Stormwater Management Studies

Financial District and Seaport Climate Resilience Master Plan

Table of Contents

Overview & Objective

This appendix supplements the Financial District and Seaport Climate Resilience Master Plan – Chapter 5: Stormwater Management. This appendix provides additional detail on the technical analyses and computer modeling conducted using a hydrologic and hydraulic (H&H) model to understand the magnitude and location of flooding that may occur with a flood defense barrier in place but absent new drainage infrastructure. Subsequently, the H&H model was used to develop solutions to reduce stormwater flooding under both present and future conditions.

The Project Team developed and competed the analysis described herein in close coordination with the New York City Department of Environmental Protection (NYC DEP). The Project Team also coordinated with the Battery Park City Authority (BPCA) to assess the potential to provide additional stormwater management benefits to areas upstream in the sewershed. While the recommendations developed as part of the Master Plan and this appendix focus on the Financial District and Seaport area, on-going coordination with the BPCA is recommended as the Master Plan advances into future phases of work.

To make the Financial District and Seaport neighborhoods resilient to both future coastal flooding and increased rainfall, new drainage infrastructure is needed to manage the stormwater behind the flood defense system. The goals of the analysis were:

1) Understand the magnitude and location of flooding that would occur today absent new drainage infrastructure, and how the effects of climate change, causing more extreme and frequent rainfall and future sea level rise, would impact flooding in the future.
2) Develop a suite of proposed drainage solutions to mitigate the flooding under future sea level rise, storm surge, and rainfall conditions.

1. Study Area

The Financial District and Seaport is characterized by paved surfaces with little green space to absorb water into the ground. As a result, water directly enters the sewer system, primarily through storm drains along the streets. During heavy rainstorms, the sewer system does not have enough capacity to manage both the stormwater and wastewater and instead directly discharges the excess into the city's waterbodies, otherwise known as a combined sewer overflow (CSO) event. In the future, when outfalls are blocked from higher tides or coastal storm surges, the combined stormwater and wastewater will back up and flood onto streets and into basements because it cannot reach the surrounding waterbodies.

As part of the Financial District and Seaport Climate Resilience Master Plan, a flood defense system is proposed to protect the nearly 240-acre study area from future tidal flooding and coastal storms. For the purposes of the H&H modeling analysis, it was assumed that a flood defense system would be constructed along the existing shoreline in the project area with two tie-in locations where the flood defense system connects to higher ground to create a complete compartment of protection. In the south, the Master Plan proposes tying into high ground near Bowling Green. In the north, the Master Plan proposes tying into higher ground near the Brooklyn Bridge. While the Project Team studied several different options for both tie-ins, additional analysis and coordination with the community will be needed as part of future phases of work to define the exact tie-in locations. For the purposes of defining the drainage study area to complete the modeling analysis, a tie-in was assumed at the southern end near Battery Park and the northern tie-in near the Brooklyn Bridge on the Manhattan side.

The Financial District and Seaport drainage study area is defined as the sewer system drainage area bordered by the assumed alignment of these flood defense systems, as shown in Figure 1.

Figure 1. Study Area and Potential Alignment of Flood Defense Systems

2. Methodology

The Project Team built upon an existing H&H model provided by the NYC DEP to understand the magnitude and extent of flooding within the study area. After the Project Team updated the existing model, various drainage solutions were tested to understand the ability of each to alleviate flooding.

2.1 Modeling Software

H&H modeling software can represent water levels and flow rates within pipes (1-dimensional, or 1D) and at the surface, such as street flooding (2-dimensional, or 2D). 2D representation is important as water can travel in many paths when at the surface; the software can estimate the quantity and direction of overland flows, and ponding over time at low points. 2D representation also allows for visualization of flooding extents and depths. Innovyze's InfoWorks Integrated Catchment Model (ICM) software was selected to conduct the study to avoid converting the existing model, also built in InfoWorks ICM, to another software.

2.2 Data Sources

Table 1 lists the data sources used for the drainage study modeling effort:

Table 1. Data Sources

Data Type	Source	Purpose
Long Term Control Plan (LTCP) 1D model	New York City Department of Environmental Protection	Used as the basis for the updated 1D-2D model.
Sewer GIS Network (i.e., existing pipes, manholes, outfalls, pumps)	New York City Department of Environmental Protection	Used to build the sewer network representation in the model environment.
Surface Elevation Data	New York City 2017 digital elevation model (DEM)/Topobathymetric LiDAR from NYC Open Data[1]	Used to build a 2D flooding surface, or mesh, in the model. The mesh consists of finite, triangular elements that, when grouped together, form a continuous surface on which water can pond and flow.
Rainfall Hyetographs	National Oceanic and Atmospheric Administration (NOAA) Atlas 14, Volume 10, 2nd Quartile[2]	Used to specify the amount of rainfall over time for storm conditions.
Sea Level Rise Conditions	New York City Panel on Climate Change (NPCC) 2019 Report Chapter 3: Sea Level Rise[3]	Used to represent the effect of climate change, resulting in sea level rise, on the tide and surge conditions simulated in the model.
Wastewater Flows*	NYC DEP Calibrated LTCP Models	Used to account for wastewater flows conveyed by the sewers that occupy a portion of the sewer conveyance capacity.
Coastal Storm Conditions	Consistent with other NYC coastal resiliency projects	Used to simulate storm surge conditions in the model.

**The last calibration of wastewater flows in the study area was completed in 2017 but no change that would significantly impact this analysis is expected.*

2.3 Model Construction

The basis for the model was the existing Long Term Control Plan (LTCP) model developed by NYC DEP. The goal of the LTCP is to identify appropriate combined sewer overflow (CSO) controls necessary to achieve water quality standards.[4] The LTCP model was built to assess the amount of water discharged into waterbodies through CSO outfalls using a 1-dimensional sewer network but was not developed for flood risk assessments that consider routing of 2D surface flows. The 1D LTCP model was therefore insufficient for the drainage study due to a lack of sewer network resolution and 2D representation of flood extents. It was updated through the following steps:

[1] https://data.cityofnewyork.us/City-Government/Topobathymetric-LiDAR-Data-2017-/7sc8-jtbz
[2] https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_temporal.html
[3] https://www.nyas.org/annals/special-issue-advancing-tools-and-methods-for-flexible-adaptation-pathways-and-science-policy-integration-new-york-city-panel-on-climate-change-2019-report-vol-1439/
[4] More information about the LTCP program can be found here: https://www1.nyc.gov/site/dep/water/citywide-long-term-control-plan.page

1. The LTCP model was expanded with additional sewer network data to add higher resolution within the study area. The 1D LTCP model included approximately 30,000 feet of pipe in the study area whereas the expanded model includes approximately 45,000 feet of pipe in the study area. The updated sewer network used in this analysis compared to the existing network in the 1D LTCP model is shown in Figure 2.
2. The model was improved further through the development of a 2D surface, or mesh. The 2D mesh allowed the Project Team to visualize the extent and depth of flooding on the surface of the study area.
3. High-resolution catchment areas were delineated for the new network to identify which areas contribute stormwater runoff to individual pipes.

Figure 2. Sewer Network Buildout within Study Area

2.4 Model Validation

After building the 1D-2D model, the model was validated against results from the 1D LTCP model to confirm that the updates did not result in significant changes from the LTCP model. Under this planning-level effort, no flow monitoring data was collected in the study area to use in calibration of the model. It is recommended that a calibration be conducted in the study area based on recent flow monitoring data for future design phases.

2.5 Design Scenarios Considered

Both future high tides and coastal storm surge will block existing CSO outfalls that typically release combined stormwater and wastewater during heavy rain events, resulting in flooding behind the flood defense system if no action is taken. The Project Team considered a range of scenarios to assess the impacts of rainfall, tides, and storm surge on flooding in the study area. The scenarios considered are shown below in Table 2.

Table 2. Scenarios Considered

Scenario	Rainfall	Coastal Storm Surge, Tide, and Sea Level Rise (SLR) Condition
1	Current 5-year	Current MHHW
2	Current 50-year	Current MHHW
3	Current 5-year	100-year surge + 2100 SLR
3A	Current 5-year	100-year surge present day (no SLR)
3B	Current 5-year	2100 SLR MHHW
4	Current 50-year	100-year surge + 2100 SLR
4A	Current 50-year	100-year surge present day (no SLR)
4B	Current 50-year	2100 SLR MHHW

The Project Team studied two different-sized rain events to understand the amount of rainfall flooding that could occur in the study area. Both events were for a duration of 24-hours, consistent with approaches used for the design of other recent New York City coastal resiliency projects.

1) The first rain event considered was the present-day five-year rainstorm, meaning that it has a 20 percent chance of occurring in any given year. The Project Team chose a five-year rainstorm because NYC DEP typically designs storm sewer infrastructure for a storm of this magnitude.
2) The second rainstorm is a present-day 50-year rainstorm, meaning it has a two percent chance of occurring in any given year. Because rainstorms will become more frequent and more intense due to climate change, a present-day 50-year rainstorm was used to approximate what a future five-year rainfall event could be, based on precipitation trends.

The rainfall hyetographs, or charts illustrating the distribution of rainfall over time, are shown below in Figure 3.

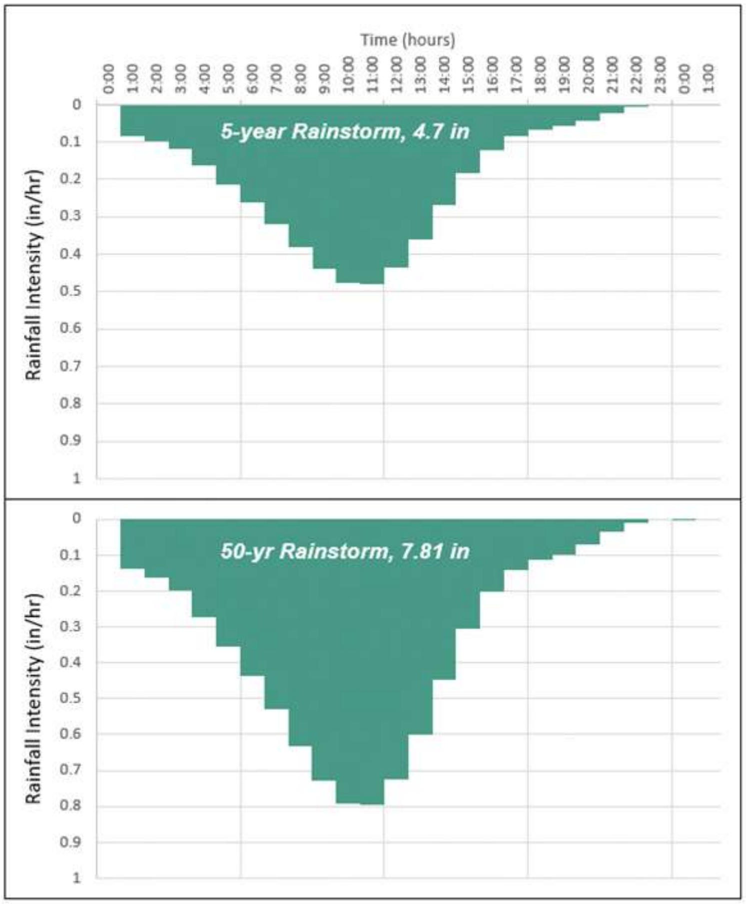

Figure 3. NOAA Atlas 14, Volume 10, 24-hour 2nd Quartile Distribution, 5-year and 50-year Rainfall

The scenarios considered the five-year and 50-year rainstorms coincident with various tide and storm surge conditions. These ranged from present-day Mean Higher High Water (MHHW) to a condition assuming a 100-year storm surge event and sea level rise projection for 2100. This combination of storm surge and sea level rise results in the peak storm surge condition shown below in Figure 4.

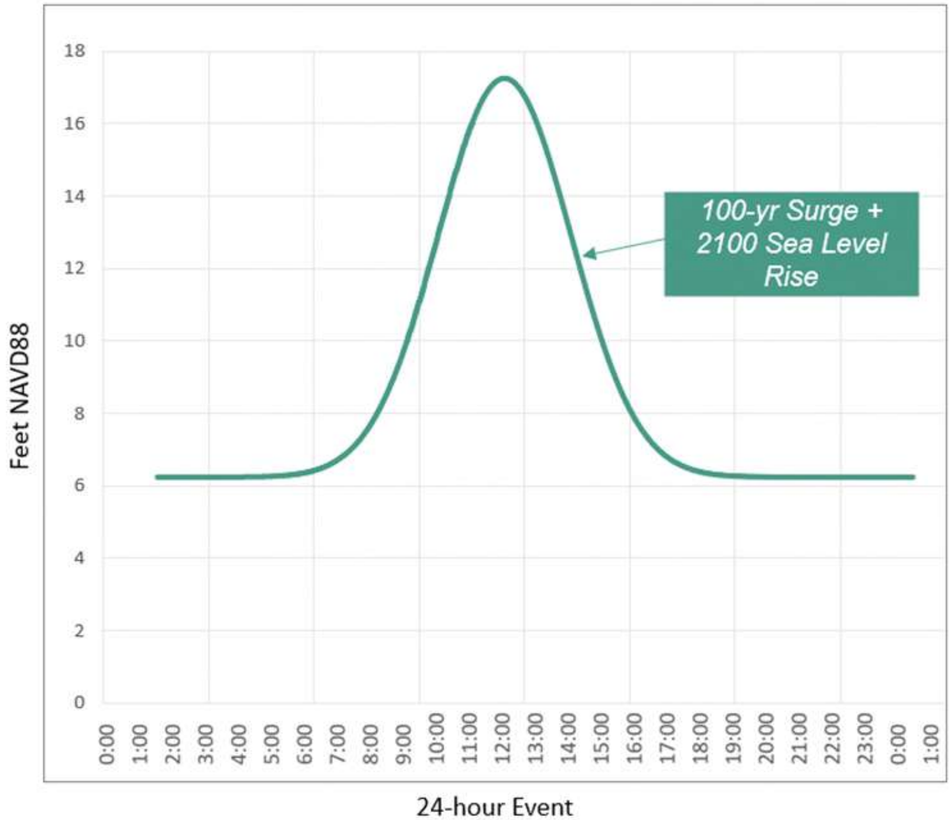

Figure 4. Simulated Water Levels in the East River in Feet (NAVD88)

The 100-year storm surge was chosen to be consistent with other NYC coastal resilience projects and the time horizon of 2100 was chosen to align with the implementation timeline of this Master Plan. Therefore, Scenarios 3 and 4 were selected as the two design scenarios considered, as presented in Table 3.

Table 3. Selected Design Scenarios

Scenario	Rainfall	Coastal Storm Surge, Tide, and Sea Level Rise (SLR) Condition
1	Current 5-year	Current MHHW
2	Current 50-year	Current MHHW
3	Current 5-year	100-year surge + 2100 SLR
3A	Current 5-year	100-year surge present day (no SLR)
3B	Current 5-year	2100 SLR MHHW
4	Current 50-year	100-year surge + 2100 SLR
4A	Current 50-year	100-year surge present day (no SLR)
4B	Current 50-year	2100 SLR MHHW

2.6 Model Assumptions

For this Master Planning analysis, the following assumptions were made:

1. The peaks for rainfall and storm surge coincide, meaning that the peaks shown in Figure 3 and Figure 4 occur at the same time. This is a conservative assumption and was implemented consistent with other ongoing New York City coastal resilience projects.

2. There are no changes in the built environment between current and future conditions (e.g., same buildings, population, acreage of open space, etc.).
3. A downstream interceptor gate would be constructed on the interceptor near the Brooklyn Bridge and this interceptor gate would be closed during the entire duration of the modeled 24-hour storm events, preventing any flow from traveling north to the Manhattan Pump Station. The duration of closure is a simplifying assumption for the purposes of this Master Plan; future design phases will further assess operation of the gate during coastal storm events. This interceptor gate is assumed as part of the Brooklyn Bridge to Montgomery Coastal Resiliency (BMCR) project, directly north of the study area, as shown in Figure 5.
4. There is a possibility that an upstream interceptor gate would be constructed between the Battery Park area and the Financial District and Seaport, and that this interceptor gate would be closed during design conditions following the same operation assumptions for the downstream gate. At the time of release of the Master Plan, it is unlikely that this upstream gate (a representative location is depicted in Figure 5) will be constructed. To understand the effect of this potential gate on the drainage solutions needed to mitigate flooding in the Financial District and Seaport neighborhoods, the model was simulated with and without the upstream interceptor gate in place to ensure that a proposed solution would work in either case.
5. The flood defense systems are infinitely high vertical flood walls, which means no storm surge overtopping of the flood defense system. Consideration of overtopping flows is recommended during future phases of the design.
6. Flood defense systems, including tide gates, are assumed to be constructed along the shoreline of the project area and in all upstream and downstream adjacent areas draining to the interceptor to prevent storm surge from reaching the sewer interceptor. This is a simplifying assumption for the purposes of this Master Planning effort.

7. Rainfall on any shoreline extension area would be managed by a combination of green infrastructure and a separate drainage system.

Figure 5. Locations of Modeled Downstream and Upstream Interceptor Gates

3. Results

3.1 Quantifying Existing Flood Risk

The H&H model was used to understand the depths and extents of flooding in conditions with and without future drainage improvements. The predicted flooding results without future drainage improvements for both the 5-year and 50-year rainstorms are presented in Figure 6. The 50-year rainstorm results in more flooding than the 5-year rainstorm, as anticipated, especially worsening in the northeast portion of the study area and along the shoreline. Proposed drainage infrastructure would be designed to mitigate the flooding presented under both scenarios.

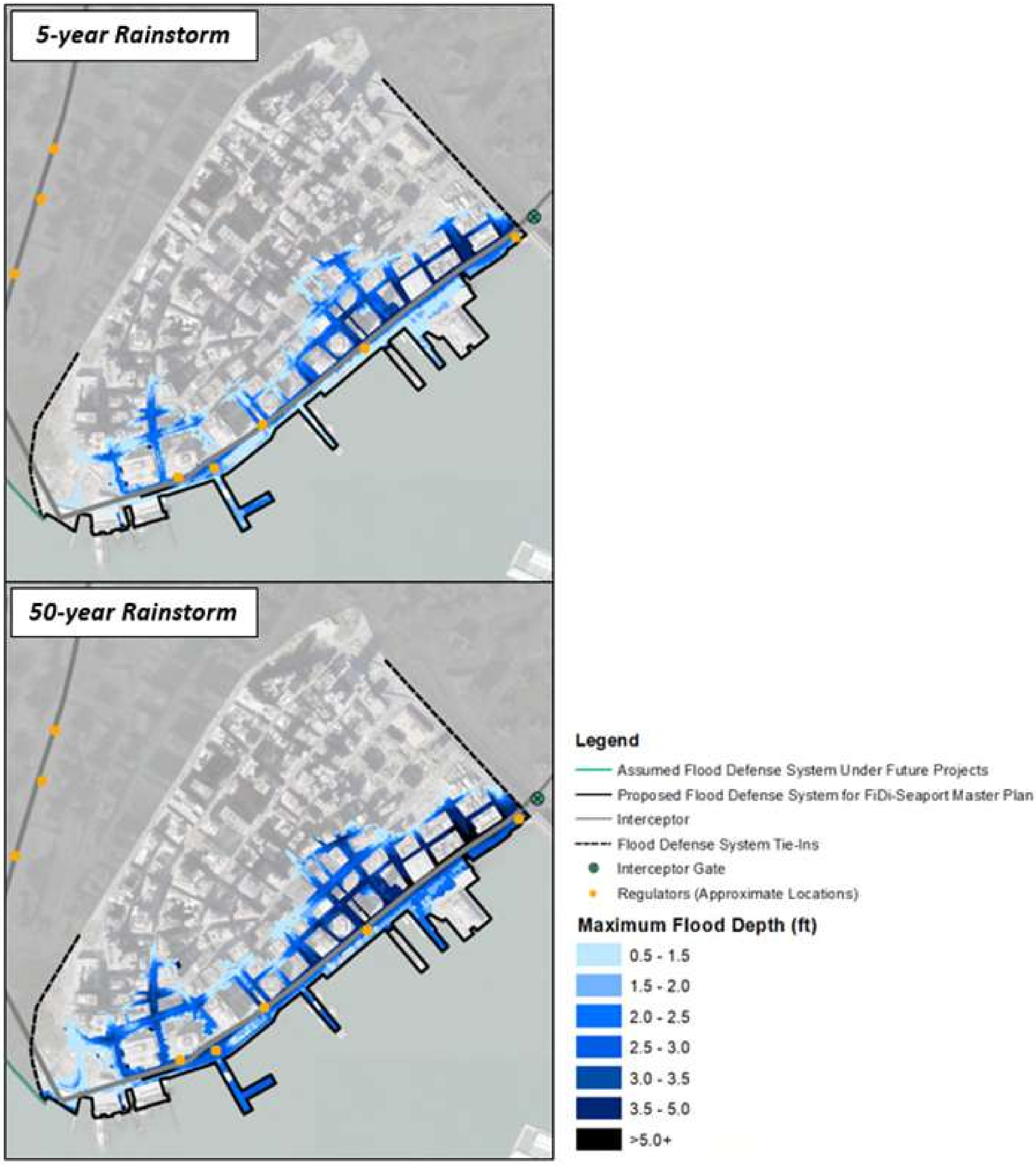

Figure 6. 5-year and 50-year Rainstorm Flooding Without Drainage Improvements

3.2 Solutions Toolkit

A toolkit of drainage solutions was developed and evaluated to mitigate stormwater flooding in the Financial District and Seaport neighborhoods. Table 4 lists and describes the options considered and presents the findings on each option after consideration or model testing.

Table 4. Stormwater Management Solutions Toolkit

Toolkit Option	Description	Findings
Green Infrastructure	Green infrastructure replicates the natural processes of capturing and infiltrating water into the ground before it enters the sewer system. These strategies serve two primary purposes: slowing and/or reducing the amount of stormwater that reaches the sewer system and filtering pollutants out of the water along the way. While it can be implemented at a smaller scale wherever possible to support larger-scale strategies, it cannot manage large volumes of stormwater associated with heavy rainfall.	Since a large quantity of water needs to be managed in the study area, green infrastructure as a standalone solution cannot mitigate the design event flooding due to space constraints and the limited capacity of green infrastructure. The Master Plan integrates green infrastructure, such as bioswales, green roofs, and permeable pavement, to manage the stormwater associated with smaller rain events before it enters the combined sewer system.
Underground Storage	Underground storage collects water during storms. The stormwater is then pumped back to the sewer system after the storm ends and sewer capacity is available. This strategy is effective when no space is available above ground, but it requires significant space underground.	Space constraints are challenging in Lower Manhattan given the complex existing network of underground infrastructure. While there are fewer utility conflicts if constructed as part of the shoreline extension, it would be very costly and complex, and insufficient to manage the amount of stormwater within the footprint needed to site flood defense. Moreover, increasing capacity in a storage facility after construction is challenging because it is underground and would require significant geotechnical and structural work, making storage facilities less adaptable to changing future conditions. Additionally, since the stormwater would be mixed with wastewater, odors may be generated by storing this mixture in underground spaces beneath streets for extended periods of time, requiring significant cleaning and maintenance. Underground storage is not proposed due to complexity, high estimated costs, and lack of future adaptability.
Pumping	Pumping moves water from lower to higher ground. Pumps push water out against high tides and coastal storm surge conditions, ensuring water does not collect behind the flood defense system. A pump station can manage a large volume of combined wastewater and stormwater within a relatively small footprint. New pipes would be needed to convey water to a pump station.	This solution was modeled and proposed as part of the drainage strategy. The Master Plan identifies several possible locations for the pump station south of Old Slip, which offers sites that minimize conflicts with existing infrastructure. The pump station requires space both above and below ground to collect water and pump it out from behind the flood defense during storm events.
Conveyance	Conveyance refers to using gravity to move water from one location to another, often through underground sewer pipes. Conveyance is a useful strategy but must be paired with other drainage strategies to discharge water to a safe location.	The Master Plan includes additional sewer pipes to bring the combined flows from areas further away to the proposed centralized pump station location to be discharged to the East River.

3.3 Key Findings

After evaluating the solutions toolkit, the Project Team modeled a pump station as a potential solution for mitigating flooding under both rainstorm conditions with coincident storm surge and sea level rise. Flooding was quantified in terms of depth and extent of ponding. All figures in this section show maximum water depth over a 24-hour event.

In the model, the proposed pump station was located at the existing United States Coast Guard (USCG) Recruiting site in Lower Manhattan at 1 South Street. Generally, constructing a pump station in the southern portion of the study area minimizes existing infrastructure conflicts. In addition to the USCG site, the area just south of Old Slip, on the proposed shoreline extension, was also considered as a potential location. The currently modeled location is representative and additional siting analysis will be completed in future design phases. Table 5 below provides a summary of key considerations for each of the two locations; however, future analysis is recommended to evaluate the technical feasibility, cost, and constructability of stormwater management infrastructure at each location.

Table 5. Future Considerations for Pump Station

Criteria	Coast Guard Location	Old Slip Location
Located on Shoreline Extension	No	Yes
Requires Property Acquisition	Yes	No

As described under *Model Assumptions*, all model simulations assumed that a downstream interceptor gate would be constructed near the Brooklyn Bridge and that this gate would be closed during the entire duration of the 24-hour design storm, preventing flow from traveling to the Manhattan Pump Station.

I. 5-year Rainstorm Results

Model simulations indicated a pump station with a capacity in the range of 100-200 million gallons per day (MGD) is required to alleviate the flooding under the 5-year rainstorm without an upstream gate, as shown in Figure 7. This pump station flow rate range is specific to the assumptions for the master planning analysis and will be refined during future phases of design. Additional short-length conveyance sewers are also proposed to convey more flow into the interceptor and to the proposed pump station; the alignment and sizing of these conveyance sewers will be further assessed under future phases of design.

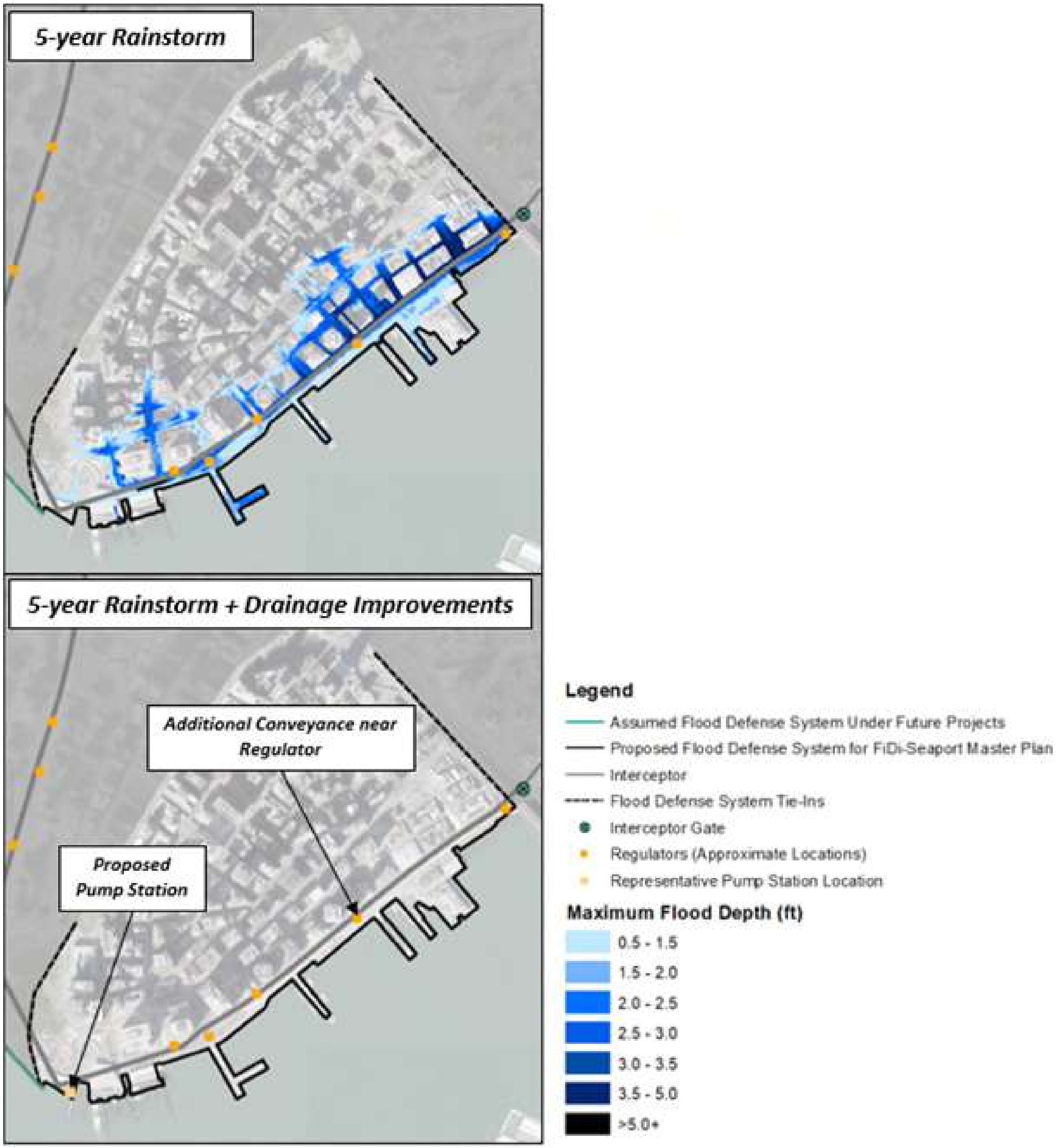

Figure 7. 5-year Rainstorm with and Without Drainage Improvements

Model results showed that only one pump station is necessary to mitigate flooding. Multiple pump stations to improve redundancy were considered but not pursued due to constructability constraints and limited available space in the study area. Additionally, fewer pump stations would reduce operational complexity. With a pump station in this general location, flow would travel backwards in the interceptor in the Financial District and Seaport area to reach the pump station during the coastal storm events for which it is operated once the downstream gate is closed. An example connection from the interceptor to the pump station is shown in Figure 8.

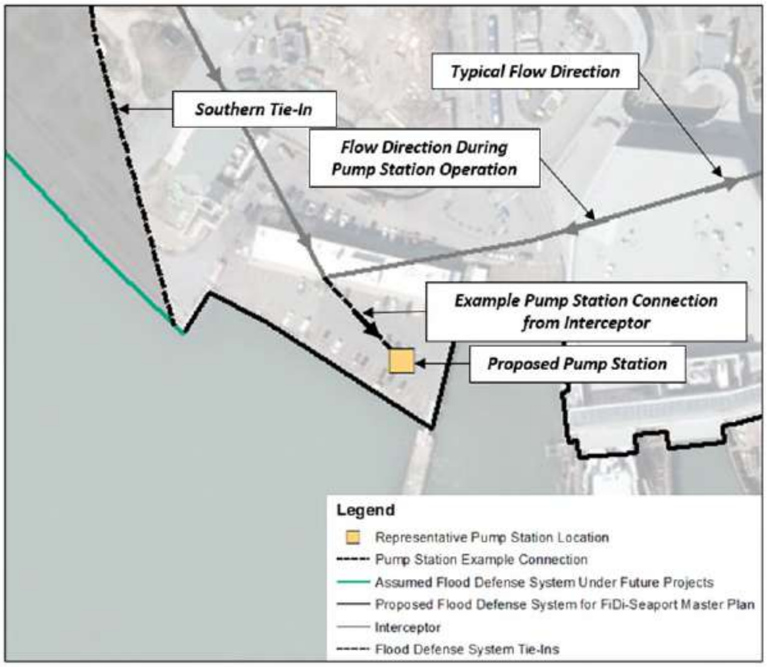

Figure 8. Example Pump Station Connection and Location

II. 50-year Rainstorm Results

Model simulations indicated a pump station with a capacity in the range of 200-300 MGD is required to alleviate the flooding under the 50-year rainstorm without an upstream gate, as shown in Figure 9. Under the 50-year event, the additional short-length conveyance sewers proposed to convey more flow into the interceptor and to the proposed pump station would need to be larger and included at three additional locations; the alignment and sizing of these conveyance sewers will be further assessed under future phases of design.

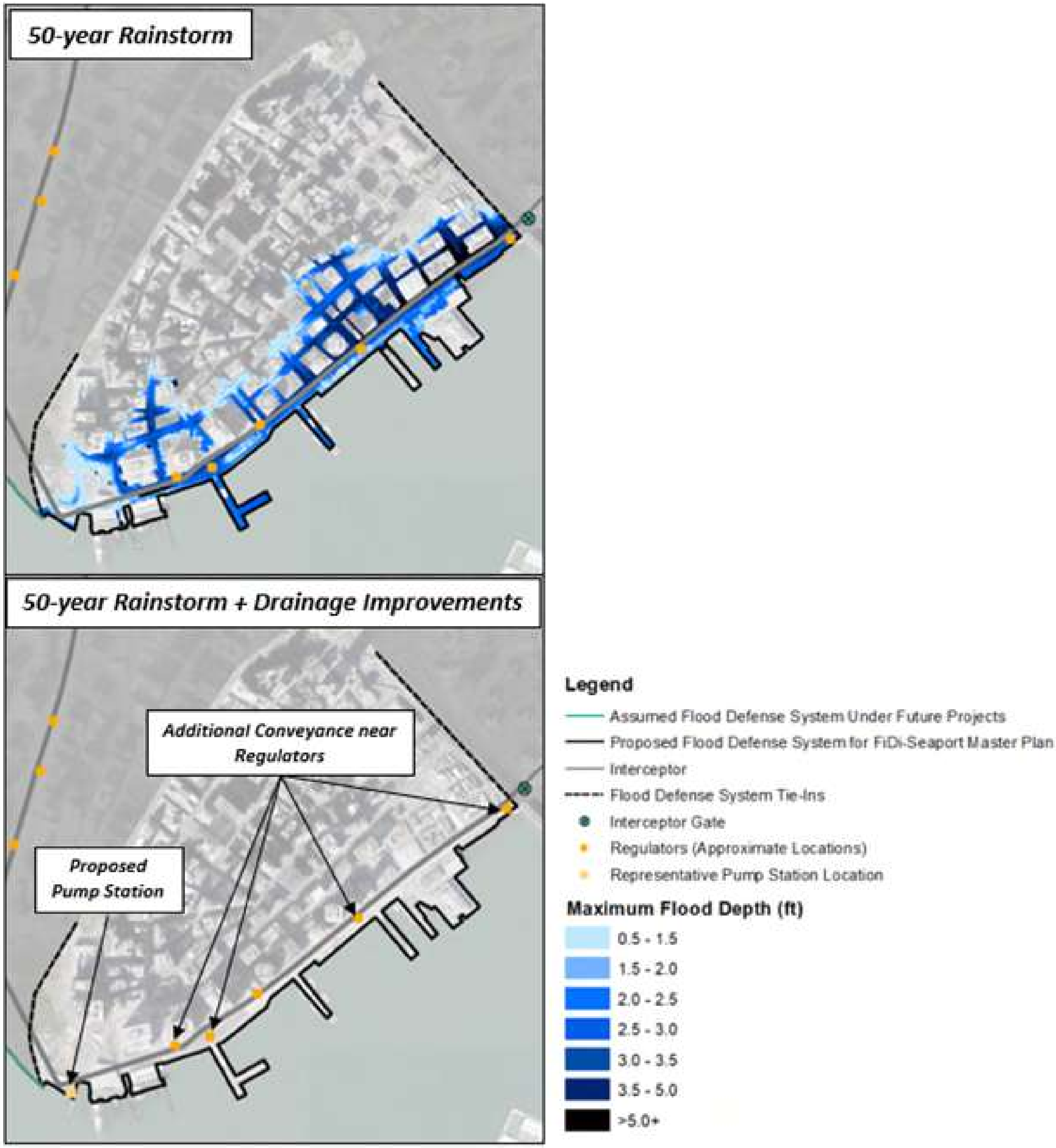

Figure 9. 50-year Rainstorm with and without Drainage Improvements

<u>Upstream Interceptor Gate Results</u>:

The solution for the 50-year rainstorm was tested with the potential upstream interceptor gate closed between Battery Park City and the Financial District and Seaport area to understand the sensitivity of the proposed drainage solution to the construction of an upstream interceptor gate. The model results indicated that, with the upstream interceptor gate in place, the required pumping capacity within the study area would decrease to the range of 75-125 MGD due to no flows entering the pump station from the upstream area.

3.4 Design Proposal & Future Work

The master plan proposes a combination of traditional gray infrastructure and green infrastructure (i.e., nature-based solutions) to manage stormwater in the study area.

Behind the flood defense system, the study area needs a new pump station and additional pipes to help route water. The Master Plan identifies several possible locations for the pump station south of Old Slip since this portion of the study area offers sites that minimize conflicts with existing infrastructure. The pump station requires space both above and below ground to collect water and pump it out from behind the flood defense during storm events. The Master Plan includes additional sewer pipes near regulator structures to bring the combined flows into the interceptor sewer and to this new centralized pump station location so that wastewater can be pumped out of the Financial District and Seaport during storm events.

To complement the pump station, the Master Plan integrates green infrastructure, such as bioswales, green roofs, and permeable pavement, to manage the stormwater associated with smaller rain events before it enters the combined sewer system. This lessens the stress placed on the existing sewer system and manages stormwater in sustainable ways. Opportunities identified as part of the Master Plan include:

- A bioswale (a shallow vegetated area designed to capture and treat stormwater runoff) corridor along the newly constructed pedestrian and bike corridor in the southern portion of the study area
- Green roofs that manage stormwater runoff on top of the proposed pump station and other buildings
- Sloped landscapes across the study area that are designed to maximize stormwater retention

The stormwater management proposal is presented in Chapter 5 of the Final Report.

In future phases of work, the stormwater management components will continue to be iteratively evaluated for constructability and cost. Evaluations will be supported by additional H&H modeling to understand the impact on performance of existing drainage infrastructure, a comparison of the two pump station site locations, and details on the sizing of individual drainage design components. Operation of future stormwater infrastructure is also a key consideration and will be assessed in future phases of work.