NEW YORK CITY STORMWATER RESILIENCY PLAN

Helping New Yorkers understand and manage vulnerabilities from extreme rain

MAY 2021

NYC Mayor's Office of Resiliency

Cover photo by Jean Schwarzwalder, New York City Department of Environmental Protection

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KEY TERMS AND ACRONYMS

Agencies and Offices

BWSO: NYC Department of Environmental Protection Bureau of Water & Sewer Operations
CAU: NYC Mayor's Community Affairs Unit
EM: NYC Emergency Management
DEP: NYC Department of Environmental Protection
DCP: NYC Department of City Planning
DOE: NYC Department of Education
DOT: NYC Department of Transportation
DSNY: NYC Department of Sanitation
FDNY: NYC Fire Department
MOR: NYC Mayor's Office of Resiliency
MOS: NYC Mayor's Office of Sustainability
MTA: Metropolitan Transportation Authority
NPCC: New York City Panel on Climate Change
NYCHA: New York City Housing Authority
NYPD: NYC Police Department
NYSDEC: New York State Department of Environmental Conservation
Parks: NYC Department of Parks & Recreation
SCA: NYC School Construction Authority

Other Acronyms and Terms:

CSO: Combined Sewer Overflow
DEM: Digital Elevation Model
FY: Fiscal Year
GIS: Geographic Information Systems
H&H: Hydrologic & Hydraulic (used to describe stormwater models)
IDF: Intensity-Duration-Frequency Curve (used to describe rainfall in stormwater models)
LiDar: Light Detection and Ranging (used to describe digital elevation models)
LTCP: Long Term Control Plan
MS4: Municipal Separate Storm Sewer System
NPCC: New York City Panel on Climate Change
PLUTO: Property Land Use Tax Lot Output map
ROW: Right of Way
Sewershed: an area of land where all sewers flow to a single WRRF.
SOP: Standard Operating Procedure
SLR: Sea Level Rise
SWMP: Stormwater Management Program
WRRF: Wastewater Resource Recovery Facility

INTRODUCTION

CLIMATE CHANGE CONTEXT

New York City is facing a wide variety of climate hazards that are not only felt today but will impact every aspect of life in the City over the coming decades. New Yorkers are well aware of the hazards associated with stronger coastal storms after Superstorm Sandy claimed 44 lives and caused over $60 billion in regional damage in October 2012. Heat waves cause over 450 emergency department visits, 150 hospital admissions, and 13 heat stroke deaths annually.[1] As a result of these hazards, New York City has initiated ambitious coastal protection projects as well as a comprehensive Cool Neighborhoods strategy. This plan initiates New York City's planning process for another climate risk, extreme rainfall events, which combined with sea level rise and other climate hazards will contribute to the city's overall climate risk going forward.

Extreme rainfall events are becoming more frequent and disruptive in New York City and beyond. According to The National Climate Assessment, which summarizes current and future impacts of climate change on the United States, the heaviest 1 percent of daily rainfalls increased by 70 percent in the Northeast United States between 1958 and 2012.[2] Climate projections suggest that this trend will continue and that New York City will likely experience increased precipitation in the future. The New York City Panel on Climate Change (NPCC) anticipates that by the end of the century, the city could experience as much as 25 percent more annual rainfall than today, and 1.5 times as many days with more than one inch of rain.[3] Without continued investment in strategies to prepare for the impacts of extreme rain events, NYC residents will experience increasing damage to private property, disruptions of surface and below ground transportation, and impacts to waterbodies. Building on the NPCC climate projections, the City has undertaken detailed research to better quantify how extreme precipitation will impact neighborhoods citywide. This analysis focuses specifically on rainfall (rather than other forms of precipitation such as snow or sleet) because it is overwhelmingly the driver of precipitation-based flooding in NYC. The research will enable new, tailored solutions to manage this climate risk.

STUDY AND MAPPING

Vulnerability to extreme rainfall is an emerging area of study for municipalities in the United States. In 2017, New York City embarked on the Stormwater Resiliency Study to gain a fuller understanding of how more frequent and extreme rain events will affect the city. The Study was spearheaded by a multifaceted team of New York City agency staff, consulting teams, and academic partners. Led by NYC Mayor's Office of Resiliency (MOR), NYC Department of Environmental Protection (DEP), and NYC Emergency Management (EM), the team was supported by staff from over 20 city agencies, external consultants, as well as an academic team from Brooklyn College, the Stevens Institute of Technology, the New School and Colorado State University.

This Study included a novel modeling effort that produced, for the first time, public maps depicting vulnerability to rainfall-driven flooding. Prior to this effort, there had been no citywide analysis performed focusing on rainfall-induced inland flooding that utilized the City's drainage models. The City has published maps of two storm scenarios, both of which incorporate future sea level rise projections. Maps can be found at nyc.gov/resiliency.

The subsequent pages describe the research and mapping effort performed during the Study that resulted in NYC's first Stormwater Resiliency Plan.

STORMWATER RESILIENCY PLAN

In 2018, New York City Council passed Local Law 172,[4] which required the City to produce maps showing areas of the city most vulnerable to increased flooding due to the anticipated effects of climate change and publish a long-term plan to prevent or mitigate such increased flooding. Consistent with the Local Law, the plan and maps will be updated at least every four years, and periodically as new modeling is available and as climate change projections are updated.

The Stormwater Resiliency Plan (the "Plan") outlines the City's approach to managing the risk of extreme rain events. Truly holistic planning for rain-driven flooding involves consideration of both large storm events and the chronic worsening of average conditions. For this reason, the Plan addresses emergency response procedures as well as accounting for increasing rainfall in standard design and long term planning of stormwater infrastructure.

The Plan commits to four goals that optimize emergency response to extreme rainfall events and ensure that future City investments manage this climate risk. Each goal includes supporting sub-initiatives.

1. Inform the public about flood vulnerability from extreme rain;
2. Update NYC's flash flood response procedures to prioritize response in vulnerable areas;
3. Advance policies that reduce urban flooding and research that informs future risk;
4. Leverage stormwater investments to help manage future flood risk from extreme rain and sea level rise. Future investments can alleviate flooding throughout the city.

This document provides an overview of NYC's existing drainage network, which is critical to understanding the base capacity to manage rain-driven flooding in the future. Flash flood emergency procedures are also examined for optimization under increasingly extreme conditions. The document interprets findings from the modeling effort, presents the public stormwater maps, and finally outlines the actions the City is taking to manage this climate risk.

DRAINAGE CONTEXT

STORMWATER INVESTMENTS

Understanding NYC's drainage network is essential to stormwater resiliency planning. DEP manages the City's water and wastewater services and has been committed to investments in, and policy changes around, drainage improvement, green infrastructure and on-site stormwater management. These have the added benefit of reducing the amount and slowing the rate of stormwater entering the City's sewer system. At the time of this report, the NYC Green Infrastructure Program has led to over 10,000 green infrastructure projects constructed or currently in construction. Green infrastructure describes an array of practices that use or mimic natural systems to manage stormwater runoff, taking into account site-specific context. Over the last 30 years DEP has constructed Bluebelts (nature-based drainage systems) for approximately one third of Staten Island's land area to provide location-specific drainage and preserve ecological function. DEP's combined improvements to the drainage network, along with the Bluebelt network and green infrastructure improvements, have increased NYC's capacity to absorb extreme rainfall. DEP's 2021 10 year capital plan includes $4.6B for sewer improvements and the agency has committed $3.8B in sewer upgrades across the city over the past 10 years. These investments include:

- Constructing new high-level storm sewers to keep stormwater out of the sewer system and reducing flooding;
- Expanding new Bluebelts to Queens and Bronx, after success in Staten Island;
- Unprecedented focus on southeast Queens with approximately $2B of investment for comprehensive drainage system improvements and $200M in the roadway network in partnership with DOT;
- Over 10,000 distributed green infrastructure assets in construction or constructed;
- New stormwater retention and detention rules for new or redeveloped properties – restricting how much and the rate at which stormwater can be added to our sewer system;
- Private property incentives for green infrastructure including grant funding for green roofs and a large-scale retrofit program kicking off in 2021.

Additional highlighted accomplishments and investments located in Appendix A.

DESIGN OF SEWERS

The City's storm and combined storm sewers are designed to convey surface stormwater runoff from rainfall events of varying intensities and durations. The methodology used to design sewers for runoff conveyance is based on precipitation intensity-duration-frequency (IDF) curves. These diagrams are constructed from observed rainfall data of varying durations, from 5 minutes to 24 hours. The data are analyzed and arrayed graphically as precipitation intensity (inches/hour) as a function of rainfall duration (minutes or hours). Statistical procedures are used to develop a series of curves for various return periods (probabilities of occurrence).

The standard design criterion in New York City is to use the intensity-duration values based on a storm with a 5-year return period (e.g., 1.75 inches per hour for a one hour storm; 20 percent chance of occurrence in any given year) to calculate how large the sewer pipes need to be sized to appropriately manage stormwater. Certain older areas of the City are designed to a 3-year storm event. The sewer design flow is then determined by application of an equation using a runoff coefficient, a rainfall intensity determined from an equation derived from the IDF analysis, and the contributory drainage area. The design of combined sewers includes allowance for the sanitary flows. The IDF curve currently used by New York City is based on historical data from 1903-1951. With climate change, the intensity and duration of a storm with a 5-year return period is likely to increase, and therefore the current curve may not be adequate for designing infrastructure that is to last decades.

Recent academic studies show that sub-daily rainfall intensity may increase over the coming decades.[5] Since rainfall information started being collected, the number of days with extreme rainfall (defined as days of rainfall over 1.75 inches in Central Park) has increased.[6] Projections created by the Northeast Regional Climate Center at Cornell University show the peak intensities of storms rising in the future. For example, the observed 5-year, 1 hour storm from 1970-1999 in Central Park produced an intensity of 1.83 inches per hour. The observed data used by DEP shows an intensity of 1.63 inches per hour. This is projected to increase to 2.15 inches per hour from 2040-2069.[7] The historical design context of NYC's sewers is essential to consider when predicting performance under future conditions and conducting long-term drainage planning.

Figure 1: Typical catch basin (photo by Jean Schwarzwalder)

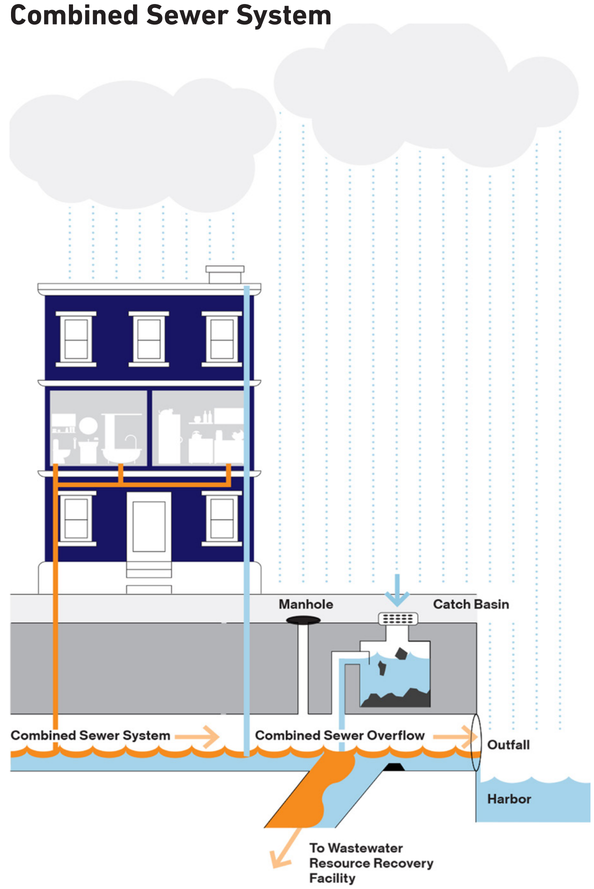
CURRENT DRAINAGE NETWORK

New York City's current infrastructure is comprised of an extensive network of over 7,400 miles of sewer pipes that collect sanitary sewage and stormwater, and the 14 Wastewater Resource Recovery Facilities (WRRFs) that receive the flow. This network is one of the City's most significant assets, and has improved the health of generations of New Yorkers. NYC's sewer system is approximately 60 percent combined, which means it is used to convey both sanitary and storm flows. When the sewer system is at full capacity, a diluted mixture of rain water and sewage may be released into the local waterways. This is called a combined sewer overflow (CSO). This type of system is not unique. Combined sewer systems are remnants of the country's early infrastructure and are typically found in older communities such as NYC. The remaining approximately 40 percent of the system are separately sewered areas, where sanitary sewers direct sewage directly to WRRFs while separate storm sewers direct runoff to waterbodies (Figure 2).

Through a mix of active treatment and improvements to sewer infrastructure, along with green infrastructure deployment, NYC has reduced CSO volume by 80 percent since the 1960s. This was achieved after $45B in investment. NYC has committed an additional $10.6B to further reduce CSO releases under its Watershed/Waterbody Facility Plan and Long Term Control Plan (LTCP) programs for each sewershed.[8] Models of the sewershed were developed under the LTCP and provide the base information for analysis in this plan, discussed in later chapters.

Finally, in 2015 the City was issued its first Municipal Separate Storm Sewer System (MS4) Permit, which significantly expanded the City's previous obligations to reduce pollutants discharging to the MS4 and required the City to develop a Stormwater Management Program (SWMP).[9] This includes numerous programs designed to reduce pollution in stormwater.

Combined Sewer System



Municipal Separate Storm Sewer System

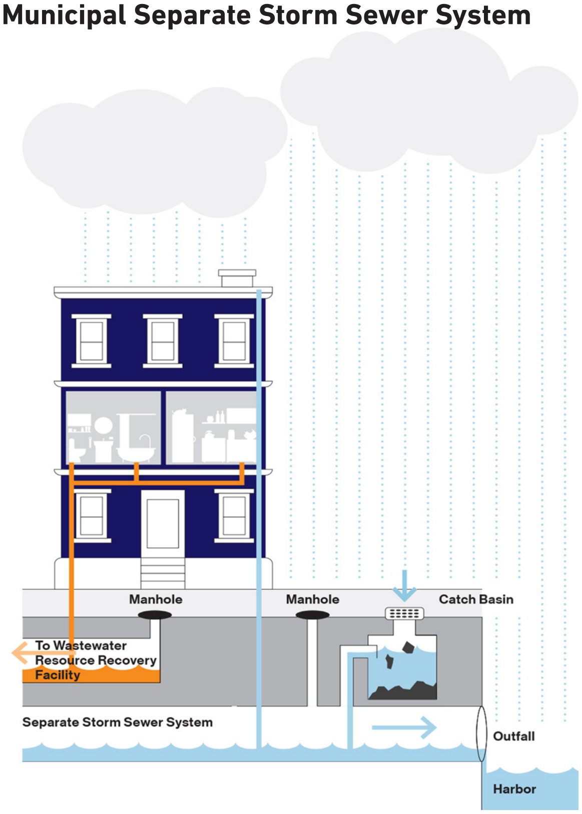


Figure 2: Combined and separate sewer systems.

FUTURE DRAINAGE CONSIDERATIONS

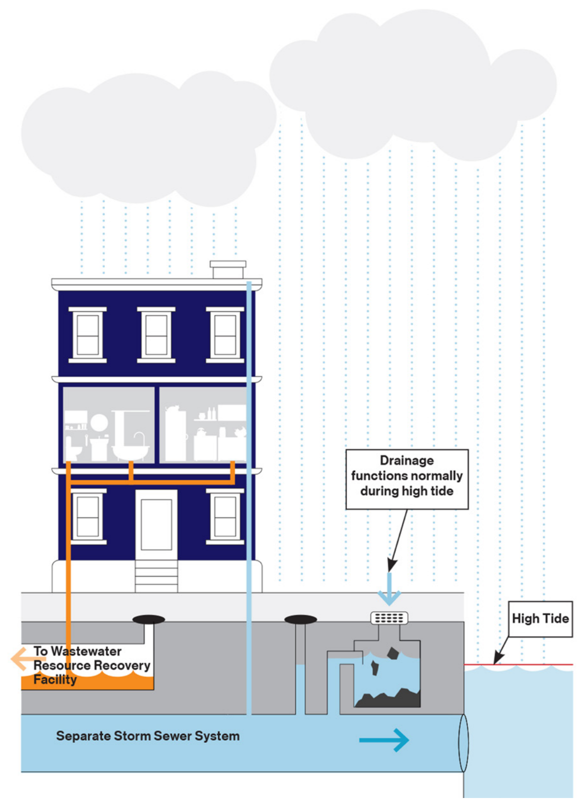
While these measures have improved overall water quality, they are often costly in terms of capital construction. Further, capital investments provide diminishing returns, as it becomes more and more challenging to treat the large volumes of stormwater released in extreme events. Physical infrastructure alone cannot fully manage the volume of water that must be managed during extreme rain events to reduce flooding.

Flooding caused by heavy rain events is distinct from coastal flooding. Stormwater infrastructure does not protect communities from high-tide or "sunny day" flooding, nor storm surge that results from coastal storms such as hurricanes and nor'easters. NYC's sewer systems depend on gravity to move water through pipes. High tides made higher by sea level rise temporarily obstruct the ability of stormwater infrastructure to drain streets as designed and prolong flooding events (Figure 3). Impacts on stormwater infrastructure in coastal areas may include:

- Coastal flooding at outfalls without tidegates may drive backflow into the system, causing upland flooding through street drains. The prolonged presence of saltwater can damage stormwater infrastructure.
- Shoreline erosion may expose stormwater infrastructure to potential damage.
- Tidal inundation introduces sediment and debris that can clog storm drains, pipes, and outfalls.
- More frequent, higher, and longer-lasting high-water events may drive up already high groundwater levels in some coastal communities. This change may reduce the soil's ability to absorb stormwater, thus increasing runoff.

The impact of current and future coastal flooding on stormwater management is a neighborhood-scale issue that demands a coordinated, integrated response. Engineered options, such as tide gates, can prevent backflows from surge events but they impede flow through the outfall and do not prevent overland inundation. More complex and expensive options that include extensive modifications of existing stormwater practices such as ponds and pumps must be considered together with a broader watershed-scale approach that aligns community growth and development with stormwater management goals. As coastal protection measures are implemented, the City will continue to develop integrated responses to address these coastal impacts on stormwater infrastructure.

Drainage with High Tide Today



Drainage with High Tide and Sea Level Rise

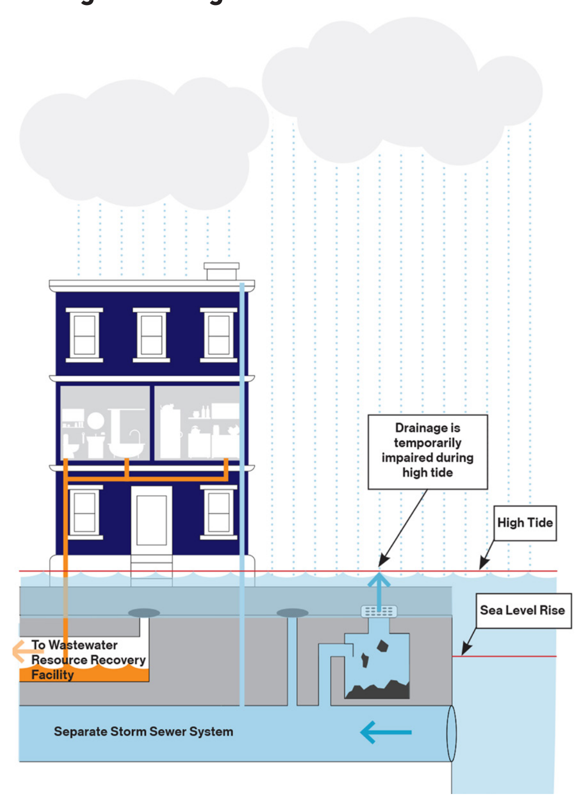


Figure 3: Separate sewer system under current and future high tide conditions..

MANAGING FLASH FLOODING

According to EM's Hazard History and Consequence Tool,[12] there have been 19 instances of significant inland flooding caused by extreme rain (an event with 3 inches or greater of rainfall total) between August 2007 and April 2021. The City has made significant progress on efforts to reduce urban flooding impacts. Water quality targets have advanced practices that help manage urban flood risk. However, most information on how and where urban flooding manifests remains highly anecdotal and focused on the most severe instances of flooding in any particular event. More detailed understanding of areas vulnerable to extreme rain events is essential to prepare for and respond to future emergencies, and was a main driver of the Stormwater Resiliency Plan research.

FLASH FLOOD RESPONSE

Response to flash flooding is a multi-stakeholder endeavor that requires both reactive emergency response procedures and proactive preventative measures. Within the city, extreme rain events can cause backups into basements, streets, and subway tunnels, disrupting daily life.[10] Despite the actions taken to implement source controls for stormwater and improve water quality (see Appendix A), urban flooding persists in New York City. Causes of this flooding vary with location. Flooding related 311 complaints from 2004-2020 show a higher density of complaints in areas influenced by tidal flooding, such as the Rockaways and Coney Island. Inland flooding complaints are prevalent in Southeast Queens and Southern Brooklyn.[11] More information on flood cause and frequency is essential to better prepare for and respond to future emergencies.

ROLES AND RESPONSIBILITIES

A significant rain event in August 2007 and the subsequent interagency coordination spurred the creation of the Flood Mitigation Task Force, and the creation of an Flash Flood Emergency Plan, managed by EM. Flash flood response is the responsibility of several agencies:

Department of Environmental Protection (DEP):
DEP is the City agency with equipment available to proactively clean the insides of catch basins, either before or during an event. DEP's Catch Basin Inspection Program identifies catch basins that have a high likelihood of clogging during extreme rain events, and proactively cleans these basins before rain events. Additionally, DEP's Bureau of Water and Sewer Operations (BWSO) is responsible for maintaining NYC's sewer networks in good working order and addressing problems as they arise. BWSO addresses hundreds of sewer-related 311 complaints each year and activated its flash flood emergency plan 35 times in 2020 alone.

Emergency Management (EM):
EM is responsible for monitoring weather and activating the flash flood emergency plan. The department provides interagency coordination when issues arise during a flash flood event and can monitor 311 flooding complaints. EM also manages Community Emergency Response Teams (CERT), which are groups of volunteers across the City that may be deployed to help keep catch basin covers clean and alert agencies to flash flooding problems in neighborhoods.

Department of Transportation (DOT):
DOT is responsible for ensuring that the tops of catch basins are clear on major arterial roads during flash flood emergencies, and maintaining city's roadway network in a state of good repair.

Department of Sanitation (DSNY):
DSNY is responsible for ensuring that the tops of catch basins are clear on minor roadways and can deploy equipment to help clear blockages, downed trees, and other hazards using their street sweeping units.

Fire Department (FDNY):
FDNY is notified of flash flood emergency plan activation and is on call to provide dewatering equipment or personnel to assist in the event of a flash flood emergency.

Police Department (NYPD):
NYPD is notified of flash flood emergency plan activation and is on call to provide equipment or personnel to assist in the event of a flash flood emergency. NYPD's responsibilities include traffic management for flooded roadways and assistance with security as needed.

Metropolitan Transportation Authority (MTA):
MTA is responsible for responding to flash flood emergency issues impacting their subways, buses, commuter rail assets, bridges, and tunnels.

Community Affairs Unit (CAU):
The Community Affairs Unit (CAU) within the Mayor's Office monitors flash flood emergencies to determine whether there will be populations requiring assistance during or after a flash flood emergency due to property damage or other issues.

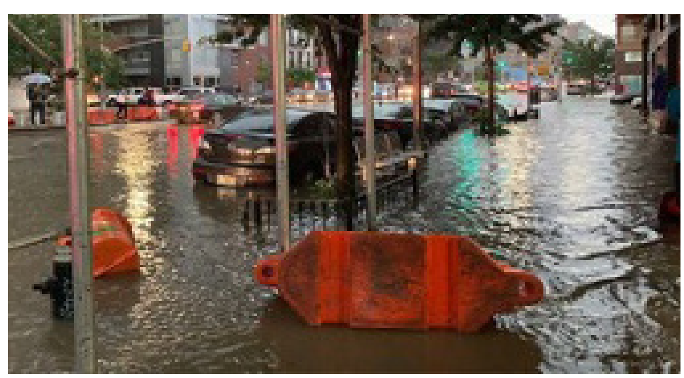


Figure 4: Carroll Street and Fourth Avenue, Brooklyn Flash flood July 22, 2019

DESCRIPTION OF RESEARCH EFFORT AND MODELING METHODOLOGY

This modeling effort is the first of its kind in NYC for citywide analysis of rainfall-induced inland flooding. Given limited past knowledge on areas in NYC prone to flooding from extreme rain events, DEP, MOR and EM embarked upon an ambitious effort to model these effects across the City in 2017. Modeling this type of flooding requires consideration of multiple urban flood drivers including development of representative rainfall hyetographs (a graphical representation of the distribution of rainfall intensity over time), consideration of tidal conditions and climate change, and an understanding of localized sewer network capacity and overland drainage pathways. These components are complex individually, and when combined and considered on a city-wide scale, require detailed hydrologic and hydraulic (H&H) models to evaluate and predict flood risk. Although various individual analyses have been undertaken historically across the city, these have been on a localized scale and often driven by coastal inundation as opposed to inland rainfall. Given the complexity and scale required to understand inland urban flood risk across the entire city, the City took a two-phased approach to modeling this vulnerability.

PHASE 1

Through the City's Town and Gown partnership program, DEP engaged an academic team led by Brooklyn College to carry out the New York City Stormwater Resiliency Study and to develop hyetographs for scenarios used in the analysis as well as a preliminary H&H model. DEP used the hyetographs developed under Phase 1 as well as the results of the Phase 1 models to identify hot-spots for more detailed H&H modeling.

The Phase 1 models did not include a detailed representation of the sewer system network (which was a focus in Phase 2 modeling). The academic team delivered the Phase 1 H&H model results to the City in mid-2019 for use in Phase 2.

The City also made significant efforts to identify a range of current and future storm scenarios that would allow for adequate scenario planning. In particular, the City prioritized understanding the relationship between flooding driven by extreme rain and sea level rise, particularly for instances where sea level rise may impede the normal functioning of the City's drainage infrastructure.

PHASE 2

The Phase 2 modeling developed an H&H model for each hydraulically independent area of the city, resulting in 13 different models, largely defined by the sewer networks draining to each of the WRRFs. The models input complex rainfall hyetographs compounded with tidal conditions and sea level rise for applicable scenarios to output simulated stormwater flooding across the city. The base models for the analysis were the City's calibrated LTCP models. Through this work, DEP leveraged the LTCP models while improving their applicability for flooding analyses by adding a 2-dimensional overland component and significant sewer network resolution. DEP developed an innovative composite rain-on-mesh approach to model extreme rainfall events, further described in Appendix B. Note that certain areas of the sewer system could not be modeled (for example, large private properties, large parkland areas, areas with incomplete information). These areas were masked on the maps developed for this effort and may be considered under subsequent modeling phases.

HOT SPOT ANALYSIS

The modeling approach for Phase 2 increased resolution of the LTCP models to facilitate street-level flooding analysis. "Hot spots," or areas particularly vulnerable to flooding, were identified by processing the Phase 1 model results to determine the most significant flood-prone areas.

SEA LEVEL RISE AND INUNDATION

For sea level rise, the models predict the rain-derived flooding from the combined impact of rainfall and the coincident tidal condition applied against the sewer outfalls. The maps also include coastal tidal inundation layers sourced from the NYC Flood Hazard Mapper.

MAPPING APPROACH

To create the flooding layers shown in the maps, two ranges of ponding depth were depicted: areas with depth greater than 4 inches, and areas with depth greater than 1 foot. These two layers were created for each of the 13 models, then merged into city-wide layers.

MODEL VALIDATION AND UNCERTAINTY

The Phase 2 models were validated using the sewer flow monitoring data collected under the LTCP program, as well as associated rainfall and tidal conditions. Additional sewer flow or surface flooding data was not collected as a part of this effort.

FUTURE MODELING EFFORTS

Future efforts can continue to provide more insight and refined maps, including:

- Additional model buildout to contain a higher percentage of the sewers in each sewershed including refinement of the sewer network and additional survey;
- Calibration data collected for larger storm events at more locations across the city;
- Quantitative surface-level calibration data to provide insight to flooding extent and depth, as well as in-sewer response. Existing calibration data is focused on the flows in the sewers at select locations and not flooding in the streets.

For additional details about the modeling methodology, see Appendix B

NEW YORK CITY STORMWATER FLOOD MAPS

The New York City Stormwater Flood Maps depict areas of predicted rain-driven flooding to help New Yorkers understand and prepare for this risk. The City has created city-wide maps of two scenarios: moderate stormwater flooding under future conditions and extreme stormwater flooding under future conditions (Figure 5). These maps are the first step to better understand increasing rainfall in NYC, and additional maps will be released as information is available.

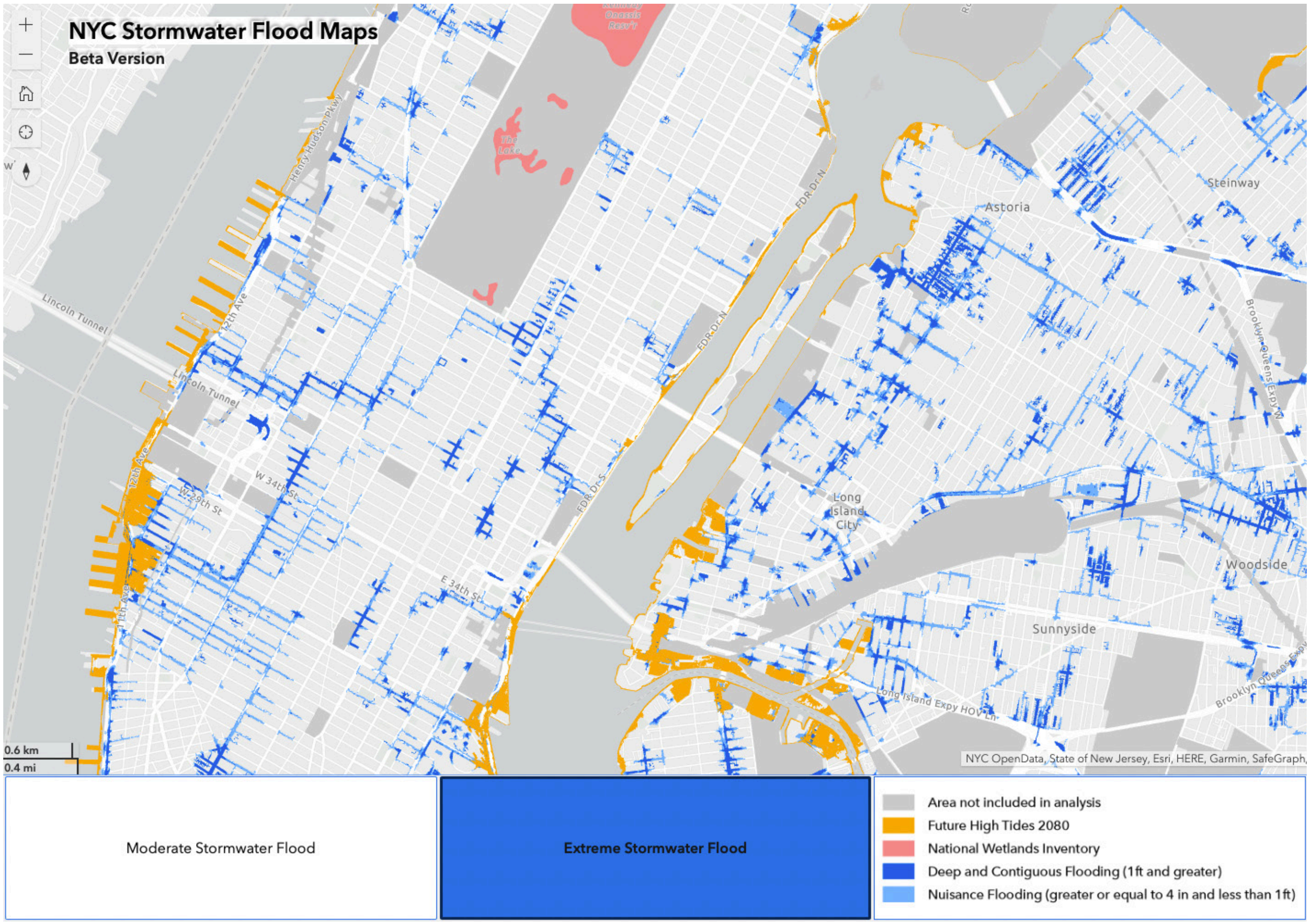


Figure 5: NYC stormwater flood map. Depicted here is the "extreme stormwater flood" scenario. Public maps can be accessed at nyc.gov/resiliency

STORMWATER FLOOD MAPS

These maps will help the City to prepare for future long-term investment and target that investment in the most flood-prone areas. They also are intended to help individual New Yorkers understand risks related to extreme rainfall events. The maps show areas of potential flooding from two scenarios of extreme rainstorms, both of which include future sea level rise conditions. Incorporating sea level rise allows the City to better understand the magnitude of the risk in the coming decades as well as preview the performance of the existing drainage system.

The maps show flooding impacts mainly concentrated in low lying areas or areas with lower density of green/vegetated spaces that can increase stormwater infiltration. During coastal storm events there may be additional flooding caused by storm surge in neighborhoods close to the shoreline (Table 1). Public maps can be found at MOR's website at nyc.gov/resiliency and linked on DEP and EM's websites.

RAIN-DRIVEN VERSES COASTAL FLOODING

There are key differences between rain-driven flooding and coastal flooding that must be considered in short-term emergency planning and long-term design. Coastal flooding refers to both flooding caused the tidal cycle as well as coastal storm events. When planning for emergency response, the relative predictability of the tides can allow for greater preparation or evacuations, and the duration of the flooding conditions may be longer (minutes to hours). Rain-driven flooding can occur suddenly and intensely, but flood conditions may subside more quickly (seconds to minutes). Finally, as depicted on the maps, rain-driven flooding can be highly localized - intensely impacting smaller areas in dispersed locations. Coastal flooding may impact a larger, consistent length and extent of the coastline. When rain events, coastal storms, and the tidal cycle compound, additional flooding may occur.

Selected Impacts	Rain Driven Flooding	Coastal Flooding (includes tidal flooding + coastal storms)
Warning	Often comes with little warning	Tide cycle predictions allow for coastal flood warning
Duration	Most major ponding lasts seconds to a few minutes	Tidally influenced storm surge lasts 20 minutes to an hour
Damage	Impacts interior drywall. Impact vehicles on the street or subgrade parking structures. Potential electric/structural damage	Salt water permanently damages electrical equipment
Geographic extent	Impacts targeted areas based on location of heaviest rain. Dispersed impacts.	Impacts broad geographic area based on location/timing of tides, surge

Table 1: Distinctions between rain-driven and coastal flooding

MODELED SCENARIOS

The models are based on conservative assumptions to ensure the maps were as accurate as possible without underestimating rainfall flood risk. The maps were built by analyzing a range of rainfall scenarios to determine how flood patterns may change. They are based on the simplified assumption that rainfall occurs uniformly across the city in order to conservatively assess possible impacts in all neighborhoods. Additionally, the model assumes the drainage system is fully functioning and that catch basins are free of debris or sediment. Both the moderate and extreme scenarios show a severe rainstorm event that exceeds the design capacity of the existing drainage system. Added sea level rise illustrates areas that temporarily cannot drain due to tidal conditions blocking storm drains and outfalls. The maps do not incorporate impacts from anticipated coastal protection projects in Manhattan, Staten Island, and Queens.

The maps show flood depth represented in two categories: "nuisance" and "deep and contiguous." Nuisance flooding is classified as flooding at least 4 inches but less than 1 foot deep, and was chosen to represent a low level of inundation that poses a less significant threat to public safety or major property damage. Deep and contiguous flooding is categorized as flooding 1 foot deep or greater, and was chosen to represent a high level of inundation that poses a significant threat to public safety and property damage.

Map	Rainfall	Sea Level Rise
Moderate	10-yr	MHHW + 2.5 feet
Extreme	100-yr	MHHW + 4.8 feet

Table 2: Stormwater flood map conditions.
MHHW = mean high high water

MODERATE STORMWATER FLOOD SCENARIO

This scenario illustrates the city streets which could experience flooding during a moderate rainstorm combined with future sea level rise. The map can be useful in identifying specific areas where new public and private infrastructure will likely be required to supplement the sewer system. Flooding from this rainstorm would temporarily disrupt transportation and enter buildings and basements, causing minor damage to contents and surfaces.

This scenario reflects approximately two inches of rain falling in one hour (also referred to as the 10-year storm, with approximately 10 percent chance of occurrence in any given year) combined with 2.5 feet of SLR (NPCC 90th percentile estimate for the 2050s) (Table 2).[13] Flooding in this scenario is the result of the compounded effects of both rainfall and the impacts of potential blocked storm drains and outfalls from sea level rise.

EXTREME STORMWATER FLOOD SCENARIO

This scenario shows significant flooding impacts of an extreme rainstorm combined with future sea level rise. The map highlights the considerable land areas that are predicted to flood and is useful for evaluating neighborhood-wide strategies to manage flood risk.

This scenario reflects approximately 3.5 inches of rain falling in one hour (also referred to as the 100-year storm, with approximately 1 percent chance of occurrence in any given year) combined with 4.8 feet of SLR (NPCC 90th percentile estimate for the 2080s) (Table 2).[14] Flooding in this scenario is the result of the compounded effects of both rainfall and the impacts of potential blocked storm drains and outfalls from sea level rise.

NEW YORK CITY STORMWATER RESILIENCY PLAN

The Stormwater Resiliency Plan ensures that future investments made by City agencies consider impacts on rain-driven flood vulnerability, and that the City is tailoring operational resources to respond to more frequent and severe rain events. This is an unprecedented effort involving a wide variety of stakeholders and highly complex infrastructure. Within this context, the City has identified strategic changes over a 10 year period that will better manage flood risk from extreme rain for New Yorkers. The Plan will provide the City with the necessary information for decision-makers to reasonably assess emergent risks of rainfall-driven flooding and to take appropriate measures for managing those risks. While the Stormwater Resiliency Plan will allow the City to better anticipate future flooding, there will still be limits as to what can be managed. Private property owners should continue to take efforts to minimize flood risk, and utilize resources included in DEP's Flood Prevention page[15] and EM's Flood Preparedness page.[16] The City has identified four key goals that guide the implementation of the Stormwater Resiliency Plan. Initiatives will support the achievement of these goals over the 10 year timeframe.

GOAL #1: INFORM THE PUBLIC ABOUT FLOOD VULNERABILITY FROM EXTREME RAIN

Initiative 1: Release initial flood vulnerability maps to the public

AGENCY OWNER: MOR/DEP | COMPLETION DATE: 2021

The maps supporting this plan are publicly available and linked on DEP and MOR's website with explanation of context and intended use, as well as added to EM's online Hazard Mitigation Plan.[17] Maps depicting additional storm scenarios will be available in subsequent Plan updates as new modeling is available and as climate change projections are updated.

Initiative 2: Initiate stakeholder engagement

AGENCY OWNER: MOR | COMPLETION DATE: 2021

Upon the release of the stormwater maps, the City will conduct outreach to ensure that impacted stakeholders understand the maps, how flood risk from extreme rainfall affects them, and what steps they might take to avoid the worst impacts of flash flooding. The stakeholder engagement will be led by MOR and supported by partner City agencies. MOR will develop a presentation available on its website explaining the maps (including model assumptions and uncertainties) and will partner with DEP to ensure distribution of DEP's toolkit of resources. MOR will reach out to community boards and elected officials to distribute the mapping and involve communities in understanding their specific vulnerabilities along with making plans for reducing risk exposure.

Initiative 3: Build maps into interactive online platform showing citywide flood vulnerability from rain, coastal storms, and sea level rise

AGENCY OWNER: MOR | COMPLETION DATE: 2024

In the longer term, MOR will work with city agencies to ensure that New Yorkers can look up their coastal and rain driven flood vulnerability in one place. Currently, coastal flood maps are available on New York City's Flood Hazard Mapper.[18] NYC will move towards an integrated flood mapping platform in the coming years.

GOAL #2 UPDATE NYC'S FLASH FLOOD RESPONSE PROCEDURES TO PRIORITIZE RESPONSE IN VULNERABLE AREAS

Initiative 1: Update Stormwater Mitigation Study Areas

AGENCY OWNER: EM | COMPLETION DATE: 2021

After the August 7, 2007 extreme rain event, a Task Force convened by Mayor Bloomberg identified NYC Stormwater Mitigation Study Areas (SMSAs), where it was believed that urban flood issues were most acute. EM worked with partner agencies to integrate these areas into the City's Flash Flood Emergency Plan, prioritizing them for flash flood response. Since 2007, the City has implemented projects that have reduced urban flood risk and shifted the nature of urban flood risk across the City. MOR will work with EM to coordinate across agencies to update, change, or remove the SMSA designations in the Flash Flood Emergency Plan.

Initiative 2: Ensure DEP's Flood Activation and Notification procedure and NYC's Flash Flood Emergency Plan are optimally aligned

AGENCY OWNER: EM/DEP | COMPLETION DATE: 2022

As part of the City's Flash Flood Emergency Plan update, EM will coordinate across agencies to integrate any changes and align with DEP's Flash Flood Plan Activation and Notification Standard Operating Procedure (SOP). This will help to optimize operational agencies' resource allocations.

Initiative 3: Evaluate key locations to ensure coastal storm shelters maintain operational continuity during extreme rain events.

AGENCY OWNER: EM | COMPLETION DATE: 2023

EM will evaluate pre-identified locations (such as coastal storm emergency shelters and commodity distribution points) critical to response during a coastal storm. Evaluation may include securing funding for additional facility-specific analysis, identification of alternate locations in extreme rain events, and updating response plans to reflect considerations for changing locations.

Initiative 4: Develop notifications for basement dwellings to keep residents out of harm's way

AGENCY OWNER: EM | COMPLETION DATE: 2023

EM will pre-draft messaging regarding potential dangers for residents living in basement dwellings to be used for outreach and notification in advance of forecasted extreme rain events.

Initiative 5: Model additional storm scenarios to further tailor NYC's response management for various events

AGENCY OWNER: MOR/DEP/EM | COMPLETION DATE: 2024
EM will partner with MOR and DEP to support additional storm scenario modeling to further refine the City's response to extreme rainfall events.

GOAL #3: ADVANCE POLICIES THAT REDUCE URBAN FLOODING AND RESEARCH THAT INFORMS FUTURE RISKS

Initiative 1: Call on NPCC to develop rainfall intensity projections for future years and collect ongoing rainfall intensity observations

AGENCY OWNER: MOR | COMPLETION DATE: 2021
When planning for future extreme rain, it is most important to understand the intensity of future rainfall, as rainfall intensity drives flood impacts during storms. The NPCC estimates that rainfall events will get more severe as climate change accelerates in the region. However, there are not precise estimates of how rainfall intensities will change over time. Developing more precise rainfall intensity projections would help New Yorkers design smarter and more cost effective facilities and allow for more informed planning.

Initiative 2: Facilitate green roof deployment in priority areas

AGENCY OWNER: MOR/MOS | COMPLETION DATE: 2023
In 2019, the New York State legislature renewed the Green Roof Property Tax Abatement available for property owners installing green roofs. It reauthorized the reimbursement of $5.23 per square foot of installed green roofs, and allowed the City to designate community districts that would receive an enhanced abatement of $15 per square foot. With new information about urban flood vulnerability, there is an opportunity to include urban flood vulnerability in the list of variables that the City might consider when designating priority community districts receiving the enhanced abatement.

Initiative 3: Update on-site stormwater management requirements to reduce the amount and rate of stormwater entering city sewer system

AGENCY OWNER: DEP | COMPLETION DATE: 2021
DEP is proposing amendments to Chapters 31 and 19.1 of Title 15 of the Rules of the City of New York (RCNY) as part of a Unified Stormwater Rule. The Unified Stormwater Rule, to be administered citywide, will update and align Chapter 31 stormwater quantity and flow rate requirements with Chapter 19.1 Construction/Post-Construction permitting program water quality requirements. Under Chapter 31 amendments, the Unified Stormwater Rule increases the amount of stormwater required to be managed on-site and further restricts the release rates for all new and redevelopment projects that require a DEP House or Site Connection Proposal.

Additionally, under Chapter 19.1 amendments, sites that disturb 20,000 square foot or more of soil or increase impervious surfaces by 5,000 square feet or more will also be required to manage the Water Quality Volume (WQv), currently defined as 1.5 inches, using stormwater management practices (SMPs) dictated by DEP SMP hierarchies. DEP has developed hierarchies for both combined and separate sewer areas. The SMP hierarchies prioritize vegetated retention SMPs for both drainage areas with stormwater volume control and stormwater treatment communicated as the underlying goals for combined and separate sewer areas, respectively.

In September 2020, New York City Council passed Local Law 91 enabling DEP to move forward with the Chapter 19.1 amendments necessary to package the Unified Stormwater Rule amendments.[19] Draft rules are anticipated to be published in Spring 2021 and in effect in 2022. A new New York City Stormwater Management Guidance Manual will accompany the Unified Stormwater Rule to provide clear guidance on requirements and design options. The draft manual will be published with the draft rules in Spring 2021.

Initiative 4: Incorporate stormwater flood mitigation into NYC's Climate Resiliency Design Guidelines

AGENCY OWNER: MOR | COMPLETION DATE: 2023
The Climate Resiliency Design Guidelines establish City-wide guidance for incorporating forward-looking climate data into City capital projects.[20] Over the next three years, MOR will partner with agencies to review capital programs and identify projects in areas that face high levels of risk from extreme rainfall. For these projects, MOR will work with project teams to identify design solutions to protect the asset as well as capture the maximum amount of rainwater on-site with consideration to future climate projections. For example, in street and sidewalk resurfacing in flood-vulnerable areas, and pedestrian plaza construction in these areas, designers should consider design solutions focused on retention/detention of floodwaters and pervious materials wherever possible. MOR will subsequently incorporate lessons learned from these projects into these Guidelines.

GOAL 4: LEVERAGE STORMWATER INVESTMENTS TO HELP MANAGE FUTURE FLOOD RISK FROM EXTREME RAIN AND SEA LEVEL RISE. FUTURE INVESTMENTS CAN ALLEVIATE FLOODING THROUGHOUT THE CITY.

Initiative 1: Conduct additional modeling to identify the most effective interventions that best manage flood risk

AGENCY OWNER: DEP | COMPLETION DATE: 2023
Under this initiative, DEP will integrate climate change forecasts in the development of coordinated long-range resiliency goals in its ongoing mission to provide world-class and sustainable water and wastewater services now and for future generations. Utilizing engineering analysis and operational knowledge, DEP is creating a toolbox of resiliency interventions from which engineers and planners can identify those that maximize effectiveness based on site-specific conditions. The citywide stormwater model

will be a constantly evolving tool for evaluating the design of proposed capital projects and identifying investments which are cost effective and scalable to manage future flood risks. DEP will continue leveraging its in-house resources, augmented by several ongoing contracts, to expand and refine its citywide stormwater model and evaluate impacts of future climate projections developed by the Cornell University Northeast Regional Climate Center and the New York City Panel on Climate Change.

Initiative 2: Analyze water and wastewater rate structure options that could provide a more sustainable revenue stream and greater flexibility for investing in climate resiliency

AGENCY OWNER: DEP/MOR | COMPLETION DATE: 2023

Capital expenses are expected to rise in the coming decades due to new mandates and necessary upgrades to aging infrastructure, to maintain and enhance DEP's level of service, including addressing climate change. At the same time, per capita water consumption is expected to remain at current low levels, or further decline. Thus, an increased total cost of service is spread across a smaller demand number, which will increase budgetary pressures and make it more difficult to balance competing needs. To address this, DEP is carrying out the Sustainable Rate Structure Analysis, which is a holistic rate structure study that will analyze water and wastewater rate structure options and customer assistance and credit programs. This study will provide recommendations and implementation options for DEP to achieve a more predictable, equitable, and sustainable revenue stream to allow for more flexibility in balancing regulatory objectives with the growing need to invest in climate resiliency and sustainability, while maintaining customer affordability.

Initiative 3: Establish criteria for tiering neighborhoods based on flood vulnerability

AGENCY OWNER: DEP/DCP/MOR | COMPLETION DATE: 2023

As seen in the maps, heavier rain and sea level rise is expected to increase the frequency, extent, and duration of chronic and acute flooding events. DEP, in coordination with DCP and other City agencies, will establish criteria for tiering neighborhoods based on their vulnerability to flooding. While vulnerability to flooding indicated by modeling results will be a primary indicator of vulnerability, other factors such as additional climate risks, existing infrastructure capacity, current and future projects, and environmental justice will also be considered to ensure an equitable approach towards implementing solutions for flooding hotspots.

Initiative 4: Assess and evaluate feasible flood risk strategies for implementation based on tiers

AGENCY OWNER: DEP | COMPLETION DATE: 2027

Strategies for addressing flooding should be tailored to the specific characteristics of a neighborhood and the feasibility and cost of interventions. As a part of the process of tiering neighborhoods based on flood vulnerability, DEP, in coordination with other City agencies, will develop a framework for mitigating flooding in high-risk areas based on the specific needs of a neighborhood that assesses and evaluates the role that different interventions have in mitigating flooding, while also greening urban areas and providing co-benefits to communities.

Initiative 5: Incorporate lessons learned into long term planning and revise drainage planning as appropriate with flood risk management as a key decision variable

AGENCY OWNER: DEP | COMPLETION DATE: 2031

As discussed previously, DEP's current sewer design standard is based on IDF curves derived from historical rainfall data. Design efforts for sewer infrastructure must take into account projected future sea level rise (SLR), increased precipitation, and frequency of high intensity storm events whenever possible. To reduce future vulnerability from these elements, new and existing infrastructure shall undergo risk-based engineering analyses to protect against the impacts of climate change. DEP is currently revising its drainage planning procedures to use a projected 5-year storm event in the final year of the sewer's useful life, and will continue to evaluate the drainage network under future storm scenarios.

The capacity of a proposed sewer should be able to provide a level of service in which the system can adequately convey the current 5-year storm event without surcharging while providing a level of service equal to the 5-year storm event at the end of the useful life of that piece of infrastructure. Sewer infrastructure has a design life of approximately 50 years, and a useful life of approximately 100 years. As such, in 2021, the rainfall scenario that should be used for evaluating future sewer projects is the projected average rainfall intensity values for the years 2070-2099.

Additionally, DEP will expand upon the modeling completed for this effort and continue developing a citywide hydrologic and hydraulic (H&H) model to better estimate runoff flow for various climate scenarios to be included in the drainage planning process. This model is expected to be sufficiently complete to allow evaluation of future rainfall scenarios to inform necessary and constructible design changes to sewer construction projects scheduled for award in FY 2024. By modeling forward-looking rainfall and SLR scenarios, DEP can evaluate the sewer system for future rainfall scenarios as well as extreme rainfall scenarios that may occur with more frequency due to climate change. DEP can be better prepared to allocate and prioritize resources for capital improvement projects to prevent future damage from increased rainfall and sea level rise predictions in the future as a result of climate change.

Finally, DEP will continue to exchange best practices for addressing issues related to managing intense rainfall and sea level rise with other cities facing similar challenges. DEP's ongoing partnership with the City of Copenhagen will focus on enhancing stormwater management and resiliency through storage and surface flow conveyance in addition to drainage network buildouts, that also creates inspiring urban areas with co-benefits for communities. Successful partnerships such as this allow DEP to identify and develop innovative solutions to prepare for more extreme rain events, or cloudbursts, brought about by climate change.

GOAL #1: INFORM THE PUBLIC ABOUT FLOOD VULNERABILITY FROM EXTREME RAIN		
INITIATIVES	**NYC AGENCY OWNER**	**COMPLETION**
1: Release initial flood vulnerability maps to the public	MOR	2021
2: Initiate stakeholder engagement	MOR/DEP	2021
3: Build maps into interactive online platform showing citywide flood vulnerability from rain, coastal storms, and sea level rise	MOR	2024

GOAL #2: UPDATE NYC'S FLASH FLOOD RESPONSE PROCEDURES TO PRIORITIZE RESPONSE IN VULNERABLE AREAS		
INITIATIVES	**NYC AGENCY OWNER**	**COMPLETION**
1: Update Stormwater Mitigation Study Areas	EM	2021
2: Ensure that DEP's Flash Flood Activation and Notification SOP and NYC's Flash Flood Emergency Plan are optimally aligned	EM/DEP	2022
3: Evaluate locations of key shelters and commodity distribution points to ensure that coastal storm shelters maintain operational continuity during extreme rain events	EM	2023
4: Develop notifications for basement dwellings to keep residents out of harm's way	EM	2023
5: Model additional storm scenarios to further tailor NYC's response management for various events	MOR/DEP/EM	2024

GOAL #3: ADVANCE POLICIES THAT REDUCE URBAN FLOODING AND RESEARCH THAT INFORMS FUTURE RISKS		
INITIATIVES	**AGENCY OWNER**	**COMPLETION**
1: Call on NPCC to develop rainfall intensity projections for future years and collect ongoing rainfall intensity observations	MOR	2021
2: Facilitate green roof deployment in priority areas	MOR/MOS	2023
3: Update on-site stormwater management requirements to reduce the amount and rate of stormwater entering city sewer system	DEP	2021
4: Incorporate stormwater flood mitigation into NYC's Climate Resiliency Design Guidelines	MOR	2023

GOAL #4: LEVERAGE STORMWATER INVESTMENTS TO HELP MANAGE FUTURE FLOOD RISK FROM EXTREME RAIN AND SEA LEVEL RISE. FUTURE INVESTMENTS CAN ALLEVIATE FLOODING THROUGHOUT THE CITY.		
INITIATIVES	**AGENCY OWNER**	**COMPLETION**
1: Conduct additional modeling to identify the most effective interventions that best manage flood risk	DEP	2023
2: Analyze water and wastewater rate structure options that could provide a more sustainable revenue stream and greater flexibility for investing in climate resiliency.	DEP/MOR	2023
3: Establish criteria for tiering neighborhoods based on flood vulnerability and risk	DEP/DCP/MOR	2023
4: Assess and evaluate feasible flood risk strategies for implementation based on tiers	DEP	2027
5: Incorporate lessons learned into long term planning and revise drainage planning as appropriate with flood risk management as a key decision variable	DEP	2031

APPENDIX

APPENDIX A: ONGOING STORMWATER INVESTMENTS

LONG TERM CONTROL PLANS

In 2012, DEP and DEC signed a groundbreaking agreement to reduce CSOs using a hybrid green and grey infrastructure approach. As part of this agreement, DEP has developed 10 waterbody specific and one city-wide Long Term Control Plans (LTCPs). The goal of each LTCP is to identify appropriate combined sewer overflow controls necessary to achieve waterbody-specific water quality standards, consistent with the Federal CSO Policy and the water quality goals of the Clean Water Act. Over the last several decades, the City has invested more than $45B in the construction and upgrade of critical wastewater and drainage infrastructure to improve the health of our City's vital ecosystems. In recent years, the City has committed an additional $10.6B to continue the legacy of innovation and investment to usher in a new era of environmental protection for its waterbodies. DEP's website summarizes the LTCP Program commitments and benefits.[21]

NYC GREEN INFRASTRUCTURE PROGRAM

New York City's 2010 Green Infrastructure Plan built upon and extended the commitments made in PlaNYC and the 2008 Sustainable Stormwater Management Plan. This plan provided a detailed framework and implementation plan to meet the twin goals of better water quality in New York Harbor and a livable and sustainable New York City. This plan was the framework through which NYC updated its consent order with New York State in 2012, and officially integrated green infrastructure and source control strategies into its water quality compliance framework. The Plan led to the launch of the New York City Green Infrastructure Program.

The New York City Green Infrastructure Program has led to over 10,000 green infrastructure practices, managing over 1,200 "greened acres," constructed or currently in construction at the time of this report.[22] Through the Program, DEP has formed important relationships with city agencies and expanded sustainable stormwater management principles to streets and public spaces. The Program has three primary implementation areas:

- **Right-of-Way (ROW) Green Infrastructure:** In 2012, DEP launched area-wide green infrastructure projects, in partnership with DOT and Parks, and has achieved the vast majority of stormwater management through the installation of ROW practices such as rain gardens and infiltration basins. DEP is currently expanding its ROW green infrastructure portfolio to include large capture median practices sized to manage precipitation events larger than standard practices.
- **Public Property Retrofits:** DEP, with Parks, NYCHA, DOE and SCA, continued green infrastructure project design development on almost 200 publicly owned properties as of the release of this report. Newly constructed projects include green infrastructure schoolyards with the Trust for Public Land and DOE and SCA.
- **Private Property Initiatives:** DEP's Green Infrastructure Grant Program offers funding for the design and construction of green roof retrofits on private property in New York City. In 2021 DEP will kick off a new large-scale green infrastructure retrofit incentive program with the goal of installing green infrastructure assets on private property that manage a stormwater volume equivalent to 200 "greened acres". The program targets large parcels, 50,000 square feet or greater, in the combined sewer areas of the City with large impervious (paved) areas.

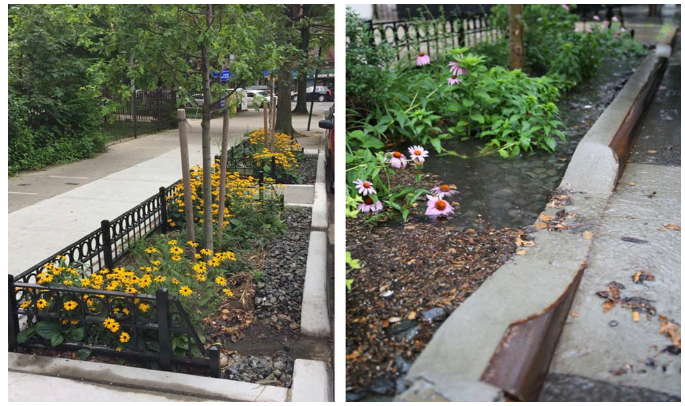


Figure A1: DEP Rain Gardens

Figure A2: NYC Greenstreets Plaza

STREET TREES

New York City's almost 700,000 street trees intercept over 1 billion gallons of stormwater every year, while reducing CO2 emissions by over 600,000 tons. The annual value of the stormwater, energy, and pollution benefits provided by street trees is $109M, according to Parks.[23] As part of the New York City Million Trees initiative, 220,000 street trees were planted, with the rest of the million trees planted either in parks or on private property.[24]

GREEN AND SOLAR ROOF MANDATES

In 2019, there were just 736 green roofs in New York City,[25] covering 60 of the 40,000 acres of rooftop space.[26] As part of the New York City Climate Mobilization Act passed in 2019, New York City Council passed Local Laws 92 and 94, which require new and substantially renovated or enlarged rooftops to incorporate sustainable roofing on all available roof space. The City anticipates that these laws will help buildings manage up to 1M additional gallons of stormwater per year, and help manage water quality and urban flooding.

GREEN ROOF TAX ABATEMENT

In 2019, the New York State legislature renewed the Green Roof Property Tax Abatement available for property owners installing green roofs. It reauthorized the reimbursement of $5.23 per square foot of installed green roofs, and allowed the City to designate community districts that would receive an enhanced abatement of $15 per square foot. The community districts were selected by rule in 2021 and the enhanced tax abatement is available in districts with higher vulnerability to extreme heat and in priority areas for CSO reduction.

GREENSTREETS AND PEDESTRIAN PLAZAS

Between 1996 and 2010, Parks and DOT partnered to add green space to rights of way, and built over 2,500 "Greenstreets". In 2010, this effort was merged with the City's Green Infrastructure Program.[27] Since 2008, DOT has converted underutilized street space into pedestrian plazas, moving streets into the public realm and reducing impervious surfaces where possible. Over 74 plazas have been created, which enhance safety and increase green space.[28]

CLOUDBURST MANAGEMENT

In 2015 DEP partnered with the City of Copenhagen to share knowledge on innovative solutions that can prepare the City for heavier and more frequent downpours or "cloudbursts" brought about by climate change. As part of this collaboration, DEP initiated the Cloudburst Resiliency Planning Study to assess risks, prioritize response, develop neighborhood-based solutions, and assign costs and benefits for managing cloudbursts.[29] As a result of the Cloudburst Resiliency Planning Study two pilot projects were identified in the neighborhood of Southeast Queens, an area that the City has committed $1.9B to build a comprehensive drainage system and alleviate flooding in neighborhoods throughout the area, to help demonstrate the feasibility of implementing the cloudburst approach. This innovative approach utilizes interconnected, below- and above-ground rainwater conveyance and storage (Figure A3). The projects aim to supplement ongoing sewer buildouts and act as a buffer for storms not captured by sewers due to the size of the storm or the lack of fully built-out storm sewer infrastructure. This would reduce flooding in areas where grey infrastructure takes longer to implement and will alleviate chronic flooding of upstream areas.

Figure A3: NYCHA South Jamaica Houses cloudburst pilot. The existing basketball court will be excavated to create underground water storage and repair the surface. The new "cloudburst" design will lower the basketball court, allowing it to fill with water during extreme rain, and providing a new seating area for residents

BLUEBELTS

Bluebelts are ecologically rich and cost-effective drainage systems that naturally handle the precipitation runoff from on our streets and sidewalks by preserving natural drainage corridors including streams, ponds, and wetlands, and enhancing them to perform their functions of conveying, storing, and filtering stormwater. Over the last thirty years DEP has built Bluebelts for approximately one third of Staten Island's land area. In the South Richmond and mid-Island areas, the City has purchased approximately 400 acres for Bluebelts that provide drainage for 19 watersheds, covering about 14,000 acres.[30]

WATER CONSERVATION AND REUSE

Water conservation and reuse provide opportunities to ensure the resiliency and reliability of the water supply system in the face of climate change. While the goal of these programs are primarily to conserve potable water, they also offer the co-benefit of reducing flows to the sewer system and wastewater facilities. Innovative programs, such as DEP's "Wait…" Program, also contribute to these reductions in flows. "Wait..." helps create additional capacity in the combined sewer system by encouraging residents to voluntarily delay their water use in their homes, such as doing laundry, washing dishes or even flushing the toilet, during rainstorms.[31] In reducing flow to sewers and freeing up capacity, water conservation and reuse could also contribute to reducing combined sewer overflows and flooding. Through 2022, DEP will continue to implement the Water Demand Management Plan, which identifies six key strategies for managing water demand in New York City and details specific initiatives to achieve targeted water demand reductions citywide.

HIGH LEVEL STORM SEWERS

High level storm sewers (HLSS) are designed specifically for stormwater and help reduce street flooding, improve the health of surrounding waterbodies, ensure the reliability of the drinking water delivery system, and make neighborhood roadways safer for all users. In 2018 DEP completed the first phase of installing high-level storm sewers along 3rd Avenue in the Gowanus neighborhood, with Phase II anticipated to be completed by 2021. This $53M project, which will increase capacity in the neighborhood's drainage system, is helping to reduce roadway flooding and the amount of pollution that may be discharged into the Gowanus Canal during heavy rainstorms. To complement the work being completed under this project, DEP also installed new stormwater and sanitary sewers on 9th Street between 2nd Avenue and the Gowanus Canal and constructed storm sewers on 9th Street between Smith Street and the Canal. Combined sewers were also constructed along 2nd Avenue between 7th Street and 9th Street, along with the replacement of an older cast iron water main.

Additionally, DEP plans to construct new, high-level storm sewers to collect stormwater runoff, divert it from the existing combined sewer system and thereby improve the health of Fresh Creek and Jamaica Bay as part of investment in infrastructure upgrades in Canarsie and East New York. The increased collection of stormwater runoff will reduce roadway and property flooding and separate out an estimated 50 percent of the stormwater flow from the combined sewers. By reducing pressure on the existing combined sewer system, modeling shows that overflows into Fresh Creek will be reduced.

SE QUEENS INFRASTRUCTURE BUILD OUT

Certain parts of New York City do not have fully built-out storm sewer infrastructure, including the neighborhoods comprising Southeast Queens. This incomplete infrastructure contributes to the level of flooding observed in the Stormwater Study maps in this neighborhood. The physical area involved is large, and the project will span several decades. Over the coming years, DEP plans to begin full sewer buildout, which will require approximately 450 miles of new storm sewers and upgrades to 260 miles of sanitary sewers and 30 miles of combined sewers, and will partner with DOT for improvements to the roadway network. In order to relieve local flooding, DEP will also construct green infrastructure assets in locations where it is appropriate, and will accelerate the planning and design of trunk sewers, in addition to building collection storm sewers and partnering with community groups to educate residents about protecting their property during rain events.

WASTEWATER MANAGEMENT INVESTMENTS

DEP continues to invest in programs required through an order by the New York State Department of Environmental Conservation to improve water quality in waterbodies adjacent to NYC. Programs such as overflow retention tanks, wastewater treatment plant upgrades, and sustainable stormwater management practices will help keep floatable trash, debris, oils, grease, and bacteria from entering waterways. By updating our stormwater management system with both traditional mechanical upgrades (such as sewer construction and pumping stations), as well as green infrastructure, the City's waterways will continue to improve.

WASTEWATER RESILIENCY PROGRAM

The 2013 New York City Wastewater Resiliency Plan set forth cost-effective strategies in order to reduce the potential damage which could be caused by flood waters to NYC's wastewater infrastructure and safeguarding public health and the environment. This comprehensive study examined buildings and process systems at DEP's 96 pumping stations and 14 wastewater resource recovery facilities, identifying and prioritizing critical infrastructure at each that is most at risk of flood damage. As a result of this, nine projects have been initiated as part of a $206M portfolio to floodproof this critical equipment by implementing a combination of the following adaptation strategies: installing permanent and/or temporary barriers, sealing buildings, elevating or floodproofing critical equipment, and installing backup power systems. The facilities that these projects will perform work at include: Bowery Bay, Hunts Point, Red Hook, Newtown Creek, Owl's Head, Port Richmond, Tallman Island, and Wards Island WRRFs. The implementation of these strategies, along with other resiliency efforts, will help reduce the risk of damage and loss of services caused by extreme weather events.

PUMPING STATION IMPROVEMENTS

New York City's pumping stations convey millions of gallons of sewage from homes, businesses, hospitals, and numerous other sources to treatment facilities, helping to mitigate street flooding and ensuring sewage does not overflow into the street or back up into basements. A number projects are currently underway to protect pumping stations and make them more resilient to service interruptions caused by flooding. In 2019, DEP announced a $10 million upgrade of the Prospect Expressway Stormwater Pumping Station to increase its capacity by roughly 50 percent and reduce flooding as part of DEP's ongoing efforts to upgrade infrastructure to account for changing climate and more intense rainstorms. Currently, the Station's pumps can move nearly 10 million gallons of stormwater a day. When the upgrade is completed, the pump station will be able to remove 16 million gallons of stormwater a day.

APPENDIX B: MODELING APPROACH

Given the complexity and scale required to understand inland urban flood risk across the entire city, the City took a two-phased modeling approach:

PHASE 1

The Phase 1 model was a rain-on-mesh model that primarily focused on overland surface routing of rainfall to identify flooded areas. The Phase 1 models did not include a detailed representation of the sewer system network (which was a focus in Phase 2 modeling). The academic team delivered the Phase 1 H&H model results to the City in mid-2019 for use in Phase 2. The City also engaged in a significant effort to identify a range of current and future storm scenarios that would allow for adequate scenario planning across City stakeholders.

PHASE 2

The Phase 2 modeling developed an H&H model for each hydraulically independent area of the city, resulting in 13 different models, largely defined by the sewer networks draining to each of the WRRFs. The hydrologic component of an H&H model transforms rainfall over a surface to runoff and ultimately inflow into the sewer system. The hydraulic component of the H&H model then routes that flow through the sewer network based on sewer capacity, accounting for tidal conditions and areas where the sewer network floods. The models were built in Innovyze's InfoWorks ICM software which facilitates coupling of a 1-dimensionsal (1-D) rainfall-runoff and sewer routing component with a 2-dimensional (2D) overland flow and flood visualization component. The models take as input complex rainfall hyetographs compounded with tidal conditions and sea level rise for applicable scenarios to simulate stormwater flooding across the city. The base models for the analysis were the City's calibrated LTCP models, here-on referred to as the "base models". Through this work, DEP developed an innovative composite rain-on-mesh approach to model extreme rainfall events.

Hot Spot Analysis and Model Buildout

The modeling approach for Phase 2 focused on maintaining the base model calibration while increasing resolution in order to facilitate street-level flooding analysis. The existing resolution of the base models only included major trunk sewers, typically greater than or equal to 48 inches in diameter. This diameter is larger than sewers on an average NYC street and therefore the base model could not be used as-is to represent drainage capacity on a NYC street resolution level and required further buildout of the sewer network. During the buildout process, additional sewers were added to the model and the hydrology in the model was refined to accommodate this higher sewer network resolution while maintaining the base model calibration.

The buildout of the sewer network was focused in hot spot flooding areas. Hot spots were identified by processing the Phase 1 model results to determine the most significantly flooded areas. Figure B1 below shows the hot spots for the Bowery Bay Phase 1 model overlaid with the base model sewer network on the left and the additional Phase 2 sewers on the right.

In addition to a higher resolution sewer network, the resolution of the hydrologic response to rainfall was updated in the base model. The model subcatchments, which transform rainfall to runoff and sewer flows, were redelineated in the hot spot areas. The delineation approach maintained the overall calibrated boundaries of the base model delineations and added resolution by further subdividing these delineations based on street centerlines and the location of sewer pipes and manholes using the higher resolution sewer network. This redelineation allows the model to simulate the various points at which inflows to the sewer network occur, better-representing street-scale conditions and potential capacity restrictions. Hydrologic parameters within each higher resolution subcatchment were recalculated following DEP's LTCP approach based on local conditions while maintaining the key calibration parameters from the base models. Figure B2 below shows an example of the sewer network buildout and subcatchment redelineation followed by Table B1 showing the percentage of sewer network buildout for each model.

As part of the model buildout, a 2D mesh was incorporated to better represent and visualize flooding conditions. The 2D mesh was constructed using Geographic Information System (GIS) processing of the 2017 Hydro-Enforced Digital Elevation Model (DEM) and created in InfoWorks ICM as a variable triangle terrain sensitive mesh. This provides ability to increase the mesh resolution in areas with complex geometries and/or elevation changes and to use a lower resolution in less complex areas to facilitate quicker model simulation times. InfoWorks ICM uses a fully integrated 1D-2D model to connect the 1D sewer network to the 2D surface, allowing the 1D sewers to flood onto the 2D mesh. All buildings were represented as voids in the 2D mesh, meaning that water cannot pond or flow over them. Stormwater runoff from building roofs was rerouted to the right-of-way as most buildings in NYC have internal roof drainage that is connected to the sewer system.

Model Validation

After completing buildout of the models to the hot spot areas and incorporating the 2D mesh, the Phase 2 models were validated to ensure that they maintained the base model calibration. Validation leveraged the sewer flow monitoring data previously collected under the LTCP program, as well as associated rainfall and tidal conditions. The Phase 2 models were simulated during these historic calibration periods and the model results were compared to both the monitor data and the output from the original base models. The Phase 2 models were considered validated if the simulated results were within a threshold of the base model results and/or improved the historic calibration relative to the monitor data. Where the historic calibration data was not available, the validation was done relative to the base model only.

MAP MASKING

Some areas of the City were masked out because there was insufficient information about their drainage infrastructure to represent the flood risk. These include Open Space Parks from the NYC Planimetric Database greater-than-or-equal-to 100,000 square feet, Non-Residential and Non-Commercial PLUTO Lots greater-than-or-equal-to 250,000 square feet, and PLUTO lots that intersected railway infrastructure. The lot size restriction was incorporated because larger lots are more likely to have on-site drainage infrastructure and therefore it would not have been accurate to represent flood risk in these areas without accounting for this. Masking was not applied to smaller public and private properties under the assumption that any existing on-site storm drainage would not have significant impact on flood risk extents. Subsequent modeling phases may further address these areas.

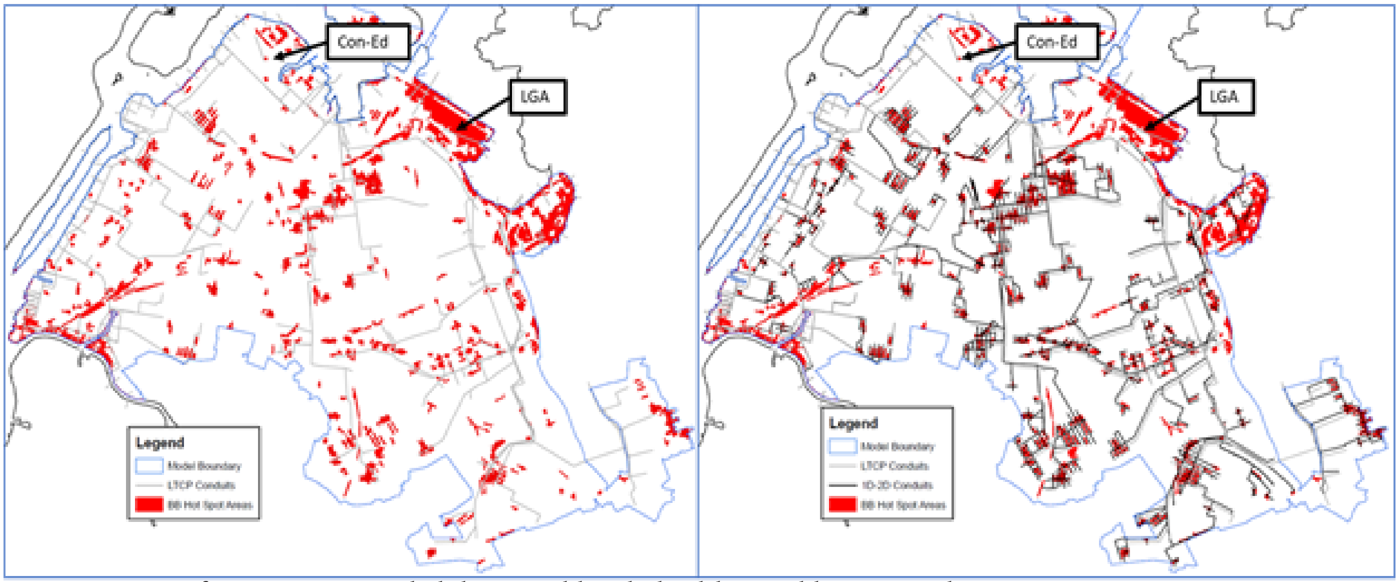


Figure B1. Hot spots for Bowery Bay Sewershed Phase 1 model overlaid with base model sewer network

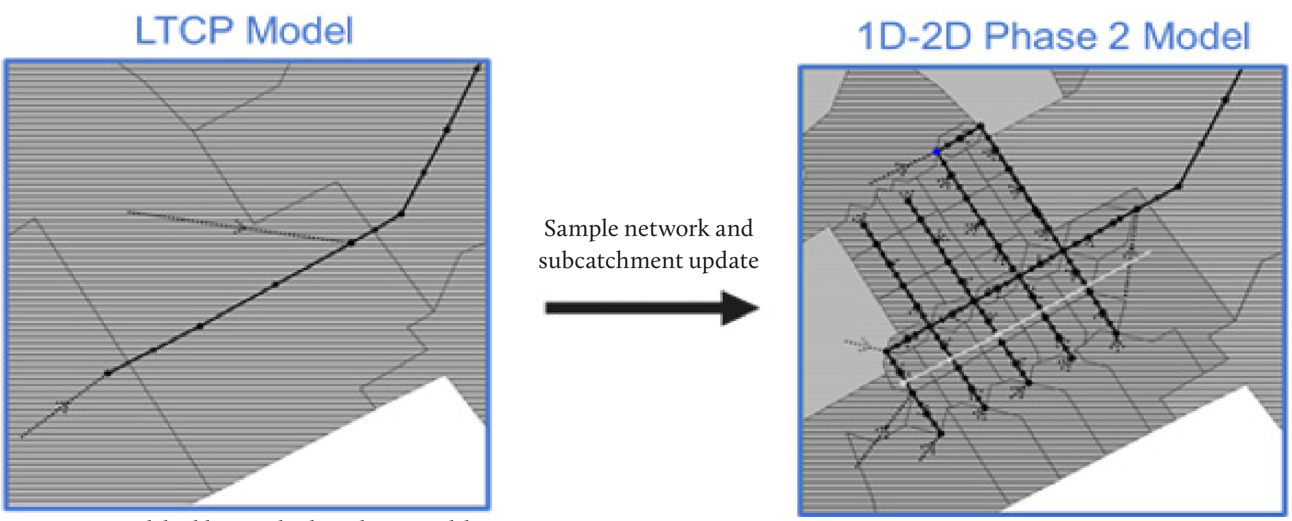


Figure B2. Sewer network buildout and subcatchment redelineation

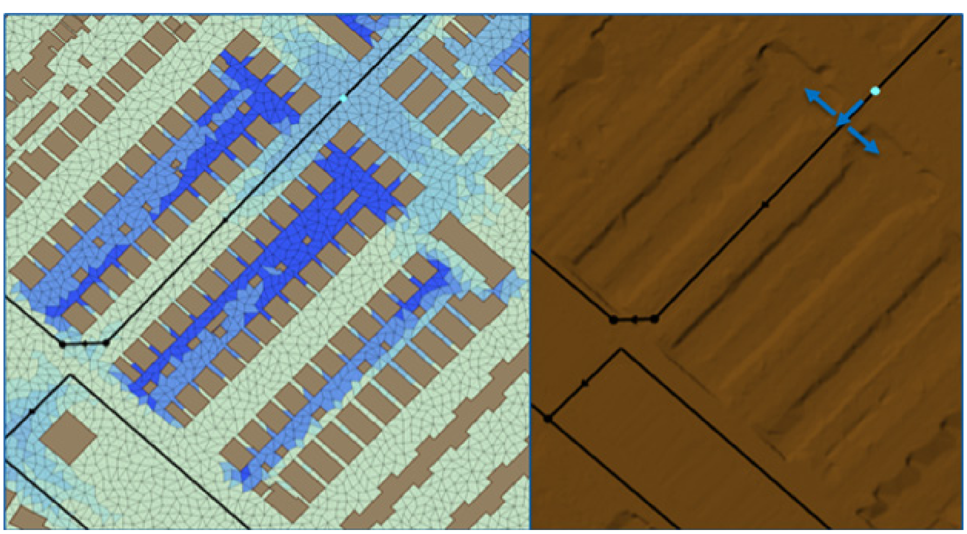


Figure B3. Flow from 1D model to 2D mesh

Table B1. Percentage of Sewer Network Buildout for Each Model

MODEL	% OF TOTAL SEWER PIPE LENGTH REPRESENTED
Bowery Bay	34
North River	26
Newtown Creek-Manhattan	39
Newtown Creek-Brooklyn	25
Red Hook	36
Hunts Point	39
Wards Island	38
Rockaway	41
Coney Island-Owl's Head	54
Jamaica-26th Ward	31
Tallman Island	26
Port Richmond	20
Oakwood Beach	NA

SIMULATION OF MAPPED SCENARIOS

The NYC sewers were historically designed for a 3-to-5-year storm event. The majority of the calibration events used for the base models, which were constructed with a primary focus on evaluating CSO discharges during a typical year precipitation, were less than a 5-year storm. To develop the flood maps for the mapping scenarios, two approaches were used and are summarized in Table B2.

Table B2. Mapped scenario approach

MODELING APPROACH	RAINFALL	SEA LEVEL RISE
1D-2D Approach	10-yr	MHHW+2.5
Composite Approach	100-yr	MHHW+4.8

For the 10-yr event scenario, which has a return period more similar to the events used in the base model calibration, the Phase 2 models were run for the associated combination of rainfall, constant tidal conditions and sea level rise.

For the 100-yr event scenario, the composite approach was developed to account for the difference between this rainfall event and the calibration events used in the base model development. The approach first simulates the Phase 2 models under a 5-year rainfall event with the associated constant tidal conditions and sea level rise noted in Table B2 for the 100-yr storm to understand the sewer network capacity and associated flooding under the 5-year event. The flooding from the sewer network under this event was exported for all nodes and used in the second step simulation to capture areas where the sewer system did not manage the 5-year event. The second step simulation assumes that the sewer pipe capacity is already utilized during the 5-year storm and accounts for the remaining rainfall volume (100-yr minus 5-yr) by introducing it directly onto the 2D mesh along with the 5-yr flooding results from the sewer system from the first step simulation. In the second step simulation, the sewer system was not incorporated in the model to manage the additional (100-yr minus 5-yr) rainfall under the assumption that the sewers are generally designed to manage the 5-yr event.

MODELING APPROACH FOR OAKWOOD BEACH WRRF AREA

A calibrated baseline model does not exist for the Oakwood Beach drainage area. Therefore, a sewer network model was not used in the Phase 2 modeling for Oakwood Beach. Instead, a rain-on-mesh only model was used. Under this approach, the entire rainfall volume was introduced directly on the Oakwood Beach 2D mesh to visualize flooding extents for both the 10-yr and 100-yr maps. This approach is conservative in that it does not account for any sewer system drainage capacity and as such, the Oakwood Beach maps generally show greater flooding than other drainage areas. The Oakwood Beach maps can be updated in future iterations upon buildout of an Oakwood Beach H&H model.

SEA LEVEL RISE AND INUNDATION

For sea level rise, the 2D H&H models predict the rainfall-derived flooding from the combined impact of rainfall and the coincident tidal condition (noted in Table B2) applied against the sewer outfalls. In addition to this rainfall-derived flooding predicted by the H&H models, the maps include additional separate layers depicting coastal inundation from the same tidal condition noted in Table B2. These inundation layers are sourced from the NYC Flood Hazard Mapper and are overlaid in the map on top of all rainfall-derived flooding from the H&H models. The inundation layer is shown under all masked areas except for Open Space Parks.

MAPPING APPROACH

To create the flooding layers shown in the maps, the peak ponding depth that occurs under the simulated scenario was exported from each grid cell in the 2D mesh of the H&H model. This data was processed in GIS to smooth-out and aggregate the raw results to show areas of flooding greater-than-or-equal to 0.25 contiguous acres with ponding depth greater-than-or-equal-to four (4) inches. The threshold of 0.25 acres was determined through an iterative approach to balance a user-friendly visualization (e.g., not show insignificantly small areas of potential flooding) with a reasonable depiction of potential flooding areas (e.g., not remove significantly large ponded areas). The maps depict two ranges of ponding depth: 1) Areas with ponding depth greater than 4 inches 2) Areas with ponding depth greater than 1 foot. In the maps, the areas with ponding depth greater than 1 foot are displayed on top of the areas greater than 4 inches, allowing a viewer to see which areas are estimated to have deeper flooding depths. These two layers were created for each of the 13 H&H models and then merged to create two city-wide layers. During the merging process, the models and results were refined in select areas to address inconsistencies along individual model boundaries.

MODEL LIMITATIONS AND UNCERTAINTY

While the base models were calibrated and the expanded 1D-2D models were validated to preserve this calibration, the majority of calibration events were less than a 5-yr storm using the available in-sewer pipe flow data. Very little quantitative data exists on surface flooding conditions (extent and depth), especially for more extreme storms. Additionally, the model sewer networks were built out in detail to only the identified hot spot areas and do not cover the entire city sewer network.

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