain away quickly, the accumulated water is called urban flooding. Urban flooding also occurs when curbs, gutters and other parts of stormwater drainage systems cannot contain the flow of water from extreme or heavy precipitation. These drainage problems are also called stormwater flooding, local flooding, or nuisance flooding.

Precipitation is considered extreme or heavy when the amount of rain or snow from an event substantially exceeds what is considered to be normal. These events can be measured by their frequency, their return periods (the chance that the event will be equaled or exceeded in a given year), or the amount of the precipitation in a certain period. It is common to describe storms in terms of the inches of rain falling in one hour or over a 24-hour period.

Urban flooding from extreme or heavy rainfall or rapidly melting deep snow can overwhelm drainage systems and damage property. In vulnerable areas, buildings may be damaged when this runoff enters basements or below-grade areas (such as parking garages). The property damage may be structural, non-structural, or both. It can include damage to building service equipment and contents. Also, the flooding of basements and below-grade areas puts people’s lives at risk if they get trapped without a way to escape.

Extreme Rainfall Runoff in New York City

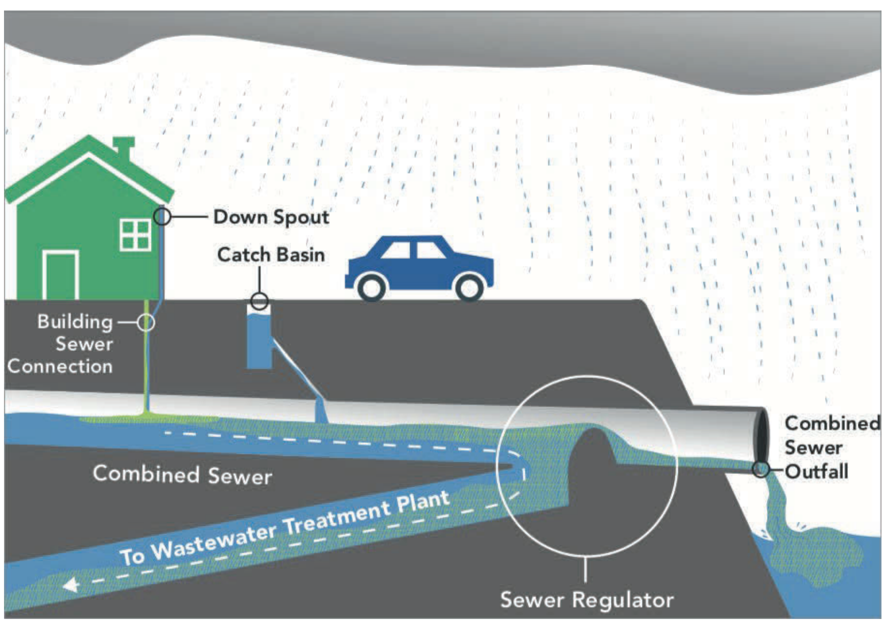
The New York City Mayor's Office of Climate & Environmental Justice reports that extreme rainfall events, such as Hurricane Ida, are becoming more frequent. The city considers a rainfall event to be extreme if more than 1.74 inches of rain fall in Central Park. During Hurricane Ida in 2021, the peak rainfall intensity in Central Park was 3.15 inches per hour. This is nearly double the intensity-duration value the city has used to design its stormwater infrastructure since about 1970. Hurricane Ida produced significant surface flooding in Queens, Brooklyn, the Bronx, and Staten Island. In all those areas, the capacity of the stormwater drainage systems was exceeded.

3. Urban Stormwater Drainage System Basics

Communities build stormwater drainage systems to collect and convey surface runoff to minimize impacts on buildings, infrastructure, streets, and other property. The components of a drainage system include curbs and gutters, drainage swales and ditches, inlets where water flows into catch basins, and below-ground stormwater pipes. The whole system is intended to carry rainfall runoff and snow melt to a stream, river, or tidal body of water.

In general, there are two types of stormwater systems:

- **Combined sewer systems.** These systems use a single set of pipes to carry flows from sanitary sewer systems and stormwater runoff to waste treatment plants for processing (Figure 4). During normal rainfall events, well-maintained combined sewer systems function effectively. During extreme rainfall events, combined systems can "surcharge," which refers to flows that exceed the capacity of the system. Surcharged systems may create backup flows that enter the plumbing systems of buildings. Combined systems are built with bypass locations that allow excess flows to discharge into receiving streams, rivers, or tidal waters without treatment. These points are identified as combined sewer outfalls. They are governed by regulations on water quality treatment.



Source: NYC DPW

Figure 4. Schematic of Combined Sewer System

- **Separate stormwater sewer system.** These systems use two sets of pipes that separate sanitary sewer flows from stormwater flows. Because the systems are separate, heavy stormwater runoff does not overwhelm wastewater treatment plants. This minimizes overflow sewage discharges to receiving waters.

For years, many cities designed their stormwater drainage systems to handle the runoff from what is called the "5-year storm" or the "10-year storm." The intensity of the rainfall associated with those storm frequencies varies by location. Cities and urbanized areas recognize that, as rainfall runoff increases, the stormwater drainage infrastructure will be challenged in several ways:

- As storms get more intense and occur more frequently due to climate change, the rainfall runoff will exceed the capacity of the drainage system more frequently.
- As systems get older, they may not perform as intended. This is especially true in areas where buildings and impervious surfaces have been added, which increases the amount of runoff and may contribute to property damage and safety hazards.
- Drainage systems must be inspected and maintained to keep them working properly. Maintenance typically includes removing debris and leaves, cleaning out catch basins and stormwater pipes, and making repairs.
- The use of rain gardens, stormwater ponds, special paving materials, and other features is increasing. These measures help runoff soak into the ground instead of flowing to stormwater systems. Methods and features that reduce rainfall runoff by increasing infiltration are often called "green infrastructure."

Stormwater Drainage Systems in New York City

- About 60% of New York City is served by combined sewer systems. The other 40% has separate stormwater and sewer systems.
- In most areas of the city where storm drains were built before 1970, the drainage system components were designed to handle the runoff from a 3-year storm event.
- In areas where stormwater drainage systems were built after 1970, the components are designed for a higher-impact event, using the intensity-duration values for a storm with a 5-year return period (equivalent to 1.75 inches per hour for a 1-hour storm).

4. New York City Stormwater Infrastructure and Initiatives

New York City has an extensive program to monitor and maintain its stormwater drainage and sewer systems. To function properly, stormwater infrastructure must be inspected, maintained, and repaired. Especially in areas where extreme storms produce urban flooding that damages buildings, debris and leaves must be removed from inlets and catch basins. The city inspects and maintains its system using a data-driven approach.

The city routinely identifies where improving the stormwater infrastructure in certain areas can increase its capacity. Increased capacity is needed, as more extreme storms are expected in the future. The city examines inefficient inlets and underground pipes to see if improvements are feasible. However, the city recognizes that, in many areas, the stormwater sewers cannot be enlarged.

Physically increasing the capacity of a stormwater drainage system is expensive. Even where feasible upgrades are identified, implementation may take decades. Given the acknowledged importance of addressing many problem areas subject to urban flooding, the city established a long-term vision to increase its stormwater resilience. The vision merges traditional stormwater approaches with plans for a citywide network of blue and green infrastructure. This network would intercept more rainfall runoff before it reaches the stormwater drainage system.

4.1. Pursue the Long-Term Vision

In 2022, New York City updated its approach to managing stormwater. It released "Increasing Stormwater Resilience in the Face of Climate Change: Our Long Term Vision." In 2021, back-to-back storms with heavy rainfall—Hurricanes Henri and Ida—spurred the city to take action. It reaffirmed that its stormwater infrastructure was never intended to manage frequent events with such intense rainfall runoff. Highlights of this plan are available at: https://www.nyc.gov/assets/dep/downloads/pdf/climate-resiliency/increasing-stormwater-resilience-in-the-face-of-climate-change.pdf. The highlights include:

- Upgrade and rehabilitate the sewer system, using historical records, topography, and the likelihood of future flooding to prioritize areas for work (see Section 4.2)
- Keep the stormwater on private property (see Section 4.3)
- Promote infiltration and green infrastructure (see Section 4.4)
- Expand Bluebelts and daylight historic streams and wetlands (see Section 4.5)
- Implement "cloudburst" management Infrastructure (see Section 4.6)
- Adapt to climate change, provide online Stormwater Flood Maps, and administer Rainfall Ready NYC, an action plan with short-term steps that the city and its residents can take to prepare for urban flooding (see Section 5.1)
- As a part of FloodNet, install sensors, monitor flood conditions, and increase awareness (see Section 5.2)

4.2. Upgrade and Rehabilitate the Sewer System

New York City's stormwater drainage system includes more than 7,000 miles of sewers and many other components. As a whole, it is not intended to handle the rainfall runoff from extreme storms. In addition, some parts of the city do not have fully built systems. The city uses a variety of factors to prioritize areas to upgrade the system in order to relieve urban flooding. These factors include the projected sea level rise and environmental justice for residents.

The city has a long-term objective to upgrade and rehabilitate all systems to the current design standard. That standard calls for the system to handle the runoff from 1.75 inches of rain in one hour. As of mid-2023, the city is evaluating the adequacy of that standard, given the growing frequency and intensity of extreme storms.

On the first anniversary of Hurricane Ida, Mayor Eric Adams announced a suite of stormwater initiatives. He highlighted completed and ongoing projects in several parts of the city, including upgrading and increasing the size of sewers, building new stormwater drainage systems, raising some streets, and separating combined sewer systems to increase capacity and improve water quality, Read more at https://www.nyc.gov/office-of-the-mayor/news/637-22/mayor-adams-dep-honor-first-anniversary-hurricane-ida-suite-stormwater#/0.

4.3. Retain Stormwater on Private Property

A significant initiative in New York City's long-term vision is to increase retention of rainfall runoff on private properties. In 2022, the city adopted amendments to its Unified Stormwater Rule. The amendments change requirements for how to manage stormwater on newly built or rebuilt properties. Hydrologic and hydraulic models estimate that by 2030, this rule change will reduce combined sewer overflows citywide by approximately 360 million fewer gallons. This will also help improve the health of New York Harbor.

The changes to the Unified Stormwater Rule modified the rate of flow for house and site connections to the city's combined sewer system. The city must determine sewer availability and approve any new connections to the system. Sewer certifications may be required when a site is altered or renovated in a way that increases sanitary flows or stormwater flows. To meet the new requirements, developers will use a variety of measures to retain or detain stormwater onsite and to increase rainfall infiltration into the ground. Some of those measures are described in Section 4.4. Find more information at https://www.nyc.gov/site/dep/water/stormwater-management.page.

4.4. Promote Infiltration and Green Infrastructure

Increasing infiltration of rainfall runoff through various methods is an effective way to reduce the amount of runoff that flows to and through stormwater management systems. The term "green infrastructure" refers to a variety of ways to increase infiltration. New York City has built or encouraged thousands of green infrastructure installations. Green infrastructure offers significant benefit in areas of the city served by combined sewer systems because the measures help reduce the number and frequency of untreated sewer overflows to receiving waters. Combined sewers are described in Section 3.

The types of green infrastructure installed in New York City include rain gardens, infiltration basins, stormwater greenstreets, green roofs, blue roofs, permeable paving, subsurface detention systems, and rain barrels and cisterns. Figure 5 illustrates two of these methods. The city offers some financial incentives to developers and owners to install green infrastructure on private property. Learn more about these measures at https://www.nyc.gov/site/dep/water/types-of-green-infrastructure.page. The site also has an interactive map to show where green infrastructure measures have been installed.

Figure 5. New York City site with porous pavement and green roof

4.5. Expand the Bluebelt Program

"Bluebelts" are developed as components of New York City's drainage system. They are ecologically rich and cost-effective ways to handle rainfall runoff from streets and sidewalks. Areas with Bluebelts do not have to rely entirely on traditional stormwater drainage system components, such as underground pipes. The program preserves natural drainage corridors including streams, ponds, and wetlands. It enhances those

Source: NYC Water

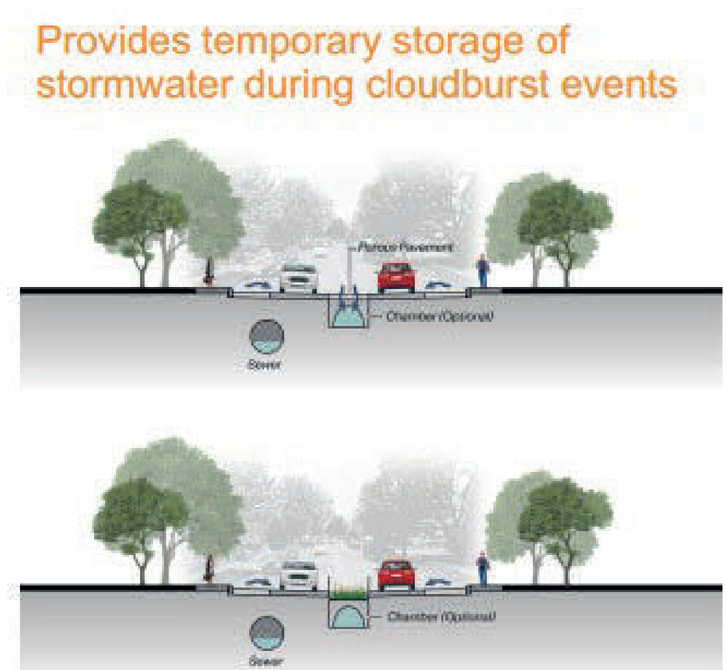
Figure 6. Sweet Brook Bluebelt

features to allow them to perform their functions of conveying, storing, and filtering runoff. Bluebelts also provide open green space and diverse habitat for wildlife (see Figure 6). Bluebelts are part of the city's initiatives to prepare for heavier rains due to climate change. Learn more at https://www.nyc.gov/site/dep/water/the-bluebelt-program.page.

Prior to the first Bluebelt initiative in Staten Island, very few streets in the Sweet Brook area had catch basins or storm drains. Streets often flooded during heavy rainstorms. The Bluebelt project modified drainage in several ways, including adding catch basins to direct rainfall runoff to wetlands. As of mid-2023, the city has more than 75 separate Bluebelts at locations throughout the city.

4.6. Implement Cloudburst Management

A "cloudburst" is a sudden, heavy downpour, where a lot of rain falls in a short time. It is another term for extreme or heavy precipitation that substantially exceeds what is considered normal. In New York City, cloudburst management combines methods, including green infrastructure, to absorb, store, and transfer stormwater (see Figure 7). In this way, it reduces the strain on the city's stormwater drainage system. The goal is to minimize flooding and damage to property and infrastructure.



Source: NYC DEP

Figure 7. Two ways to provide median storage

The city considers many factors when planning cloudburst management projects. Factors include a site's existing physical features, available space, below-ground conditions, existing utility infrastructure, and whether it is possible to connect runoff to green infrastructure. The city also looks at local social and economic factors in each area that may incorporate special amenities and public open spaces. Learn more at https://www.nyc.gov/site/dep/environment/cloudburst.page.

5. Increasing Public Awareness of Urban Flooding

The effects of urban flooding vary, ranging from water ponding in low areas to unsafe conditions for pedestrians and drivers and damage to buildings. FEMA NYC MAT Fact Sheet 1, What Building Owners and Tenants Should Know About Urban Flooding (FEMA P-2333), briefly explains how flooding differs from the flood hazard areas shown on FEMA flood maps. It also describes safety risks and how flooding affects buildings and occupants.

New York City is working to increase public awareness of urban flooding and the risks and effects of urban flooding. This section highlights initiatives that support that goal.

5.1. AdaptNYC, Stormwater Flood Maps, and Rainfall Ready NYC

AdaptNYC is New York City's plan to adapt to climate change. Adapting requires citywide, multi-generational efforts. It also requires significant investment. The initiative will improve how the city communicates about flooding risks. One focus is on neighborhoods in low-lying areas with poor drainage and insufficient stormwater drainage systems. The goal is to help people understand the potential risks of flooding. The city hopes to raise awareness of urban flooding caused by extreme rainfall events. Learn more at https://climate.cityofnewyork.us/initiatives/adaptnyc/.

The city developed an online tool to generate Stormwater Flood Maps. The maps depict a range of scenarios to show how stormwater and coastal flooding patterns may change over time. The tool allows users to see the flood risks for scenarios with and without sea level rise. Rising sea levels will keep some storm drain outfalls from fully draining. This will cause those storm drains to back up, which will increase street flooding. It also creates the potential for sewer backups into buildings. The map in Figure 8 shows an extreme stormwater flood scenario (about 3.5 inches of rainfall in one hour), with the 2080 projected sea level rise. Access the maps at https://climate.cityofnewyork.us/challenges/extreme-rainfall/.

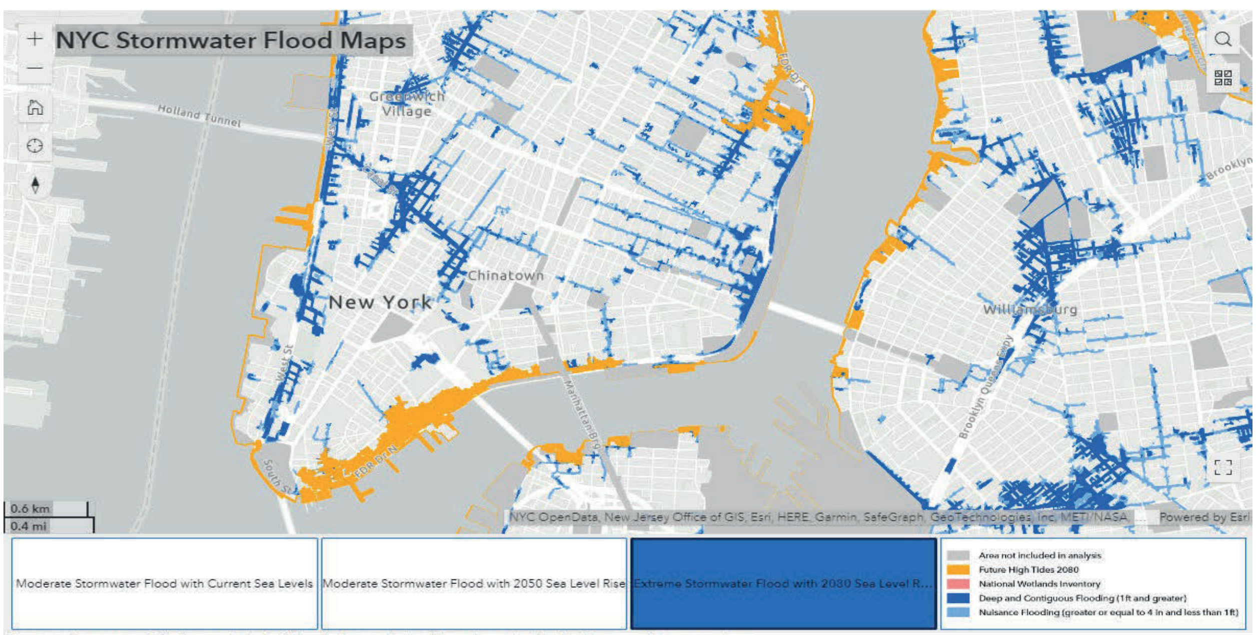


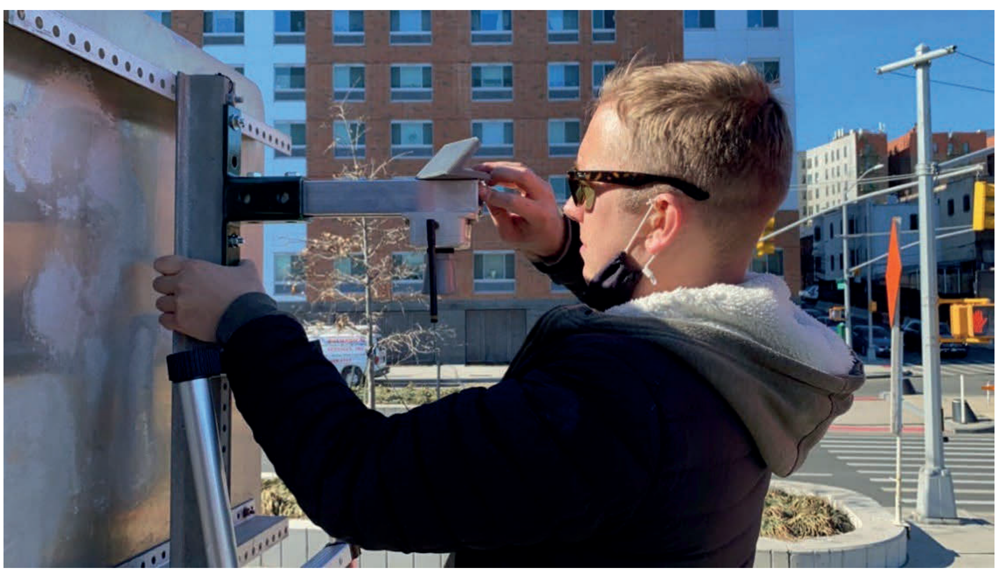
Figure 8. NYC Stormwater Flood Map for Extreme Stormwater Flooding with 2080 Sea Level Rise

Rainfall Ready NYC Action Plan engages the public through a website. The website explains actions the city takes to plan and prepare for urban flooding. For example, it informs residents and owners about flood risks and offers resources to help them protect their properties. The city monitors conditions in real time and communicates with the public about hazards. The website advises people on ways to plan and prepare for intense storms, monitor conditions during storms, and recover rapidly after damaging events. People can sign up to receive alerts from the city's official source of information about emergencies, including weather events. Learn more and sign up at https://www.nyc.gov/site/dep/whats-new/rainfall-ready-nyc.page.

5.2. FloodNet

New York City uses a variety of tools to monitor flood conditions, including traffic cameras, social media, 311 complaints, and other sources. One resource is FloodNet, a cooperative of communities, researchers, and the city government. This group works to better understand the frequency, severity, and impacts of flooding in the city.

As part of FloodNet, the city is installing sensors to detect flooding from any source in real time. The sensors will be installed throughout the city in public places that are prone to flooding (see Figure 9). The sensor system is designed to inform city officials, who can then issue public warnings of the potential for damaging surface flooding. The network is slated to have 500 sensors by 2027, to give both officials and residents real-time flood information. It will also maintain a hyperlocal historical record of flooding that can be used to inform future mitigation work. Learn more at https://www.floodnet.nyc/.



Source: NY1/Ari Ephraim Feldman

Figure 9. New York University researcher installs a flood sensor on a traffic sign located on Sheridan Boulevard, near the Bronx River, in the Crotona Park section of the borough

6. Recommendation

This Technical Report briefly summarizes some of New York City's stormwater infrastructure programs and initiatives. The city acknowledges that the urban flooding problem is too big to resolve through construction alone. Instead, the city is using green infrastructure and other measures to supplement the stormwater drainage system. These measures are vital to increase the infiltration of rainfall to reduce the amount of runoff that flows to and through the stormwater management systems.

The city has made major investments in stormwater infrastructure and green infrastructure. It also has several programs to require or encourage owners to retain stormwater on their properties and increase infiltration. Despite this, many buildings will remain vulnerable to damage by urban flooding. Buildings with below-grade areas and basements have the greatest risk because they may fill up once water finds a way in.

Hurricane Ida MAT Technical Report 1, Recommendation 4, describes options for the city to encourage property owners to act. Some options to consider include:

- Develop messaging and mechanisms to contact the owners and managers of buildings in areas where urban flooding has caused damage, with a focus on buildings with basements and below-grade areas. The messages should encourage them to first evaluate their buildings, and then determine whether to engage a qualified professional for a more detailed inspection.

- Develop training and inspection materials for building managers and design professionals to build on evaluations that may be undertaken by owners and managers. The materials can explain how to determine whether and how surface flooding enters buildings, and how to identify feasible mitigation options.

- Encourage design professionals and the special inspectors who conduct annual and triannual inspections of dry floodproofed buildings in Special Flood Hazard Areas in accordance with the New York City building code to learn how to evaluate buildings at risk of urban flooding to identify feasible mitigation options.

- Consider whether to provide financial assistance to building owners to have evaluations performed and to implement feasible mitigation options.

Hurricane Ida MAT Technical Report 1, Recommendation 5, briefly describes the benefits of evaluating flood risk to buildings with basements and below-grade areas. It describes a number of mitigation options to keep water out of those areas. The feasibility of each option depends on site factors and building characteristics. Options include:

- Permanently raise the lowest points of entry for surface water. Points of entry may be doorways, street-level windows and vents, loading bays, exterior basement stairways, ramps to below-grade parking, and driveways.

- Reinforce basements walls, or fill in basements, of homes with unreinforced concrete or masonry basement walls.
- Obtain temporary barriers and develop emergency implementation plans to deploy the barriers to block points of entry when permanent solutions are not feasible.
- Raise critical components of mechanical systems above basement floors and relocate electrical system components to higher locations, and install backflow preventer valves in sumps and floor drains.
- Use materials that resist flood damage for basement interiors.

7. References

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For More Information

See the FEMA Building Science Frequently Asked Questions at https://www.fema.gov/emergency-managers/risk-management/building-science/faq.

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