Gowanus Canal Storm Surge Barrier Study

Final Report

Prepared for

New York City Economic Development Corporation and the Mayor's Office of Recovery and Resiliency

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Executive Summary

The Gowanus Canal (the Canal) is a channelized water body surrounded by the Gowanus neighborhood. It is a United States Environmental Protection Agency (USEPA) Superfund Site that is planned to be remediated over the next few years. The low-lying lands on either side of the Canal are subject to flood hazard, as the Canal brings waters from Gowanus Bay inland. On October 29, 2012, Hurricane Sandy demonstrated these areas' vulnerability, with more than 150 acres of land along the Canal inundated by the storm (**Figure ES-1**).

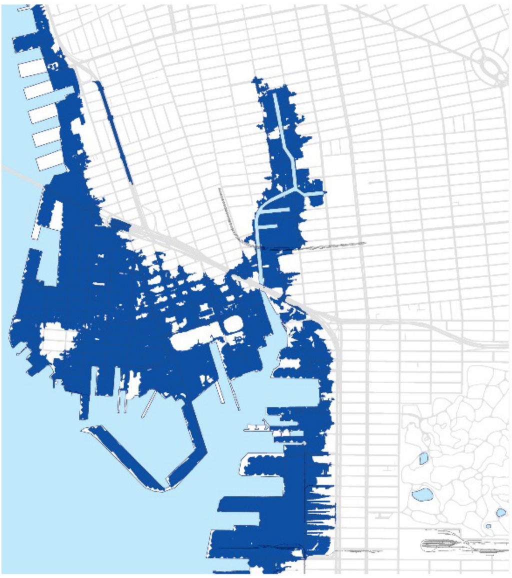


FIGURE ES-1
Hurricane Sandy Inundation in the Gowanus Area

The Gowanus Canal and Newtown Creek Storm Surge Barriers Study project is a conceptual feasibility study that may be used in assessing the need to advance to more detailed studies and could inform these studies or the project implementation that may follow. This report focuses on the Gowanus Canal Storm Surge Barrier Study. The primary study goals are as follows:

- Identify a flood protection strategy that benefits communities in the Gowanus Canal study area.
- Produce a study that complements and informs New York City (the City) and United States Army Corps of Engineers (USACE) planning activities.
- Consider opportunities for tie-ins between a Gowanus project and future resiliency projects for the adjacent communities in Red Hook and Sunset Park, including the Red Hook Integrated Flood Protection System.

To achieve these goals, the study adopted a conservative design flood elevation (DFE) of +17-foot North American Vertical Datum of 1988 (NAVD88). This DFE established the natural elevation contour to which a Gowanus Storm Surge Barrier system would extend and terminate. The study then compared multiple concept options that combined in-water barriers and upland defense systems, identifying fatal flaws for each option and evaluating each on relative cost, benefit, reliability, and ease of implementation. This comparison led to a preferred concept option of an in-water barrier near the Hamilton Avenue Bridge and upland defenses along the Hamilton Avenue right-of-way. The study then analyzed the impacts of this concept option, including high-level hydrodynamic modeling and a preliminary benefit-cost analysis, and provided a road map for implementation, including potential funding strategies and permitting considerations. The study did not include detailed design solutions.

The results of this study are intended to advance discussions with USACE, which could potentially proceed with this project on one of two pathways. On the first pathway, the project would be incorporated into and recommended by the USACE studies of the New York-New Jersey Harbor and Tributaries focus area (one of nine pilot areas identified in the USACE North Atlantic Coast Comprehensive Study), which is already authorized and is estimated to commence in the first quarter of 2016. On the second pathway, the project would not be recommended by the NY NJ Harbor and Tributaries study, leaving the study area vulnerable; USACE would therefore obtain authorization for an independent study of the project with an estimated commencement date post-2019. The start of construction and project implementation is assumed to be contingent upon the completion of Superfund remediation, implying a time horizon of 10 or more years.

The study includes numerous recommendations for next steps the City could take, including:

- Refine cost-estimating methodologies with USACE to obtain more accurate cost/benefit ratios.
- Establish flood protection funding and financing mechanisms such as assessment districts;
- Revisit the City's zoning text and flood-resistant construction requirements to develop a long-term strategy that is responsive to sea level rise;
- Implement zoning changes and coordinate planning to integrate parcels and infrastructure into a flood protection system, including further investigation into potential public-private partnerships to capture private funding through parcel development integration;
- Establish administrative processes and operational protocols for flood defenses;
- Acquire strategic parcels and easements to support flood defense projects; and
- Define an approach to surface water flood mitigation to be integrated with storm surge defenses.

The remainder of this Executive Summary poses and answers the key questions investigated by the study in order to help the City advance discussions among a variety of stakeholders, including City Hall, City Agencies, USACE, political leaders, and community members.

What is a storm surge barrier system, as envisioned at Gowanus Canal?

- A storm surge barrier system would comprise three connected parts: A. in-water barrier, B. upland defenses and C. natural elevation (at the project DFE).
- The in-water barrier location and gate type are typically selected first.
  - Location is based on a variety of siting considerations and physical constraints.
  - Gate type selection criteria include the required gate width and depth, space available for recesses or access, ease of operations, navigation height restrictions, vulnerability to damage from navigation impact, time for barrier closure, and landscape impact.
  - This study's preliminary investigation suggests that a miter gate by Hamilton Avenue could be a preferred in-water barrier type (**Figures ES-2 and ES-3)**.

FIGURE ES-2
Miter Gate: Ipswich Tidal Floodgate, UK. Single 50-foot gate.

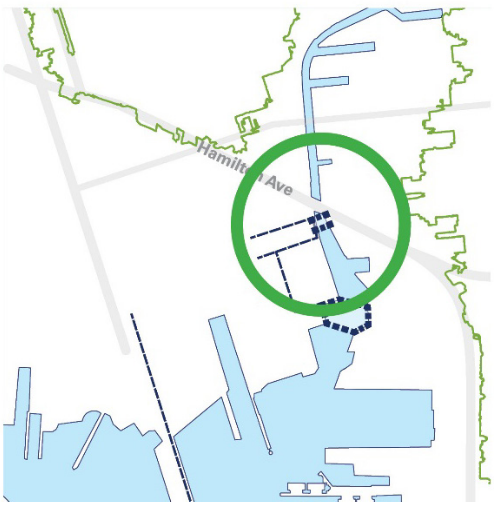


FIGURE ES-3
Hamilton Avenue In-water Barrier Location

- Following selection of the in-water barrier, upland defenses are then designed to tie the in-water barrier to natural elevations at the desired DFE.
  - Design of the alignment can be influenced by a number of factors important to the City and local stakeholders, including urban design considerations, physical constraints, environmental impacts, as well as cost.
  - Similar to in-water barrier gate selection, the type of upland defenses erected is influenced by available space, opening width and height requirements, ease of maintenance and operations, storage requirements, visual impact, cost and the trade-offs each defense type offers. While permanent components such as embankments, levees, rock revetments, and flood walls offer greater reliability, and lower operations and maintenance demands than do deployable components such as operable gates and post and panel segments, permanent features can require more physical space and can impose barriers to access and connection.

   – Given the urban context and the myriad types of activities that need to be accommodated, any storm surge barrier system is expected to combine permanent and deployable components, namely, flood walls, deployable barriers, and operable gates (**Figure ES-3**).

- The in-water barrier and any deployable components remain in the open/non-deployed position during normal day-to-day operating conditions and are closed only in lead-up to a storm event or during annual test exercises.

FIGURE ES-4
Precedent Upland Defense Types

What could a Gowanus Canal storm surge system protect?

- A storm surge barrier system could successfully limit risk at the Gowanus Canal up through a 500-year storm event, based on a +17-foot NAVD88 DFE, and enable the City to achieve three essential goals:
   – Protecting Socially Vulnerable Residents.
      - The Protected Area (all properties that would be inundated during a 500-year flood event without the project, but would not be inundated with the project) surrounding the Gowanus Canal is home to 7,000 residents, many of whom are low-income inhabitants and face other challenges indicating social vulnerability, and most individuals live in older buildings not built to flood-resistant standards. Furthermore, if the area were to be rezoned to allow more residential development, as has been proposed by local elected officials, its population would grow considerably, particularly within the 100-year flood zone.
      - Many local residents share demographic characteristics that indicate a particular vulnerability to the challenges posed by storm surge and other hazards. Nearly half live in the Gowanus Houses, a New York City Housing Authority (NYCHA) development with more than 1,100 apartments. The Protected Area also contains Mary Star of the Sea, a 100-unit building for low-income seniors.
      - Half of all families in the Protected Area earn less than $60,000 a year, and more than 40 percent earn less than $40,000 annually, indicating higher levels of poverty than the City as a whole, where approximately 36 percent of families earn less than $40,000 a year.

  - Including the Gowanus Houses, approximately 90 percent of all residential units are in buildings constructed before 1961, when the New York City Zoning Resolution led to the construction of buildings more resistant to flood damage.

- Protecting Jobs and Businesses.
  - Gowanus is a unique mixed-use neighborhood, with more than 100 traditional and innovative industrial businesses and a thriving arts community in close proximity to residences. Although overall density of commercial activity is low, there are still more than 2,500 jobs in the Protected Area. Many jobs are in industrial sectors, performing critical functions within the local economy and providing employment opportunities for persons with low educational attainment or limited English language proficiency, as well as minority and immigrant populations.
  - Across all sectors, the 350 businesses and 2,600 employees in the Protected Area generate more than $2 billion in direct annual economic output and earn nearly $670 million in compensation. Applying economic multipliers, this direct economic activity generates nearly 15,200 jobs, $1.1 billion in earnings, and $3.2 billion in total output.

- Protecting Critical Infrastructure.
  - The Protected Area includes the F and G train subway lines, which run above ground along 9th Street between Smith Street and 4th Avenue, but have vulnerable entrances; the elevated Gowanus Expressway viaduct that runs over Hamilton Avenue; operable bascule bridges crossing the Gowanus Canal at Hamilton Avenue, 9th Street, 3rd Street, Carroll Street and Union Street; as well as a handful of water treatment/power stations, fuel and waste stations and food manufacturing facilities.

What other benefits could a Gowanus Canal storm surge barrier system convey?

- *Protection beyond current standards*. While Appendix G of the New York City Building Code requires flood-resistant construction for new or substantially improved buildings in the 100-year flood zone, the storm surge barrier system would offer extra flood protection since it incorporates additional freeboard (a safety factor that compensates for factors such as wave action that could contribute to higher flood heights exceeding those calculated for a select flood condition) and an adjustment for sea level rise. The 2015 New York City Panel on Climate Change report projects that, due to climate change, the 100-year flood in the 2050s may reach an elevation up to 2.5 feet higher than today's 100-year flood. A building built to code today would flood under these circumstances, but a storm surge barrier system built to the 17-foot design elevation would still offer protection. Similarly, today's standards do not protect against the less frequent but more severe 500-year flood event, with a 15-foot elevation, while the flood barrier would.
- *Reduced flood insurance and avoided mandatory floodproofing costs*. A storm surge barrier project could help community members realize substantial savings through both reduced flood insurance premiums and avoided mandatory floodproofing costs.
- *Habitat enhancement*. Crevices and habitats could be designed into a barrier structure or bulkhead surfaces could be supplemented with material to promote bivalve or crab colonization.
- Additional benefits that could be conveyed to the City and its residents that should be studied in detail as part of a complete feasibility study include:
  - Avoided loss of life and injuries.

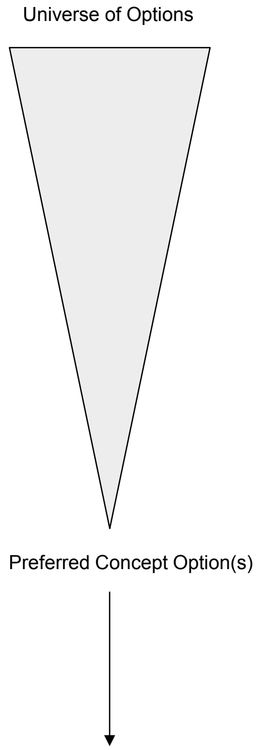
- Avoided evacuation costs.
- Avoided relocation costs.
- Avoided business interruptions.
- Preserved services and protected infrastructure.
- Pedestrian/bicycle improvements.
- Green infrastructure secondary benefits.

How real is a Gowanus Canal storm surge barrier project?

The Gowanus Canal Storm Surge Barrier Study follows from other New York City resiliency studies that are ongoing or nearing completion and that have worked to open and advance discussions with USACE. Unlike some other similar studies, there is currently no funding identified in the City's 10-year capital program for a Gowanus Canal storm surge barrier system. However, given the importance of the two industrial waterways and the dynamic changes taking place around them, the City has elected to study potential storm surge barriers and to envision how resiliency efforts in these locations might look. Any potential project would be very expensive and very complex, as it would tie into the pre-existing urban fabric. However, by starting to advance thinking now, and engaging with USACE from the onset, the intent is to set up and position the study so that the City can transition the work to USACE to carry forward as USACE undertakes and completes its NY NJ Harbor and Tributaries study.

What did the Gowanus Canal Storm Surge Barrier Study explore?

At this conceptual stage, the objective was to identify fatal flaws and determine whether a storm surge barrier system, consisting of both an in-water storm surge barrier and upland defenses, could be a possible solution for the City or USACE to further investigate and consider. High-level preliminary analysis was completed to answer, or in some cases, identify for future investigation, critical questions around how a potential flood defense system could tie into the existing, dynamic urban fabric, and how a system would intersect with the City's operational partners. Detailed design solutions were not a part of the study's scope, but rather, a roadmap has been developed for next steps should the study outputs be transitioned and advanced. This roadmap includes suggestions for further site and engineering investigations, stakeholder engagement, permitting and regulatory considerations, funding and financing approaches, and policy implications. The study process is summarized in **Figure ES-5**.



- **Two-stage Comparative Evaluation Process**
  - **Part I: In-water barrier screening**
    - Coarsely evaluate and compare potential barrier locations
    - Funnel study towards more feasible barrier locations around which to develop the upland defense schemes
    - Address key siting considerations
  - **Part II: Comparative alignment screening**
    - Evaluate potential concept options (in-water + upland connections) relative to each other to identify preferred concept option
    - Consider costs, benefits, reliability and implementation
    - High-level assessment. Quantify or evaluate metrics and convert to relative comparative scores where applicable
- **Project Analysis**
  - High-level hydrodynamic modeling: storm surge, flushing and rainfall assessment
  - Preliminary benefit-cost analysis
  - Local funding strategies
  - Implementation and permitting

FIGURE ES-5
Study Process

This study used a filtering approach to develop and consider a number of alternative concept options. Initially, the analysis identified three potential in-water barrier locations. One concept option was dropped from consideration based on a number of major weaknesses. The two remaining concept options advanced to the development stage where the potential for upland defense tie-ins to natural elevation were assessed.

Three alternative concept options were developed around the two in-water barrier sites to explore different issues with which the City or USACE might grapple should a project be pursued beyond this conceptual study. These options included one along the bulkhead on the west edge of the Canal, and one along the Hamilton Avenue right-of-way (ROW) alignments. Each alignment offered different strengths and weaknesses, and highlighted tradeoffs and challenges that add to the overall understanding of the opportunities and complexities entailed in adopting a storm surge barrier system as part of the City's overall approach to flood defenses and resiliency. The screening outcomes are summarized in **Figure ES-6**.

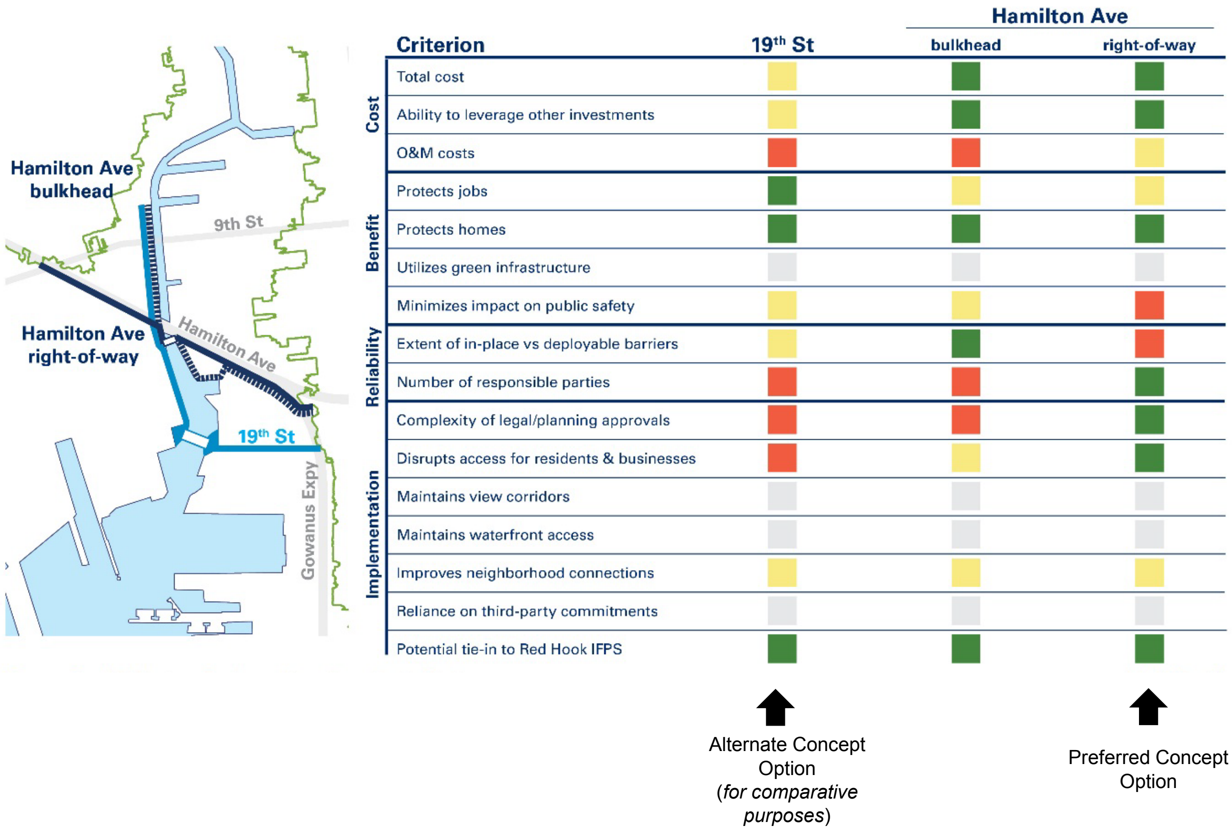


FIGURE ES-6
Concept Option Comparative Screening Results

What is the preferred Gowanus Canal storm surge barrier system concept option?

Based on the evaluation screening, discussions with the New York City Economic Development Corporation (NYCEDC) and the Mayor's Office of Recovery and Resiliency (ORR), and feedback from City agencies, the Hamilton Avenue Right-of-Way (ROW) concept option was selected for additional analysis as the preferred concept (**Figure ES-7**).

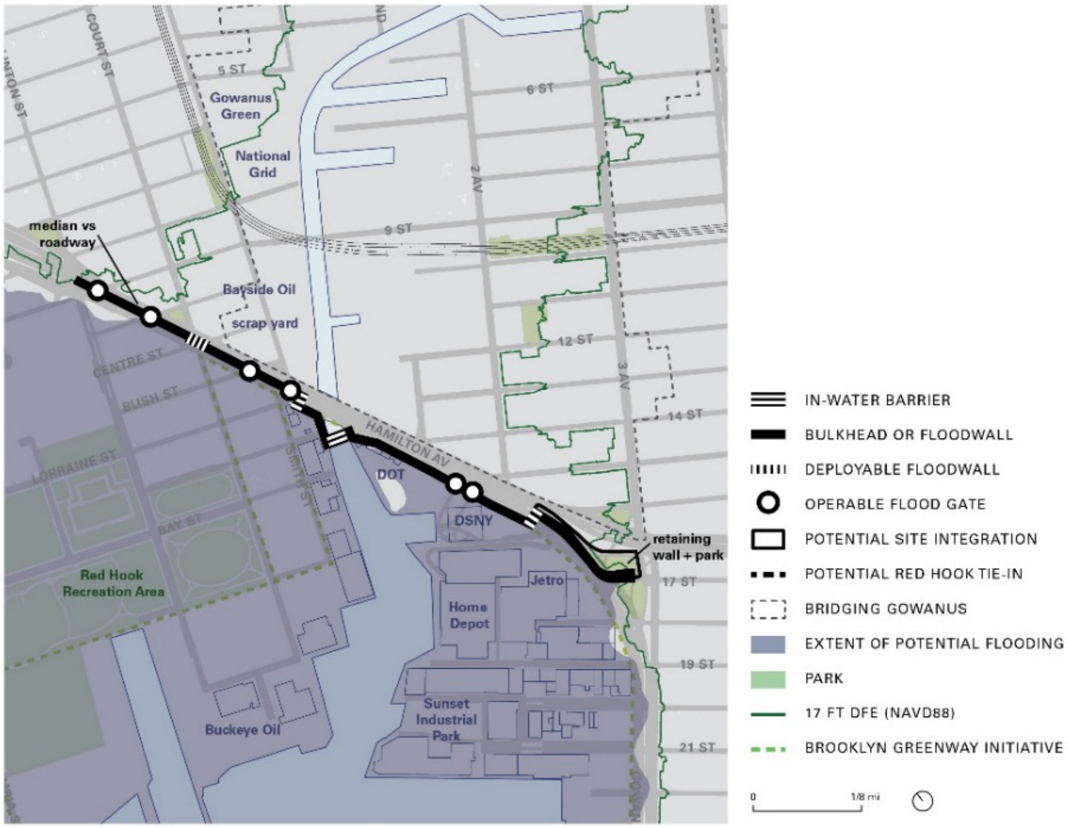


FIGURE ES-7
Preferred Concept Option: Hamilton Avenue ROW Alignment

- Some of the benefits and implications of the preferred concept option include the following:
  - It minimizes disruption to business activities by avoiding active berths and driveways to the extent possible. Operable gates ensure access to essential facilities, such as the New York City Department of Transportation (NYCDOT) Asphalt Plant and the City of New York Department of Sanitation (DSNY) Marine Transfer Station (MTS).
  - Compared to other alternatives, it has a simpler legal and planning process as it is erected almost entirely in the public right of way (ROW), and includes potential for integration with existing infrastructure under the Gowanus Expressway.
  - There is potential to integrate with the future greenway along Hamilton Avenue that may run along the southernmost lane and for which the upland defenses could provide a buffer from vehicular traffic.
    - It is anticipated that it could convey a positive return on investment for the City and its partners, though the Protected Area is limited geographically and a more detailed study would be required for a definitive answer. The preliminary Benefit-Cost Ratio (BCR) at this conceptual stage was found to range between 0.59 and 1.15. The range reflects the sensitivity of the project benefits to the replacement structure values used in quantifying avoided damages and the variation in construction estimation data sets such as Marshall & Swift (M&S) as compared to local construction market intelligence. Capital costs are estimated at $108 million.

  - Operations and maintenance (O&M) costs are estimated to be $626,000 on an annualized basis or $15 million on a 50-year present value basis.
  - The present value of expected annual damages (EAD) for the 50-year period of analysis, the benefits, are $74 million or $3.1 million annualized.
  - Net benefits are estimated at ($52) million based on one data set. However, the value of avoided damages relies significantly on the real estate construction values used and could be substantially greater.
  - Construction estimation data sets, such as M&S, understate the value of avoided damages. A future detailed feasibility study should include research and verification of market construction values for New York City.
  - Greatest uncertainty and cost risk are likely to come from barrier gate sizing, stormwater pumping or storage requirements (an allowance accounting for approximately 57% percent of the in-water barrier conceptual cost estimate including contingencies, or approximately 28% of total storm surge barrier system costs, was made at this study stage), utility and service diversions, environmental remediation separate from Superfund works, Red Hook tie-in requirements, land acquisition, and legal challenges. These are areas that should be further investigated at a complete feasibility study stage beyond this initial study.
  - The benefits reflected in the BCR are limited to avoided damages. The future feasibility study stage should expand the criteria to capture and monetize the broader set of benefits.
- The major weakness of the Hamilton Avenue ROW alignment is its reliance on deployable components and the associated O&M requirements, however, given the existing urban fabric and activities at the Gowanus Canal, any storm surge barrier system option will require some deployable components.
  - Mobilization activities in a storm event are more complex and require more lead time than a permanent barrier solution.
  - Nearby equipment storage areas would need to be identified.
- Easements or land acquisition to support access and operations are likely to be required. The two most critical sites are those adjacent to the east and west of the Hamilton Avenue Bridge. The first 90 to 100 linear feet of berth at the asphalt plant would be behind the barrier and lost to barge use.

What alternative concept option might be considered for a Gowanus Canal Storm Surge Barrier?

The alternate concept option is the 19th Street alignment (**Figure ES-8**). It was analyzed for purposes of comparison and completeness, but the challenges of tying into the natural elevation on the eastern terminus near 3rd Avenue make this option less desirable.

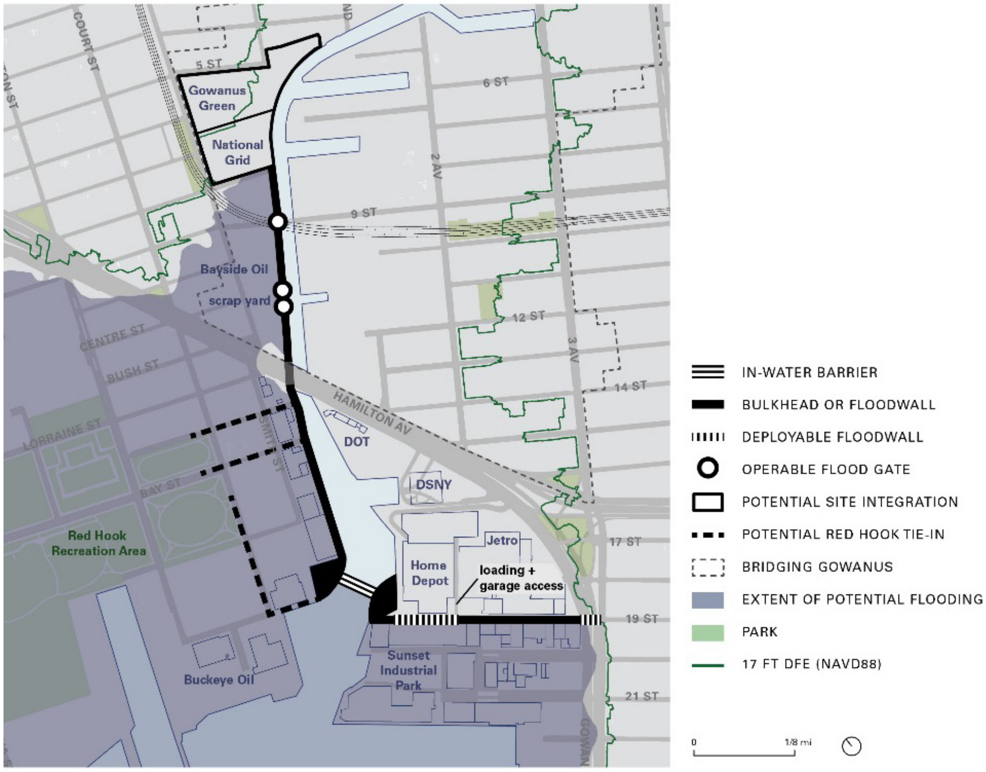


FIGURE ES-8
Alternative Concept Option: 19th Street Alignment

- It has major adverse impacts on commercial and industrial activities in the area, including operable gates across active berths, and significantly alters movement along 19th Street. Parking, loading spaces, and 19th Street access to Sunset Industrial Park would be lost.
- It has a more complex legal and planning process and would require easements along private waterfront parcels and additional coordination with the Superfund remediation works.
- Despite substantially larger estimated capital costs, the 19th Street alignment is not anticipated to convey proportionally greater benefits. The preliminary BCR at this conceptual stage was found to range between 0.47 and 0.93.
  - There is very little difference in the zones of protection provided by the 19th Street and Hamilton Avenue ROW concept options, and, even using larger locally adjusted construction values to calculate the avoided damages, this alternate concept option fails to achieve a BCR approaching or exceeding one.
  - Capital costs are estimated at $160 million.
  - O&M costs are estimated at $739,000 on an annualized basis or $17.7 million on a 50-year $ present value basis.
  - The present value of expected annual damages (EAD) for the 50-year period of analysis, the benefits, are $86 million or $3.6 million annualized.
  - Net benefits are estimated at ($97) million, but could be substantially greater in value when local construction market values are factored into the analysis.

What is the relationship between the Gowanus storm surge barrier system and the Red Hook Integrated Flood Protection System?

Since the Integrated Flood Protection System (IFPS) has funding allocated, it is assumed although not certain that the IFPS would precede any project in Gowanus, and would eventually tie into a Gowanus Canal flood defense system. Depending upon the alignment adopted in the Red Hook project, an eventual Gowanus Canal project could have different tie-in points, or may ultimately have lower capital costs than described in this study if the required extent of the upland defenses decreases.

What level of storm surge risk reduction will a Gowanus Canal storm surge barrier system provide?

- As part of coordination and initial planning between the City and USACE for a full feasibility study, a policy decision will be required to set the DFE and the level of risk reduction for the project to achieve.
  - This study assumed a conservative +17-foot NAVD88 DFE for the upland defenses and a +21-foot NAVD88 DFE for the in-water barrier. This includes allowances for freeboard and sea level rise. (**Figure ES-9**). Sea level rise allowances reflect the New York City Panel on Climate Change's 2015 findings that forecast mid-range (25^{th} – 75^{th} percentile) changes in sea level rise of 11-24 inches by the 2050s and 18-39 inches by the 2080s.
  - Federal policy may dictate that funded would only be provided for a DFE lower than that assumed in this study. This could impact minimum design elevations and funding limits.
  - City preference for greater risk reduction may require a Locally Preferred Plan, in which the City is financially responsible for capital costs above and beyond the USACE plan. Alternatively, the City might consider a gradual approach, expanding the barrier and increasing the height over time.
  - The study DFE and analysis is based on the FEMA 2013 FIRM (Flood Insurance Rate Map) data. During the course of this study, after much of the project analysis had been completed, the City filed an appeal asserting that FEMA's updated FIRMs overstate Base Flood Elevations. In general, in the case that the City's appeal is successful, and less conservative FIRMs are issued, it is anticipated that the estimated benefits, as well as capital costs could decrease as a lower DFE requirement would be anticipated. This caveat is not study specific, but rather, is applicable to all City resiliency studies whose assumptions have been based off the FEMA 2013 p-FIRM data.

FIGURE ES-9
Study Design Flood Elevations

How vulnerable would the Gowanus Canal storm surge barrier system be to sea level rise?

- The preliminary storm surge modeling found no overtopping of the barrier system up through today's 500-year storm event and today's 100-year storm event plus 3 feet of SLR (assumes the 2015 New York City Panel on Climate Change's 50th percentile SLR value for 2100). As with any storm surge defense system, over time, as sea level rise occurs and the frequency and level of flood events changes, a storm surge barrier system's DFE may be raised and the system expanded to respond to changing risk.

Would a Gowanus Canal storm surge barrier worsen flooding or water quality?

- The preliminary storm surge modeling performed as part of this study found that the potential storm surge barrier system did not increase the risk of flooding to properties outside of or adjacent to the barrier due to storm surge.
- This study did not perform detailed drainage modeling or analysis of stormwater pumping stations or storage options. Instead, a preliminary, high-level analysis of rainfall and storage capacity was performed in order to point to the need for future investigations and to anticipate required stormwater infrastructure. This preliminary capacity analysis found that longer duration storms likely cannot be contained within the Canal when the gate is in the closed position beginning at low tide (maximum storage capacity scenario). In the open/non-deployed position, the storm surge barrier system would not impact existing stormwater drainage.
  - In this simplified analysis, storms larger than the 1-hour, 1-year event rainfall volume were not contained within the canal/creek system.
  - Stormwater pump stations will almost certainly be required as part of a storm surge barrier system to pump rainwater out of the creek over the barrier. Conceptual cost estimates built up for this study have made an allowance for an additional stormwater pump station for all concept options, but the requirements could be significantly larger.
  - A detailed surface water and drainage study would need to be performed as part of a complete feasibility study and a policy/design determination made as to the appropriate barrier design condition—expressed as the joint probability of a particular rainfall event occurring at the same

time as a particular storm surge event. Such a study should consider ongoing New York City Department of Environmental Protection (NYCDEP) efforts to increase capacity, improve CSO outfalls, and alleviate stormwater flooding that occurs periodically in parts of the study area during heavy rains.

- A high-level flushing analysis found that in-water barriers do not appear to worsen the tidal exchange at the Gowanus Canal. The flushing tunnel appears to provide sufficient flow to offset any marginal effects from the barrier.

How will operations and maintenance responsibilities be handled for a Gowanus Canal storm surge barrier?

- A Gowanus Canal storm surge barrier project is just one of many Citywide resiliency efforts and a Gowanus project will be preceded by many other storm surge protection projects, including the adjacent one being planned for Red Hook. O&M protocols and roles and responsibilities will be in place long before project implementation.

How have City, Stakeholder, and community concerns been addressed by the study?

- For this stage of preliminary fatal flaw analysis, stakeholder engagement was limited to City and State agencies, including NYCDEP, NYCDOT, New York City Department of Parks and Recreation (NYCDPR), New York City Department of City Planning (NYCDCP), New York City Department of Housing, Preservation and Development (NYCHPD), New York State Department of Transportation (NYSDOT), and USACE. Community engagement would be conducted should a Gowanus project proceed beyond this conceptual study stage. That said, in order to highlight trade-offs and build on community feedback the City had gathered previously, a broad array of evaluation criteria, reflecting City and community interests, were considered when identifying potential in-water barrier locations and in developing the upland defenses. These criteria included navigation, interface with developments, impacts to waterfront access and view corridors, disruptions to the business and residential communities, the ability to attract or leverage private investment or other publicly financed projects, the ability to achieve Federal Emergency Management Agency (FEMA) certification, protected jobs and affordable housing, share of green infrastructure, protection of critical infrastructure and impact on public safety.
- Any project at the Canal will present challenges. It will face a complex regulatory and permitting process comprising federal, state, and City reviews and approvals; require major investment; and demand close coordination with agencies, regulatory bodies, and the community to foster a better understanding of the risks and the tradeoffs at stake in adopting a solution. Stakeholder and community engagement will play an important role in any USACE-led feasibility study. Specific topics expected to be explored as part of outreach and engagement at such a future stage include the following:
  - The ultimate configuration of a Red Hook alignment, which would likely be constructed prior to any Gowanus Solution, will dictate where tie-ins between the two flood defense systems are ultimately placed. Early coordination efforts during the planning stages for the Red Hook IFPS can help to ensure that future Gowanus connections are considered.
  - Plans for Superfund remediation within the Canal are underway. Coordination with USEPA, NYCDEP and other parties involved with the Gowanus Canal Superfund remediation work should take place. There may still be opportunities for bulkhead improvements and overall design work, especially around the barrier locations where the channel depth is expected to increase

between 10 and 20 feet, to be designed to accommodate the in-water storm surge barrier, as well as any floodwalls that run along the Canal edge.

- Engagement with the Gowanus Canal communities to explain the challenges and trade-offs associated with erecting a flood defense system in such a vibrant and dynamic community will be a vital component of building allies and public acceptance for a storm surge barrier project to be successful. Community members and developers will want to know about design impacts on access to businesses, residences, the planned Greenway extension, and parking, as well as impacts to adjacent neighborhoods and the surface water flooding that affects areas of the community during heavy rains.
- FEMA certification, essential to realizing flood insurance savings, requires that a flood protection system be owned and maintained by a community participating in the National Flood Insurance Program or an agency created by such a community. Where any site elevation components are pursued as part of a flood defense scheme or components of a flood defense system are incorporated across privately owned parcels, easements will need to be obtained in order to ensure 24-hour access to berms, barriers or operable gates and for maintenance activities. Early engagement with FEMA officials can help ensure the City meets its objectives for certification and savings for property owners.
- The potential for integration with existing infrastructure. For example, the Hamilton Avenue retaining wall could offer an opportunity to leverage other public investment and reduce the need to erect new infrastructure. Based on preliminary information from NYSDOT, the retaining wall on Hamilton Avenue by 17th Street could be integrated, provided that it was reinforced and waterproofed. Future coordination with NYSDOT would be required should this opportunity advance.
- In addition, preliminary discussions with NYCDOT suggested the Hamilton Avenue ROW concept option might integrate the upland defense system with the proposed greenway to provide a buffer between the greenway and vehicular traffic. The incorporated floodwall and upland defense options could have architectural attributes. For example, rather than erecting a solid concrete floodwall, higher segments could be topped with three feet of high-strength glass flood wall panels. Murals or other artistic elements could also be incorporated to create a safer, more inviting environment.
- Easements or land acquisition to support access and operations are likely to be required. For the Hamilton Avenue alignment, the two most critical sites are those adjacent to the east and west of the Hamilton Avenue Bridge to ensure access to the in-water barrier. For the 19th Street concept options where a floodwall or gate runs across a driveway or waterfront, easements would be required onto private parcels to ensure 24-hour access to operable gates and for maintenance activities. In places where defense systems run across private property, there are typically two gates, with the public agency operator having its own key and point of entry.
- The preferred level of protection for the NYCDOT asphalt plant and the DSNY Marine Transfer Station ultimately needs to be decided. There are variations of the concept options that could afford differing levels of protection and access. Maintaining the line of defense along Hamilton Avenue and ensuring site access via operable gates would be the most efficient from a cost and engineering perspective, if leaving either site outside the line of defense is a tolerable approach. Altering the line of defense to protect these sites would add to the overall design complexity and cost in order to minimize impact to the busy operations across active berths and the additional length of required upland defense running along the bulkhead.

   - Storage of demountable components is a consideration for any upland defense alignment that incorporates them. There might be space within the NYCDOT asphalt plant or the DSNY MTS that could accommodate storage of posts, panels, and other equipment. Alternatively, as noted above, the City might consider acquiring nearby property for storage and O&M activities.

How could a Gowanus Canal storm surge barrier system be funded?

- The estimated capital costs for the storm surge barrier system are $108 million and under USACE funding guidelines, the City would be responsible for 35 percent of capital costs, or $38 million. The City would also be responsible for O&M costs, with an annualized estimate of $634,000; the present value of this annualized cost is $15 million. Thus, the total cost to the City of protecting this area is just more than $50 million.
- An assessment district is one potential funding path. Many of the benefits of a storm surge barrier system accrue to private property owners, and the City would therefore be justified in trying to capture some of this value to meet part of its obligations for 35 percent of capital funding and all O&M costs. Furthermore, the Gowanus community has expressed an interest in raising local infrastructure funds through a value capture tool, in view of the fact that the Bridging Gowanus plan recommended a tax increment financing district.
   - A conceptual model of a more general assessment district suggests that this tool may be a promising source of funds for O&M because districtwide net benefits would far exceed the required assessment, and average assessment rates would be well under 1 percent of assessed value.
   - However, raising a significant share of capital costs would likely not be justified based on the benefits accrued and would represent relatively high financial burdens.
- Capital cost reductions through new urban design requirements and leveraging private investment are a second potential funding pathway which may be available for specific sites. Potential actions include:
   - Publicly Owned Sites:
      - Establish design standards for new parks and streets.
      - Invest in elevating existing parks and streets.
      - Require development of city-owned parcels to integrate into a flood defense system.
   - Privately Owned Sites:
      - Require private redevelopment that is still in need of City action or approvals to integrate into a flood defense system.
      - Approach as-of-right redevelopment site developers about the potential for site integration into a flood defense system.

What future investigations are anticipated to be included in a detailed feasibility study?

- Future studies, investigations, and analyses that are anticipated to be scoped into a detailed feasibility study in order to refine cost and benefit estimates include, but are not be limited to:
   - Elevation spot checks of LIDAR (aerial laser topography) data as part of storm surge modeling.
   - Comprehensive drainage and water quality modeling, including combined probability analysis of storm surge and rainfall events.

  - Sampling and detailed environmental site investigations on parcels along the storm surge barrier alignment.
  - Utility investigations and as-needed service diversions or relocations studies.
  - Real estate studies and plan.
  - Benefit valuation methodologies to reduce uncertainty around local replacement construction values as well as interruption impacts.
  - Expanded benefits quantification and monetization, such as avoided relocation costs, avoided business interruptions, preserved services and protected infrastructure, and green infrastructure secondary benefits.

What is the potential implementation timeline for a Gowanus Canal storm surge barrier system?

- Two potential pathways are currently envisioned:
  - A. The project is incorporated into the USCAE NY NJ Harbor and Tributaries study, which is estimated to begin in the first quarter of 2016; or
  - B. The project is not recommended by NY NJ Harbor and Tributaries study, the study area is left vulnerable by the recommended regional project, and, therefore, a separate study authorization is pursued with an estimated commencement date post-2019.
- The start of construction and project implementation is assumed to be contingent upon the completion of Superfund remediation, implying a time horizon of 10 or more years.
- Other uncertainties likely to affect timing are the potential need for a stable environmental baseline period post-remediation, the complexity of multi-agency coordination, and the timing of Congressional Authorizations for funding.

What can the City do in lead-up to a project and to strengthen its overall city-wise resiliency efforts?

- There is much that the City can do to prepare for a storm surge barrier system, including:
  - Establish flood protection funding and financing mechanisms, such as assessment districts or zoning changes and coordinated planning to integrate parcels into a flood protection system.
    - Further study into a potential assessment district should examine the legal process, the distribution of benefits and financial burden and the relationship to other public policy goals.
    - Interagency discussions should continue to investigate the potential for private parcel site integration and new urban design standards as means for reducing public capital contributions.
  - Develop a long-term strategy that considers how sea level rise and adaptation tie into the City's zoning text and flood-resistant construction requirements.
  - Refine cost-estimating methodologies with USACE.
  - Build support with both local stakeholders and congressional representatives.
  - Establish administrative processes to improve the efficiency of approvals, permits, and implementation for flood defense projects.

- Establish protocols, roles and responsibilities for O&M of a storm surge barrier system that will comply with FEMA certification requirements.
- Acquire strategic parcels and easements as part of a real estate plan developed to support flood defense projects.
- Define an approach to surface water flood mitigation that can be integrated with storm surge defense projects.

Conclusion

Gowanus is a unique mixed-use neighborhood with an industrial waterfront and a high concentration of low-income residents both in the Gowanus Houses and in private residences. Residents and businesses face significant flood risk from storm surge, and a barrier system has the potential to alleviate this risk.

Although a storm surge barrier system may still be more than a decade from construction, the City can act now to increase the project's likelihood of success. The first step is for the City to recognize the broad array of benefits that could accrue beyond those recognized by USACE. Next, by refining valuation methodologies and aligning public investments and regulatory tools to reduce project costs, the City can increase the project USACE BCR and the likelihood of federal funding. Finally, by employing a value capture tool, the City can limit the amount of public funding that will be necessary to realize this flood protection.

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Acronyms and Abbreviations

2D	two-dimensional
AIS	Automatic Identification System
ASA/CW	Assistant Secretary of the Army for Civil Works
BCR	benefit-cost ratio
BFE	base flood elevations
BID	Business Improvement District
Canal	Gowanus Canal
CEQR	City Environmental Quality Review
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
City	New York City
COC	constituent of concern
CSO	combined sewer overflow
DDF	depth-to-percent damage function
DFE	design flood elevations
DRV	depreciated replacement value
DSNY	City of New York Department of Sanitation
EAD	expected annual damage
EIS	environmental impact statement
FEMA	Federal Emergency Management Agency
FIA	Flood Insurance Administration
FIRM	Flood Insurance Rate Map
GIS	geographic information system
HAZUS	FEMA Hazards United States model
HEC-FDA	Hydrologic Engineering Center’s Flood Damage Assessment model
HUD	Department of Housing and Urban Development
IBO	Independent Budget Office
IBZ	Industrial Business Zone
IDC	interest during construction
IFPS	Integrated Flood Protection System
kV	kilovolt
LCC	Locally Preferred Plan
LTCP	Long-Term Control Plans

M&S	Marshall & Swift Valuation Service
mg/L	milligram per liter
MGP	manufactured gas plants
MOTF	Modeling Task Force
MTS	marine transfer station
NACCS	USACE's North Atlantic Coast Comprehensive Study
NAPL	non-aqueous phase liquid
NAVD88	North American Vertical Datum of 1988
NED	National Economic Development
NEPA	National Environmental Policy Act
NER	National Ecosystem Restoration
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NPCC2	New York City Panel on Climate Change
NPL	National Priorities List
NPV	net present value
NWI	National Wetland Inventory
NYC	New York City
NYCDEP	New York City Department of Environmental Protection
NYCDEP	New York City Department of Environmental Protection
NYCDOT	New York City Department of Transportation
NYCDPR	New York City Department of Parks and Recreation
NYCEDC	New York City Economic Development Corporation
NYCHA	New York City Housing Authority
NYCOER	New York City Mayor's Office of Environmental Remediation
NYCRR	New York Codes, Rule and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOT	New York State Department of Transportation
NYSOEM	New York State Office of Emergency Management
O&M	operations and maintenance
OEM	Office of Emergency Management
OLTPS	Office of Long-Term Planning and Sustainability
OMB	Office of Management and Budget
OMRRR	Operation, Maintenance, Repair, Replacement, and Rehabilitation
ORR	Office of Recovery and Resiliency

OSE	Other Social Effects
p-FIRM	preliminary Flood Insurance Rate Map
PMP	Project Management Plan
PPA	Project Partnership Agreement
PV	present value
PVC	polyvinyl chloride
RED	Regional Economic Development
ROD	record of decision
ROW	right-of-way
SFHA	Special Flood Hazard Area
SLR	sea level rise
TBC	Tug & Barge Committee
ULURP	Uniform Land Use Review Procedure
USACE	United States Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VOC	volatile organic compounds
WOPC	without project condition
WPCP	water pollution control plants

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Part I:
Project Overview and Baseline Information

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1 Project Overview

1.1 Study Goals and Objectives

The Gowanus Canal and Newtown Creek Storm Surge Barriers Study is a conceptual study that may be used in assessing the need to advance to more detailed studies and could inform these studies or the project implementation that may follow. This report focuses on the Gowanus Canal Storm Surge Barrier Study. The primary study goals are to:

- Identify a flood protection strategy that benefits communities in the study area.
- Produce a study that complements and informs City of New York (City) and United States Army Corps of Engineers (USACE) planning activities.
- Consider opportunities for tie-ins between a Gowanus project and future resiliency projects for the adjacent communities in Red Hook and Sunset Park, including the Red Hook Integrated Flood Protection System.

The Gowanus Canal Storm Surge Barrier Study follows from other New York City resiliency studies that are ongoing or nearing completion and that have worked to open and advance discussions with the USACE. Unlike some other similar studies, there is currently no funding identified in the City's 10-year capital program for a Gowanus Canal surge barrier. However, given the importance of the industrial waterway and the dynamic changes taking place around it, the City has elected to study potential storm surge barriers and to envision how resiliency efforts in these locations might look. Any potential project would be very expensive and very complex, as it would tie into the pre-existing urban fabric. However, by starting to advance thinking now, and engaging with the USACE from the onset, the intent is to set up and position the study so that the City can transition the work to the USACE to carry forward as the Corps undertakes and completes its NY/NJ Harbor and Tributaries Feasibility Study.

At this conceptual stage, the objective is to identify fatal flaws and determine whether a surge barrier flood defense system, consisting of both an in-water storm surge barrier and upland defenses, may be a possible solution for the City or USACE to further investigate and consider. High-level preliminary analysis is being completed to answer, or in some cases, identify for future investigation, critical questions around how a potential system could tie into the existing, dynamic urban fabric, and how a system would intersect with the City's operational partners. Detailed design solutions are not a part of the study's scope, but it provides a roadmap for next steps should the study outputs be transitioned and advanced. This includes suggestions for further site and engineering investigations, stakeholder engagement, permitting and regulatory considerations, funding and financing approaches, and policy implications.

1.2 Engineering Goals

The overarching engineering goal for this study is to design a system, at a conceptual level, to reduce the risk of flooding during extreme events. This study developed and assessed a number of alternative concept options for the study site. As conceived, such a system, and thus each concept option, would comprise three connected parts:

A. In-water barrier
B. Upland defenses
C. Natural elevation

For the purpose of the preliminary study phase, a conservative approach has been employed to establish design flood elevations (DFE). As potential projects advance to subsequent stages, such as feasibility analysis and potential implementation—especially by USACE—the DFE typically undergoes an engineering review and economic assessment. This process maximizes the level of protection for a given level of investment and provides a policy review to determine the level of protection the City ultimately wants. However, for this conceptual evaluation stage, where the objective is to identify and understand the broad array of anticipated challenges and complexities that might be encountered, the conservative approach has been adopted.

In accordance with the guidance outlined in Sections 2.4 and 2.5 of this report which describe the Federal Emergency Management Agency (FEMA) and USACE design requirements, the DFE for the in-water storm surge barrier is based on the FEMA 2013 preliminary-Flood Insurance Rate Map (p-FIRM) 500-year flood elevation of +15-foot North American Vertical Datum of 1988 (NAVD88). Allowance is provided for 3 feet of freeboard and 3 feet of sea level rise for a total elevation of +21-foot NAVD88 DFE. The DFE for the upland defenses is based on the FEMA 2013 p-FIRM 100-year flood elevation and allows for 3 feet of freeboard and 2 feet of sea level rise for a DFE of +17-foot NAVD88 DFE. The sea level rise allowances reflect the New York City Panel on Climate Change's 2015 findings that forecast mid-range (25^{th} – 75^{th} percentile) changes in sea level rise of 11-24 inches by the 2050s and 18-39 inches by the 2080s. This difference between the in-water barrier and upland defense DFE reflects the difficulty and expense of retrofitting an in-water barrier as compared to future-proofing the upland defenses. For the storm surge barrier, this includes not just raising the gate height, but expanding the foundations, operational equipment, and support infrastructure—which is much more challenging than expanding upland defense systems. This conservative approach, with differences between the in-water and upland DFE, is commonly employed in Europe as well.

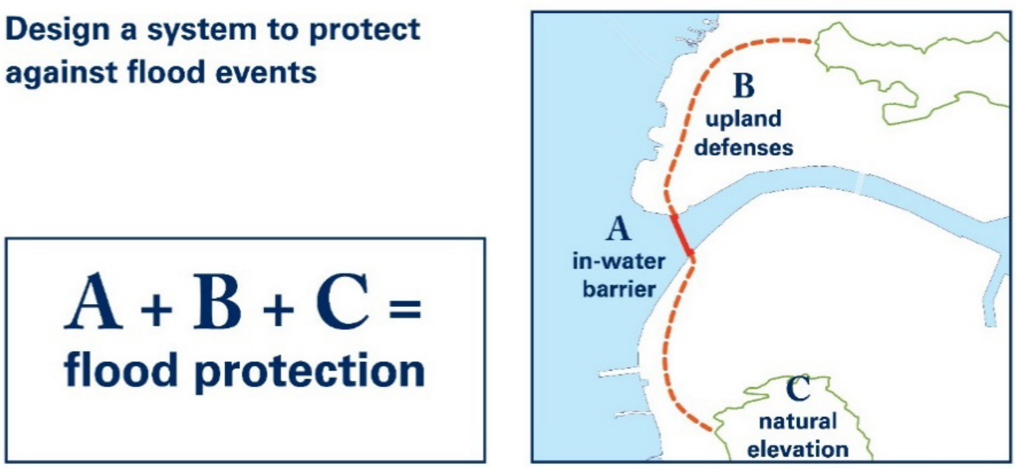

FIGURE 1-1
Storm Surge Barrier System Components

FIGURE 1-2
Study Design Flood Elevations

As shown in **Figure 1-3**, the boundaries of the +17-foot NAVD88 DFE for the Gowanus Canal are roughly along Hamilton Avenue to the southwest, then running northeast from Court Street and Hamilton Avenue to Bond and Third streets, before veering northwest to Smith and Bergen streets. The eastern boundary for the +17-foot NAVD88 catchment area runs mostly along 3rd Avenue. While the study treats a potential Gowanus solution as a stand-alone project, a potential storm surge barrier system could also protect the adjacent Red Hook and Sunset Park neighborhoods, and this has been considered in evaluating different in-water barrier locations. The Red Hook Integrated Flood Protection System (IFPS) project has funding. Thus the assumption is that it would precede any project in Gowanus, but that a Gowanus Canal flood defense system could tie into a Red Hook IFPS.

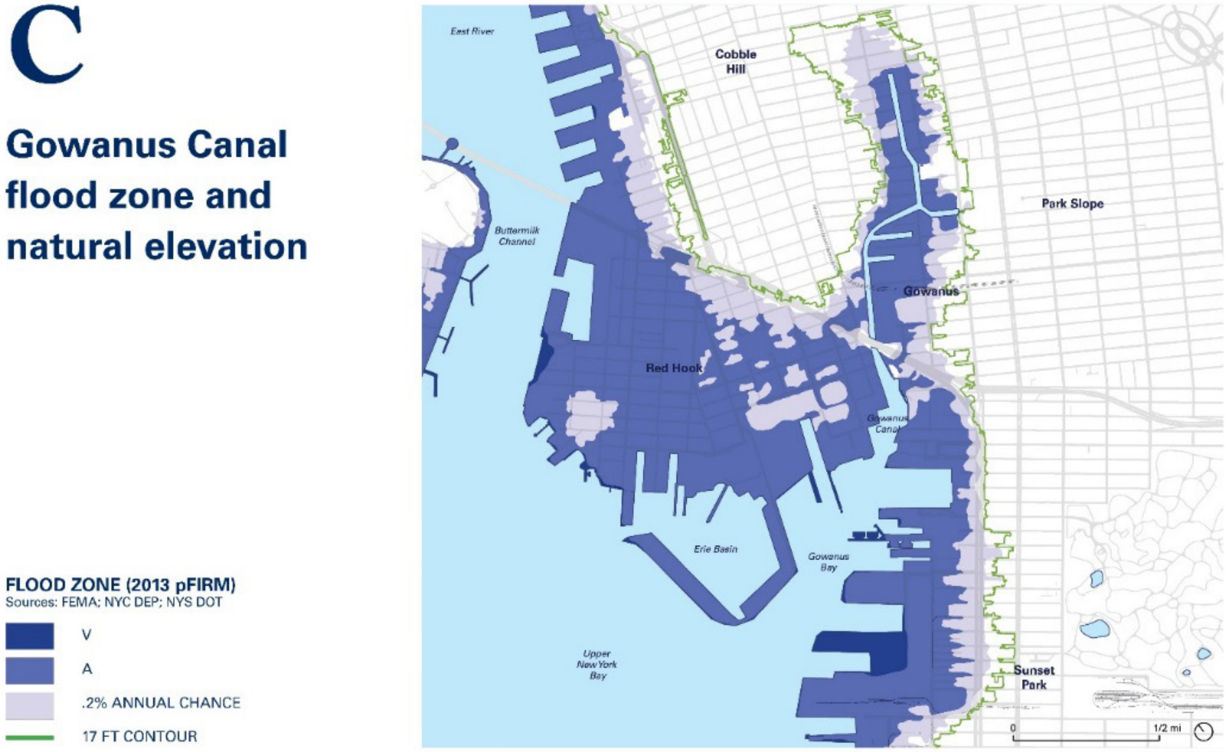

FIGURE 1-3
Gowanus Canal Flood Zone and Natural Elevation

During the course of this study, on June 26, 2015, after much of this study's analysis had been completed, the City of New York filed an appeal of FEMA's preliminary flood insurance rate maps following an independent review that identified scientific and technical errors in FEMA's modeling approach. The City's appeal argues that FEMA's 2015 p-FIRMs overstate base flood elevations (BFEs) by more than 2 feet in many areas of New York City and have unnecessarily placed 26,000 buildings and 170,000 residents in the Special Flood Hazard Area.

The Gowanus Canal Storm Surge Barrier Study methodology uses the FEMA 2013FIRM data as the basis of the analysis. Throughout this report and subsequent deliverables, caveats and discussions are provided around potential implications of a reissuance of FEMA's 2015 p-FIRMs at a future date on this study's findings and analyses.

In general, in the case that the City's appeal is successful, and less conservative FIRMs are issued, it is anticipated that the estimated benefits, especially around avoided damages, would be lower than those calculated in this study. At the same time, estimated capital costs would also be expected to decrease as a lower DFE requirement would be anticipated. This caveat is not study specific, but rather, is applicable to all City resiliency studies whose assumptions have been based off the FEMA 2013 p-FIRM data.

1.3 Influences on Alignment Development

The study looked at existing conditions as well as lessons learned and best practices from other storm surge barrier projects. These conditions and themes generally fell into four priority areas, which include:

- Protect lives and livelihoods.
- Support an active and healthy waterfront.
- Integrate flood protection into neighborhoods.
- Facilitate funding for a flood protection system.

Combined, these considerations influenced the siting analysis and the principles guiding concept option development. Many of the considerations are reflected in the evaluation framework developed for the study and described in more detail in Section 3 of this report. Within the study's evaluation framework, they have been translated into evaluation categories consistent with the USACE planning regulations framework for purposes of consistency and potential transition. Discussion around the siting considerations and evaluation criteria is presented in Section 6 and Section 8 where the in-water storm surge barrier and the concept option assessments are described.

Some factors, such as Superfund remediation work, environmental conditions, habitat creation or impact, and future development potential, influence timing and implementation.

1.3.1 Protect Lives and Livelihoods

Protection of lives and livelihoods considers residential, commercial, and industrial land use to assess where the people and jobs are located within the study sites. The category also considers the location of critical infrastructure for which a potential storm surge barrier system could eliminate or reduce the risk of damage by flooding.

As far as land use, the profile of the two study sites are almost opposite. Gowanus Canal is primarily industrial at the mouth of the waterway, with residential land use further upstream. The specific zone of protection corresponding to the alternative concept options is presented and compared in subsequent sections of this report for both the 100 and 500-year flood zone. A zone of protection is defined as the area that is inundated without the project, but is not inundated with the project, according to hydrodynamic modeling (see Section 9). Appendix N contains the complete tables of socioeconomic benefits, as well as sources and methodology.

Within the 100- and 500-year flood zones surrounding Gowanus Canal, there is a sizeable community that could be protected, depending upon the ultimate alignment of a storm surge barrier system. Relative to New York City overall, this community's population has a similar proportion of children (20 percent are under age 18, compared to 21 percent across the city) and seniors (9 percent older than the age of 65 compared to 12 percent). The population also has a smaller percentage of racial and ethnic minorities, as 63 percent are white non-Hispanic, compared to just 33 percent of the city. There are relatively fewer low- and moderate-income residents in the area compared to the city overall, with 15 percent and 28 percent of families earning below $40,000 and $60,000 a year respectively, compared to 36 percent and 51 percent for the city as a whole. For the 500-year flood event, the ages of the protected populations are similar, but in the larger area the racial and ethnic composition is very similar to the city as a whole, with around two-thirds of residents being non-white or Hispanic. The 500-year protected area has a slightly greater concentration of low- and moderate-income residents than the city as a whole, with 41 percent of families earning less than $40,000 a year (36 percent citywide) and 54 percent earning less than $60,000 (51 percent citywide).

The Gowanus Canal vicinity is part of the Southwest Brooklyn Industrial Business Zone (IBZ), which is home to 11 percent of all jobs in IBZs citywide. For all of the concept options, there is a job density of around 40 jobs per acre, quadruple the job density along the New York City waterfront, considering jobs per acre in the 2007 FIRM 100-year flood zone. Furthermore, the industrial job density of more than 18 jobs per acre is more than 6.5 times that of the city as a whole. Business density is also high, at almost 4 per acre, more than triple the city average. With more than 300 buildings and 3.3 million square feet of built area (3.9 million square feet for the 19th Street option), the protected areas are 60-70 percent more densely built than the general New York City waterfront, as measured by the 2007 FIRM 100-year flood zone.

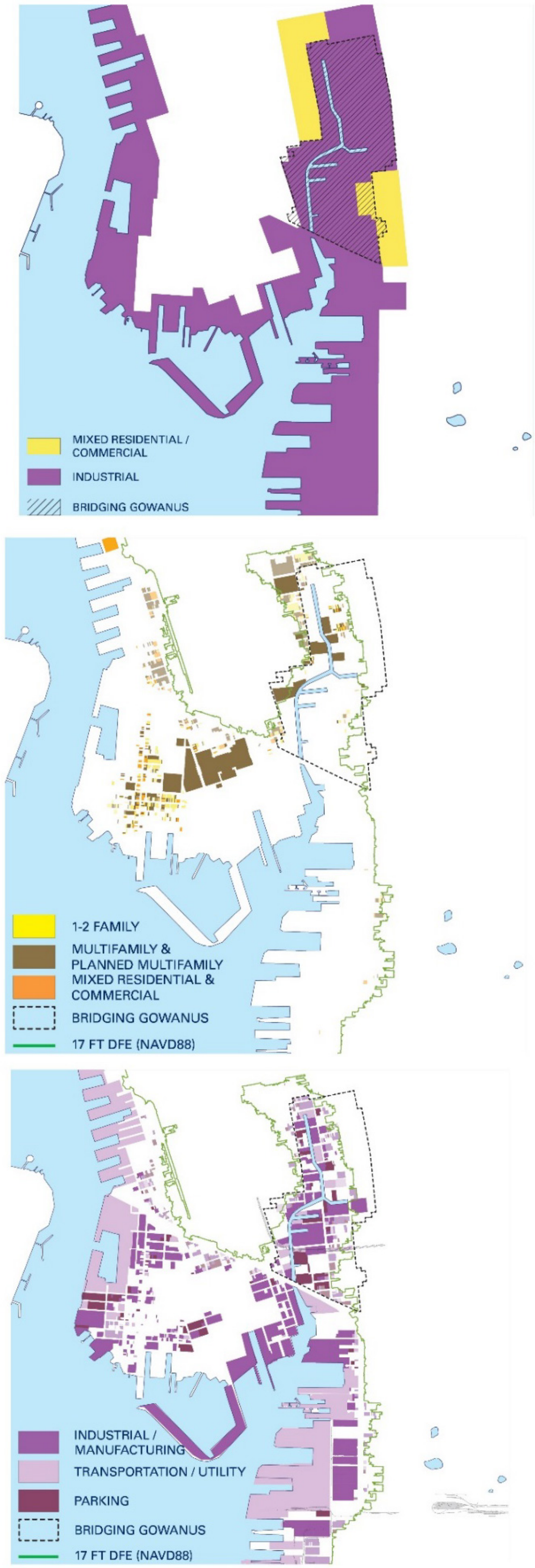

FIGURE 1-4
Gowanus Canal Existing Conditions

Critical infrastructure at Gowanus Canal that could be affected by flooding includes:

- The F and G train subway lines, which run above ground along 9th Street between Smith Street and 4th Avenue, but have vulnerable entrances, as well as the D, N, and R lines, which run underground along 4th Avenue.
- The elevated Gowanus Expressway viaduct that runs over Hamilton Avenue. There are a number of operable bascule bridges crossing Gowanus Canal, including Hamilton Avenue, 9th Street, 3rd Street, Carroll Street, and Union Street.
- The City of New York Department of Sanitation (DSNY) Marine Transfer Station at Hamilton Avenue and New York State Department of Transportation asphalt plan directly adjacent to the Hamilton Avenue Bridge.
- A number of water treatment/power stations, fuel and waste stations, and a handful of food manufacturing facilities located within the study area.
- A major high-voltage cable shown on navigation charts, extending from the east side of Gowanus Bay, around 25th Street, out through the mouth of the bay.

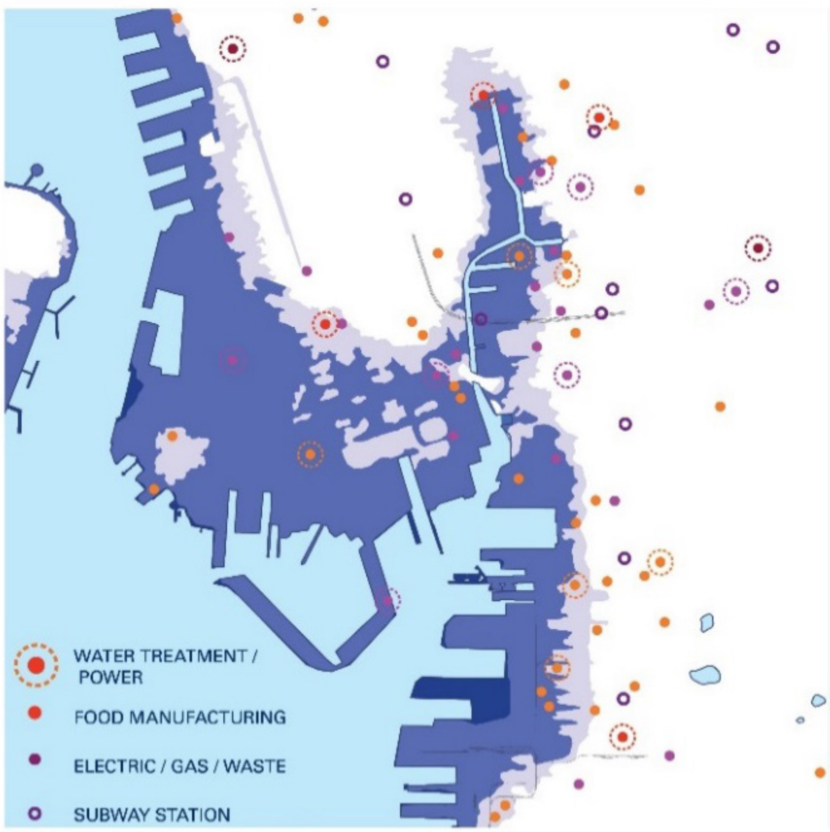

FIGURE 1-5
Gowanus Canal Critical Infrastructure Sites

1.3.2 Support an Active and Healthy Waterfront

Ensuring that any potential storm surge barrier system supports an active and healthy waterfront requires consideration of current and future waterway usage. This includes understanding current vessels operating in the waterways both in terms of size and maneuvering. The study team conducted preliminary discussions with New York City Department of Environmental Protection (NYCDEP) and the Tug & Barge Committee (TBC) of the Maritime Association of the Port of New York and New Jersey to get initial feedback on navigation constraints and possible in-water storm surge barrier locations. The study team also reviewed a one-month sample data set of vessel tracking at Gowanus Canal. Moffat & Nichol collected the Automatic Identification System (AIS) data set for an ongoing bulkhead-raising study it is conducting for NYCEDC.

Support for an active and healthy waterfront must also consider potential impacts to the existing water quality and marine habitat. The study team performed flushing analyses for the with-project situation to assess potential impacts to water exchange by an in-water storm surge barrier. Marine habitat surveys were also undertaken to assess existing conditions and potential impacts. It is recognized that existing conditions will change post-Superfund remediation work and that a future detailed feasibility study would be anticipated to consider such changed conditions.

A guiding principle applied to the development of all of the concept options is to minimize any potential adverse water quality impacts by maintaining the current cross-sectional width to the degree possible. More detailed discussion of these considerations and analyses is provided in Section 6.2, *Storm Surge Barrier Assessment,* and Section 9, *Hydrodynamic Modeling, and in the Appendices*.

1.3.3 Integrate Flood Protection into Neighborhoods

Given the active and dynamic nature of the Gowanus neighborhood, and in particular, the level and types of street activity, integrating a potential upland flood defense system at any location poses challenges and complexities. The requirement of tying into high ground at the +17-foot NAVD88 DFE requires that any concept option will require at least some segment that connects with or runs along public right-of-way (ROW).

Erecting a flood-defense system in or adjacent to a street leads to design questions about how an upland flood-defense system would interfere with or could work around a variety of street elements, including on-street parking, sidewalks, bicycle lanes, street light distribution, street trees, curb cuts, drainage and utility systems, building entrances and exits, and loading docks. From a day-to-day City operations perspective, there are challenges associated with fire and life safety emergency access, roadway maintenance, snow removal, street cleaning, and waste collection.

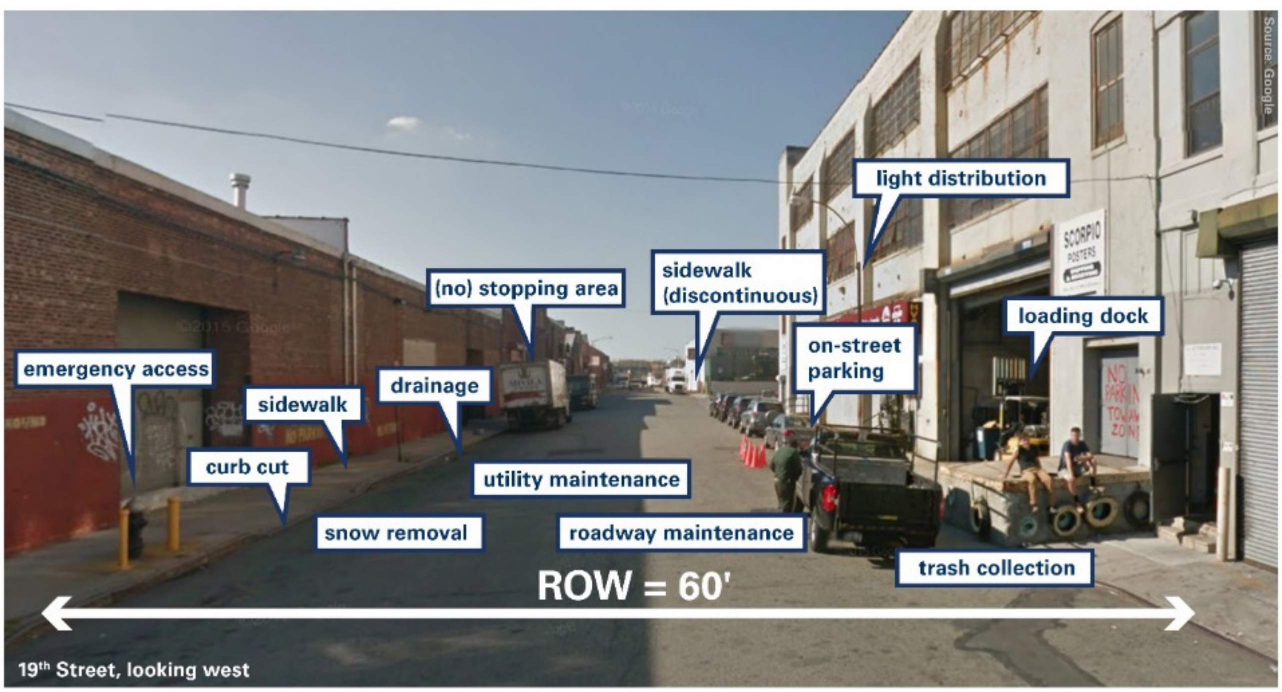

FIGURE 1-6
Profile of Commercial Street Activity

FIGURE 1-7
Profile of Residential Street Activity

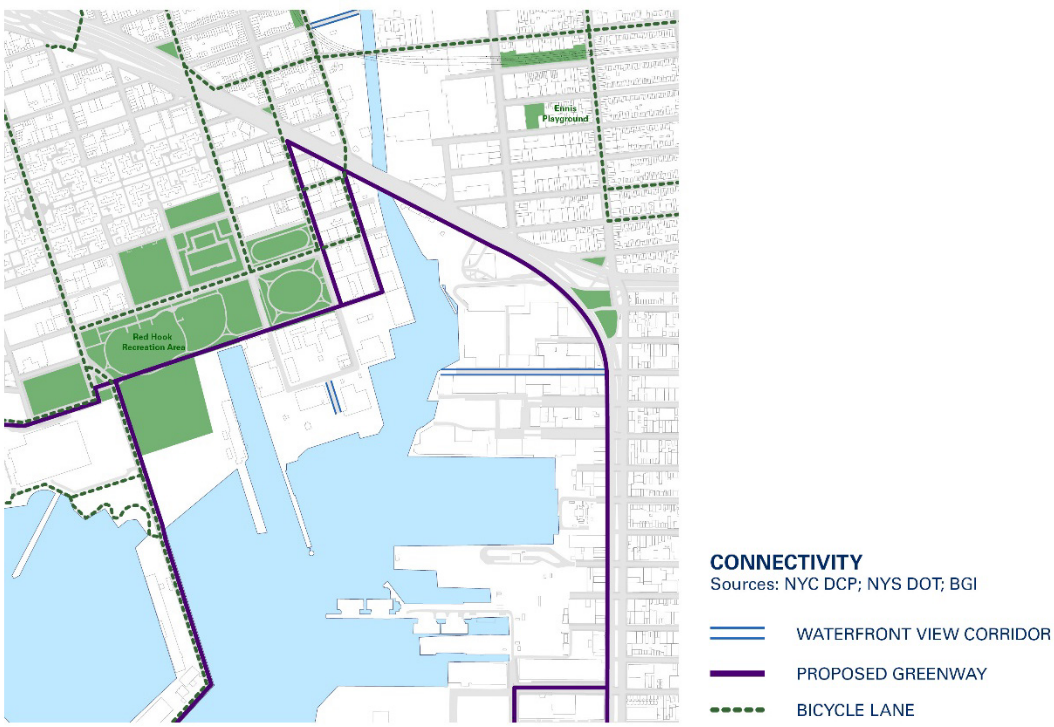

FIGURE 1-8
Proposed Brooklyn Greenway

The development of alternative concept options considered future development plans, waterfront access, and view corridors. To the degree possible, the concept options aim to minimize neighborhood disruptions. This included understanding the location of retail corridors, street widths, competing street uses, and curb cuts. A wider ROW could have better capacity to absorb an upland defense component, depending upon the streetscape activity and other competing factors.

Curb cuts are another street element that add to design complexity. Access to driveways, especially for industrial and commercial businesses, is critical, and requires the inclusion of operable gates to preserve access. To the degree possible, the concept options work to minimize access disruptions. For example, Hamilton Avenue is a corridor that could work to avoid the majority of active driveways and building entrances, though important access points to the NYCDOT asphalt plant and the DSNY marine transfer station are both located on Hamilton Avenue.

Neighborhood integration also considered where connections might be strengthened or extended. This included the potential to expand or connect to existing or planned Greenways, or opportunities to introduce new pedestrian and bicycle connections, possibly via new bridge amenities. A concept option alignment might integrate into the proposed greenway for Sunset Park and Red Hook, or add additional connection to Gowanus.

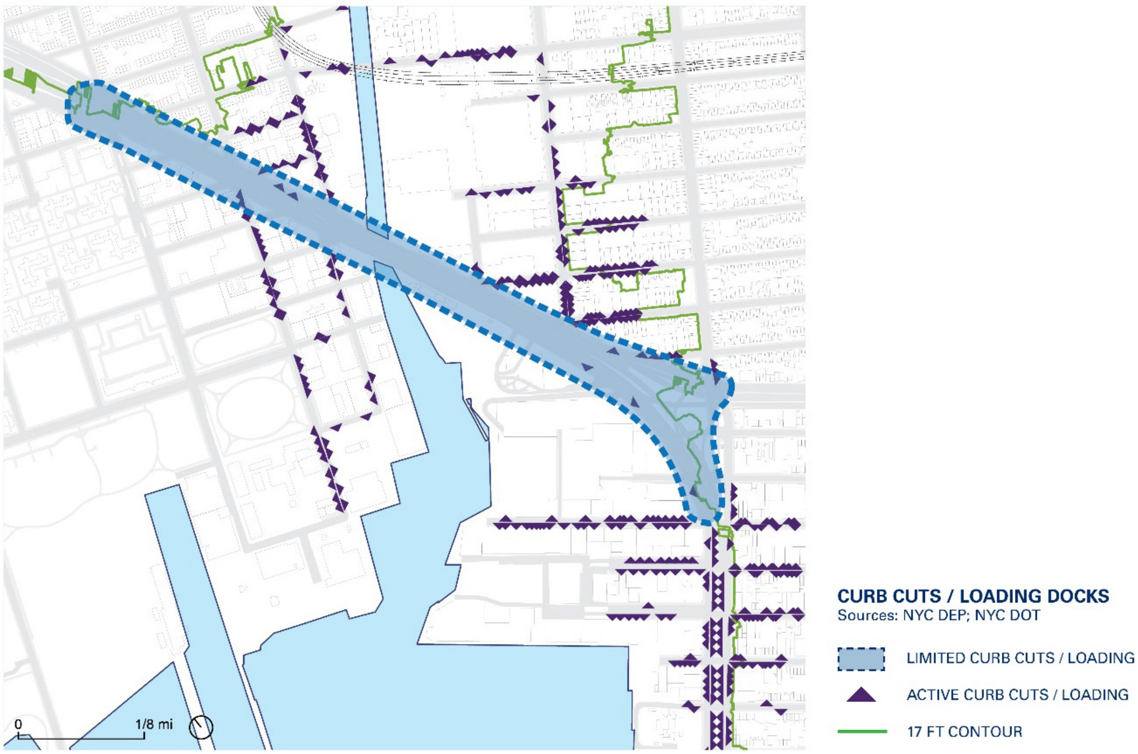

FIGURE 1-9
Gowanus Canal Curb Activity

What becomes clear from the siting considerations and complexity around upland defense alignments, as elaborated on in detail in Section 8, is that any selection and ultimate implementation of a storm surge barrier system necessitates trade-offs in priorities, impacts, and benefits.

1.3.4 Facilitate Funding for a Flood Protection System

A final area of focus in thinking about concept option development and the potential implementation of a storm surge barrier system addressed funding considerations, and anticipated changes to the built environment. If the USACE were to ultimately advance a project for this study site, the federal contribution would be expected to be 65 percent of total capital costs while non-federal sources would need to fund 35 percent.

A number of funding-related criteria were considered during the concept option development and screening stages. These included opportunities to reduce capital costs, the potential for incorporating and leveraging the investments from future private and public projects, and the influence of ownership on potential funding and implementation strategies. Consideration of public or private ownership implies trade-offs between cost, control, reliability and flood insurance benefits.

FIGURE 1-10
Capital Cost Reduction Strategies

Understanding anticipated timing of changes to the study site communities over the foreseeable future is important. There are many planned or anticipated projects that are taking place over the next decade, and given the long time horizon before any project is likely to be realized at Gowanus Canal, the concept options developed have worked to account for these to the degree possible.

At the Gowanus Canal, U.S. Environmental Protection Agency/Superfund remediation plans are in progress and work is expected to be completed within the next 10 years. Gowanus Green, at the corner of Smith and 5th streets, is a known planned redevelopment. The Bridging Gowanus plan, being developed by local elected officials, outlines additional future changes to the existing neighborhood through additional rezoning and potential redevelopment.

Raised site elevation is one of the factors considered in looking at ways to leverage developer contributions in order to reduce total capital costs. Where a development site could be elevated, and an engineered landscape element could form a component of the upland defense system, the total amount of floodwall or upland defense to be funded by the public sector could be reduced.

1.4 FEMA Certification Requirements

One goal of this project is to develop concepts for a flood protection system that will ultimately be accredited by FEMA, which allows a reduction in flood insurance requirements on the protected side of the system. To be accredited by FEMA, technical and operation data must be provided as part of a certification submittal. The following briefly discusses these requirements as identified in 44 Code of Federal Regulations Part 65 More detail on federal requirements, including 44 CFR 65.10 as well as other guidance memos, is provided in Appendix P.

1. Freeboard: A system must provide a minimum base freeboard of 3 feet. Additional height above the base freeboard is required in certain locations (e.g. at constrictions and upstream limit of the system). The base freeboard can be reduced by up to 1 foot (for a minimum base freeboard of 2 feet) if supported by a risk and uncertainty analysis.
2. Evidence that all closures (e.g., storm drains) have closure devices.
3. Engineering analyses to show that the embankment protection is adequate.
4. Engineering analyses to show that the embankment and foundation is stable. Specific load cases as identified in USACE guidance document "Design and Construction of Levees" (EM 1110-2-1913) must be provided.
5. An evaluation of settlement. This evaluation must comply with the USACE guidance document "Soil Mechanics Design - Settlement Analysis" (EM 1100-2-1904).
6. An analysis of the interior drainage: This analysis should be based on the joint probability of flooding between the interior (protected) and exterior (flood) side of the system.
7. Operation and Maintenance (O&M) Plans: These plans must be officially adopted by a community or agency of a community that participates in the National Flood Insurance Program (NFIP). These plans must cover all aspects and features of the flood protection system. Where human intervention is required for operation, the flood warning system to allow for adequate implementation time must be documented. All maintenance activities (inspection, testing, and training) to be performed, the frequency (typically annually), and the party responsible must be detailed. In some cases, an O&M plan, separate from the floodwall system O&M plan, may be developed for the pump station (where pump stations are required).

These considerations of the FEMA requirements have been incorporated into the alternatives in Section 8 in order to provide for ultimate FEMA accreditation of the system. Should a project advance beyond this conceptual study, early discussions between the City and FEMA may help to establish a clear pathway for coordination from planning and design through to system accreditation.

1.5 USACE Design Considerations

The concept designs have been developed to assess the potential feasibility of storm surge barriers in terms of expected costs and benefits (damages reduced), including consideration of environmental impacts. Barrier system concept designs with a likely positive benefit to cost ratio may be candidates for further study, design, and implementation through cost-shared storm and flood risk management programs of the USACE.

If barrier systems are to be advanced through a USACE cost-shared program, design would need to be performed in a manner compliant with applicable USACE design guidance. Applicable USACE design guidance includes but is not limited to:

- Design and Construction of Levees. Engineer Manual 1110-2-1913. United States Army Corps of Engineers. April 30, 2000.
- Design of Coastal Revetments, Seawalls, and Bulkheads. Engineer Manual 110-2-1614. United States Army Corps of Engineers. June 30, 1995.
- Coastal Engineering Manual. Engineer Manual 110-2-1009. United States Army Corps of Engineers. April 30, 2002.
- Geotechnical Investigations. Engineer Manual 1110-1-1804. United States Army Corps of Engineers. January 1, 2001.

- Retaining and Flood Walls. Engineer Manual 1110-2-2502. United States Army Corps of Engineers. September 29, 1989.
- Real Estate Handbook. Engineer Regulation 405-1-12. United States Army Corps of Engineers. November 20, 1985.
- Planning Guidance Notebook. Engineer Regulation 1005-2-100. United States Army Corps of Engineers. April 22, 2000.
- Engineering and Design for Civil Works Projects. Engineer Regulation 1110-2-1150. United States Army Corps of Engineers. August 31, 1999.
- Civil Works Cost Engineering. Engineer Regulation 1110-2-1302. United States Army Corps of Engineers. September 15, 2008.
- Hydraulic Design for Coastal Shore Protection Projects. Engineer Regulation 1110-2-1407. United States Army Corps of Engineers. November 30, 1997.
- Hazardous, Toxic and Radioactive Waste Guidance for Civil Works Projects. Engineer Regulation 1165-2-132. United States Army Corps of Engineers. June 26, 1992.
- Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures. United States Army Corps of Engineers. April 30, 2014.

The USACE guidance provides engineering considerations and requirements for the further design of the barrier system through USACE programs. USACE does not prescribe a level of protection for storm damage reduction projects. Typically a USACE feasibility study would include optimization analysis to identify the levee height and configuration that results in maximum net benefits (benefits minus cost) as the National Economic Development (NED) plan.

As previously noted in Section 2.1, for this preliminary study, the proposed top elevation for the barrier system was set at +21-foot NAVD88 (in-water storm surge barrier) and +17-foot NAVD88 (upland defense components) based upon current FEMA regulatory floodplain mapping conducted as part of the NFIP. USACE guidance on the agency's procedures for NFIP levee system evaluation can be found in:

- USACE Process for the NFIP Levee System Evaluation. Engineer Circular 1110-2-6067. United States Army Corps of Engineers. August 31, 2010.

USACE Civil Works planning guidance does not necessarily support federal funding of construction of storm damage reduction projects to the same elevation required for NFIP levee certification. USACE program regulations specify that the federal interest is to fund a specified percentage (typically up to 65 percent) of the NED plan. The elevation that provides this maximum net benefit may not equal the elevations used in this analysis as required to obtain levee certification through the NFIP.

For example, a barrier system designed to a lower elevation than that required for NFIP certification could be identified as the NED plan if it provided greater net benefits. In such a case, USACE could only fund up to the federal share of the construction costs of the NED Plan and any additional height required for NFIP certification would be at 100 percent local cost. If future cost shared studies of the barrier options are conducted with USACE, these studies would likely include more detailed design consistent with the above engineering guidance, more detailed evaluation of expected costs and benefits, identification of the NED plan, and determination of cost sharing percentages consistent with USACE policy.

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2 History

2.1 Site History and Background

2.1.1 Site History

Excerpted and expanded from the US Environmental Protection Agency (EPA) Gowanus Canal Superfund Site – Community Involvement Plan, March 2014 (6-9) unless noted.

The Gowanus Canal (Canal) was originally a tidal creek in the saltwater marsh of western Brooklyn (**Figure 2.1**). Local legend has it that Dutch farmers named the tidal creek Gowanes Creek after Chief Gouwane of the local Lenape tribe. The Gowanus wetlands provided ideal habitat for many species of fish and other wildlife, of note were the large oysters that flourished in the brackish water of the creek. In fact, the Gowanus oyster became one of the first exports to Europe by Dutch settlers.

FIGURE 2-1
Gowanus Bay, 1782 (Source: British Head Quarters Coloured Manuscript, Map of New York & Environs, 1782)

By the mid-1800s, the City of Brooklyn had become the third largest city in America. Starting in 1867, the Gowanus Canal was bulk-headed and dredged in order to create a passageway that would allow access for industrial needs. The Canal, whose construction was authorized by the New York State Legislature in 1849 was completed in 1869, it soon became one of the nation's busiest waterways, supporting manufactured gas plants (MGPs), paint and ink factories, coal yards, cement makers, soap makers, tanneries, machine shops, chemical plants, and oil refineries.

While parts of the Canal were dredged to accommodate industrial uses, other elements were filled. At 1st, 4th, 5th, and 7th Streets, turning basins that ran perpendicular to the main canal (**Figure 2.2**) were created in the 1870s and filled in at distinct moments over the next century.[1]

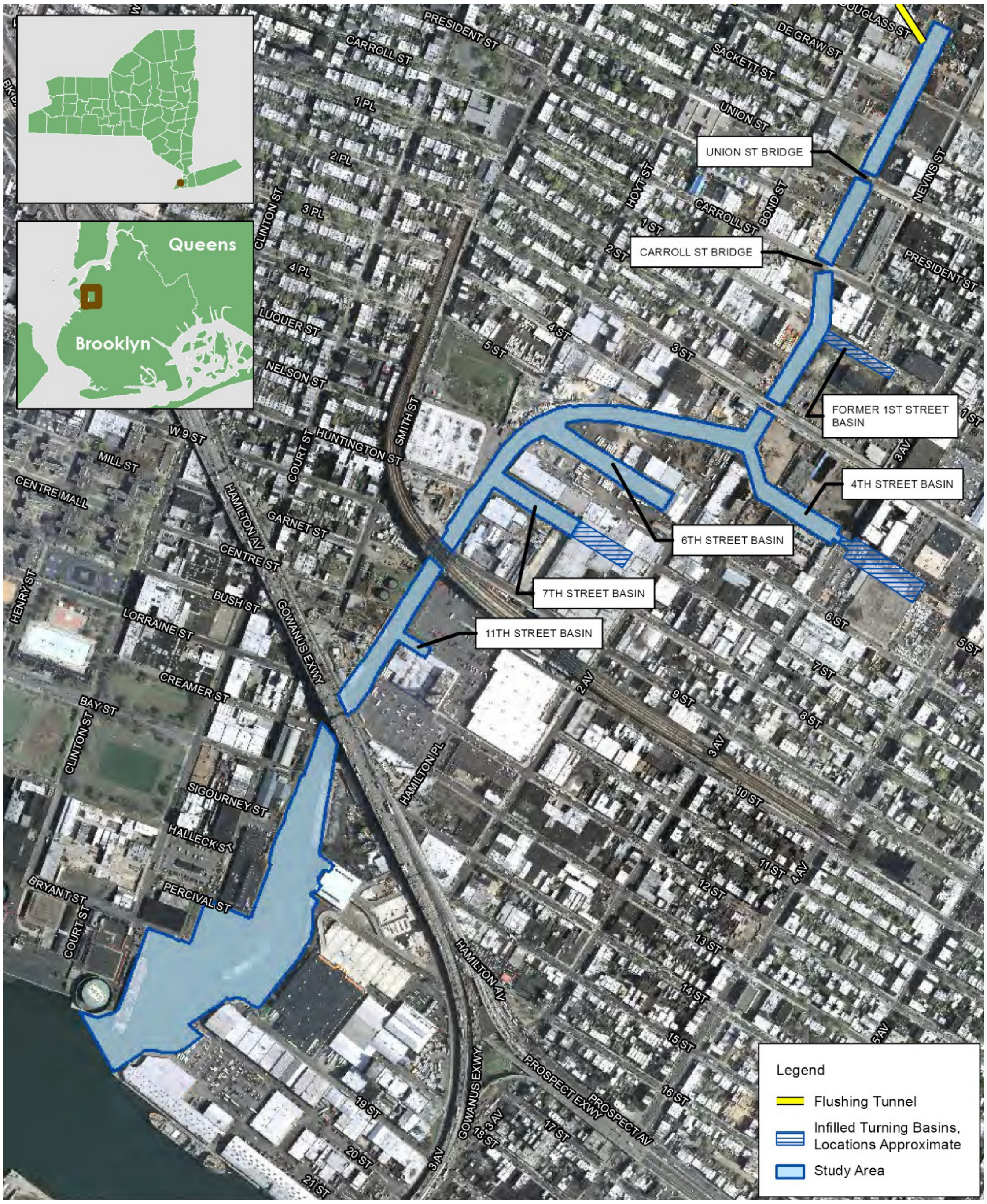

FIGURE 2-2
Gowanus Canal Site Location Map (Source: EPA, Gowanus Canal Feasibility Study - Figures, 2011)

[1] USEPA, *Draft* Feasibility Study Gowanus Canal – Figures, prepared by CH2M HILL. December 2011. Accessed online at http://www.epa.gov/region02/superfund/npl/gowanus/ri_docs/692106_gowanus_canal_rod_9_27_13_final.pdf.

Untreated industrial wastes, raw sewage, and surface water emptied into the Canal and continued for decades resulting in the Canal becoming one of New York's most polluted waterways. Industrial effluents were not the only pollutants pouring into the Canal; South Brooklyn's burgeoning population was housed in buildings that lacked sewer connections, which drained directly into the water body.

In 1911, to address the stagnant, polluted water, New York City (City) initiated the construction of a pumping station at the head of the Canal and a tunnel that brought water in from Buttermilk Channel to the west.[2] The "Flushing Tunnel" aimed to stimulate water circulation by replacing the polluted water in the Canal with fresh, oxygen-rich water.

Three events in the middle of the 20th century brought about the further decline of the waterway. First, the construction of the Gowanus / Brooklyn-Queens Expressway facilitated the expansion of truck distribution and rendered transport by land more affordable than transport by water. Second, following from the rise of trucking, the Army Corps ceased regular dredging of the Canal in 1955. Third, and most damaging, the pumping station broke down in 1961 and was abandoned. By the late 1970s, more than half of the buildings along the Canal were no longer in use.[3]

Forty years later, an environmental mitigation and restoration effort began to take shape. The New York City Department of Environmental Protection (NYCDEP) restored and reactivated the Flushing Tunnel in 1999. The Gowanus Canal Community Development Corporation began work on a bulkhead study and public access document, funded by a City Council allocation.[4]

From the late 1990s to the early 2000s, city, state, and federal agencies and elected officials demonstrated an increasing interest in developing and implementing environmental remediation and neighborhood revitalization plans and activities, among them the New York City Department of Parks and Recreation (NYCDPR), New York State Governor Pataki, New York City Mayor Giuliani, U.S. Congresswoman Nydia Velasquez, and the United States Army Corps of Engineers (USACE).

2.1.2 Superfund Designation

In April 2009, U.S. Environmental Protection Agency (USEPA) proposed that the Gowanus Canal be placed on the National Priorities List (NPL). The NPL is a published list of hazardous waste sites in the country that are eligible for extensive, long-term clean-up actions under the Superfund program. The site was listed on the NPL on March 4, 2010.

Also in 2010, the Flushing Tunnel was shut down by NYCDEP to perform facility improvements. This effort include[d] the installation of more efficient pumping systems and was completed in May 2014. The reconstruction of the Gowanus Wastewater Pump Station, which began in February 2010, increased the pumping capacity to deliver sewage to the Red Hook wastewater treatment plant.

Sampling results have shown that sediments in the Gowanus Canal are still contaminated with a variety of pollutants, including polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), pesticides, and metals. PAH concentrations were found to be as high as 45,000 milligrams per kilogram (4.5 percent) and the contamination was found along the entire length of the Canal. As they did a century ago, the pollutants come from a variety of sources including runoff and sewage. At present, there are ten active combined sewer outfalls (CSOs) and three stormwater outfalls discharging to the Gowanus Canal, with the greatest concentration of CSO discharging in the middle and lower portions of the Canal (**Figure 2.3**).[5]

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[2] The Gowanus Dredgers Canoe Club, "Gowanus Canal History." Accessed online at http://www.gowanuscanal.org/history.html (accessed February 10, 2015).

[3] Ibid.

[4] Ibid.

[5] USEPA, *Record of Decision: Gowanus Canal Superfund Site, Brooklyn, Kings County, New York*, 6. Accessed online at http://www.epa.gov/region02/superfund/npl/gowanus/ri_docs/692106_gowanus_canal_rod_9_27_13_final.pdf (accessed February 10, 2015).

FIGURE 2-3

Gowanus Canal Stormwater / CSO Outfall Locations (Source: EPA, Gowanus Canal Feasibility Study - Figures, 2011)

Many of the detected contaminants are known carcinogens. The contaminated sediments pose an immediate risk to the fishery located just downstream of the Canal in Gowanus Bay. This fishery is well documented, and fish caught there are consumed. Residents have a very high level of interest in the Gowanus Canal. Many community groups actively supported placing the Gowanus on the NPL.

In September 2013, the Gowanus Canal was declared a Superfund Site by the USEPA, which pledged more than $500M toward its cleanup. Recommended remedies for the site included the following:

> Dredging of accumulated sediments, capping, off-site thermal treatment of dredged non-aqueous phase liquid (NAPL)-impacted sediments in the Canal and existing turning basins, in-

situ stabilization of native sediments with high levels of NAPL, excavation and restoration of a portion of the filled-in former 1st Street [turning basin] and a portion of the 5th Street turning basin beginning underneath the 3rd Street bridge, stabilization of sediments not impacted by NAPL and reuse off-site, institutional controls and combined sewer overflow controls.[6]

2.1.3 Site Characteristics

Excerpted and expanded from the EPA Gowanus Canal Superfund Site – Record of Decision, March 2014 (13-17) unless noted.

2.1.3.1 Site Hydrology

The Gowanus Canal is a tidally influenced, dead-end channel that opens to Gowanus Bay and Upper New York Bay. The Canal experiences a semidiurnal tidal cycle (i.e., two high tides and two low tides of unequal height each tidal day), with a vertical tidal range from 4.7 to 5.7 feet. The only fresh surface water inflows to the Canal are wet-weather CSO and stormwater discharges. Because of its narrow width, limited freshwater input and enclosed upper end, the Canal has low current speeds and limited tidal exchange with Gowanus Bay. Circulation is enhanced by the addition of water from the flushing tunnel located at the head of the Canal, when it is operating.

The Canal upstream of the Gowanus Expressway has been designated “Use Class SD,” which indicates that the surface waters should be suitable for fish survival. The area downstream of the Gowanus Expressway is designated “Use Class I,” which indicates that the waters should be suitable for finfish propagation and survival as described in Title 6 New York Codes, Rule and Regulations (NYCRR) Part 701.

2.1.3.2 Site Hydrogeology

Four geologic units (in order of increasing depth and age) lie beneath the area surrounding the Gowanus Canal: fill; alluvial/marsh deposits; glacial sands and silts; and bedrock. Fill materials are associated with Canal construction and subsequent industrialization and re-grading of the area, much of which was originally marshland. The fill consists of silts, sands and gravels mixed with ash and fragments of brick, metal, glass, concrete, wood, and other debris.

The alluvial/marsh deposits lie below the fill and are composed of sands (alluvial deposits from flowing water bodies), peat organic silts and clays (marsh deposits). These alluvial/marsh deposits are associated with the original wetlands complex (i.e., native sediment) that was present when the area was settled.

A thick sequence of glacial deposits occurs below the alluvial/marsh deposits. The full thickness of the glacial deposits was not penetrated, but the observed glacial deposits were composed mostly of coarser grain sediments (sands and gravel) and occasional beds of silt. These glacial sands, silts and gravel were deposited as glacial ice melted during the retreat of the last ice age. At the base of the glacial sequence lies a layer of dense clay, deposited by the glacier or prior to glaciation.

Weathered and competent bedrock underlies the glacial deposits. The bedrock consists of a medium- to coarse-grained metamorphic rock known as the Fordham Gneiss.

The primary aquifer beneath the Gowanus Canal and surrounding uplands is identified as the Upper Glacial Aquifer, which generally occurs in the thick sequence of glacial deposits but may include sandy units in the alluvial/marsh sediments. The Upper Glacial Aquifer appears to be generally unconfined, although local beds of silt and clay may confine underlying sand beds. In the Upper Glacial Aquifer, regional groundwater flows to the west/southwest toward Gowanus Bay. Groundwater-bearing zones in the fill and alluvial/marsh deposits discharge to the Canal.

The Canal is located within the area designated for the Brooklyn Queens Sole Source Aquifer. Groundwater is not, however, used as a potable water supply in this part of Brooklyn.

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[6] USEPA, *Record of Decision: Gowanus Canal Superfund Site, Brooklyn, Kings County, New York*, 7. Accessed online at http://www.epa.gov/region02/superfund/npl/gowanus/ri_docs/692106_gowanus_canal_rod_9_27_13_final.pdf (accessed February 10, 2015).

Multiple lines of evidence were developed in the 2011 Remedial Investigation (RI) to characterize the hydraulic relationships between local groundwater and the Canal. The measurements suggest that, at the water table, groundwater flows toward the Canal. Screenings of intermediate wells in the glacial deposits depict a more complex pattern, with groundwater generally flowing upward toward the Canal, which is typical of a discharge area. Data from a five-day tidal evaluation indicate that at specific locations adjacent to the Canal, Canal elevations at high tide consistently exceeded groundwater elevations in the shallow fill/alluvium, creating hydraulic conditions for surface water to intermittently flow into shallow aquifer sediments.

2.1.3.3 Sediment Characteristics

The sediments in the Canal consist of two distinct layers. The upper layer is referred to as “soft sediment.” The soft sediment has accumulated in the Canal over time since its last dredging. The soft sediment layer ranges in thickness from approximately 1 foot to greater than 20 feet, with an average thickness of about 10 feet. The thickest deposits are found at the head of the Canal and within the turning basins. The soft sediment consists, generally, of a dark gray to black sand/silt/clay mixture that contains variable amounts of gravel, organic matter (e.g., leaves, twigs, vegetative debris) and trash. Odors described as “organic,” “septic-like,” “sulfur-like,” and “hydrocarbon-like” were commonly detected in the soft sediment during the RI, as were visible sheens. The soft sediments are underlain by the alluvial and marsh deposits of the Gowanus Creek complex that were present prior to the Canal’s construction. These deposits are referred to as “native” sediments and consist of brown, tan and light-gray sands, silts, silty sand, sandy clay, clay and peat.

2.1.3.4 Shoreline and Bulkhead Characteristics

NYCDEP has documented that the shorelines of the Gowanus Canal are entirely altered (**Figure 2.4**).[7] While there are areas where the shoreline consists of riprap and piers, the shorelines are dominated by bulkheads. A bulkhead inventory performed along the entire length of the Canal by Brown Marine Consulting (2000) indicated that there are four primary types of bulkheads:

- Crib-type bulkheads, which are constructed of interlocking timbers or logs that are filled with backfill to form a type of gravity retaining structure.
- Gravity retaining walls, which are built so that the weight of the wall itself provides stability.
- Relieving platforms, which consist of a deck of timber or concrete supported on piles, typically timbers or logs, at an elevation high enough above the mean low water line to not require underwater construction techniques but low enough to keep the pilings continuously submerged.
- Steel sheet-pile bulkheads, which are flexible walls constructed of steel sheets with interlocking joints. The steel is capped with concrete or masonry construction. Anchorage systems prevent outward movement and consist of tie-rods and anchors (e.g., structures buried inshore of the bulkhead, such as massive concrete blocks or steel sheet-piles). The bulkheads north of Hamilton Avenue are generally constructed of wood or steel.

[7] NYCDEP, *Gowanus Canal: Waterbody / Watershed Facility Plan*, 2008: 4-30.

FIGURE 2-4
Existing Physical Characteristics of Gowanus Canal Shorelines (Source: NYCDEP, Gowanus Canal Waterbody/Watershed Facility Plan, 2008)

The survey concluded that the existing structures were sufficient only to support present loading conditions and that any type of dredging activity could threaten bulkhead stability due to the deteriorated condition of the structures. The survey was based only on visual examinations of structures without physical or laboratory testing and recommended that a more thorough investigation of bulkhead integrity be performed if dredging is planned. The report also noted that an estimated 42 percent of the bulkhead length was in fair condition or worse.

Hunter Research et al. quantified bulkhead conditions in 2003. In that survey, they evaluated bulkhead construction and determined that approximately 73 percent of the bulkheads along the main Canal and turning basins were crib-type bulkheads with timber construction. Approximately 10 percent of the bulkheads consisted of concrete or bridge abutments and 17 percent were timber or steel sheet-piling-type barriers.

Limited environmental investigations of the shoreline were conducted immediately adjacent to the Canal and beyond the limits of the upland source areas. These investigations revealed the presence of coal tar at certain locations in the Canal bank at the same elevation as the tar in the Canal. These findings suggest that tar might have migrated along the Canal and re-infiltrated into the bank at locations away from the original source areas. These areas of bank-stored tar may act as secondary sources of contamination to the Canal.

2.2 SIRR Report and Lessons Learned

2.2.1 Sandy and Its Impacts

Excerpted from PlaNYC, A Stronger, More Resilient New York, June 2013 (11-12).

[Hurricane] Sandy hit New York with punishing force. Its surge and waves battered the City's coastline along the Atlantic Ocean and Lower New York Bay, striking with particular ferocity in neighborhoods across South Queens, Southern Brooklyn, and the East and South Shores of Staten Island, destroying homes and other buildings and damaging critical infrastructure. Meanwhile, the natural topography of the city's coastline channeled the storm surge that was arriving from the ocean northward into New York Harbor, elevating water levels in Jamaica, Sheepshead, Gravesend, and Gowanus Bays, as well as in Upper New York Harbor and the East and Hudson Rivers. At the same time, the storm surge also was pushing water into Long Island Sound, and from there south.

In short, the ocean fed bays; the bays fed rivers; the rivers fed inlets and creeks. Water rose up over beaches, boardwalks, and bulkheads. It was an onslaught of water.

2.2.2 What Happened During Sandy

Excerpted from PlaNYC, A Stronger, More Resilient New York, June 2013 (43).

[One of three ways] Sandy's surge impacted the City was via less direct routes. In these cases, the City's many bays, inlets, and creeks functioned as "backdoor" channels, funneling ocean waters inland. For example, much of the flooding in Southern Brooklyn came not only over the area's beaches, but also via Coney Island Creek and Sheepshead Bay. Likewise, floodwaters from Jamaica Bay contributed to the inundation of the Rockaway Peninsula, where, as area residents explained, "the ocean met the bay." The Gowanus Canal overflowed its banks, flooding Red Hook and other adjacent neighborhoods.

2.2.3 Brooklyn-Queens Waterfront

Excerpted and expanded from PlaNYC, A Stronger, More Resilient New York, June 2013 (237-268).

Sandy highlighted the area's vulnerabilities. Although the waterfront's sheltered location largely protected the area from destructive waves, the storm surge did cause extensive flooding throughout the area—in many places more than six feet deep. Not surprisingly, flooding occurred along the Harbor and River-facing western edge of the waterfront, inundating neighborhoods, industrial properties, and retail corridors. The surge also made its way up the Gowanus Canal, flooding areas much farther inland. The result of this deluge was damage to building systems and contents, loss of power, displacement of residents, and weeks to months of lost revenue for businesses and nonprofits.

2.2.3.1 Area Characteristics

Because of the significant amount of area occupied by industry, the waterfront area has a relatively low population density (20 people per acre) as compared to the citywide average (42 people per acre). Gowanus is one of the only exceptions (43 people per acre), which has more concentrated residential areas.

Gowanus is home to nearly 18,000 residents has a long industrial history centered on the 1.8-mile Gowanus Canal, which extends inland from Gowanus Bay. Although the present-day Canal supports much less maritime activity than in the past, that activity is facilitated by the five New York City Department of Transportation (NYCDOT) movable bridges that cross the water body. Residents of Gowanus tend to live in attached walkup apartment buildings (many of which were built for industrial workers) or 1- and 2-family homes. Additionally, Gowanus Houses and Wyckoff Gardens, New York City Housing Authority (NYCHA) developments, together contain more than 1,600 housing units. In recent years, Gowanus has seen the construction of some new low- and midrise residential buildings. More such buildings have been proposed for the future.

2.2.3.2 What Happened During Sandy

In Gowanus, the impacts from Sandy came mainly from Gowanus Bay, which, as it filled with Sandy's surge, elevated water levels in the Gowanus Canal. Sandy's floodwaters eventually overtopped the Canal's bulkheads, inundating industrial and residential buildings surrounding the Canal. Although a significant community concern in the wake of the storm was whether the floodwaters from this Superfund site had contaminated the area, USEPA testing showed that the toxic sediment at the bottom of the Canal remained largely undisturbed, and that bacteria levels in the floodwaters did not pose a significant health risk.

Overall, along the Brooklyn-Queens waterfront, more than 8,000 residential buildings were within the inundation area. These buildings contained nearly 49,000 residential units and housed almost 100,000 people. In many cases, Sandy's inundation forced people out of their homes for days, weeks, and even months. In some cases, this was because they lived in flooded ground-floor or basement apartments that were destroyed by flooding. In others, such as along Pioneer Street in Red Hook, it was because vital building mechanical systems supporting their living spaces were knocked out of service.

Also impacted by Sandy were waterfront businesses, which were impacted significantly by the storm, particularly as floodwaters filled ground floors and basements, damaging building systems and contents. In total, approximately 3,100 businesses employing some 34,600 people were impacted by Sandy.

2.2.3.3 What Could Happen in the Future

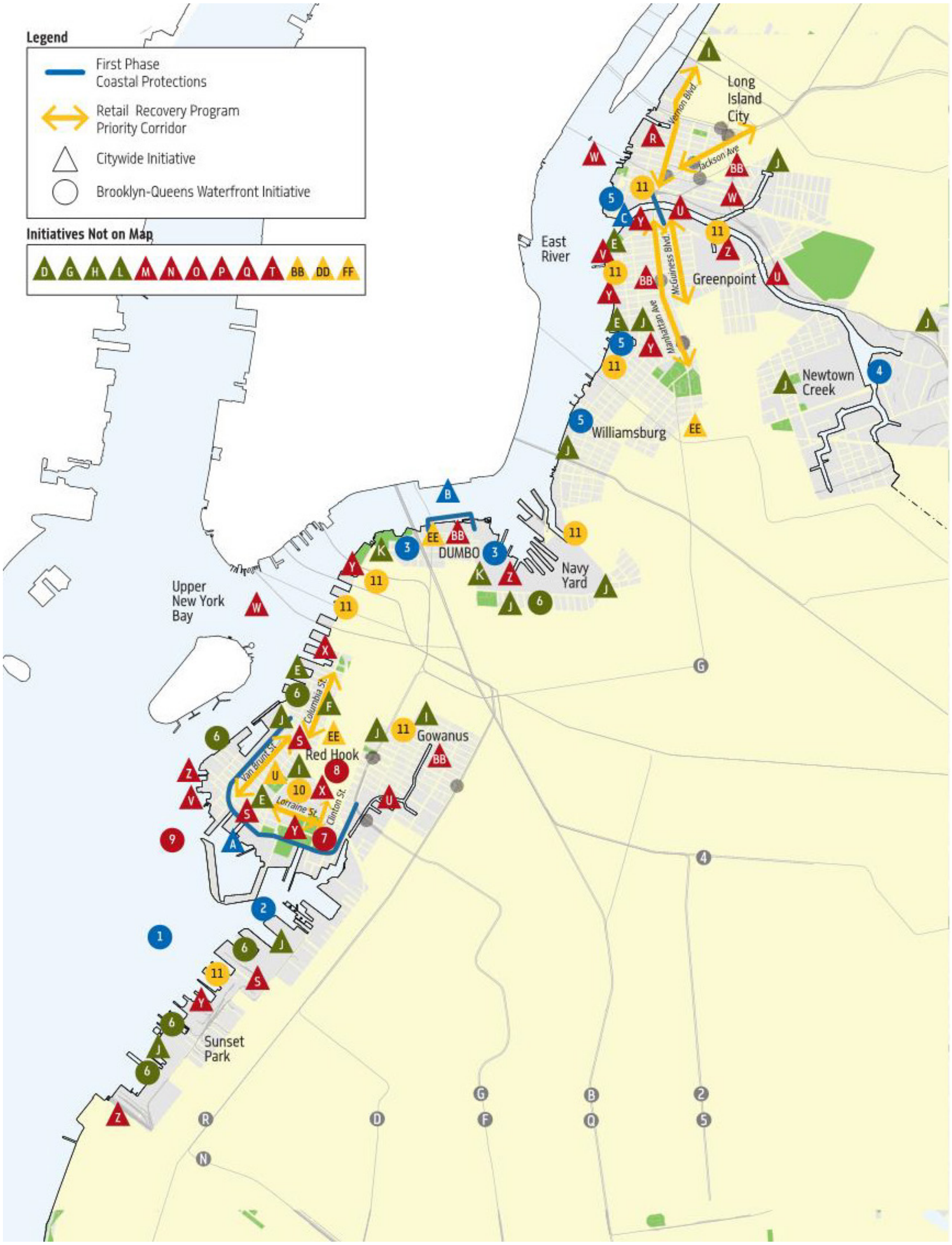
Given the waterfront's coastal exposure, the most significant climate change-related risks for its neighborhoods are storm surge and flooding from coastal storms, which is likely to be exacerbated by projected sea level rise. This risk is significant even today along the waterfront, as illustrated by flood maps released in June 2013 by the Federal Emergency Management Authority (FEMA). According to these Preliminary Work Maps (PWMs), the 100-year floodplain, the area with a 1 percent or greater chance of flooding in any given year, has expanded beyond that shown on the 1983 maps that were in effect when Sandy hit. In the new maps, the growth in the floodplain is most pronounced in Red Hook, Greenpoint, and Long Island City. The new maps show an expanded V Zone, the area where waves could exceed 3 feet in height, along the length of the waterfront's coastline, including along piers containing buildings and equipment.

As the 100-year floodplain has expanded in size, there has been also an increase in the number of buildings in the floodplain—a 6 percent rise in residential buildings (from approximately 850 to 900 buildings) and a 15 percent increase in commercial buildings (from almost 1,350 to nearly 1,550 buildings). In addition, approximately 100 buildings—all commercial—are now located in a V Zone. Base flood elevations (BFE)—the height to which floodwaters could rise during a storm—have increased 1 to 3 feet throughout the area.

2.2.3.4 SIRR Initiatives

Brooklyn-Queens Waterfront Initiative 2: Call on and work with the USACE to develop an implementation plan and preliminary designs for a local storm surge barrier along the Gowanus Canal

Much of the area surrounding the Gowanus Canal lies within FEMA's 100-year floodplain, even without accounting for climate change. The land surrounding the Canal supports a variety of land uses and densities, with all structures in the area at risk of flooding (See **Figure 2-5**). Because flood protection along the length of the coastal edges of the Canal may be extremely expensive, disruptive, and in some cases nearly impossible, the City, through Office of Long-Term Planning and Sustainability, will call for the USACE to create an implementation plan and complete preliminary designs for a local storm surge barrier at the mouth of the Gowanus Canal. Such a barrier could provide comprehensive protection for the entire area. As the Gowanus Canal is a Superfund site, proper coordination with the USEPA and others would be required to implement the project successfully. One potential location for the proposed barrier is across the Gowanus Bay from Erie Basin to 29th Street in Sunset Park. Such a barrier would be supported by a raised levee along both piers connected to natural high points, preventing flooding to properties near the barrier. The barrier would have the added benefit of creating a new stormwater basin that could be used to facilitate drainage. The barrier would be navigable to allow for continued shipping traffic along this working waterfront.



Source: Special Initiative for Rebuilding and Resiliency, A Stronger, More Resilient New York, June 2012, 253-254.

FIGURE 2-5
Brooklyn-Queens Waterfront Initiative Summary

Transportation Initiative 5: Install watertight barriers to protect movable bridge machinery

The mechanical equipment that moves 25 of the city's bridges—including five over the Gowanus Canal—is vulnerable to flooding. Damage to this equipment could, if it were to lock bridges in either an open or closed position, disrupt marine and roadway traffic. Therefore, over the next three years and subject to available funding, NYCDOT will install watertight barriers to protect the bridges' mechanical equipment.

Brooklyn-Queens Waterfront Initiative 7: Improve connections between Red Hook and the rest of Brooklyn

As Sandy showed, the lack of transportation options in Red Hook made it more challenging for Red Hook residents to access services during and after the storm, as it does in non-storm conditions. Hamilton Avenue's current configuration further exacerbates the area's isolation by impeding direct, safe access to and from the neighborhood by pedestrians and public transit users. The City, therefore, will invest in improvements to provide residents and visitors alike with quicker, safer, and more reliable transportation options, available during both emergencies and under normal conditions.

Water and Wastewater Initiative 8: Reduce combined sewer overflows (CSOs) with Green Infrastructure

As climate change brings increasing rainfall volume to the New York area, the city may also experience shifts in the frequency and volume of CSOs. The City will continue to implement its Green Infrastructure Plan and CSO Long-Term Control Plans (LTCPs) to reduce such CSOs. For this purpose, NYCDEP, working with the DPR and NYCDOT, will continue to pursue its plan to capture the first inch of runoff in 10 percent of impervious surfaces citywide by 2030. At the same time, NYCDEP also will continue to develop LTCPs to evaluate long-term solutions to reduce CSOs and improve water quality in New York City's waterways. NYCDEP will issue an LTCP for Alley Creek in Queens in 2013, with nine additional water body-specific LTCPs and one citywide LTCP to follow through 2017—including for Coney Island Creek, the Gowanus Canal, Newtown Creek, and Jamaica Bay. NYCDEP will continue to implement this program in 2013, with the Gowanus Canal LTCP targeted for issuance in 2015 and Newtown Creek LTCP in 2017.

Water and Wastewater Initiative 9: Reduce combined sewer overflows with high-level storm sewers

While the construction of new, green infrastructure is an effective solution for managing rainfall and reducing CSOs in some locations, in other areas, it will be more cost-effective to enhance the city's existing sewer system. The City, through NYCDEP, will augment existing combined sewers with so-called "high-level storm sewers" in certain areas, including along the Waterfront. These high-level storm sewers sit on top of a combined sewer and accept stormwater from the street before diverting it to a nearby waterway, capturing up to 50 percent of rainfall before it enters combined sewers. NYCDEP, therefore, will continue to pursue high-level storm sewer projects along the waterfront, including at 3rd Avenue in Gowanus; West Street in Greenpoint; and at multiple locations in DUMBO. These projects are to be completed by 2023.

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3 Existing Conditions

Existing site conditions at the Gowanus Canal (Canal), which provide baseline data and influenced the siting assessment and development of the in-water storm surge barrier and upland flood defense options, are summarized here. Photos from a January 2015 site visit are provided in **Appendix A**. Additional detail and baseline maps of the study area are provided in **Appendix B - E**. Key findings and information relevant to the concept option siting and development are summarized in the following sub-sections. While this preliminary investigation provides a general characterization of conditions at the site and is sufficient for information assumptions at this conceptual stage of study, should a Gowanus Canal storm surge barrier system project advance beyond this conceptual study, detailed site investigations will be needed to fully characterize soil properties, bulkhead and other structural conditions, potential environmental site contamination, in addition to other due diligence investigation in order to inform detailed design of a barrier and flood protection system.

3.1 Physical Characteristics

3.1.1 Bathymetry

Bathymetry data within the creek is shown in the figures below.

This is based on the following data sets:

- 2010 survey, performed for the U.S. Environmental Protection Agency (USEPA) and the National Grid, provided by New York City Department of Environmental Protection (NYCDEP). The coverage of this data is shown in **Figure 3-1**. The survey was provided in the form of xyz data with a horizontal state plane projection system, NAD 1983 – New York Long Island, with elevations in feet relative to North American Vertical Datum of 1988 (NAVD88).
- MIKE C-MAP database (MIKE by DHI, 2012), which is based on bathymetric data in nautical charts. Coverage is shown in **Figure 3-2**. This was used to supplement the NYCDEP survey data, after correction for the different vertical datum.

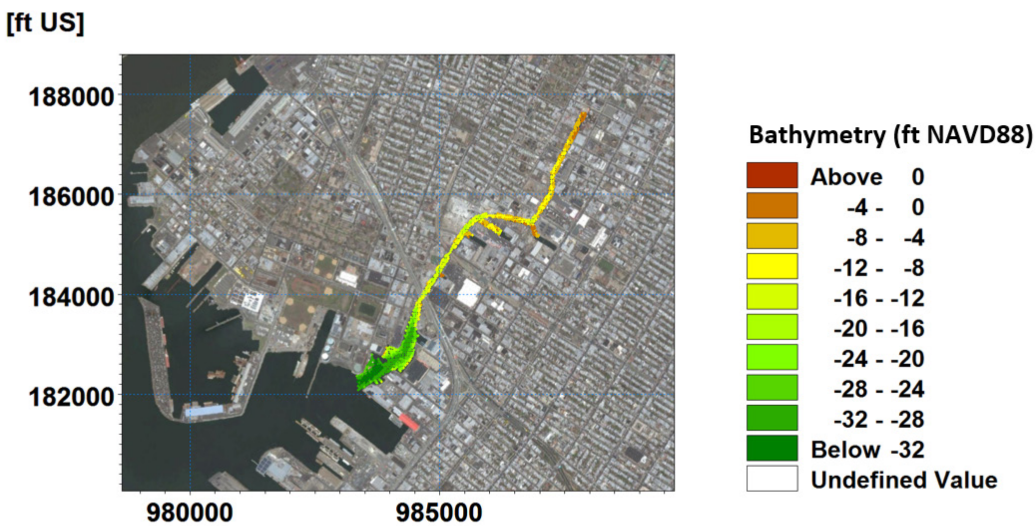


FIGURE 3-1
NYCDEP 2012 Bathymetry Scatter Data, Gowanus Canal; Horizontal Datum NAD 1983 NY – Long Island (feet)

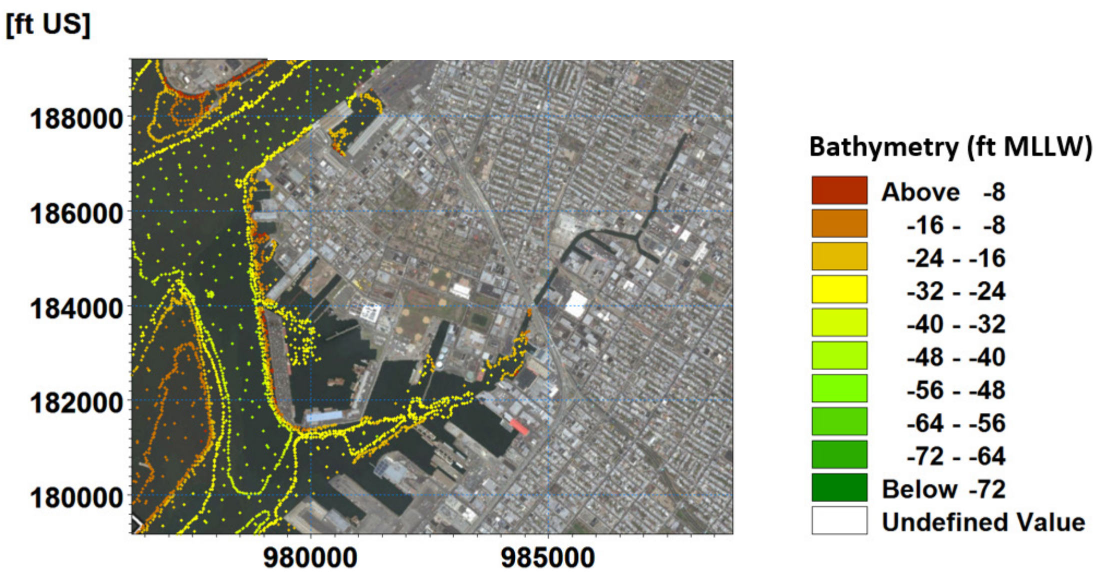


FIGURE 3-2
CMAP Scatter Data near Gowanus Canal; Horizontal Datum NAD 1983 NY – Long Island (feet)

3.1.2 Geology and Geotechnical Conditions

The general geological conditions in the vicinity of the Gowanus Canal can be characterized as follows, based on the USEPA feasibility study (USEPA, 2011). The following geologic units (in order of increasing depth and age) lie beneath the area surrounding the Gowanus Canal:

- Fill
- Alluvial/marsh deposits
- Glacial sands and silts
- Bedrock

Fill materials are associated with canal construction, bulkhead and pier creation and general industrialization and re-grading of the area, much of which was originally marshland. Alluvial/marsh deposits lie below the fill and are composed of sands (alluvial deposits from flowing water bodies), peat, organic silts, and clays (marsh deposits). These alluvial/marsh deposits are associated with the original wetlands complex (i.e., native sediment) that was present when the area was settled. A thick sequence of glacial deposits occurs below the alluvial/marsh deposits, composed mostly of coarser grain sediments (sands and gravel) and occasional beds of silts deposited during the retreat of the last ice age. The full depth of these deposits was not penetrated in the Superfund Remedial Investigation, but the observed glacial deposits were. A layer of dense clay lies beneath the glacial deposits. Weathered and competent bedrock underlies these deposits, consisting of a medium- to coarse-grained metamorphic rock known as the Fordham Gneiss.

Within the upper section of the canal that falls within the Superfund site, sediments consist of two distinct layers. The upper layer is referred to as “soft” sediment that has accumulated in the canal since it was first constructed. This layer varies from approximately 1 foot thick to greater than 20 feet thick, with an average thickness of about 10 feet. Beneath the soft sediments are alluvial and marsh deposits of the Gowanus Creek complex that were originally present.

The Superfund Remedial Investigation data and plans were reviewed to determine anticipated post-remediation depths that were considered as part of the in-water storm surge barrier siting assessment.

3.2 Natural Features and Habitat

3.2.1 Biological Resources Survey

The following section is a summary of a desk study of existing ecological conditions across the Gowanus Canal for the purpose of assessing the potential risks to existing habitat from interventions proposed for flood protection and also for the potential to improve ecological value as part of a proposed intervention. The review references several reports published between 1997 and 2011, with greatest emphasis given to the Gowanus Canal Remedial Investigation Report (USEPA, 2011) and the Gowanus Bay and Canal Ecosystem Restoration Studies (United States Army Corps of Engineers, 2004).

A large number of surveys and assessments have been performed in the canal in the past decades, each of them acknowledging the severity of contamination, degradation of habitat, and risks of exposure to toxic materials and disease. The highly altered environment and legacy of industrial and sanitary discharges have largely degraded ecosystems associated with the Gowanus Canal and the former tidal wetlands. There exist no recognized wetlands in the basin outside of the littoral zone of the canal itself, and water levels prohibit the establishment of rooted plant species. A small number of aquatic and avian species are expected to spend limited time foraging in the canal waters, but given the existing high levels of industrial contamination are at risk of bioaccumulating toxins.

Most critical to the assessment of potential impacts to the habitat and ecology of the Gowanus Canal is evaluation of intact ecosystems that have value and should be protected. The canal's degradation began in the mid-19th century as the tidal wetlands were filled and the 100-foot wide canal was bulkheaded and dredged for navigation and industry. Conditions deteriorated quickly from pollution and the combination of hard edges, isolation of open water from terrestrial wetland zones, and deepening of open water which eliminated emergent vegetation. Within several decades it was recognized that contamination within the stagnant canal from industrial and sanitary discharges was becoming a source of disease and unpleasantness, and New York City (City) sought to mitigate the problem through construction of a "flushing tunnel" with pumps to force the exchange of water with the harbor. The tunnel came on-line in 1911 and improved conditions until a mechanical failure caused it to be shut down in the 1960s. In 1999, after stagnation and contamination in the canal had worsened to the degree that its use by industry had diminished, the NYCDEP reopened the flushing tunnel and conditions began to improve, resulting in increases in dissolved oxygen and reductions in fecal coliform and enterococci, especially at the head of the canal where conditions had been most compromised. Mechanical issues again forced the tunnel's closure in 2010, the same year the USEPA added the canal to the Comprehensive Environmental Response, Compensation, and Liability Act National Priorities List, commonly known as Superfund. For several years the NYCDEP maintained aeration facilities in an effort to promote water quality until the tunnel was once again reopened in 2013. However, combined sewer overflows continue to be discharged at eleven points within the canal, limiting the rate at which conditions can improve even with the tunnel operating.

3.2.2 Wetland Mapping

To ensure that any short or long term strategies related to the Gowanus Canal storm surge barrier system project are both in compliance with local, state, and federal regulations and cause no disturbance to any existing critical habitats, a wetland mapping review was conducted through the evaluation of the National Wetland Inventory (NWI) published by the United States Fish and Wildlife Service (USFWS) and the New York State Department of Environmental Conservation (NYSDEC) Tidal Wetland maps. In addition to assessing wetland extent, a desktop review of tidal elevations was performed by reviewing National Oceanic and Atmospheric Administration tidal stations (harmonic and subordinate) data as well as a limited tidal investigation completed as part of the USEPA's Remedial Investigation Report. The wetland mapping and tidal investigation will inform habitat preservation and restoration efforts, noting the estuarine conditions of the water body such as typical tidal patterns, channel geometry, and boundary conditions.

The Gowanus Canal is a tributary of Upper New York Bay, which is an expansive open water marine system. The NWI classifies the entirety of the Gowanus Canal and the adjacent Gowanus Bay as Estuarine, Subtidal, Unconsolidated Bottom, Subtidal, Excavated (E1UBLx). The NWI defines Estuarine systems as “deepwater tidal habitats and adjacent tidal wetlands that are influenced by water runoff from and often semi-enclosed by land.” Being classified by the NWI as Subtidal, the Gowanus Canal has no instances of tidal wetlands along its shores, which are dominated by bulkheads constructed of wood, metal, concrete, and riprap. Its Unconsolidated Bottom is permanently flooded and consists of cobbles, gravel, at least 25 percent cover of particles smaller than stones (6-7cm), and vegetative cover less than 30 percent, and the Canal’s overall channel geometry has been modified by humans through various means. NYSDEC classifies the entirety of the Gowanus Canal as 2020 LZ Littoral Zone, which includes all lands under tidal waters not included in other NYSDEC categories and not deeper than six feet at mean low water (http://www.dec.ny.gov/lands/5120.html). Map 8: Wetland Mapping demonstrates both the NWI and NYSDEC extents.

Despite the lack of existing wetlands in the Gowanus Canal, habitat improvements can be realized through “softening” of channel walls or riprap edge conditions. Opportunities within the intertidal zone include native low salt marsh restoration of *Spartina alterniflora* (planted in the upper third of the mean tidal range) and high salt marsh restoration of *Spartina patens* (planted between mean high water and mean higher high water). Salt marsh plays an essential role in the marine ecosystem, providing nutrients and organic matter for lower trophic organisms, which subsequently support the establishment of insects, decapods and ultimately wading bird populations.

3.2.3 Field Investigation

On June 12, 2015, study team member eDesign Dynamics performed a field visit of the Gowanus Canal by kayak to confirm the biological resources characterization and wetland mapping. These field visits took place in June to maximize the visibility of existing habitat conditions. While no sampling was performed, visual inspection of edge and habitat conditions confirmed that the Canal is a highly altered environment with limited high-value habitat.

The observed edge conditions of the Gowanus Canal and Newtown Creek were generally consistent with those documented in published literature. Recent property developments may have changed the reported edge conditions, such as the currently inaccessible 2nd Street boat launch to the Gowanus Canal. The waterway is largely bulkheaded with a few stretches of riprap, and vegetative cover consisting mostly of non-native and/or invasive trees. *Paulownia tomentosa*, *Populus deltoids, Ailanthus altissima*, *Morus alba*, and *Robinia pseudoacacia* were commonly found in the Gowanus Canal. *Phragmites australis* was also found in the intertidal zone and upland areas of the waterways and *Fallopia japonica* was found in the upland areas. All of this vegetation suggests that the edge conditions consist of high pH disturbed soils and urban fill.

Given the Gowanus Canal bulkheaded condition, there are limited opportunities for native salt marsh to establish. The only observed patch of *Spartina alterniflora* (**Figure 3-3**) was adjacent the Gowanus Canal Conservancy’s Salt Lot (north end of 2nd Avenue) and was very likely planted by the Conservancy. The grasses appeared to be healthy despite the dilapidated riprap conditions. A few pockets of mudflats were also observed at areas of sediment deposition, such as the end of the canal basin adjacent to the Lowe’s parking lot.

Given that this field visit was performed by kayak, visibility was limited to fauna immediately visible by the water. One key observation was the extent of mussel colonization of the degraded wooden bulkhead in the Gowanus Canal. The mussels were observed within the crevices and notches of the wooden planks (**Figure 3-4**). Mussels were not observed in any other areas of the Gowanus Canal, suggesting that degraded wood can serve as a suitable colonization surface for mussel restoration in these waterbodies. A few fiddler crabs were also observed along the wooden bulkhead. In terms of birds, barn swallows were observed nesting under a few bridges, including the Carroll Street Bridge.

FIGURE 3-3
***Spartina alterniflora* in the Gowanus Canal**

FIGURE 3-4
Mussel Colonization of Degraded Wooden Bulkhead

3.3 Shoreline Investigation

A high level visual inspection of the waterfront was undertaken by boat on March 17, 2015. The scope of the inspection was limited to what could be seen above water at the time of inspection while traveling on a boat alongside the waterfront. A topside inspection of the upland areas and the retained fill was not performed and the scope of the investigation is considered to be more cursory than a Rapid Level inspection, as defined in the EDC's Waterfront Facilities Maintenance Management System (WFMMS). As a result, the structure types are based on engineering judgment from what was observed above water during the time of inspection. In addition, it should be noted that condition assessment ratings were not assigned to structures that were inaccessible to the boat or where the inspector was not able to get close enough to the structure for a meaningful visual inspection.

The survey focused on the area where a potential barrier and associated upland flood defenses might be constructed. It started on the west side of Erie Basin and extended along the west side of Gowanus Bay to the Hamilton Avenue Bridge. The survey continued up as far as 9th Street. The survey then continued down the east side of Gowanus Bay to the north end of South Brooklyn Marine Terminal. An inventory of structure type and condition is given in the **Table 3-2.** The condition of the structure was characterized using the scoring system given in **Table 3-1**, which is based on the condition assessment ratings in the EDC's WFMMS. It is noted that the primary objective of the inspection was to categorize the type of structures along the waterfront and that the condition assessment ratings being assigned to each structure will need to be verified with a more in-depth inspection of the structure. In particular, the pile-supported relieving platform type structures should be re-inspected below water to confirm its condition.

Typically structures fell into the following categories:

- Vertical bulkheads in a range of conditions, in some cases acting as operating berths (e.g., Hess terminal, Department of Sanitation berth, asphalt berth).
- Piled relieving platforms and piers, such as the Gowanus Bay Terminal.
- Armored slopes, either riprap or stone armor that has been designed as slope protection, with a fairly uniform stone grading, slope and stone profile, or more ad hoc protection, often from construction waste materials such as broken concrete blocks.

TABLE 3-1
Structure Condition Rating

Code	Condition Rating	Description
1	GOOD	No problems or only minor problems noted. Structural elements may show some very minor deterioration, but no overstressing observed.
2	SATISFACTORY	Minor to moderate defects and deterioration observed, but no overstressing observed.
3	FAIR	All primary structural elements are sound; but minor to moderate defects and deterioration observed. Localized areas of moderate to advanced deterioration may be present but do not significantly reduce the load bearing capacity of the structure.
4	POOR	Advanced deterioration or overstressing observed on widespread portions of the structure, but does not significantly reduce the load carrying capacity of the structure.
5	SERIOUS	Advanced deterioration, overstressing, or breakage may have significantly affected the load bearing capacity of primary structural elements. Local failures are possible and loading restrictions may be necessary.
6	CRITICAL	Very advanced deterioration, overstressing, or breakage has resulted in localized failure(s) of primary structural elements. More widespread failures are possible or likely to occur and load restrictions should be implemented as necessary.

TABLE 3-2
Gowanus Canal Waterfront Structure Inventory

Location	Defense Length Reference	Structure Type	Condition (see Table 3-1)
Erie Basin	A	Timber pile-supported wharf	Fair
	B	Steel sheet pile bulkhead	Satisfactory
	C	Timber pile-supported platform	Satisfactory
	D	Steel sheet pile with riprap protection	Poor
	E	Concrete wall with riprap protection	Satisfactory
	F	Steel sheet pile with riprap protection	Satisfactory
Gowanus Bay Terminal	G	Riprap with concrete debris	Fair
	H	Steel sheet pile bulkhead	Satisfactory
Hess Terminal	I	Gabions and steel sheet pile bulkhead	Satisfactory
	J	Steel sheet pile bulkhead	Satisfactory
Bryant Street/Smith Street	K	Retaining wall (timber crib)	Poor
	L	Rubble/debris slope	Fair

TABLE 3-2
Gowanus Canal Waterfront Structure Inventory

Location	Defense Length Reference	Structure Type	Condition (see Table 3-1)
Bryant Street to Hamilton Avenue Bridge (west side)	M	Timber pile-supported platform with steel sheet pile bulkhead	Fair
	N	Steel sheet pile bulkhead	Fair
	O	Rubble/debris slope w/ remnants of timber bulkhead	Poor
	P	Timber pile-supported relieving platform	Satisfactory
	Q	Retaining wall (timber crib)	Poor
Hamilton Avenue to 9th Street (west side)	R	Retaining wall (concrete wall)	Poor
		Steel sheet pile bulkhead	Satisfactory
	S	Retaining wall (timber crib)	Fair
	T	Retaining wall (timber crib)	Poor
	U	Rubble/debris slope	Poor
	V	Retaining wall (Concrete/stone wall)	Poor
9th Street to Hamilton Avenue (east side)	W	Timber pile-supported platform and retaining wall (timber crib)	Satisfactory
	X	Retaining wall (concrete and timber crib)	Fair
	Y	Rubble/debris slope w/ timber crib	Poor
Asphalt berth	Z	Timber pile-supported relieving platform	Satisfactory*
Department of Sanitation Hamilton Avenue Transfer Station	AA	Steel sheet pile bulkhead w/ timber facing	Satisfactory
	AB	Timber pile-supported platform	Satisfactory
Home Depot	AC	Riprap slope protection	Fair
Sunset Industrial Park	AD	Steel sheet pile	Fair
	AE	Riprap slope protection	Satisfactory
	AF	Steel sheet pile bulkhead	Fair
	AG	Timber pile-supported platform/apron	Fair
22nd to 24th Street	AH	Steel sheet pile bulkhead	Fair
Lafarge	AI	Timber pile-supported platform	Satisfactory
25th Street	AJ	Rubble/debris slope	Fair
US PowerGen Gowanus Station	AK	Timber pile-supported pier	Fair
28th Street	AL	Retaining wall	**No Rating***
	AM	Riprap slope protection	Satisfactory
	AN	Retaining wall (steel soldier piles w/ timber lagging)	Satisfactory
	AO	Retaining wall (stone wall)	Satisfactory
Sims Recycling	AP	Riprap slope protection and semi-submerged rock reefs	Good**
	AQ	Steel sheet pile bulkhead	Satisfactory**
South Brooklyn Marine Terminal	AR	Retaining wall (concrete wall)	Fair**
		Timber pile-supported platform	Poor**
	AS	Riprap slope protection (north side)	Good**
		Steel sheet pile bulkhead (west end)	Fair**

* Structure was partially inaccessible at the time of inspection due to berthed vessel.
** Condition rating is based on a Routine Inspection of the structure performed by CH2M in April 2015.

3.4 Utilities and Water Quality

Utilities and water-related data that are of relevance to the barrier feasibility study are discussed below.

3.4.1 Subsea Pipeline and Cables

A high voltage cable is shown on the navigation charts, extending from the east side of Gowanus Bay, around 25th Street, out through the mouth of the bay.

No other cables or pipelines are indicated as subsea hazards, though this should be confirmed with utilities for the preferred barrier location. Any future plans for infrastructure and utilities will need to be identified.

3.4.2 Combined Sewer Overflows and Stormwater Drainage

The Gowanus Canal sewershed drains to two different water pollution control plants (WPCPs): Red Hook and Owls Head. During significant rainfall events, the canal receives discharges of combined sewage via reliefs from the combined sewer system, as well as relatively small discharges of stormwater runoff via storm sewers and direct overland runoff.

This section presents a description of the existing sewer system facilities, the collection system, and characteristics of discharges to the Canal. Combined sewer overflows (CSOs) discharging into the Canal are shown in **Figure 3-5**, reproduced from the Gowanus Canal Waterbody/Watershed Facility Plan. **Table 3-3** summarizes the CSO discharges to the canal.

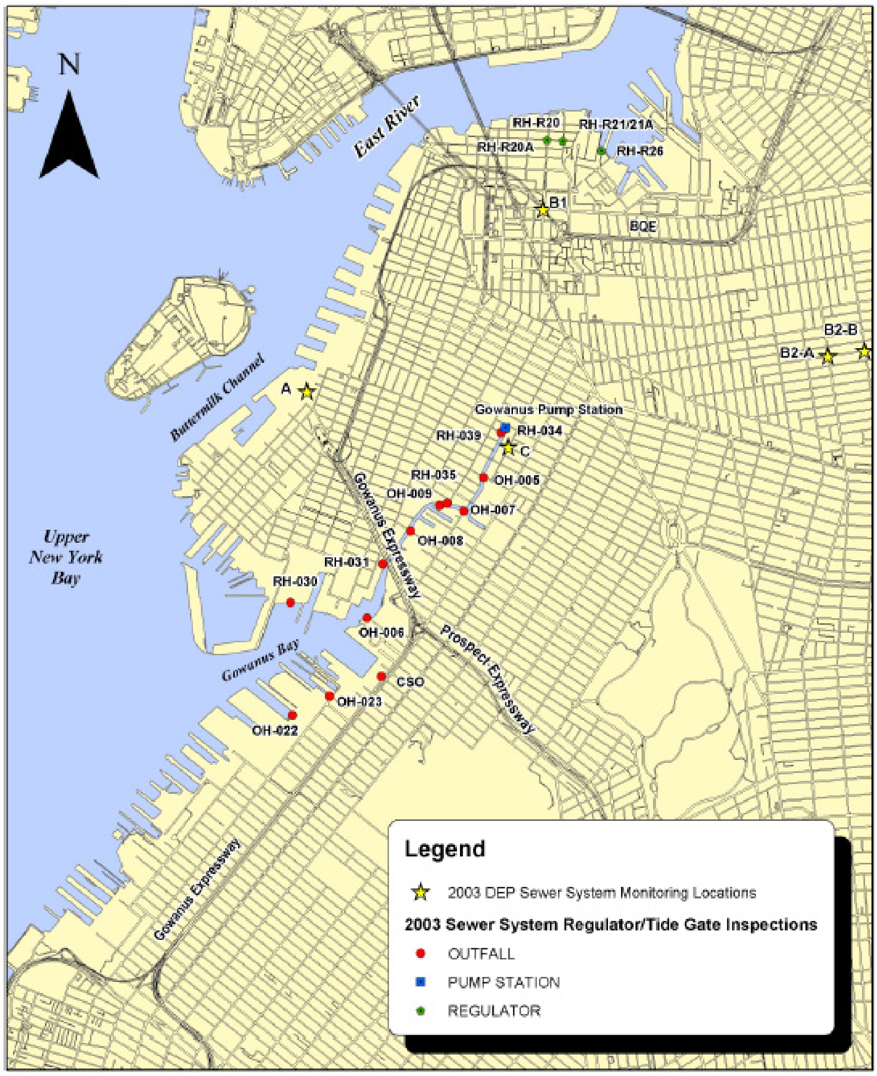
TABLE 3-3
CSO Discharges to Gowanus Canal (from DEP, 2008)

Outfall Permit Number	Outfall Location	Outfall Size	CSO Discharge From	Regulator / Relief Location	Combined Sewer Area (Acres)
RH-031	Creamer Street	72” diameter	Bond- Lorraine Sewer Relief	Lorraine Street and Smith Street	70
RH-033	Douglass Street	38”W x 44”H	Regulator R-25	Nevins Street and Douglass Street	5
RH-034	Butler Street	4 barrels, each 163” diameter	Gowanus Pump Station	Douglass Street	657
RH-035	Bond Street	48” diameter	Bond- Lorraine Sewer Relief	Bond Street and 4th Street	88
RH-036	President Street	18” diameter	Regulator R-22	Nevins Street and President Street	10
RH-037	Sackett Street	18” diameter	Regulator R-23	Nevins Street and Sackett Street	7
RH-038	Degraw Street	144”W x 62”H	Regulator R-24	Nevins Street and Degraw Street	10
RH-039	Douglass Street	38”W x 44”H	Bond- Lorraine Sewer Relief	NA (closed)	NA
OH-005	5 feet south of Carroll Street Bridge	42” diameter	3rd Avenue Sewer Relief	3rd Avenue and Carroll Street	34
OH-006	19th Street (north side)	36” diameter	3rd Avenue Sewer Relief	3rd Avenue and 19th Street	306
OH-007	east of 2nd Avenue	78” diameter	2nd Avenue Pump Station	3rd Avenue and 7th Street	339

TABLE 3-3
CSO Discharges to Gowanus Canal (from DEP, 2008)

Outfall Permit Number	Outfall Location	Outfall Size	CSO Discharge From	Regulator / Relief Location	Combined Sewer Area (Acres)
OH-009	5th Street	78" diameter	3rd Avenue Sewer Relief	NA (closed)	0
OH-024	23rd Street	42"W x 24"H (Oval)	3rd Avenue Sewer Relief	3rd Avenue and 23rd Street	NA
Total Combined Sewer Area (Acres)					**1,612**

Notes:
OH denotes the collection system tributary to the Owls Head WPCP catchment.
RH denotes the collection system tributary to the Red Hook WPCP.



Source: Gowanus Canal Waterbody/Watershed Facility Plan (NYCDEP, 2008)

FIGURE 3-5
Locations of Key Stormwater Infrastructure

In addition to CSOs, there are numerous stormwater-only discharges to the Canal, summarized in **Table 3-4**. As drainage and surface water management are studied in detail at a complete feasibility study stage, gravity drainage outfalls should be looked at to ensure they are sealed during flood events in order to maintain the integrity of the flood defenses and prevent flood water ingress into the areas being protected. For example, flap valves may need to be provided or replaced and would need to be maintained.

TABLE 3-4
Gowanus Canal Stormwater Outfall Discharges

Stormwater Outfall	Outfall Location	Outfall Size	Stormwater Sewer Area (Acres)
RH-601	West 9th Street	12-inch diameter	2
RH-615	10 feet north of Union Street Bridge	8-inch diameter	0
OH-607	East 9th Street	12-inch diameter	8
OH-601	22nd Street	36-inch W x 48-inch H (Egg)	22
OH-602	30 feet south of Gowanus Expressway	18-inch diameter	10
Total Stormwater Drainage Area			**42**

Source: NYCDEP, 2008.

Drainage and storage capacity around the Gowanus Canal are understood to be constrained. At present, the area surrounding the Gowanus Canal is subject to flooding due to heavy rainfall, separate from any storm surge. For example, a July 15, 2015, storm dropped about 1 inch of rain in less than one-hour, resulting in flood conditions reaching many inches deep and reportedly up to 4 feet, especially near 9th Street. NYCDEP is completing a Long-Term Control Plan (LTCP) that would significantly reduce overflow volumes. The with-project hydrodynamic modeling assessment is looking at potential runoff accumulation behind the storm surge barrier flood defense system, the “bathtub effect,” for an indication of the scope of a potential problem and requirements for a pump station as part of any barrier system.

3.4.3 Water Quality

The Gowanus Canal represents a 19th century industrial transformation of a natural tidal wetland. For much of the Canal’s history, industrial waste was discharged directly to the Canal without treatment, creating a layer of benthic sediment pollution that is now being addressed under a USEPA Superfund Project. Intermittent pollution of the Canal’s water by CSO discharges is a continuing problem that is being addressed by the NYCDEP LTCP.

The New York City Water Quality Standards designate the Gowanus Canal as a Class SD area, for which the best use is fishing. This classification requires that the water quality in the Canal be maintained as suitable for fish survival, and it is applied to areas in which natural or man-made conditions keep the waters unsuitable for secondary contact recreation and the growth of fish communities. This standard requires that a dissolved oxygen (DO) concentration of never less than 3.0 mg/l be maintained The SD designation applies to other heavily industrialized water bodies in the City such as the Arthur Kill, Kill van Kull, and Newtown Creek. This level of DO will ensure survival of fish biota, but is below the level considered necessary (4.0 milligram per liter [mg/L]) for minimally healthy fish communities.

The New York City Harbor Survey program has collected data on water quality in the waters surrounding the City for more than a century, and it maintains several sampling stations in the canal and its vicinity. The survey reports indicate a generally improving state of water quality for the Inner Harbor, of which the Gowanus Canal is one tributary—the result of decades of improvement in wastewater treatment and CSO controls. However, the physical configuration of the canal restricts the amount of tidal circulation that can dilute and remove pollutants, especially in the portions near the head end, leaving its water quality particularly vulnerable to impacts from CSO discharges.

3.5 Known Environmental Contamination Issues

3.5.1 Superfund Context

As noted in Section 2, the Gowanus Canal was bulk-headed and dredged in the late 1800s to facilitate the construction of a marine passageway for use by the numerous industrial facilities in the area, including manufactured gas plants (MGPs), tanneries, machine/metal works, chemical production plants, oil refineries, and various manufacturing facilities. Such uses, combined with the discharge of raw sewage and stormwater runoff (i.e., from CSOs), contributed to the widespread contamination of the waterway and surrounding subsurface. Despite early efforts to reduce contamination, including the implementation of pumping stations to dilute/treat canal water, contamination from prevalent industrial uses persisted and the Gowanus Canal was placed on the National Priorities List (NPL) by USEPA in March 2010 and declared a Superfund site in September 2013. Preliminary subsurface investigations noted in the USEPA's September 2013 Record of Decision (ROD) for the Gowanus Canal Superfund Site identified contaminant source areas associated with several former MGP facilities (primarily the Fulton, Metropolitan, and Public Place MGP facilities), indicating sediment/soil/groundwater contamination from coal-tar wastes/non-aqueous phase liquid (NAPL).[1] Baseline sediment sampling referenced in the USEPA documentation indicated elevated concentrations of polycyclic aromatic hydrocarbons (PAHs), petroleum-related volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), pesticides, and metals in varying locations/depths throughout the canal.

Ongoing remedial investigations are being conducted under the NPL and Superfund programs and in connection with various state programs (including the New York State Brownfield and Voluntary Cleanup Programs) to address residual contamination in the waterway sediment and contaminated upland sources, including the former MGP facilities. Improvements to reduce CSO and stormwater discharge to the Canal are also being implemented, as noted in the 2013 ROD, in conjunction with engineering and institutional controls outlined in the USEPA documentation to reduce contaminant migration and improve overall water quality.[1,2]

Any storm surge barrier and its upland infrastructure would require close coordination with the ongoing Superfund remediation efforts and compliance with all local and federal guidance on disturbance within the affected areas.

3.5.2 Municipal E-Designations Context

At a municipal level, New York City has created a system of "E-designations" to identify properties that have additional environmental review and compliance requirements based on a potential for adverse conditions present on a site or based on site development. They are triggered by land use review and rezoning actions subject to the City Environmental Quality Review (CEQR).

There are three basic types of E-designations including hazardous materials, air quality, and noise. Air quality and noise E-designations are intended to implement or identify redevelopment requirements associated with the additional measures necessary to avoid future potential impacts (i.e., building attenuation standards to achieve acceptable indoor noise standards or restrictions on the fuel or location of emission stacks to avoid a future stationary source air quality impact). Hazardous material E-designations are identified for parcel that have a likelihood of existing environmental impairment and require the fee-owner of a property to conduct a subsurface testing protocol and remediation, where appropriate, to the satisfaction of the New York City Mayor's Office of Environmental Remediation (NYCOER) before the issuance of a Building Permit and Certificate of Occupancy. These designations would be most applicable to use of upland parcels as part of the implementation of a storm surge barrier system and related flood prevention improvements.

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[1] Source: http://www.epa.gov/region2/superfund/npl/gowanus/ri_docs/692106_gowanus_canal_rod_9_27_13_final.pdf.

[2] Source: http://www.nyc.gov/html/dep/html/harborwater/gowanus_canal_drainage.shtml.

As the result of prior limited rezoning initiatives already in place, including the Park Slope and South Park Slope rezonings, Appendix C show that several properties in the greater surrounding area have been assigned hazardous materials E-designations. These are located primarily on blocks east and northeast of the Canal along Fourth Avenue. It is noted that no existing e-designations have been assigned to properties bordering on or located adjacent to the Canal (including the area near the mouth of the Canal, in the area of the proposed the storm surge barrier improvements) primarily since there have not been major land use or rezoning efforts in these areas.

However, due to the current and former industrial and automotive uses in this area, subsurface disturbance associated with the proposed storm surge barrier system could encounter contaminated media (e.g., soil, sediment and ground/surface water). As redevelopment and rezonings continue in the area, it is anticipated that additional parcels along the canal (including in the vicinity of the proposed project) and proximal upland facilities will receive hazardous materials E-designations to address areas of potential contamination not identified in previous studies requiring further coordination with NYCOER. It is assumed that a similar level of review would be associated with the development of the storm surge barrier and related improvements.

3.5.3 Environmental Site Investigation

A desktop review of environmental site conditions was conducted as part of the study. A summary of potential hazardous materials along the concept option alignments and suggested future investigations is provided in Appendix H.

3.6 Navigation

3.6.1 Land

Main road connections include the interstate highway (Brooklyn Queens/Gowanus Expressway) connecting to Manhattan via the Battery Tunnel and arterial roads, including canal crossings at the 9th Street and Hamilton Avenue Bridges. As part of the existing conditions information collection, truck and bike routes were indicated, and public transit connections, including bus, subway, and ferry routes were documented. The interfaces with these transportation routes and facilities have been considered in developing the upland defense alignments.

3.6.2 Marine

The Gowanus Canal begins at Butler Street and extends southward approximately 8,500 feet to its mouth with depths ranging from 4 feet to approximately 15 feet at Hamilton Avenue, then rapidly increasing in depth to approximately 30 feet for the rest of the canal heading out to Gowanus Bay.

The canal is approximately 100 feet wide up to Hamilton Avenue where it widens and flows into Gowanus Bay and Upper New York Bay. Present land uses along the Canal consist primarily of manufacturing, industrial, and commercial uses. The canal shorelines are entirely altered consisting almost exclusively of bulkheads with some areas of riprap and piers. Traffic is primarily barges with tug escort. Vessel traffic through the canal is limited with only the federal navigational channel maintained south of Hamilton Avenue. There are four turning basins located north of Hamilton Avenue at 4th Street, 6th Street, 7th Street, and 11th Street. These basins experience limited marine traffic as they are not part of the main navigational channel and are primarily used as a means for vessels to reverse direction during transit.

Due to the relatively shallow water depth, narrow channel width, and numerous air draft restrictions (with moveable bridges closed), vessel traffic is restricted primarily to tugboats and barges. This is especially true for the traffic traveling further inland. Based on a review of waterfront land use, typical vessel characteristics are likely within the ranges shown below.

TABLE 3-5
Indicative Vessel Characteristics

	Air Draft (feet)	Water Draft (feet)	Length (feet)	Beam (feet)
Barge	10-35	3-12	25-150	20-45
Tugboat	20-50	8-20	50-120	20-40

Additional discussion of navigation considerations is presented in Section 6 in the in-water storm surge barrier assessment.

3.7 Built Environment

A series of maps characterizing the built environment and urban design considerations were created as part of the existing conditions inventory. They are presented in Appendix E. These include: blocks and lots, land use, ownership, retail frontage, recent and upcoming development sites, open space, zoning and historic and/or cultural assets, view corridors, Design Flood Elevation conditions, roadbed widths, rights-of-way, loading docks, curb cuts, built/vacant lots, single-story buildings and connectivity.

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4 Project Overview Storm Surge Barrier System Components

4.1 In-Water Storm Surge Barrier Gate Types

There are a variety of in-water storm surge barrier gates that may be used, depending upon site conditions. All barrier gate types would be expected to offer the same level of protection and performance as far as storm severity because the design standards for defense elevation would be the same. Rather, unique site conditions such as width limitations, subsurface depths and conditions, siltation rates, navigation use, speed of closure, or operation and maintenance requirements make some gate types better suited to a specific location than other gate types. Whole life costs, both capital and operating/maintenance, as well as adaptability to future expansion to accommodate sea level rise are two other considerations that factor into gate selection.

Table 4-1 below summarizes how different storm surge barrier gate types perform against different attributes typically considered in selecting a gate most suitable to a given location.

TABLE 4-1
Comparison of Storm Surge Barrier Gate Types
Note: G=green (good performance), Y=yellow (moderate performance), R = red (not possible/worst performance)

	Miter Gate	Flap Gate	Vertical Rotating Gate	Vertical Lift Gate	Horizontal Rotating Gate	Caisson Gate	Inflatable Gate
Gate width >100 feet	R	G	G	G	G	G	G
Gate width >300 feet	R	G	R	R if lowered* G if raised *	G	R	Y**
Gate depth > 35 feet	G	G	G	G	G	G	R
Avoid spatial requirements (gate recess, etc.)	G	G	G	G	R	Y	G
Ease of operation	G	G	G	G	G – if large width R	R	Y
Ease of maintenance	G	R	Y	G	G	Y	Y
Navigation height restriction	G	G	G	R if lowered* G if raised *	G	G	G
Vulnerability to damage from navigation impact	G	Y	Y	Y	Y	G	R
Time for barrier to close	G	G	G	G	G – if large width R	R	Y
Landscape impact	G	G	G	R	Y	Y	G

** There are two designs or operational configurations. The first configuration has a gate submerged in a recess which lies below the channel bed and is raised to the required flood defense position. The alternate configuration retains the gate above water by towers/supports on either side and is lowered to the flood defense position with the gate sealing against the sill/channel bed.*

***Precedent projects using inflatable gates have a maximum width for each gate that approaches 300 ft. For larger widths, multiple gates are linked together.*

In addition to the characteristics compared above and the key features of each gate type described in the following sections, there are a number of engineering or design assumptions that were considered in both assessing the particular gate type best suited for a given in-water barrier location, or which are assumed to apply across any location.

Siltation is a consideration in selecting an appropriate gate as certain types, such as a flap gate, are more susceptible to operational and maintenance issues caused by the substantial accretion of silt on top of or adjacent to the gate. Although most gate types can be designed in such a way that the hydraulics are sized to account for onerous siltation conditions, this will have significant operational and whole life cost implications associated with it. However, based on the study team's understanding of the existing conditions, and the current limited frequency of dredging undertaken by the United States Army Corps of Engineers in the canal, it has been assumed that the rate of siltation is not a significant factor. The proposed gates identified by this study are less susceptible to siltation, and hydraulics can be sized to clear the anticipated level of silt accretion.

Scouring of the river bed can also be a problem for any in-water structures. However, based on the study team's understanding of the likely flow velocities through the barrier, the relatively limited tidal range, and the flow control created by the existing bascule bridges, it has been assumed that scour immediately upstream and downstream of the storm surge barrier is unlikely to be a significant factor. This is reinforced by the fact that the in-water storm surge barriers would probably be built over creek bed capping installed as part of any future Gowanus Canal (Canal) Superfund remediation work.

An additional factor influencing gate choice is the excavation depth required for a gate sill and base foundation. Given the contaminated nature of the creek's existing channel bed, and the likely remediation and capping plans, gate types selected for the locations have sought to minimize the depth of excavation/dredging in order to minimize to the degree possible, the excavation and mobilization of contaminated material within the waterbody, and the disturbance of potential future Superfund remediation.

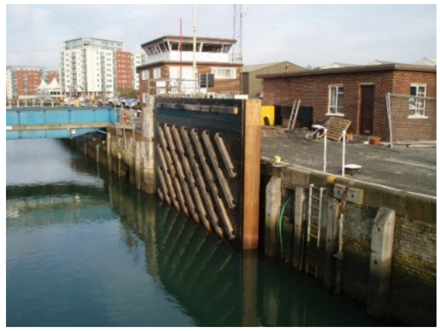
Consideration has also been given to the anticipated vertical height of any storm surge barrier and resultant vulnerability to wind loading or challenges to closing a gate in high-wind hurricane conditions. Gates with a very large "sail" area, such as the vertical lift gate, can be problematic in extreme high wind conditions. The section that follows introduces the various gate types in use globally and in the United States, and lists key advantages and disadvantages for each.

4.1.1 Miter Gate

Miter gates consist of double leaf gates where the leaves rotate about their quoins/hinges, and close against an underwater sill, to meet and form an angle pointing in the direction of the tidal surge. Miter gates are commonly used on canals and smaller waterways and generally represent the simplest storm surge barrier option with the lowest cost and ease of operations.

Ipswich Tidal Floodgate, UK – single 50-foot gate

Miter gate in closed position



Miter gate in open position

FIGURE 4-1
Miter Gate

The gates are operated by hydraulic rams which are designed together with the gate to have the size and strength required to clear general siltation and sediment out of the way so long as it is not excessive.

Advantages miter gates offer include the following:

- They have no restriction on navigation clearance height.
- They have a relatively simple design and construction.
- Their closure time is relatively quick, requiring shorter lead-up time before closure and coordination with vessel operators.
- Their operation and maintenance is comparatively easy, requiring a single operator and having no confined space-entry requirements.
- They offer a proven concept with good reliability and simple back-up procedures to close gates.
- They normally require little upland area, which can minimize cutting into the existing bulkhead and land behind it, and thus enable the barrier to be located where space is constrained by existing development and land use. Construction and whole-life costs are generally lower in comparison to other barrier gate types.

Miter gates present a few disadvantages or limitations to their use, including:

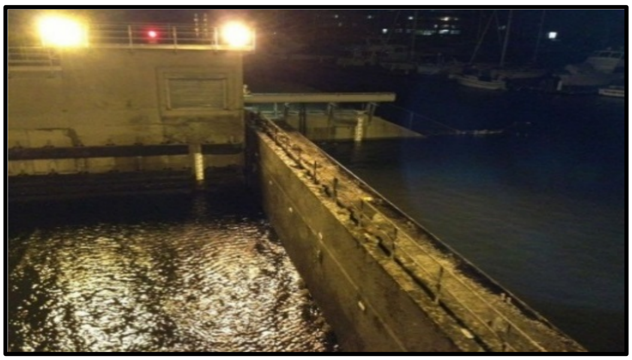
- Gate width is generally limited up to about 100 feet, which precludes their use in all but of one of the locations considered for a barrier location at the Canal.
- They can only operate one way and cannot deal with reverse head, although this is unlikely to be an issue for the functionality that the gate is required to provide at Gowanus Canal. Control is problematic when operating under flow or wave conditions.

4.1.2 Flap Gate

Flap gates rely on a submerged bottom hinged arrangement at the sill and a gate that is raised either by hydraulic rams or by lifting wires. In the open position, the gate generally lies in a horizontal position flat on the channel bed.

Stamford Hurricane Barrier, CT– single 90-foot gate.

Aerial view of barrier with gate in open position lying flat on channel bed. Source: USACE, 2008



Barrier flap gate in closed position during Hurricane Sandy surge event in October 2012. Source: USACE

FIGURE 4-2
Flap Gate

Flap gate advantages include the following:

- Large gate spans are feasible, meaning they can accommodate any of the locations considered at Gowanus Canal.
- They present no restriction on navigation clearance height.
- The gate design is relatively simple, although civil works construction can be complex, such as the installation of an underwater foundation to support the gate hinge and gate recesses. They are suitable for use in deep water.
- Their operation is relatively easy, requiring an average closure time of about 20 minutes and only one or two operators, depending on size.
- They offer a proven concept with good reliability.
- They provide reasonable control when operating the gate in flow or wave conditions.
- They normally require little upland area, which can minimize cutting into the existing bulkhead and land behind it, and thus enable the barrier to be located where space is constrained by existing development and land use.

Flap gates present a few disadvantages or limitations to their use, including:

- There are potential issues with the gate recess silting up or silt deposition on top of gate while it is in open position, although this is believed to be less of a concern at the potential Gowanus Canal locations.
- Flap gates are difficult to inspect, maintain, and replace, particularly the submerged hinges.

- The gate can only operate one way, although this is unlikely to be an issue for the functionality that the gate is required to provide at Gowanus Canal.

4.1.3 Vertical Rotating Gate

There are two types of vertical rotating gates: rising sector gates and falling radial (or tainter) gates. Rising sector gates normally lie open in a horizontal position within a recess in the sill below the channel bed level. To close for the vertical flood defense position, the gate is raised by rotating it 90 degrees. In contrast, a falling radial gate is held in the raised open position above normal water levels and is lowered by rotating it down until it seals against the sill provided to close the gate.

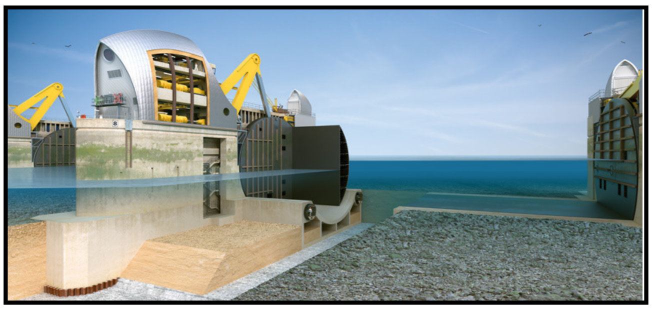
The vertical rotating rising sector gate's advantages include the following:

- Large gate widths up to 200 feet are feasible. Such a gate width would accommodate most (but not all) of the locations considered for Gowanus Canal.
- They present no restriction on navigation clearance height.
- They are ready for immediate deployment and have a relatively fast closure time of around 5 minutes. Their operation is relatively easy, and depending on size, may require only one or two operators.
- They can accommodate reverse head and/or flow, thus having the ability to provide both storm surge defense and retention of a raised water level upstream of it. Reasonable control is possible when operating the gate in flow or wave conditions.
- They offer a proven concept with good operational reliability. The gate can be rotated out of the water for inspection and maintenance.
- They normally require little upland area, which can minimize cutting into the existing bulkhead and land behind it, and thus enable the barrier to be located where space is constrained by existing development and land use.

Thames Barrier, London, UK – combination of 4No. 200-foot and 2No. 103-foot wide vertical rising sector gates.

Source: Environment Agency

Overall aerial view of barrier



Visualization of sector gate in closed (left) and open (right) positions.

FIGURE 4-3
Vertical Rotating Gate

Vertical rotating rising sector gates present a few disadvantages or limitations to their use, including:

- The gate design and associated mechanical and civil works are relatively complex with high tolerance required for construction of the sill and gate recess.
- There can be potential issues with silting up of the gate recess or debris/objects accumulating within it that can damage the gate or inhibit its opening.
- Confined space entry is required for operators to inspect and maintain the gate's internal mechanisms.
- The sill is relatively deep to house the gate and would require a greater amount of excavation and disturbance of remediated and capped material.

4.1.4 Vertical Lifting Gate

Vertical lifting gates are a widely used type of storm surge barrier gate, and generally have a satisfactory record of operation. There are two designs or operational configurations. The first configuration has a gate submerged in a recess which lies below the channel bed and is raised to the required flood defense position. The alternate configuration retains the gate above water by towers/supports on either side and is lowered to the flood defense position with the gate sealing against the sill/channel bed. Given the contaminated nature of the existing channel bed, the remediation and cap activity planned as part of Superfund remediation works, and the preference to minimize disturbance to the remediated channel bed, the lowered vertical lifting gate (drop gate) is the more suitable configuration of this gate type for the Gowanus Canal locations.

The vertical lifting gate's advantages include the following:

- Large gate spans, up to around 360 feet wide are feasible, so they can accommodate any of the locations considered at the Canal.
- Their operation is relatively easy, requiring an average closure time of about 20 minutes and one or two operators, depending on size.
- The raised gate is accessible for maintenance, so no confined space entry is required apart from any internal gate inspection and maintenance. Working from height is an issue that needs managing.
- They offer a proven concept with good reliability.
- Reasonable control is possible when operating the gate in flow or wave conditions.
- They normally require little upland area, which can minimize cutting into the existing bulkhead and land behind it, and, thus, enable the barrier to be located where space is constrained by existing development and land use.

Hull Barrier, UK – single 100-foot-wide vertical lifting gate that is lowered into position.

Barrier lifting gate in semi-lowered position above water.

Lifting gate in normal open position rotated 90 degrees to maximize navigation clearance.

FIGURE 4-4
Vertical Lifting Gate

Vertical lifting gates present a few disadvantages or limitations to their use, including:

- The raised gate configuration (drop gate) imposes a clearance height constraint for navigation. The higher the water level within the channel, the greater the gate height required above navigation clearance, which can increase the size and complexity of the structure.

- The raised gate configuration is subject to wind load.
- There are potential operational and maintenance issues with the wearing of gate guide wheels and with underwater marine growth affecting gate movement.
- The vertical lifting gate may be sensitive to hydrodynamic-induced vibration.

4.1.5 Horizontal Rotating Gate

The horizontal rotating gate comprises circular sector or radial gates that rotate on a vertically mounted pivot and close in a horizontal plane. In the open position the gate leaves retract and lie within a recess alongside and clear of the navigation channel. Larger gates generally use floating gates that are pushed across the channel and then filled with water to lower them onto the constructed sill and channel bed.

Lake Borgne Barrier, New Orleans – the barrier is a single, 150-foot-wide, vertically hinged horizontal rotating sector gate.

Overall aerial view of barrier. Source: USACE, 2012

Horizontal sector gates in normal open position recessed into areas adjacent to the channel and clear of navigation. Source: USACE, 2012

FIGURE 4-5
Horizontal Rotating Gate

The horizontal rotating gate's advantages include the following:

- Large gate spans, in excess of 600 feet wide, are feasible, so they can accommodate any of the locations considered at the Gowanus Canal.
- They present no restriction on navigation clearance height.

- They are suitable for use in deep water. This advantages is especially relevant for some of the Gowanus Canal barrier locations as where Superfund remediation may add 10 to 20 feet to existing depths.
- Rapid closure time of between 5 to 10 minutes is possible for smaller gates (including those circa 150 feet wide), though larger gates can take up to 60 minutes.
- Location of gates in “dry dock” recesses allow offline maintenance in the dry.
- They offer a proven concept with good reliability.

Horizontal rotating gates present a few disadvantages or limitations to their use, including:

- Use of infill areas within the channel would be required to create the necessary recesses unless the recess were into the adjacent upland areas of the canal. Depending on the size of the infill, there may be opportunities to create new recreational space or habitat if all of the infill is not used to house the recessed gates.
- Confined space entry is required to undertake internal gate inspection and maintenance for larger size gates.
- The gate design is relatively complex.
- If the gate runs on wheels across the sill, then the build-up of silt can be both an operational and maintenance issue. However, this is not believed to be a major problem in the canal and the hydraulics would be sized to clear the anticipated level of silt accretion.

4.1.6 Caisson Gates

There are three types of caisson gates: floating, sliding, or hinged caisson (or barge). A floating caisson gate is moored to a pier, then moved into position by tugs and filled with water to lower it into the constructed recess. This gate type is often used for large size dry docks. In contrast, a sliding caisson gate is a floating gate located in a recess to suit, pushed or pulled across the channel and then filled with water and lowered to seal onto a sill. A hinged caisson gate is operated in a similar fashion but can be rotated around into position using either a side or bottom hinge.

The caisson gate’s advantages include the following:

- They can accommodate large gate widths.
- They present no restriction on navigation clearance height.
- A floating caisson gate can be maintained away from the channel without interfering with navigation.
- Except for a hinged caisson gate, they are suitable for reverse head.
- A floating or hinged caisson gate requires little upland area.

Royal Chatham Docks, UK – single sliding caisson gate circa 100 feet wide.

Sliding caisson gate post refurbishment being lowered into normal open position. Source: Beckettrankine.

Lake Borgne Barrier, New Orleans – single barge gate 150 feet wide.

Barge gate in normally closed position on left alongside horizontal rotating sector gates. Source: USACE, 2012

FIGURE 4-6
Caisson Gate

Caisson gates present a few disadvantages or limitations to their use, including:

- Bottom hinged gates are not suitable to deal with heavy silt build up on top of the gate while in the open position.
- In general, they are not suitable for deep waters, which depending upon post-Superfund remediation depths, could preclude this gate option.
- They offer very little or no control when operating the gate in flow or wave conditions.
- Relatively complex operating equipment is required, such as having a tug on-hand to maneuver the caisson gate into position.
- Slide gates require relatively complex civil works, particularly those associated with the construction of the required gate recess.
- Sliding caisson gates require a large upland area to accommodate the recess and would require cutting into the existing bulkhead/waterway edge.

- Floating caisson gates normally require confined space entry for inspection since they are large hollow steel structures, similar to barge gates, with internal piping requiring internal structural and mechanical inspections.
- Very slow deployment/closure speed of around 30 minutes is required, and closure for floating caisson gates can take up to half a day or longer due to tug availability and high operational manpower requirements.

4.1.7 Inflatable Rubber Dam

An inflatable rubber dam consists of a rubber bladder attached to the bottom of the channel that is inflated to form a dam/barrier across the channel opening. They are used widely throughout the world but currently with limited application as storm surge barriers. Inflation can be with air, water, or a combination of both. In the open position, the rubber bladder is deflated and lies relatively flat in the recess provided on the channel bed.

Ramspol Barrier, Holland – 3No. 246-foot-wide, inflatable rubber dams.

Overall aerial view of barrier.

Rubber dams in deflated open position.

Rubber dams in inflated closed position.
Image source: Waterschap Groot Salland

FIGURE 4-7
Inflatable Rubber Dam

The inflatable rubber dam's advantages include the following:

- They can accommodate spans up to 300 feet wide, though a series of inflatables would be used to bridge the total expanse.
- They present no restriction on navigation clearance height.
- They offer a proven concept with good reliability.
- They normally require relatively little upland area, which can minimize cutting into the existing bulkhead and land behind it, and thus enable the barrier to be located where space is constrained by existing development and land use.
- They provide a direct transfer of hydraulic load.
- They can be erected and deflated in flowing water.
- They do not require hinges or a drive system.
- They are not sensitive to siltation.

Inflatable rubber dams present a few disadvantages or limitations to their use, including:

- They are generally not suitable for waters deeper than 30 feet, which would preclude locations at the Gowanus Canal.
- They have a lengthy closure speed of around 55 minutes.
- It is difficult to inspect, maintain, and replace the rubber dam element, and confined space entry is required.
- They are more vulnerable than other types of barriers to navigation or debris impact when in the deployed position.

4.2 Upland Defense Types

There are a variety of upland defense structures that may be used, depending upon unique site conditions for a given location. An important consideration is whether the structure can be left permanently in place or must be deployed and then removed between flood events to allow for access.

Permanent structures consist of earthen berms and vertical floodwalls inland and shoreline stabilization (bulkheads and rock revetments) along the shoreline. For the inland features, earthen berms are nearly always more cost effective but require a larger footprint, so can take away from active recreation areas, although passive recreation may be accommodated. Vertical floodwalls require a significantly smaller footprint but are more costly and require a subsurface foundation. Vertical floodwalls are typically constructed of concrete or sheet pile, though a variety of vendor products are available (such as vinyl piles, glass walls, etc.). Along the shoreline, rock revetments are generally more cost effective and offer in-water habitat, but have a larger required footprint. Bulkheads offer more opportunities to integrate active recreational features as a result of the narrower footprint.

A variety of deployable structures may be used. The specific site conditions such as width, clearance, subsurface conditions, and operation and maintenance requirements make some deployable types better suited to a specific location than other types. **Table 4-2** summarizes how different deployable upland defense types perform against different considerations.

TABLE 4-2
Comparison of Deployable Upland Defense Types

	Slide or Roller Gate	Swing Gate	Demountable Panels
Opening width >80 feet	R	R	G
Avoid spatial requirements (clearance to open)	G	R	G
Ease of maintenance	Y	Y	G
Ease of operation/implementation	G	G	R
Storage requirements	G	G	R
Visual Impact	Y	Y	G
Cost	R	R	Y

The following section discusses each of the upland defense structures and lists key advantages and disadvantages for each.

4.2.1 Earthen Berms/Levees/Revetments

Earthen levees typically have a 10-foot wide top width and 2:1 ratio side slopes at a minimum. It is typical to have an additional 15 feet of clearance on each side of the levee toe for inspection, maintenance, and flood-fighting access. They need a properly prepared foundation, which may require over excavation, utility relocations, and additional ROW acquisition. Earthen levees are constructed of engineered soils to resist issues with stability, seepage, and settlement. The riverward side requires erosion protection, such as riprap or grass.

FIGURE 4-8
Earthen Berms

The advantages of using earthen berms include:

- They offer a proven concept and have been shown to be reliable with adequate inspection and maintenance.
- They tends to be the most cost-effective levee solution when onsite space and soil materials are available.

Use of earthen berms also present a few disadvantages, including:

- They typically occupy a large footprint that could require relocations and right-of-way (ROW).
- There are potential issues of cutting off local drainage that would have to be captured and routed through/under the levee.
- Construction will likely require significant imported soil materials to meet specifications. This could translate into traffic issues with number of trucks, staging, and dust control.
- Earthen berms are discontinuous at crossings.

FIGURE 4-9
Revetments

4.2.2 Vertical Floodwalls

Vertical floodwalls are typically constructed of reinforced concrete or steel sheet piles. It is typical to have an additional 15 feet of clearance on each side of the floodwall for inspection, maintenance, and flood-fighting access. Reinforced concrete floodwalls need a properly prepared foundation, which may require over excavation, utility relocations, and additional ROW. An underground footing is required that has a width greater than the surface wall, unless a sheet pile "I-Wall" is used. Steel sheet pile floodwall depths and sections depend on existing subsurface soil conditions, but are deeper than the footing of a concrete wall. The depth of embedment may require utility relocations. Vertical floodwalls are engineered to resist stability, seepage and settlement issues. The materials used for construction typically provide erosion protection without additional revetment.

FIGURE 4-10
Vertical Floodwall

Advantages to using vertical floodwalls include the following:

- Vertical floodwalls offer a proven concept that is reliable with adequate inspection and maintenance.
- They require a smaller footprint compared to an earthen berm.

Disadvantages the vertical floodwalls present include the following:

- Typically, the foundation preparation and driven sheet piles require relocations and ROW acquisition. Pile driving can present vibrational risks to nearby buildings.
- There are potential issues cutting off local drainage that would have to be captured and routed through/under the floodwall.
- Construction requires imported materials, which could translate into traffic issues with number of trucks and staging.
- Vertical floodwalls are discontinuous at crossings.

4.2.3 Deployable Structure: Slide or Roller Gate

Slide or roller gates are typically constructed with a reinforced concrete foundation and/or reinforced concrete or steel superstructure. Additional space is required adjacent to (in-line with) the gate to store it while in the open position. Clearance for inspection and maintenance is also required in front of the open gate. The reinforced concrete foundation may require over excavation, and utility relocations. Slide or roller gates are engineered to resist stability, seepage, and settlement issues. The materials used for construction typically provide erosion protection without additional revetment.

FIGURE 4-11
Slide Gate

Advantages a deployable slide or roller gate include the following:

- Slide or roller gates offer a proven concept that is reliable with adequate inspection and maintenance.
- Closure speed is relatively fast (circa 15 minutes), and time requirements are relatively short. When accounting for manning and closure checks, time requirements can be up to 2 hours, especially for the larger gates. Manning time requirements could take longer, depending upon traffic diversions and road closures put in place as part of any traffic operations and management plan.
- The gate opens in-line with the closed position, minimizing the perpendicular onsite space required.

Disadvantages a deployable slide or roller gate present include the following:

- They are only practical for a limited closure width (up to 80 feet with two adjacent gates).
- There are potential operational and maintenance issues with the wearing of gate guide wheels and the foundation plate due to traffic.
- Construction will require imported materials, which could translate into traffic issues with number of trucks and staging.

4.2.4 Deployable Structure: Swing Gate

Swing gates are typically constructed with a reinforced concrete foundation and steel gate structure. Additional space is required adjacent to (both in-line and perpendicular) the gate to operate and store it while in the open position. Clearance inspection and maintenance is also required. The reinforced concrete foundation is typically robust and may require piles, over excavation, and utility relocations. Swing gates are engineered to resist issues with stability, seepage and settlement. The materials used for construction typically provide erosion protection without additional revetment.

Advantages a swing gate presents include the following:

- Swing gates offer a proven concept and are reliable with adequate inspection and maintenance.
- Closure speed is relatively fast (circa 15 minutes), and time requirements are relatively short. When accounting for manning and closure checks, time requirements can be up to 2 hours, especially for the

larger gates. Manning time requirements could take longer, depending upon traffic diversions and road closures put in place as part of any traffic operations and management plan.

- There are no vertical clearance issues.

FIGURE 4-12
Swing Gate

Disadvantages of using a swing gate include the following:

- They are only practical for a limited closure width—up to 80 feet with two adjacent gates.
- Construction will require imported materials which could translate into traffic issues with number of trucks and staging.

4.2.5 Deployable Structure: Demountable Panels

Demountable panels are typically constructed of reinforced concrete foundations, steel intermediate posts, and aluminum panels. The reinforced concrete foundation may require piles, over excavation, and utility relocations. Demountable panels are engineered to resist issues with stability, seepage and settlement. The materials used for construction typically provide erosion protection without additional revetment.

FIGURE 4-13
Demountable Panels

Advantages demountable panels present include the following:

- There are no limits to closure width (although there is a limit to individual panel widths and column spacings).
- Demountable panels offer a proven concept and are reliable with adequate storage, inspection, and maintenance
- Tends to be the most cost-effective closure solution when onsite space is tight.

Disadvantages of using demountable panels include:

- Closure speed and time requirements are longer: approximately 2 hours for smaller systems and up to 4 hours for the larger systems. More manpower required for installation as compared to swing/slide gate operation. Any installation, especially for larger ones where a crane is required, will present health and safety challenges in hurricane for wind conditions. Early closure may be dictated, leaving little scope for last minute emergency access to the zones in front of the upland defenses.
- Typically the foundation preparation requires utility relocation and ROW acquisition.
- Construction will require imported materials, which could translate into traffic issues with number of trucks and staging.

The **Table 4-3** shows typical implementation times and equipment requirements for the three deployable systems discussed.

TABLE 4-3
General Guidance of Implementation and Use of Closure Structures within Floodwalls

Type	Dimensions	Implementation Time* (does not include delivery)	Manpower	Equipment Needed**
Post/Panel System (small)	Height: <5 feet Length: <50 feet	2 hours	3-man crew	Truck (delivery) Forklift (installation)
Post/Panel System (large)	Height: 5 feet to 15 feet Length 50 feet to 200 feet	4 hours	12-man crew	Truck (delivery) Crane (offload) 2 Forklifts (installation)
Slide gate	Height: <15 feet Length: <40 feet (or 80 feet with center column)	2 hour	3-man crew	Truck (installation) Forklift
Swing gate	Height: <15 feet Length: <40 feet (or 80 feet with center column)	2 hour	3-man crew	Truck (installation)

* Additional activity to make the structure watertight (i.e. polyvinyl chloride (PVC) sheeting and sandbags) are not included.

** The best option truck used for delivery of the posts and panels would include a flatbed with a truck-mounted crane. The slide gate and swing gate trucks would need to include tools as needed to complete the closure.

4.3 Lessons-Learned

This section identifies and documents lessons learned and best practices from other storm surge barrier projects in the United States and overseas, which are applicable to the potential barriers being considered for the Canal.

The lessons learned and best practices have been categorized under the topic areas listed below, which generally determine the key requirements and their impacts upon the design and delivery of storm surge barrier schemes.

FIGURE 4-14
Conceptual image of barrier in Newtown Creek from SIRR.

The topic areas are as follows:

- Land use
- Navigation and transport
- Bathymetry and geomorphology
- Topography
- Hydrology, hydraulics and hydrodynamics
- Climate
- Engineering and design
- Environment
- Operation and maintenance
- Regulatory impacts

Generally all of the lessons learned and best practices detailed below are applicable to both the Gowanus Canal and Newtown Creek studies. Where relevant, individual reference is made where it specifically relates to one of the two locations.

For ease of reference, the various barrier projects used as references regarding lessons learned are as follows:

- Lake Borgne Barrier (IHNC), New Orleans, U.S.
- Ipswich Barrier, Suffolk, UK
- Boston Barrier, Lincolnshire, UK
- Thames Barrier, London, UK
- Hull Barrier, Yorkshire, UK
- Ramspol Barrier, Netherlands
- Saint Petersburg Barrier, Russia
- Mose Barrier, Venice, Italy

It should be noted that there are three storm surge barriers in the eastern United States that are not on this list of information: the Fox Point Hurricane Barrier, Independence, Rhode Island; the New Bedford Harbor Hurricane Barrier, Massachusetts; and the Hurricane Barrier, Stamford, Connecticut. The project team has had no access to lessons learned of any note from these locations, but it is worthwhile noting that the

United States has, through these hurricane barriers that were built following the 1938 Long Island Hurricane and subsequent hurricane flooding in the 1950s, some of the oldest storm surge barriers in the world.

4.3.1 Land Use

It is important to identify the land use—past, present and future—adjacent to a proposed barrier location as it can prove to be either a showstopper as regards location, result in very high costs for the remediation of contaminated land, or have significant influence as to the cost or impacts of the barrier scheme whether short-term during construction or long-term after construction.

- The Ipswich Barrier scheme undertook the construction of the defenses required to tie the barrier into high ground as an earlier phase of the works. This has enabled these works to be designed to form part of the adjacent Griffin Wharf development proposals on its west bank before the development is completed (see **Figure 4-15**). This has avoided the cost of reconstructing the landscaped area as well as compensation claims for disruption, blight to property sales, etc. during construction. This is something to consider, particularly with respect to the Hunters Point South and Greenpoint developments at the mouth of Newtown Creek.

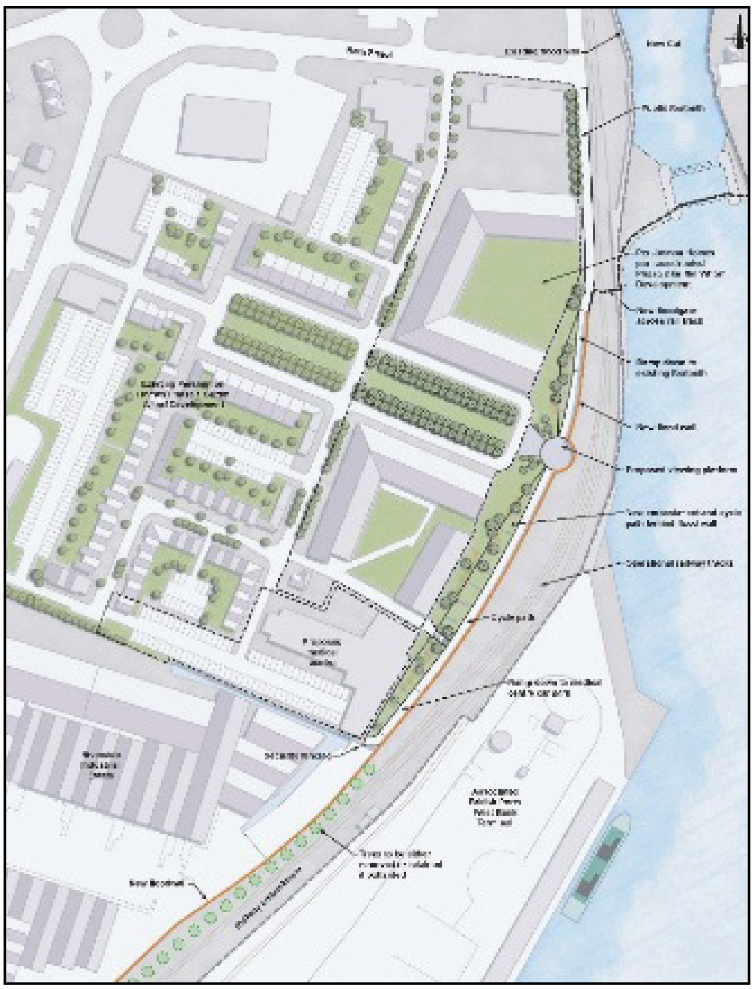


FIGURE 4-15
Plan of Ipswich Barrier West Bank Works which were undertaken as early works prior to barrier construction.

- For the above Griffin Wharf development in Ipswich, new apartments are to be constructed which have unimpeded views to the River Orwell estuary. Following consultation with the developer at an early stage of the barrier project, the barrier location was modified so as not to impede these views and hence avoided the compensation claim for blight and loss of property value that the developer would otherwise have sought. Again this could be relevant when considering the planned new developments at the mouth of Newtown Creek.

- It is important to ascertain what future developments/land use are proposed in the study area for the barriers, and that consideration is given to the location of the barrier such that, if possible, it does not prevent their future implementation, e.g., the Ipswich Barrier and its control building have been located to the south away from the proposed alignment for a potential future road bridge crossing. Alternatively there is the opportunity of combining the barrier with the construction of a road or rail bridge as per the Saint Petersburg Barrier (**Figure 4-16**) or Tees Barrage. This is a consideration for Gowanus where there could be potential to integrate a cycle/pedestrian bridge link as part of the Brooklyn Greenway.

FIGURE 4-16
Saint Petersburg Barrier, Russia includes a roadway.

- For flood defense schemes, there is generally a limit to the extent of flood risk area that can be justified for improved flood protection. Sometimes these schemes require land from, or cause major impact to, landowners who lie outside of the protected area, i.e., lots of impact but no benefit. This can often result in substantial claims for compensation or objections from those affected which in turn can involve extended legal action and therefore substantial costs and project delays.
- Storm surge barrier schemes generally involve an interface with existing services such as electricity, gas, telecommunications, water, sewerage, oil, etc. It is important to understand as early as possible the importance of those services, their condition, and the scale of likely diversion works that will be required as it can have a significant impact on the barrier location and/or cost. The cost of these diversion works can be disproportionately high versus the cost of the barrier construction, as demonstrated by the Ipswich Barrier scheme where the enabling works to divert two 50 year old 132 kilovolt (kV) cables is costing circa $17 million in comparison to the $33 million contract to construct the barrier. This could be a key issue for the Newtown Creek barrier due to the cables and pipelines located along the bed of the creek, which potentially may need to be diverted.
- Early identification of high risk areas of contaminated land from past records, site history and usage, are important as the potential remediation cost and/or environmental impacts can be so significant that the barrier location, form or layout has to be substantially changed to minimize any disturbance to the contaminated land, or to avoid contaminants leaching/being mobilized into the surrounding water table. For both Gowanus and Newtown the extent of contamination with the Superfund sites will need to be taken into consideration.

4.3.2 Navigation and Transport

Storm surge barriers, being located in a waterway, by their very nature interface to varying degrees with the navigation traffic that uses the waterway. This can vary from large commercial sea-going vessels to small recreational craft. The passage of this navigation traffic through the barrier is a critical requirement which impacts upon the barrier location, type, dimensions, operation and cost.

- In order to limit the vulnerability of the barrier to impact and damage from vessels passing through it, training walls on the approaches to the barrier, and impact protection such as dolphins and fendering, are necessary (see Lake Borgne Barrier, **Figure 4-17**). The scale of these protective measures, and hence cost, increases significantly the larger the size of vessel to be designed for. On the Boston Barrier scheme in the UK, the preferred barrier location was significantly influenced by avoiding interaction with the large commercial shipping using the Port of Boston's facilities.

FIGURE 4-17
Lake Borgne barrier, New Orleans showing training walls for navigation.

- It is important to understand the alignment of the navigation channel in relation to the location and orientation of the barrier opening. One should seek to locate the barrier on a relatively straight section of channel—if it is on a bend then issues arise regarding risk of impact and/or damage to the barrier; the protection measures (long term maintenance / replacement costs), and the vessels themselves. Problems also arise with navigational safety, e.g., lack of line of sight of navigation traffic approaching the barrier from the opposite direction.
- Early identification of existing constraints on navigation width/draft/height and flows within the river channel enables one to determine a starting point for a minimum barrier width, e.g. Hamilton Avenue Bridge for Gowanus Canal (**Figures 4-18**).

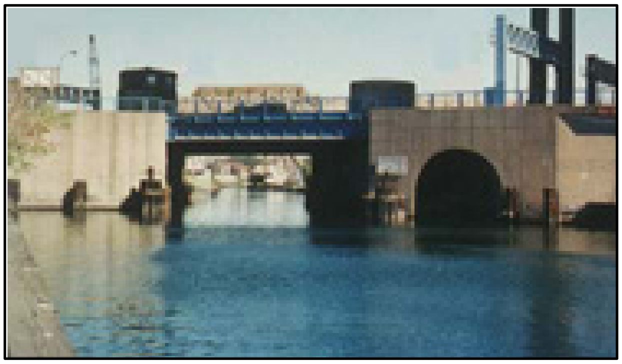


FIGURE 4-18
Hamilton Ave Bridge on the Gowanus Canal restricts width of navigable channel.

- It is important to understand the size and operating regimes for the navigation traffic using the waterway which the storm surge barrier will span across. Dimensions of the vessels including beam, draft, height, and length, are required, as well as details of the frequency and timing of when they pass through the barrier location. This information is vital for understanding the requirements for the permanent barrier dimensions as well as the size of temporary passage/bypass channel to be provided during the barrier construction.
- Early engagement with the Coastguard, Harbor or Port Authority, and other river users (commercial and recreational), will ensure that the key navigation information and constraints are established at the start of the concept/outline design development. On the Lake Borgne Barrier project, a lesson learned was that engagement with the Coastguard should have been sooner than it was. On the Boston Barrier scheme, the team did not initially engage fully with some recreational river users until later on when significant impacts (and hence mitigation) were identified. In both these two instances, modifications were required resulting in delay and/or additional cost.
- When assessing the location of the barrier, it is important to consider the barrier's buildability and how it can be constructed so as to avoid or minimize unnecessary interference with the normal traffic and commerce of the waterway. One should seek to position the barrier within the waterway channel such that it enables partial closure of the waterway and the construction of the whole or part of the gated barrier structure or abutments in the dry e.g. within a sheet piled cofferdam. This is particularly relevant for barrier locations where the waterway channel width is relatively small and the scope to provide a sufficiently large enough temporary bypass channel is very constrained e.g. the Ipswich and Boston Barriers and the potential barrier locations further upstream in Newtown Creek and Gowanus Canal.

4.3.3 Bathymetry and Geomorphology

It is important to understand the bathymetry and geomorphology of the river channel and to determine its shape/characteristics.

- An early bathymetric survey of the area, if not already available from the port or harbor authority, provides a sound baseline to highlight any natural change to the geomorphology of the existing river channel bed prior to the construction of the storm surge barrier. It provides important information so that cross sectional and other design data is available to inform the development of a conceptual or outline design, e.g., the depth and profile of any berms to be constructed as part of the tie-in walls to the barrier structure.

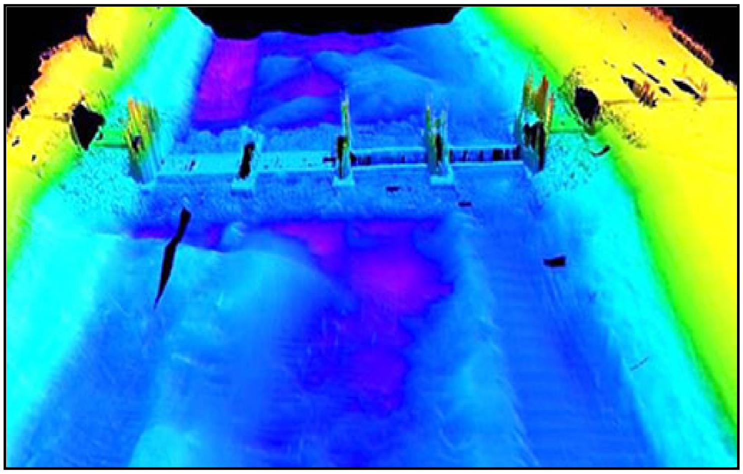


FIGURE 4-19
Typical bathymetric survey output.

- The impact of a storm surge barrier scheme on the geomorphology of the existing watercourse is an important issue that needs to be carefully considered throughout the scheme's development. Any significant sediment deposition/accretion or scour/erosion, increased dredging requirements either for the barrier operator or the local port/harbor authority, and increased scour protection all incur substantial whole life costs (e.g., as demonstrated by the ongoing extensive erosion protection works required at the Eastern Scheldt Barrier). Therefore there is a need to look at the barrier design and layout to minimize siltation occurring especially in the navigation channel such that it minimizes maintenance dredging requirements. It is also advisable to consider preventing silt build up in the barrier opening through regular operation of the barrier gate. Preliminary modelling as undertaken for the Boston Barrier (**Figure 4-20**) can be very useful to quickly ascertain whether sediment accretion or erosion is a significant issue in the vicinity of the barrier.

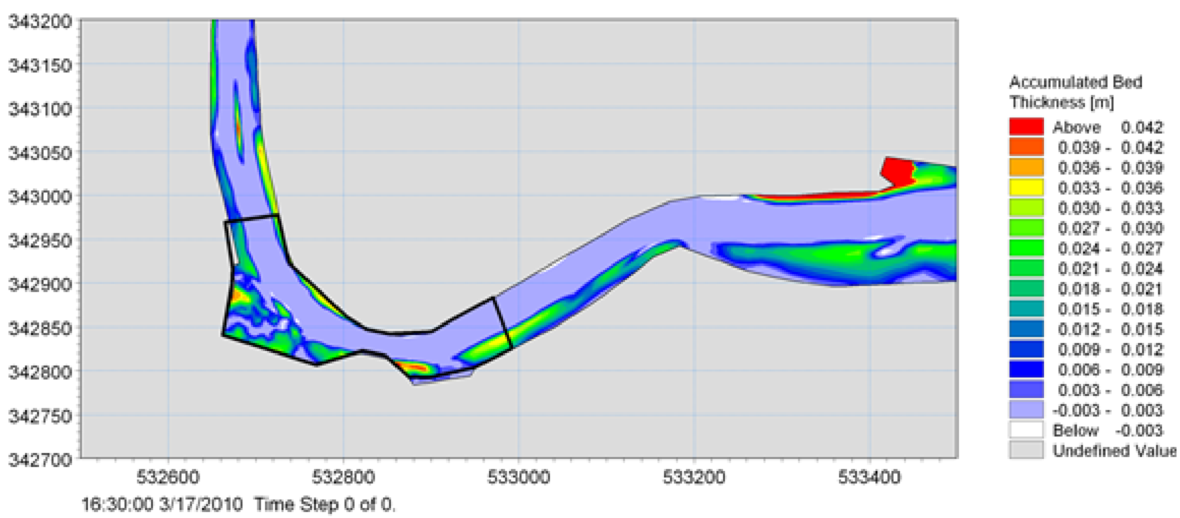


FIGURE 4-20
Sediment transport modeling for Boston Barrier (UK).

4.3.4 Topography

Fundamental to any storm surge barrier scheme is the construction of the flood defenses that link back to higher ground on both sides of the waterway. It is important to establish that the higher ground is consistently above the required defense height and that there are no low spots which would allow the barrier and its defenses to be outflanked by the flood waters.

- A lesson learned from the Boston Barrier scheme is that, if LiDAR topographical survey information is used, the level of accuracy of that information should be understood and the potential level of uncertainty established. Where the levels are critical, on site spot survey checks to verify the level information is advisable.

4.3.5 Hydrology, Hydraulics and Hydrodynamics

A clear understanding is required of the hydrology, hydraulics and hydrodynamics that can affect or be affected by the construction of a storm surge barrier across the river channel.

- A basic requirement for a storm surge barrier scheme is that during an event there is sufficient upstream storage available for any fluvial flows arriving behind the barrier and which can back up whilst the barrier gate is closed and the tidal surge event precludes any discharge downstream of the barrier. This can be problematic where the ability to create sufficient storage capacity is limited and a large scale pumping station may be required to pump this water over the barrier and defenses during the surge event to avoid fluvial flooding occurring. This has had to be considered as a potential future requirement for the Ipswich Barrier should sea level rise and rainfall intensity increase as predicted. This is relevant, particularly for Gowanus Canal, where the extent of upstream waterway, and hence storage capacity, is relatively small.
- In many cases the construction of the barrier will permanently reduce the overall channel width and cross sectional area at its location. As a result, it is important to check that this reduction will not significantly impact upon the discharge of a large fluvial flood event such that the risk of fluvial flooding upstream of the barrier is increased.
- The accuracy of flood forecasting is also important to establish as it affects closure response times as well as the number of times that the barrier is closed - in particular those closures which occur but were not actually required as the event was less than predicted due to forecasting error. For the Mose Barrier in Venice closure model testing has been undertaken over an extensive period and this has allowed the forecasting accuracy to be significantly improved long before the completion of its construction.
- When considering the width of the barrier opening it is important to consider the hydraulics and flow velocities through the barrier such that it is safe for all the types of vessel passing through it. A lesson learned from the Boston Barrier scheme was that, in determining these flow velocities, the cross sectional area of the barrier opening should be reduced by the area occupied by the beam and draft of the vessel.
- Undertaking physical modelling of the proposed barrier can prove to be very effective as demonstrated by its use on the Lake Borgne and Ipswich Barrier projects (see **Figure 4-21**). It has enabled the designers to test and see the effects of complex wave loading scenarios, check to see whether any gate vibration is induced under different scenarios, and to better determine the extent of river bed scour protection required. For the Ipswich Barrier, the $200,000 cost of the physical model was more than offset by the $375,000 cost saving as a result of it demonstrating that the proposed scour protection could be reduced. A key lesson learnt was that this physical modelling should be undertaken early enough for results to feed into the detailed design. On the Ipswich Barrier it has proved to be a powerful piece of visual proof to reassure and/or convince navigation stakeholders that the effects of the barrier should not have a significant impact upon them. For the Thames Barrier significant scale modelling and testing was undertaken to ensure that the barrier had a minimum effect on the river hydrodynamics.

FIGURE 4-21
Ipswich barrier physical model.

- A lesson learned from the Lake Borgne Barrier is that one should consider the merits of an in-situ hydraulic test as part of the construction to prove the design and performance of the barrier gate rather than the use of sensors to monitor performance under load afterwards during post-construction storm events. The use of an in-situ hydraulic test as part of the commissioning process has been adopted for the Ipswich Barrier; however it is generally only feasible where the complete barrier gate and its associated structure are built within a single cofferdam, which is designed to hold water within it to a level that provides an adequate check of the gate's performance under load.

4.3.6 Climate

Climate has an impact on the design parameters for a storm surge barrier. This includes the need to consider what allowances are appropriate to allow for potential climate change factors such as sea level rise, increased storminess, and increased rainfall intensity. The determination of these allowances is generally dictated by guidance provided by the relevant lead flood authorities. However there are some others factors such as wind and ice to consider depending on the barrier gate type or location.

- The design levels for water levels and wave effects are dependent on the climate effects, as well as on the design life and the level of reliability that the design must deliver.
- For wind there is a need to ensure that adequate provision is made in the gate design for resistance to wind loads and that dynamic loading effects are considered. This is especially relevant if considering a vertical lift type gate such as the Hull Barrier (**Figure 4-22**) or the Bayou Bienvenue gate. Safe access in windy conditions to exposed areas of the gate for its operation and maintenance also needs consideration.
- Depending on where the barrier is located in the world, how one deals with ice and ensuring it does not compromise the operation of the barrier gate can be important. For the St Petersburg Barrier scheme heating pads were considered in order to release the sluice gates which might have been frozen onto their concrete substructures. An air bubble system has been installed to keep the water at the gates, which defend the permanent dry docks for the large radius sector gates, from freezing. This is a

potential issue that may need to be considered for the proposed storm surge barriers at Newtown Creek and Gowanus Canal.

FIGURE 4-22
Hull Barrier

4.3.7 Engineering, Design and Construction

There are various lessons learned and best practice examples described under other topic headings that are integral to the development of the design of storm surge barriers and the associated engineering solutions. Some additional lessons learned specific to this topic area are described below.

- In developing a storm surge barrier design solution, it is important that there are clear reliability and design standards defined early on in the process, as they can have a significant effect on the proposed solution. As evidenced by the amount of work that has been undertaken on existing barriers worldwide, the review of the barrier's likelihood of failure and required emergency operating procedures has resulted in an enormous amount of remedial work, such as retrofitting extra closure mechanisms.
- The design process should be driven by a set of functional requirements that reflect the required outcome of the project in terms of its performance. The primary functional requirements will be to open and close on demand, and be able to withstand the design loadings. Secondary functional requirements may be provided to set the following: design life; acceptable levels of risk, reliability and consequence; maintenance strategy; buildability strategy; and aesthetics, environmental and ecological targets. The process should be set out in a project design basis document.
- Design should also consider issues that affect reliability, such as 'defense in depth' in terms of providing multiple sources of power to the barrier machinery, and to spatial separation such that common mode failures can be gauged to have a sufficiently low level of risk of occurrence. Recovery scenarios should also be considered if the primary system fails; for example on the Thames Barrier, despite having multiple power sources, the gates can still be hand-cranked (albeit slowly) closed.
- On the Lake Borgne Barrier project, there has been a post-construction review of the operation and maintenance requirements for the barrier and queries were raised about the inspection and maintenance of fracture critical design members within the barrier gates. This highlighted the importance of considering in the design how these members would be accessed for future inspection and maintenance and that, where possible, one should seek to minimize the number of these members being located under water or in a more aggressive wet/dry zone. It also highlighted the importance of designers being involved throughout the preparation of the operations and maintenance manual for the barrier.

- Consideration should be given to the transition between different defense structures and the differential settlement that can occur between them particularly in locations where there is a step change in the depth of foundations (i.e., shallow versus deep). The lesson learned on the Lake Borgne Barrier project was that this should be considered early on in the design process.
- It is important to establish as early as possible the barrier gate requirements such as opening and closing times, ability to open or close under a reverse head, speed and ease of closing, and the ability to provide a dual function such as a barrage or velocity control. These requirements will have a significant influence on the selection of the type of gate for the barrier. For the Lake Borgne Barrier, the selection of a vertically hinged horizontal sector gate was influenced by the need to close the gate as late as possible to allow for late-arriving navigation traffic such as fishing vessels to pass through the barrier and seek shelter in the protected area behind it.
- Early contractor involvement has proven to be beneficial on both the Ipswich and Boston Barrier schemes in setting out an outline construction methodology that informs stakeholder engagement, and assessment of potential temporary impacts that will be caused by the construction. Their involvement also enables any potential key buildability issues to be addressed.
- The use of precast or modular units, where possible, to minimize working in the wet and to reduce the working time required at the barrier site is generally beneficial in reducing the construction period and costs. This has been adopted on a number of barrier projects such as the Thames Barrier and more recently the Lake Borgne Barrier.
- Preparation of a materials logistic plan to ensure that the right materials are stored and delivered at the time that they are required to the project site(s) can be beneficial to avoid delays and costs during construction. It can also potentially reduce the amount of land take required for site working areas.

4.3.8 Environment

There are numerous environmental factors and impacts to be considered when constructing a storm surge barrier. Some of the key areas and issues that are regularly encountered, need to be addressed and potentially require mitigation are listed below.

- Fish passage – the change in wet cross section, and flow velocity through the barrier, as well as a change in the salinity gradient in the river channel upstream of the barrier can have a detrimental impact on the passage of fish in the affected water body. This can influence the width and depth of the barrier opening and/or require the construction of a fish pass alongside the barrier—estimated fish pass cost for the Boston Barrier is circa $2 million.
- Compensatory habitat – the footprint of a storm surge barrier scheme, particularly within the river channel, involves the destruction or disturbance of existing habitat. This, coupled with the potential increased erosion of marginal habitat such as saltmarsh due to holding or advancing the flood defense line, often dictates that the scheme is required to create compensatory habitat in the adjacent area. This can be both very costly and difficult to find appropriate sites nearby.
- Water quality – it important to consider the impacts on tidal flows particularly into and out of the channel upstream of the barrier both during and after construction. Throttling of the flow can cause a reduction in the water quality (e.g., reduced level of dissolved oxygen); or change in salinity due to the upstream fluvial fresh water flows becoming more predominant. For the Lake Borgne Barrier scheme, an environmental requirement was imposed on the Bayou Bienvenue gate construction that dictated a minimum through flow was to be maintained at all times.
- Invertebrates – should the barrier result in significant accretion or erosion of river bed sediments or permanent submersion of intertidal mud flats, this can have a detrimental impact on the habitat of invertebrates in the affected river bed.

- Transportation of contaminated sediments – it is important to establish what level of contamination is present in the existing sediments and material that occurs on the bed of the river channel. Any dredging of those sediments can create significant issues with their mobilization in the water body due to the disturbance created by the dredging operation, and transportation/migration into nearby environmentally designated sites, or areas dredged by others such as a port authority. All of this has significant cost implications including disposal costs, stringent containment measures, and compensation for increased dredging costs/delays/operational impacts on the port due to the contamination caused.
- It is beneficial to undertake a scoping exercise early on in the process to establish any environmental impacts that could significantly affect the development of the barrier scheme and its delivery.

4.3.9 Operation and Maintenance

The flooding of New Orleans from Hurricane Katrina was, to some extent, due to a lack of an integrated management plan for what was a series of individual flood schemes with differing levels of defense and, in some cases, lack of appropriate maintenance. The reliability of the storm surge barrier to operate and close on demand is therefore fundamental to the success of the scheme in reducing the risk of flooding to the infrastructure and properties behind it. The operation and maintenance (O&M) of the barrier is vital to ensure this reliability, and would draw heavily on the project design basis document referred to in Section 4.3.7 above.

- It is critical to establish at a very early stage in the development of a storm surge barrier scheme who the authority/organization is that will be responsible for the O&M of the barrier. It is important that that organization is involved in defining the design requirements and how the operation and maintenance of the barrier is to be undertaken in the future. With the Lake Borgne Barrier scheme, although O&M was considered during the design, the ultimate authority responsible for the O&M, the Southeast Louisiana Flood Protection Authority, was not fully involved in the design development. As a result, when it came to the handover of the barrier and its associated assets, they had issues regarding the works and the O&M requirements/liabilities they would be taking on.
- The early preparation of an outline control philosophy for the proposed barrier as well as a Barrier Management Plan can be very helpful to understand interfaces with navigation traffic as well as help define the roles and responsibilities of the authority designated to take over the operation and maintenance of the barrier. A good example of a Barrier Management Plan for a smaller size barrier is that produced for the Ramspol Barrier which is very clear in defining how the barrier is to be operated and maintained, and is based on the use of a temporary team of operatives with appropriate skills and training, and with back-up provision in an emergency.
- It is important to consider how the inspection and maintenance of the barrier and its associated assets is to be undertaken in a safe and secure manner. Consideration needs to be given to identifying the spatial requirements, ensuring ease of access to undertake tasks, health and safety, replacement and stocking of parts and strategic spares, etc. The refurbishment works recently undertaken on the Hull Barrier provide a good example of how insufficient consideration for future maintenance at design stage can result in significant additional costs and risks. For the Hull Barrier, side paneling to the barrier structure had to be removed, a special crane attachment designed for delivering the new parts inside the barrier, and the construction of a mock up away from site to ensure that the replacement plant could be fitted safely and securely in the confined space available (**Figures 4-23** and **4-24**).
- It is worth considering including an extended maintenance contract (say 5 years) as part of the capital construction contract to ensure an effective handover of knowledge and expertise to the operating authority's own staff. This is being adopted for the delivery of the Ipswich Barrier.
- The design and selection of materials should be considered from a whole life cost perspective and where a higher cost specification is justified in minimizing future maintenance. This can be especially relevant if

capital funding is available for construction but long term revenue funding to pay for the future O&M costs is constrained and/or difficult to obtain.

- For smaller-sized storm surge barriers, the barrier operation could potentially be undertaken by a third party who already have a permanent presence and necessary skilled operatives at the site, or they could provide emergency back-up, in order to reduce the costs of manning the barrier. At Ipswich the port authority, Associated British Ports, operate the Wet Dock Lock floodgate on behalf of the Environment Agency, the flood defense authority, as port operatives are already present for operating the port's lock gates. Depending on the location and size of the barrier this could be considered in conjunction with those operating the Hamilton Avenue Bridge.

FIGURE 4-23
Hull Barrier remedial works.

FIGURE 4-24
Hull Barrier remedial works.

4.3.10 Regulatory Impacts

The delivery and construction of the Lake Borgne Barrier and its associated works, has been achieved in a relatively short timescale when compared to the delivery periods of over 20 years from inception (normally started due to an unwelcome trigger event which causes significant damage) to completion for other barrier projects both in the USA and worldwide. This has been due to the streamlined delivery program and because political pressure was brought to bear on providing a solution as rapidly as possible to demonstrate to the nation that what had been a national disaster would not happen again. It is worthwhile noting that, statistically speaking, there is no such thing as an absolute and, therefore, a small residual risk of a similar event remains.

It is potentially worthwhile to consider how programs for the delivery of the Gowanus Canal and other planned storm surge barrier projects in the area can be streamlined by proposing a process of regulatory inspections and staged approvals of design and construction plans and having this concept accepted by the regulatory bodies.

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Part II:
Concept Option Development and Evaluation

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5 Evaluation and Analysis Framework

5.1 Overview of Concept Option Screening and Project Analysis Process

The study team developed and applied a two-part evaluation process to screen potential concept options and ultimately arrive at a preferred concept option for the Gowanus Canal (see **Figure 5-1**). Principles guiding the framework's development include the following:

- Develop a transparent tool for multiple audiences to understand the study process and leverage the work for future efforts.
- Provide a documented approach to filter potential alignments toward the preferred concept option for each site.
- Capture engineering, community/public, and implementation considerations.
- Ensure compatibility with USACE-accepted approaches and translatability to USACE terminology.
- Reflect the broad range of local New York City (City) benefits, interests, and policy goals.

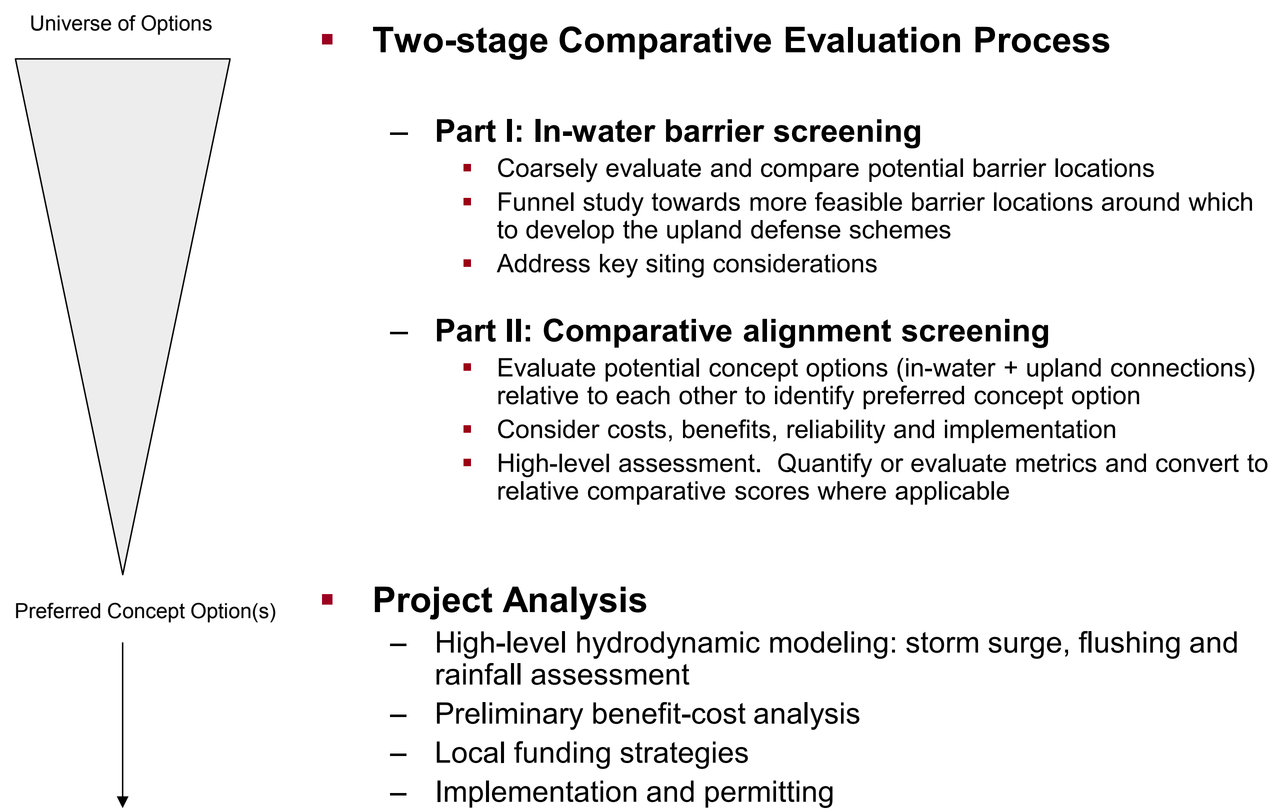

FIGURE 5-1
Study Evaluation Framework

The criteria reflect the broad range of local City benefits, interests, and policy goals. At the same time, to best position the study's outputs for a transition to USACE, the study team's evaluation framework and criteria are aligned to those criteria used by USACE in its project evaluation. The criteria framework uses categories that are consistent with terminology used by USACE in its planning regulations, namely efficiency, effectiveness, completeness, and acceptability. Effects evaluated are categorized within the four USACE accounts as defined in USACE Planning Regulation: National Economic Development (NED), Regional

Economic Development (RED), National Ecosystem Restoration (NER), and Other Social Effects (OSE). The criteria and metrics proposed in the framework for the Gowanus Canal storm surge barrier study are intentionally broad. The suggested criteria address both specific USACE needs and requirements and the feedback from USACE to capture as broad an array of benefits as possible. The filtering process responds to USACE's desire to see documentation explaining how alternative concept options dropped out of consideration.

The Part I screening made a coarse assessment of potential in-water barrier locations based on key siting considerations. The Part I screening funneled the study toward more feasible in-water barrier locations around which to develop the upland defense alignments.

The Part II screening then compared the concept option alignments against one another along a series of cost, benefit, reliability, and implementation criteria. The Part II screening identifies the strengths, weaknesses, and key tradeoffs among the concept options (see **Table 5-1**).

From this evaluation process, the study team, in collaboration with the NYCEDC and ORR, and with incorporation of feedback from the interagency workshops, identified a preferred concept option for each site.

The preferred concept option underwent more detailed project analysis, including hydrodynamic modeling to define the zone of protection and a preliminary benefit-cost analysis, the results of which are summarized in this report. The project analysis identified potential local funding strategies In addition, phasing, timing and permitting were considered as part of developing a potential roadmap for future project implementation should a storm surge barrier project at Gowanus advance beyond this conceptual study phase.

5.1.1 Part I In-water Storm Surge Barrier Screening

The Part I In-Water Barrier threshold screening documents demonstrate—at a coarse level—how the team identified potential barrier sites, given considerations of anticipated costs and benefits, the level and extent of protection offered by the barrier, the ability to be constructed given site constraints (physical depth and width, contamination, property availability, land-tie in complexity, etc.), the ability to protect navigation, and the ability to be permitted. The categories, criteria and factors assessed during the Part I screening are presented in the **Table 5-1**.

TABLE 5-1
Part 1 In-water Storm Surge Barrier Screening Components

Category*	Criterion	Factors Assessed
Economic Efficiency	Anticipated costs and benefits	Order of magnitude in-water barrier costs Connection to upland defenses (proxy for upland defense alignment costs) Potential zone of protection (proxy for damages avoided)
Engineering Effectiveness	Level and extent of protection	Protection provided at design flood elevation (barriers equally effective at all sites)
Completeness	Ability to be constructed	Barrier depth and width Construction staging Physical in-channel constraints Operations and maintenance access Interface with waterfront usage and development, including visual impact
Acceptability	Ensures/protects navigability	Temporary during construction Permanent post-construction
	Ability to be permitted	Infill/land reclamation considerations Preliminary water quality considerations

* These are the four evaluation categories defined in established USACE planning regulations.

5.1.2 Part II Concept Option Comparative Screening

The Part II Comparative Alignment Screening compare the full concept option alignment (in-water storm surge barrier plus upland connections to the tie-in with the 17 foot elevation). The Part II screening takes a high level review of the concept option alternatives to compare how they perform against the various criteria. At this screening stage, the criterion scoring is indicative and relative based on preliminary analysis and quantification of some information as well as the team’s professional experience. The cost and benefits criteria are consistent with what the USACE would evaluate, such as life cycle costs and expected avoided damages. These criteria also go beyond USACE NED requirements, capturing metrics important to New York City residents, such as percentage of capital costs borne by the private sector, percentage of costs leveraging other publicly financed projects, protected jobs and affordable housing, share of green infrastructure, protection of critical infrastructure and impact on public safety. The Part II screening also looks at questions of reliability and implementation as far as ownership, responsibility, funding potential, interface with private property, waterfront access and other factors. The Part II screening criteria are presented in **Table 5-2**.

TABLE 5-2
Part II Comparative Concept Option Screening Components

Category	Sub-Category (USACE Plan Evaluation Account)	Criterion
Costs	Capital costs (NED)— *National Economic Development*	Total capital cost Percentage of capital cost borne by private investments (i.e. raised sites) Percentage of capital cost borne by other public investments (i.e. Department of Parks and Recreation (DPR) projects)
	Operating costs (NED)	Total operations and maintenance costs

TABLE 5-2
Part II Comparative Concept Option Screening Components

Category	Sub-Category (USACE Plan Evaluation Account)	Criterion
Benefits	Avoided damages (NED)	Net present value (NPV) of avoided damages
	Economic (RED)— *Regional Economic Development*	Flood insurance savings
		Number of jobs protected
	Environment (NER)— *National Ecosystem Restoration*	Flushing performance
		Impact on habitat
		Share of green infrastructure
	Social (OSE)— *Other Social Effects*	Protection of people
		Protection of housing
		Protection of non-residential space (total square feet industrial, commercial, institutional)
		Protection of critical facilities (rail yards, docks, etc.)
		Synergies with existing and planned transportation network (transit, road, on-road bike lanes)
		Impact on public safety
Reliability	Completeness	Extent of in-place versus deployable/temporary
Implementation	Regulatory (Acceptability)	Complexity of legal/planning approval process
	Community support (Acceptability)	Ability to attract funding
		Extent of blockage or interference with development sites
		Minimizes access disruptions for existing residents and businesses
		Maintains waterfront access
		Maintains view corridors
		Promotes appropriate development/redevelopment of uplands
		Improves neighborhood connections
	Ownership / Control (Acceptability)	Number of private property owners involved/percentage of alignment publicly owned
		Reliance on third-party future development commitments

5.2 Costs and Benefits Framework

The costs and benefits framework employed in this study for the preliminary benefit-cost analysis is a subset of the evaluation structure. The NED cost and benefits criteria, capital and operating costs, and avoided damages are consistent with USACE's approach to benefit-cost analysis when making decisions around funding. The benefits criteria in the study's framework also go beyond USACE NED requirements, capturing metrics important to City residents, such as protecting jobs, people, and housing, as well as flood insurance savings. Additional types of benefits are alluded to and suggested for analysis at a full feasibility study stage. While USACE studies may capture and document these other categories, under current policy, they do not factor into project funding considerations that are based around a project's benefit-cost ratio. These criteria are useful to building public support as well as generating interest and priority for funding from other sources. These additional benefits criteria are cross-walked to the corresponding USACE Plan Evaluation Account in **Table 5-3**.

TABLE 5-3
Costs and Benefits Framework

Category	Sub-Category (USACE Plan Evaluation Account)	Criterion
Costs	Capital costs (NED)— *National Economic Development*	Total capital cost (includes hazmat remediation exclusive of Superfund in-water work)
	Operating costs (NED)	Total operations and maintenance (O&M) costs
Benefits	Avoided damages (NED)	Net present value (NPV) of avoided damages
	Economic (RED)— *Regional Economic Development*	Protected jobs and businesses Reduced flood insurance costs Avoided mandatory floodproofing costs
	Social (OSE)— *Other Social Effects*	Protected existing and projected populations Protected existing and projected housing Protection beyond current standards

5.3 Project Assumptions

The study team adopted a baseline set of assumptions in order to complete the project analysis and develop an implementation and phasing plan. Discussion around these assumptions, including discussion of alternatives, uncertainty and potential next steps, is presented throughout sections of this report. These baseline assumptions include the following:

- *Funding source*: USACE is the primary funding source. Therefore, the phasing and implementation plan is developed around key steps and requirements in the USACE implementation process. Funding and financing analysis has focused on ways to reduce and/or identify the sources for the City's share of any project.
- *Timing:* A 10-year horizon, linked to completion of the Gowanus Canal Superfund remediation work, is envisioned before any project would be physically realized because it is understood that USACE would not begin construction until the remediation work is completed. Timing for feasibility and pre-construction activities could follow two pathways: 1) commencing from as early as first quarter 2016 and flowing forward from the upcoming NY NJ Harbor Feasibility Study should the Gowanus Canal Storm Surge Barrier project be included in the study scope; or 2) commencing at a later date, but potentially preceding Superfund remediation, as a separate feasibility study that might be considered. The base year for benefits is the year benefits start to be realized.
- *Benefits and baseline condition assumptions:* The benefit-cost analysis relies on current existing conditions, which is in alignment with USACE methodology. Any new development that happens between today and when a project could be constructed would be built to Federal Emergency Management Agency requirements for flood insurance and would not increase the avoided damage benefits. As far as environmental conditions, in addition to completion of the Superfund remediation work, ongoing NYCDEP combined sewer overflow abatement efforts will have made improvements to water quality, and in general, both waterways will be in a dynamic ecosystem state.
- *Governance and oversight:* The Red Hook Integrated Flood Protection System as well as other ongoing City resiliency projects will be in process or completed prior to a Gowanus Canal project's construction. As part of these broader citywide efforts, the City will have established a lead operating agency and be familiar with and/or have established any required approval processes (e.g., permitting and interagency coordination mechanisms) for flood defense systems.
- *Project delivery approach*: A design-bid-build delivery approach is pursued.

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6 Storm Surge Barrier Feasibility

6.1 Siting Considerations

To identify feasible in-water storm surge barrier locations and suitable gate types, the in-water barrier assessment examined a number of siting criteria and factors that included the level and extent of protection, anticipated costs and benefits, navigation, constructability, and permitting. Key drivers for these criteria categories included the following:

- **Level and extent of protection:** Though not a differentiator among potential barrier locations because the barrier performance will be set by the design flood elevations (DFE) and therefore common to all potential barrier locations and types, the level and extent of protection is an important consideration because it aligns with United States Army Corps of Engineers (USACE) considerations and it dictates the gate size requirements that need to be accommodated. As noted previously, in the case of this Gowanus Canal Storm Surge Barrier Study, the height of the barrier above water is specified at 21 feet. This reflects the conservative DFE calculated from the +14.9-foot NAVD88 (500-year flood) base flood elevation plus 3 feet for freeboard allowance plus 3 additional feet for sea level rise as detailed in Section 1.2.
- **Navigation:** A major driver behind siting considerations is the ability to protect existing navigation and use of the waterways as well as accommodate future activities. To the degree possible, any storm surge barrier system should minimize adverse impacts to waterway users. This includes both during and post-construction. The navigation assessment included profiling existing vessels, identifying where activity is heaviest, looking at currents and vessel-maneuvering behavior, and examining width and height constraints. A New York City (City) goal is to ensure that industrial waterway users still have access where it is needed and desired. As far as growth, the existing bridges' navigation restrictions and the limited dredging make much growth unlikely. As a conservative assumption for this stage of conceptual evaluation, the in-water barrier assessment has sought to maintain existing navigation channel width and/or introduce no additional navigation constraints to the degree feasible.
- **Constructability:** The existing physical conditions at the study site are important to constructability. Factors considered in evaluating a location's potential construction challenges included identification of in-channel constraints, depth (including anticipated post-Superfund remediation depths at Gowanus), width, and interface with upland areas, including potential tie-ins, staging, and access locations.
- **Permitting:** Permitting challenges likely to be encountered include water quality and infill of the waterway channel bed. As with navigation considerations, preference for any barrier location and gate type is not to adversely affect flushing capacity by preserving the current waterway width to the degree possible.
- **Anticipated costs and benefits:** While a full cost-benefit analysis was performed on the preferred and alternative concept options during the project analysis phase of the study, a preliminary assessment of anticipated costs and benefits was included at this stage both for consistency with USACE's Economic Efficiency category and to get a preliminary notion of whether one or more in-water barrier location options may be significantly out of line with the others as far as capital cost requirements or the potential value per unit of protection, and could present a fatal flaw. At this stage, the primary consideration was order-of-magnitude capital costs for the in-water barriers. Likely zones of protection and the relative length of upland defenses to natural elevation tie-ins were noted qualitatively.

  In addition to the above, the in-water storm surge barrier assessment also started to identify opportunities for potential new public amenity areas or habitat creation.

6.2 Gowanus Canal Storm Surge Barrier Assessment

6.2.1 Alternative Barrier Sites

Based on site visits and initial observation of waterfront properties, the waterway profile, and vessel traffic, the study team identified three potential in-water barrier locations. Then, based on specific size requirements, and efforts to minimize operation and maintenance requirements, to keep excavation as shallow as possible, and to accommodate vessel traffic and minimize gate closure time requirements, potential gate types were identified that appear to be best suited for each location. The gate type evaluation is summarized in **Table 6-1**. This evaluation is limited only to the selection of potential gate type. Evaluation of overall barrier location feasibility is described in Section 6.2.2 and summarized in **Figure 6-9**. Ultimately, the three locations and their respective in-water storm surge barrier type were identified and screened through the Part I assessment.

FIGURE 6-1
Alternative Gowanus Canal Barrier Sites

TABLE 6-1
Gate Type Evaluation for Gowanus Canal Alterative Barrier Locations
Note: Green = preferred gate type, Yellow = gate type could work, but likely better options, Red = likely fatal flaw

	Miter Gate	Flap Gate	Vertical Rotating Gate	Vertical Lift Gate	Horizontal Rotating Gate	Caisson Gate	Inflatable Gate
Option 1: Hamilton Avenue	—	RED rating dictated by requirement to close canal to navigation during construction.	RED rating dictated by requirement to close canal to navigation during construction.	Could be rated RED if restriction of navigation clearance height unacceptable.	RED rating dictated by requirement for land take.	Could be rated RED if requirement for land take on western side unacceptable.	RED rating dictated by requirement to close canal to navigation during construction.

TABLE 6-1
Gate Type Evaluation for Gowanus Canal Alterative Barrier Locations
Note: Green = preferred gate type, Yellow = gate type could work, but likely better options, Red = likely fatal flaw

	Miter Gate	Flap Gate	Vertical Rotating Gate	Vertical Lift Gate	Horizontal Rotating Gate	Caisson Gate	Inflatable Gate
Option 2: Home Depot/19th Street	RED rating dictated by this type of gate not being suitable for the width required.	RED rating dictated by requirement to close canal to navigation during construction.	RED rating dictated by requirement to close canal to navigation during construction.	Could be rated RED if restriction of navigation clearance height unacceptable.	—	Similar overall score as horizontal rotating gate, but operational reliability and maintenance are more challenging.	RED rating dictated by requirement to close canal to navigation during construction as well as required depth.
Option 3: Gowanus Bay	RED rating dictated by this type of gate not being suitable for the width required.	Could be rated RED if temporary bypass channel during construction not acceptable to navigation users.	Could be rated RED if temporary bypass channel during construction not acceptable to navigation users.	Could be rated RED if restriction of navigation clearance height unacceptable.	—	Similar overall score as horizontal rotating gate, but operational reliability and maintenance are more challenging.	RED rating dictated by gate depth required not being feasible.

The section that follows summarizes the findings for the Gowanus Canal storm surge barrier assessment. More detailed information for the Part I screening and gate selection can be found in Appendix A.

The three alternative barrier sites evaluated, moving north to south, for a potential Gowanus Canal storm surge barrier system were:

1. Hamilton Avenue (about 100 feet south of the Hamilton Avenue Bridge and perpendicular to the waterway) with a miter gate. This is the simplest option with the lowest cost and ease of operations and maintenance. The miter gate is commonly used on canals and smaller waterways. It is only suitable at locations with width less than 100 feet. The Hamilton Avenue location would require a 90-foot-wide gate, preserving the current canal width.
2. 19th Street near Home Depot with a 150-foot-wide horizontal sector gate. A vertical lift gate could also be used, although given the level of active navigation and a vertical lift gate's constraints to vessel height clearance, it is a less preferable option. The width at this location precludes a miter gate, and the horizontal sector gate has advantages over other gate types as far as minimal requirement for sill excavation depth, ability to futureproof for sea level rise, operation and maintenance complexity and reliability, navigation and visual impact.
3. Gowanus Bay near Sims Metal Management recycling facility and connecting across to the Columbia Street pier with a 200- to 225-foot horizontal sector gate. The same considerations as at the 19th Street location suggest that a long radius horizontal sector gate would be most suitable.

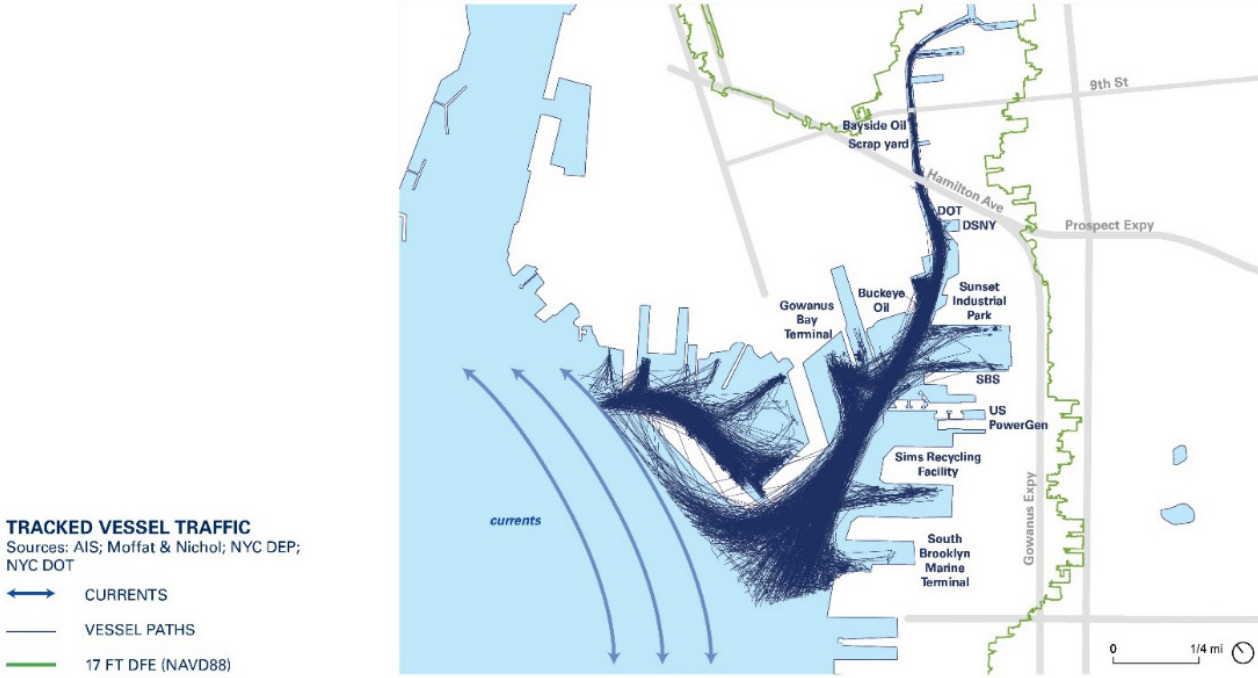
6.2.2 Siting Assessment

6.2.2.1 Navigation

Overall, the Hamilton Avenue barrier location works best from a navigation perspective. At Gowanus, the closer a potential in-water barrier moves to the mouth of the canal and Gowanus Bay, the greater the adverse impact it is likely to have on current waterway users. Moving a barrier from a Gowanus Bay location up to a Hamilton Avenue location would reduce the volume of potentially impacted traffic by 67 to 75 percent based on a one month vessel tracking sample from September 2014. The City of New York Department of Sanitation (DSNY) marine transfer station (MTS) was yet to be on-line at the time of the sample date collection, implying even heavier waterway traffic volumes that locations south of Hamilton Avenue would impact. Thus, the Hamilton Avenue location could minimize interface with the comparatively heavier traffic volumes encountered at both the Gowanus Bay with Sims, Buckeye Oil, Gowanus Bay Terminal, Vane Brothers, and Sunset Industrial Park among others. The 19th Street location would have lesser impact on a majority of users as compared with a Gowanus Bay option, but the New York City Department of Transportation (NYCDOT) Hamilton Avenue Asphalt Plant and DSNY MTS are two important users whose activity would be affected, including the detrimental effects on daily working periods during construction. Even the Hamilton Avenue location will have some impact, requiring pre-arranged temporary navigation closures with upstream users, although the number of vessels affected would be low and there is current precedent for this type of coordination and closure with some of the ongoing USEPA remediation work in the canal. The biggest impact of a Hamilton Avenue location will be on the first 100 linear feet of bulkhead at the NYCDOT asphalt facility. This 90 to 100 foot section of bulkhead/berth would be lost to active use as it would be behind the barrier gate.

Source: Automatic Identification System (AIS) vessel tracking data, Moffat & Nichol, September to October 2014.

FIGURE 6-2
Relative Vessel Traffic Volumes



Source: AIS vessel tracking data, Moffat & Nichol, September to October 2014.

FIGURE 6-3
Illustrative Vessel-Maneuvering Patterns

In addition to the number of users impacted, the vessel maneuvering patterns also influence barrier location selection. The observed vessel maneuvering patterns narrow to align more closely with the channels as the barrier location moves further north up the canal away from Gowanus Bay. This is important because wider maneuvering paths could dictate the need for a wider barrier gate, adding cost and complexity to a project. The Hamilton Avenue location would enable the gate alignment to be straight and centered on the navigation path whereas the Gowanus Bay and 19th Street locations require wider gates to allow for vessel slewing on a bend.

6.2.2.2 Constructability

In comparison to the alternate locations, the Hamilton Avenue barrier location faces the fewest constructability challenges. The existing depth at the Hamilton Avenue location is 16 feet; however, post-Superfund remediation plans following dredging and capping anticipate a depth of 22 feet. This depth, combined with the 21-foot barrier height, means that a potential barrier would require a height of 43 feet, well within the parameters of global gate precedent. As already noted, this is the narrowest of the three locations, with width of 90 feet and, therefore, suitable for a miter gate.

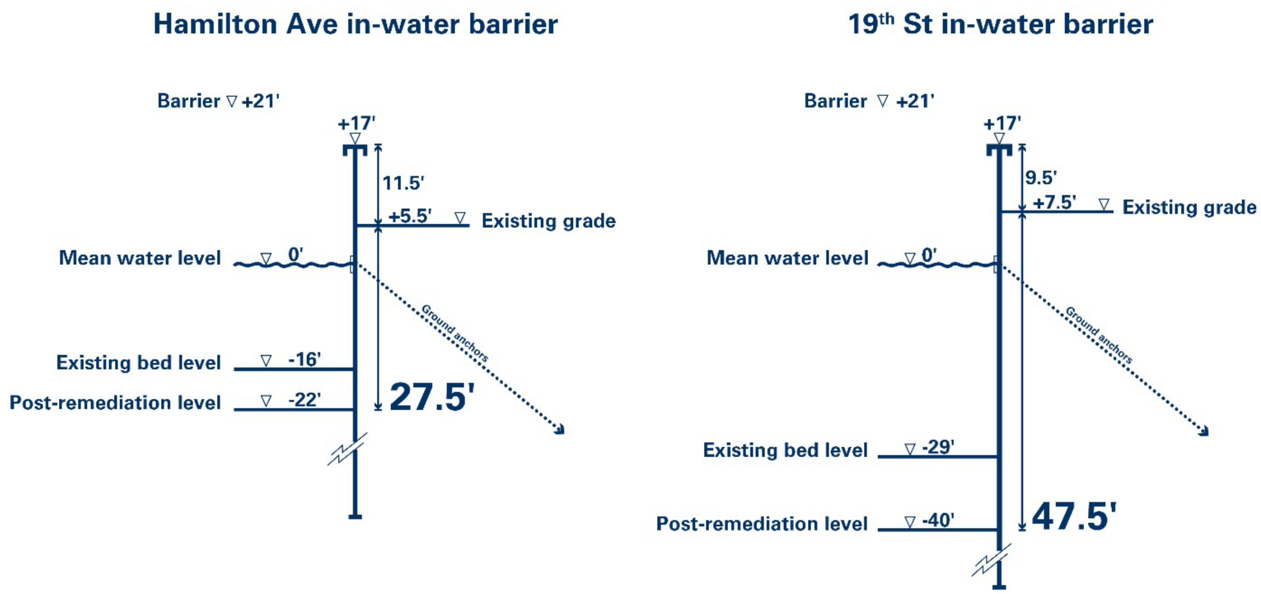


FIGURE 6-4
Post-Superfund Remediation Channel Bed Depths

The depths at the 19th Street location and Gowanus Bay make in-water barrier construction more complex. The post-Superfund remediation depth for 19th Street is anticipated to be around 40 feet. Combined with the barrier elevation, the total gate height required would be around 61 feet. To put this in context, two of the world's largest storm surge barriers in St. Petersburg, Russia and Maeslant, Netherlands have gates around 55 to 56 feet in height. To address this, an in-water barrier at 19th Street would use fill to raise the channel bed level up to the current depth of 29 feet to enable use of a gate under 50 feet in height. The barrier width would be around 150 feet. Any in-water barrier at Gowanus Bay would require a wide span, bringing additional complexity. A width between 200 and 225 feet could accommodate vessel traffic, although a larger gate might be required. The existing channel depth in Gowanus Bay is 35 feet. No remediation is planned for Gowanus Bay, so the gate height would be 56 feet.

FIGURE 6-5
Potential Staging Areas

Construction staging areas are limited and tight around any of the potential locations. Some construction would be done from the water, with pre-fabricated sections floated in. Where infill would be created, for example, at the 19th Street Gowanus option, the infill itself may provide additional staging area. There are potential access points behind Home Depot at the 19th Street termini as well as on the west side of the canal. At the Hamilton Avenue location, access to the parcel directly to the left (west) of the barrier location and opposite the NYCDOT asphalt plant would be required, whether through a lease arrangement or potential acquisition. The northwest corner of the NYCDOT asphalt property closest to the Hamilton Avenue Bridge would also likely be used.

From the perspective of waterfront usage and development interface, all three barrier locations present some challenges and adverse impacts. As previously noted, the Hamilton Avenue location would result in the permanent loss of the first 90 to 100 linear feet of quay from the Hamilton Avenue Bridge. Both the 19th Street and Gowanus Bay locations would result in permanent loss of around 700 linear feet of quay/waterfront frontage.

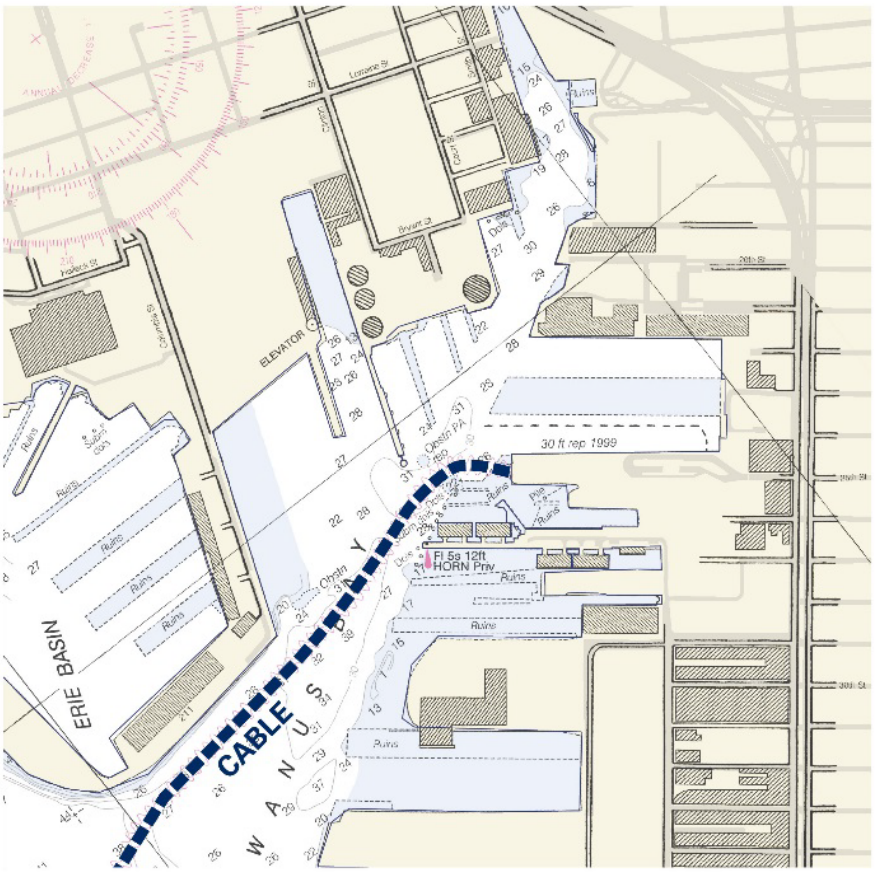


FIGURE 6-6
In-Channel Constraint

The Gowanus Bay location faces an additional obstacle to constructability that the alternative locations do not. Because a major utility cable runs south out of Gowanus Bay, any in-water barrier at Gowanus Bay would need to accommodate the cable.

The 19th Street location is the only Gowanus Canal in-water barrier option that might be able to create a new public amenity. There could be potential to introduce a pedestrian/bicycle link between 19th Street and Court Street by a swing bridge connection between the barrier abutments.

6.2.2.3 Permitting

From a permitting perspective, the Hamilton Avenue location rates best as far as preliminary infill and water quality considerations. The location and use of a miter gate enables the Hamilton Avenue location to maintain the current canal width with only a small amount of infill needed on the eastern side. It is therefore expected to have no impact on water quality. The 19th Street barrier location also rates fairly favorably for permitting. Incorporation of a horizontal sector gate would require some infill along both the eastern and western sides of the channel bed, thereby reducing the channel width somewhat. The amount of infill could be reduced and the gate widened, although at a potentially greater cost. Even with the infill, because of the flushing tunnel at the northern end of the canal, the small reduction to channel width is not anticipated to have a significant impact on water quality. The Gowanus Bay barrier location raises significant permitting concerns. It would require significant infill, potentially reducing the waterway width by around 75 percent and requiring infill, not only along alongside the barrier gate recesses, but under the Columbia Street pier upland tie-in connection. Such a change to waterway width would impose a significant constraint to the tidal exchange volume, having a detrimental effect on water quality. The location would also affect existing oyster beds and could lead to accretion.

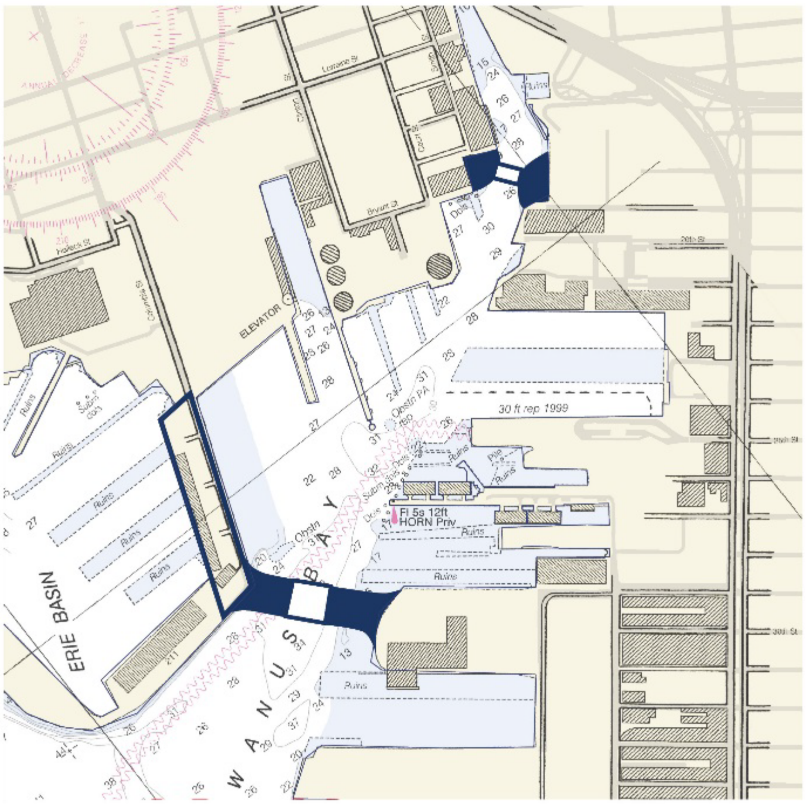


FIGURE 6-7
Illustrative Infill Requirements

6.2.2.4 Anticipated Costs and Benefits

In regard to economic efficiency, Hamilton Avenue shows the most promise. Based on conceptual order-of-magnitude costs (15 to 30 percent level of accuracy), a miter gate at the Hamilton Avenue in-water barrier location (exclusive of any upland defenses) could be in the $25 million to $30 million range for the gate alone (exclusive storm water pumping which is built into the figures presented in the Capital Cost discussion in Section 7 and detailed in Appendix L). The cost estimates escalate for the other Gowanus barrier locations because the width of the barrier increases. The 19th Street location would be two to three times greater and the Gowanus Bay option about six times greater. When upland defenses are incorporated, the total overall cost escalates, but the Hamilton Avenue location remains the best option from a cost perspective based on the distance required to reach the natural +17-foot North American Vertical Datum of 1988 (NAVD88) elevation. Conceptual engineering and cost estimates for the Hamilton Avenue and 19th Street in-water barrier options are presented in Section 7, Section 8, and Appendix L.

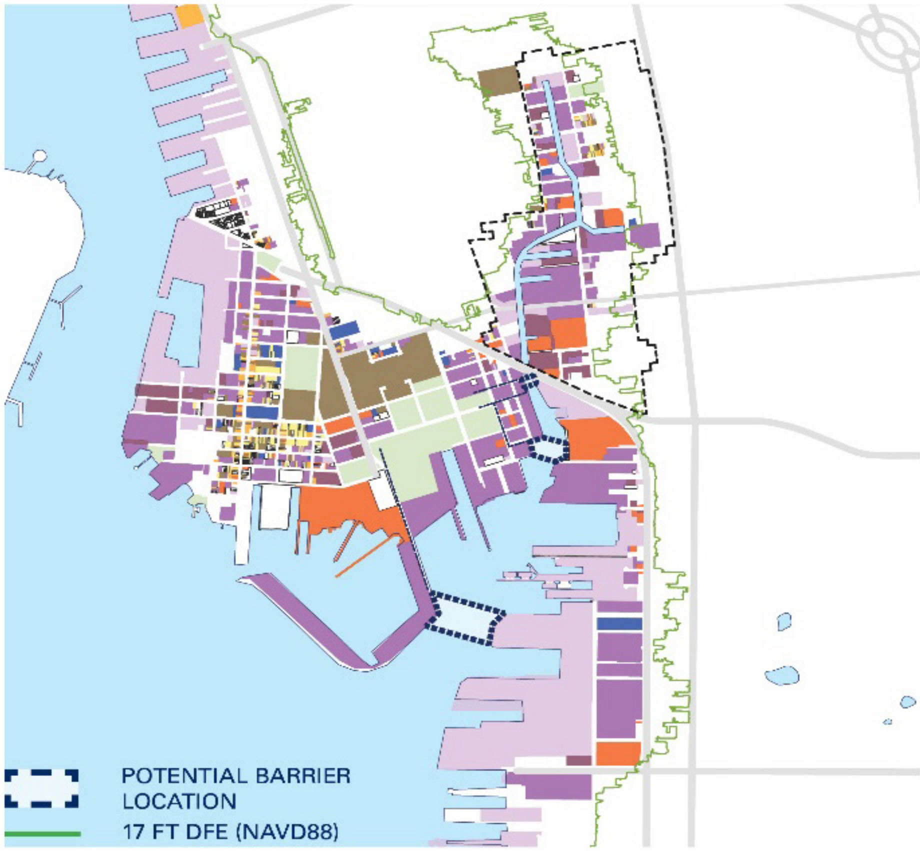
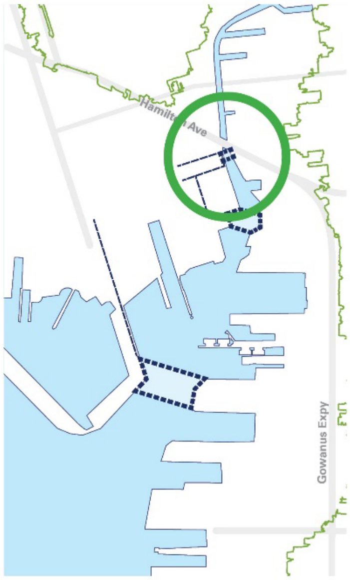


FIGURE 6-8
Current Land Use at Gowanus Canal Study Area

When starting to think about the potential zones of protection, and looking at the existing land use in the study area, it is evident that the Gowanus Bay barrier location would protect the largest area and offer better opportunities to tie into and protect Red Hook and parts of Sunset Park. There is little difference between the Hamilton Avenue and 19th Street locations, both of which would protect almost the entirety of the Gowanus neighborhood. The difference in the potential zone of protection between the two barrier locations is primarily that of a few industrial parcels, namely the Home Depot, and the City properties on Hamilton Avenue, although there are a few variations possible for protecting the asphalt plant and MTS, as discussed later in Section 8. There is also little difference between the Hamilton Avenue and 19th Street in-water barrier locations as far as potential tie-ins to the Red Hook IFPS which would be possible and which is shown in the concept option plans in Section 8.

6.2.3 Storm Surge Barrier Screening Results

Based on the Part I screening, the Gowanus Bay barrier location falls out of consideration given the significant complexity and challenges it would face to being erected. The Hamilton Avenue in-water barrier location appears to be the best option across all evaluation categories. Though it has greater challenges than the Hamilton Avenue option, the 19th Street option was also carried forward for concept option development for the sake of completion and looking at alternatives.



Category	Criterion	Gowanus Bay	19th St	Hamilton Ave
Economic Efficiency	Relative barrier cost	Red	Yellow	Green
Completeness	Ability to be constructed	Red	Yellow	Green
Acceptability	Navigable	Red	Yellow	Green
	Ability to be permitted	Red	Green	Green
In-water barrier type		Radial sector	Radial sector	Miter

FIGURE 6-9

Part I Screening for Gowanus Canal In-Water Storm Surge Barrier Site Alternatives

7 Storm Surge Barrier Concept Engineering

7.1 Overview

Following the shortlisting of the potential barrier options in Section 6.2.3 to those located at Hamilton Avenue and at 19th Street, the engineering and construction aspects of each option were considered in more detail. A high level planning cost estimate for these two alternatives was prepared for comparison purposes together with an assessment of the associated risks and uncertainties. The results of this work are summarized in Sections 7.2 and 7.3 and have been taken forward to inform the evaluation of the concept options in Section 8.

7.2 19th Street In-water Barrier option

7.2.1 Key Details

The height of the barrier has been set at +21 feet North American Vertical Datum of 1988 (NAVD88) as detailed in Section 2.4, which incorporates the 500-year flood level of +15 feet plus an allowance of 3 feet for sea level rise and 3 feet of freeboard. This precautionary approach is normal practice and is adopted as it can be very difficult and costly to retrospectively extend a barrier gate and its structure in the future. The sill level has been set at a depth of 29 feet. This includes infill to raise the post-remediation channel bed depth from 40 feet to the present depth of 29 feet. The barrier gate depth is therefore 50 feet.

FIGURE 7-1
Precedent Barrier: Lake Borgne Surge Barrier in New Orleans

The width of the barrier gate/opening is to be circa 150 feet wide. Although this provides an opening with a cross sectional area greater than that provided by the upstream Hamilton Avenue Bridge, the barrier is located on a bend in the canal alignment and as a result needs to be wider to accommodate vessels slewing as they navigate through the barrier opening and the bend.

The type of barrier proposed at 19th Street is a vertically hinged horizontal sector gate of steel fabrication, similar in size and construction to the gate used at the Inner Harbor Navigation Canal Lake Borgne Surge Barrier in New Orleans.

The barrier structure is likely to be reinforced concrete with a sill/base slab approximately 150 feet by 150 feet with the side abutments formed to create recesses on either side to accommodate the sector gates when they are in the open position.

7.2.2 Conceptual Works

7.2.2.1 Permanent Works

A control building would be required to house the necessary mechanical and electrical operating plant for the barrier and to provide a secure location from which the barrier can be managed. Clear vision into the barrier opening and both upstream and downstream of the canal would be important to ensure a safe operational interface with any navigation traffic in the vicinity.

Steel sheet pile bulkheads would be required to the immediate north and south of the main barrier structure, with infill between them, in order to tie in with the adjacent quayside and upland flood defenses on the east and west sides of the canal.

Access for plant, vehicles, and personnel will need to be provided for operational and maintenance purposes to both the east and west side of the barrier.

Navigation measures, including lights, signage, marker posts, and fendering/dolphins will be required to guide vessels through the open barrier and to protect the barrier structure against vessel impacts. This is particularly relevant due to the barrier being located on a bend in the canal alignment.

In order to reduce the risk of flooding from storm water runoff backing up within the Canal while the barrier is closed in a storm surge flood event, it is envisioned that a pumping station would be required as part of the works.

Due to the infill and hence loss of channel bed as part of these works, it is also envisioned that compensatory habitat creation to offset the loss would be required.

7.2.2.2 Temporary Works

It is envisioned that the east and west sides of the main barrier structure, including the tie-in bulkheads, would be constructed concurrently after the river bed has been infilled up to the required level of circa -29 feet. The reinforced concrete sill/slab between the two sides and its foundation piles would be installed thereafter across the navigation channel.

As a result during certain construction activities, especially during the sill construction, some closures of the canal to navigation would be necessary. The timing and duration of these activities would need to be prearranged in advance in order to minimize the detrimental impacts on the New York City Department of Transportation (NYCDOT) asphalt facility, the City of New York Department of Sanitation marine transfer station, and other navigation users upstream of Hamilton Avenue Bridge.

During construction provision would need to be made for additional temporary lighting, fendering (bumpers), etc. necessary for vessels to pass safely through the works until the barrier is completed.

A key part of the construction would be the dewatering of the cofferdams in which to create a dry working area to construct the east and west sides of the barrier structure. It is not envisaged that this would be a significant issue as there are impermeable soil layers relatively close to the surface which the cofferdam piling can key into.

Even though the Superfund remediation work along the canal would most probably have been completed before the construction of the barrier, it is likely that containment measures would still need to be put in place to control the risk of contaminants, that become mobilized in the water during dredging, migrating along the canal and into Gowanus Bay.

7.2.2.3 Future Works

As sea level rise takes place the barrier will increasingly be closing on a more regular basis and the probability of higher intensity rainfall events coinciding with a storm surge flood event will increase. As a result there is a strong possibility that over time more pumping capacity would need to be provided to deal with the increased volume of storm water run-off that could accumulate behind the barrier during a surge event.

7.2.3 Conceptual Cost Estimate

7.2.3.1 Allowances

An allowance of 25 percent of the estimated construction cost has been made in these high level estimates for the contractor's preliminary costs.

A contingency allowance of 30 percent of the estimated construction cost has been included.

An allowance of 25 percent has been included for other costs such as land purchase, compensation, ground investigation, appraisal studies, permitting, design fees, contract supervision fees, client management fees, etc.

A general utility relocation allowance of 10 percent of the estimated construction cost has been included in the cost estimate.

7.2.3.2 Assumptions

For this option it has been assumed that the bulk of the barrier structure will be constructed in a single cofferdam with the southern section completed once the main barrier is open and the temporary navigation bypass channel can be closed.

It has been assumed that the underlying soils are suitable for an average depth, size, and number of foundation piles to support the barrier structure.

7.2.3.3 Capital Cost

The conceptual cost estimate prepared is a preliminary estimate with a circa 15 to 30 percent accuracy range.

Construction of the in-water barrier will require staging and access alongside active industrial areas. This is expected to have impacts to vessel traffic and some industrial site access during construction. The accommodation works associated with these challenges are incorporated within the contractor's preliminary costs allowance and the compensation, etc., within the other costs allowance.

The estimated capital cost for this barrier option is circa $103 million, including $15 million for a storm water pump station and additional contingencies.

Appendix L provides the detailed build-up of the conceptual cost estimates for the in-water barrier works in addition to the upland defenses.

7.2.3.4 Whole Life Cost

Operational requirements for the barrier include operating staff costs, power usage, and costs associated with scheduled testing (normally on a monthly basis) and manning during a flood event. This will be impacted by the frequency of operation of the gates, which in turn is affected by the accuracy of flood forecasting. It is presumed that no daily attendance is required with respect to navigation passing through the barrier. Daily versus monthly manning would obviously be significantly more expensive.

Barrier maintenance normally involves routine annual maintenance, as well as intermittent more major maintenance work at 5 yearly, 10 yearly, and 25 yearly intervals. This includes the major refurbishment of the gate, which is likely to commence in year 25 in a phased approach. An allowance of between 1 to 2 percent of the capital cost for annual operation and maintenance is appropriate (or alternatively 5 to 10 percent of the capital cost of the gates; mechanical, electrical, instrumentation, controls, automation; control building; access; and landscape works). Based on the interface with the size and frequency of navigation vessels passing through the barrier and the anticipated small-scale sediment accretion/dredging requirements, the median of the range would be most likely.

The cost of 5 percent of the capital cost per annum is more appropriate when considering the major maintenance interventions. For comparison, the recent 25-year major refurbishment for the Hull Barrier in England (single 100-foot-wide vertical lift gate) cost more than $12 million over a period of 2 to 3 years.

7.2.4 Risks and Uncertainties

Given the conceptual pre-feasibility stage of this study, there are numerous project risks and uncertainties that would be further investigated and refined as part of any future detailed feasibility investigation. A number of these are described herein as items this study has identified and given initial consideration to potential impacts or implications, but which are not included in the order-of-magnitude cost items.

7.2.4.1 Barrier Width

As discussed in Section 7.2.1 above the barrier is located on a bend in the canal alignment and as a result needs to be wider to accommodate vessels slewing as they navigate through the barrier opening and the bend. However a more detailed study of the tugs, barges, and other vessels using the canal could dictate that a barrier width greater than 150 feet is necessary from a navigational operation and safety perspective.

Such a requirement would be expected to increase capital costs, especially as a wider sector gate would be difficult to accommodate in the in-channel space available and would require the excavation of the existing bulkheads and land behind it, including its acquisition.

7.2.4.2 Barrier Depth

The information on the planned Superfund remediation works for Gowanus Canal, available at the time of this study, outline a post-remediation depth at the 19th Street location of 40 feet. The conceptual cost estimate is based on this information and accounts for channel bed raising to the current depth of 29 feet for the sill. Any changes to remediation plans that change the post-remediation depths could have an impact on costs, increasing or decreasing the figure depending on actual post-remediation depths. For comparison, **Figure 7-2** shows the depth change and implications on the in-water barrier size at 19th Street due to Gowanus Canal post-remediation conditions.

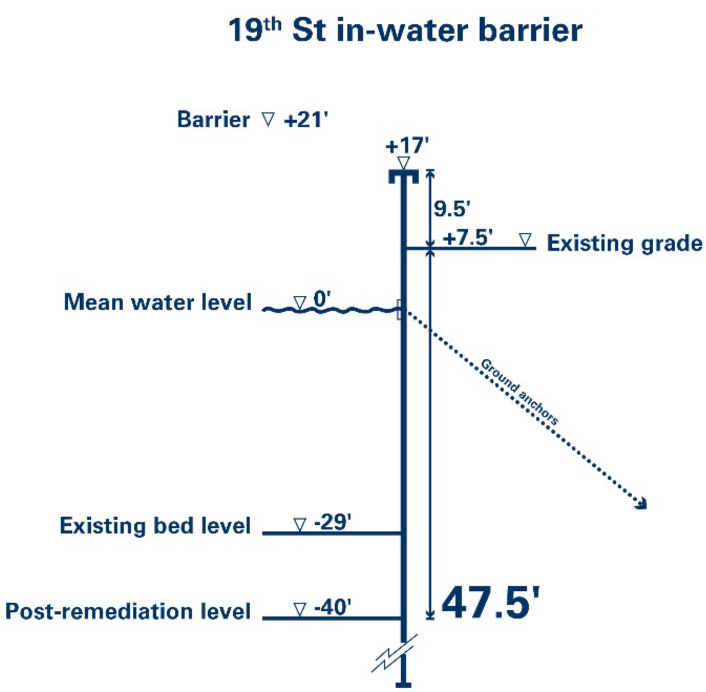


FIGURE 7-2
19th Street Post-Superfund Remediation Channel Bed and Bulkhead Profile

7.2.4.3 Upstream Storage Capacity

The hydrodynamic modeling undertaken as part of this study included a high-level analysis of the likely rainfall that could occur during a storm surge flood event; and a preliminary assessment of the volume of storm water that could accumulate behind the barrier during such an event, and the capacity of the canal to store such a volume. The findings indicated that, given the size of the catchment area and the limited capacity within the canal, there would be insufficient storage capacity upstream of the barrier and that a storm water pumping station would be required to minimize the risk of storm water flooding to property protected by the barrier from tidal flood risk during a storm surge.

Allowance for a pumping station has been included in the capital cost estimate, but future investigations would be expected to look in greater detail at the factors that affect the number of barrier closures (such as predicted sea level rise, the barrier operation/control philosophy, and the storm surge forecasting accuracy); and the factors that affect the storm water run-off upstream of the barrier (such as increasing rainfall intensity, and the existing and future storm water sewer network and infrastructure for the area).

A combined probability analysis of these factors would then be required to better determine the flows and volumes of storm water that would need to be accommodated and the storage or pumping capacity required over time, using an adaptive approach, to provide the requisite standard of combined flood risk management. The costs associated with any increase in storage or pumping capacity over and above the $15 million included in the conceptual cost estimates has not been allowed for.

7.2.4.4 Service Diversions

Utility investigations, including those for sub-channel cable and pipeline connections, and drainage outfalls, are another area that would require further more detailed appraisal and review in a future feasibility study. Based on the desk review completed for this study, it is not believed that there are active cables or pipelines that a 19th Street in-water barrier would interfere with, but this would require confirmation during detailed design.

While some contingency allowance has been included for minor utility relocations or protection (see Section 7.2.3.1 above), any more extensive works required to divert utilities or construct around utility corridors would result in an increase in capital costs.

7.2.4.5 Upland Defense Tie-ins with Active Waterfront Users

An allowance has been included both for potential land acquisition and for compensation to waterfront users and property owners whose activities would be disrupted either during construction or by the permanent works. Negotiations and legal challenges could cause these costs to escalate as well as additional permanent or temporary works provisions required to mitigate against any such disruption.

7.3 Hamilton Avenue In-water Barrier option

7.3.1 Key Details

As for the 19th Street option, the height of the barrier has been set at +21-feet NAVD88 as detailed in Section 1.2, which incorporates the 500-year flood level of +15-feet plus an allowance of 3 feet for sea level rise and 3 feet of freeboard.

The sill level has been set at a depth of 22 feet so as to lie flush with the post-remediation bed level. The barrier gate depth is therefore 43 feet.

FIGURE 7-3
Precedent Barrier: Ipswich Miter Gate Barrier in England

The width of the barrier gate/opening is to be circa 90 feet so as to provide the same channel cross sectional area as the Hamilton Avenue Bridge immediately upstream of it. It would be aligned with the existing navigation channel and opening through the bridge structure.

The type of barrier proposed at Hamilton Avenue is a mite gate of steel fabrication, similar to the gate used at Ipswich in England but wider and deeper.

The barrier structure would consist of a set of double leaf gates situated on either side of the channel with a stepped concrete sill located on the channel bed against which the gate will be rotated into the closed position.

It is envisioned that the barrier structure would be of reinforced concrete construction with a sill/base slab approximately 90 feet wide by 100 feet long with side abutments formed to create the quoin about which the gate leaves rotate, as well as the recesses on either side to accommodate the gate leaves when they are in the open position.

7.3.2 Conceptual Works

7.3.2.1 Permanent Works

A control building would be required to house the necessary mechanical and electrical operating plant for the barrier and to provide a secure location from which the barrier can be managed. Clear vision into the barrier opening and both upstream and downstream of the canal would be important to ensure a safe operational interface with any navigation traffic in the vicinity.

Steel sheet pile bulkheads would be required to the immediate north and south of the main barrier structure, with infill between them, in order to tie in with the adjacent quayside and upland flood defenses on the east and west sides of the canal. It is envisioned that ground anchor support would be required for both the bulkhead and quoin/abutment construction.

Access for plant, vehicles, and personnel would need to be provided for operational and maintenance purposes to both the east and west side of the barrier.

Navigation measures, including lights, signage, marker posts, and fendering/dolphins will be required to guide vessels through the open barrier and to protect the barrier structure against vessel impacts. This is particularly relevant due to the barrier being located immediately adjacent to the NYCDOT asphalt plant quay.

In order to reduce the risk of flooding from storm water runoff backing up within the canal whilst the barrier is closed in a storm surge flood event, it is envisioned that a pumping station of the same size for the 19th Street option would be required as part of the works.

Although the amount of infill and hence loss of channel bed as part of these works is relatively small, it is still envisaged that compensatory habitat creation would be required to offset the loss.

7.3.2.2 Temporary Works

It is envisioned that the east and west abutments of the main barrier structure, including the tie-in bulkheads, would be constructed concurrently after the river bed has been dredged to the required level of circa -29 feet less the depth of the concrete sill/slab. The reinforced concrete sill/slab spanning between the two abutments, which could potentially be pre-cast, and its foundation piles would be installed thereafter across the navigation channel.

As a result during certain construction activities, especially during the sill construction, some closures of the canal to navigation would be necessary. The timing and duration of these activities would need to be prearranged in advance in order to minimize the detrimental impacts on the NYCDOT asphalt facility, and other navigation users upstream of Hamilton Avenue Bridge.

During construction provision would need to be made for additional temporary lighting, fendering (bumpers), etc. necessary for vessels to pass safely through the works until the barrier is completed.

A key part of the construction would be the dewatering of the cofferdams in which to create a dry working area to construct the east and west abutments of the barrier structure. It is not envisaged that this would be a significant issue as there are impermeable soil layers relatively close to the surface which the cofferdam piling can key into.

Even though the Superfund remediation work along the canal would most probably have been completed before the construction of the barrier, it is likely that containment measures would still need to be put in place to control the risk of contaminants, that become mobilized in the water during dredging, migrating along the canal and into Gowanus Bay.

7.3.2.3 Future Works

As sea level rise takes place, the barrier will be closing on a more regular basis and the probability of higher intensity rainfall events coinciding with a storm surge flood event will increase. As a result there is a strong possibility that over time more pumping capacity will need to be provided to deal with the increased volume of storm water run-off that will accumulate behind the barrier during a surge event.

7.3.3 Conceptual Cost Estimate

7.3.3.1 Allowances

The same percentage allowances as for the 19th Street option (see Section 7.2.3.1) for contractor's preliminary costs, contingencies, other costs, and general utility relocation have been used for this option.

7.3.3.2 Assumptions

For this option it has been assumed that the barrier structure would be constructed as described in Section 7.3.2.2 above, and that the timing and duration of the temporary navigation closures combined with restrictions imposed by working adjacent to the Hamilton Avenue Bridge, the live highway and the asphalt plant would only result in approximately a 10 percent loss in construction productivity.

It has been assumed that the underlying soils are suitable for an average depth, size, and number of foundation piles to support the barrier structure.

7.3.3.3 Capital Cost

The conceptual cost estimate prepared is a preliminary estimate with a circa 15 percent to 30 percent accuracy range.

Construction of the in-water barrier will require staging and access alongside active industrial areas and an active transportation link. This is expected to have impacts on vessel traffic and some industrial site access during construction. Access to the land parcel to the east and west of the Hamilton Avenue Bridge would be required. The accommodation works associated with these challenges are incorporated within the contractor's preliminary costs allowance and the compensation, etc. within the other costs allowance.

The estimated capital cost for this barrier option is circa $54 million, including $15 million for a storm water pump station and additional contingencies.

Appendix L provides the detailed build-up of the conceptual cost estimates for the in-water barrier works in addition to the upland defenses.

7.3.3.4 Whole Life Cost

Operational and maintenance requirements and costs for the barrier will be of a similar order and capital cost percentages as those detailed in Section 7.2.3.4 above.

7.3.4 Risks and Uncertainties

As with the 19th Street in-water barrier option, there are numerous project risks and uncertainties that should be further investigated and refined as part of any future detailed feasibility investigation. A number of those identified in this study are detailed below, and their potential impacts considered. However no allowances for these risks and uncertainties have been included in the conceptual cost estimates prepared.

7.3.4.1 Barrier Depth

The uncertainty for barrier depth described for the 19th Street barrier in Section 7.2.4.2 applies to the Hamilton Avenue barrier location as well. If the post-remediation depths are significantly deeper than indicated in current remediation plans, infill could be required to raise the channel bed to the proposed depth.

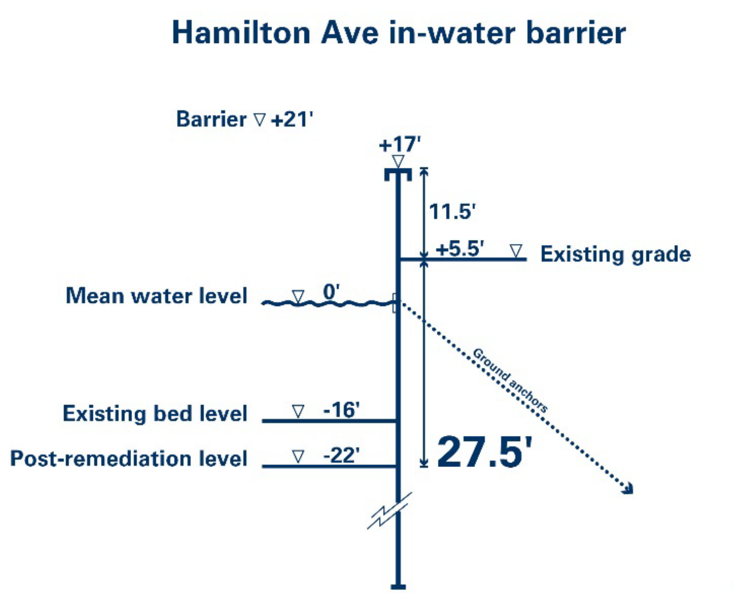


FIGURE 7-4
Hamilton Avenue Post-Superfund Remediation Channel Bed and Bulkhead Profile

7.3.4.2 Upstream Storage Capacity

The uncertainty/risk surrounding upstream storage capacity and need for additional storm water storage and pumping station capacity described in section 7.2.4.3 for the 19th Street barrier location applies to the Hamilton Avenue barrier location as well.

7.3.4.3 Service Diversions

Utility investigations, including those for sub-channel cable and pipeline connections, and drainage outfalls, are another area that would require further more detailed appraisal and review in a future feasibility study. Based on the desk review completed for this study, it is not believed that there are active cables or pipelines that a Hamilton Avenue in-water barrier would interfere with, apart from local services within the asphalt plant. However this would require confirmation during detailed design.

While some contingency allowance has been included for minor utility relocations or protection (see Section 7.3.3.1 above), any more extensive works required to divert utilities or construct around utility corridors would result in an increase in capital costs.

7.3.4.4 Interface with Adjacent Waterfront Users and Landowners

An allowance has been included both for potential land acquisition and for compensation to waterfront users and property owners whose activities would be disrupted either during construction or by the permanent works. Negotiations and legal challenges could cause these costs to escalate as well as additional permanent or temporary works provisions required to mitigate against any such disruption.

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8 Concept Options

8.1 Gowanus Canal Concept Options

Advancing from the Part I in-water barrier screening, three alternative concept options were developed and evaluated for the Gowanus Canal around the two potential barrier locations. Each concept option developed presents different strengths and weaknesses. These differences highlight trade-offs and challenges that add to the overall understanding of the opportunities and complexities entailed in adopting a storm surge barrier system as part of the New York City's (City) overall approach to flood defenses and resiliency.

The three concept options are:

- 19th Street
- Hamilton Avenue bulkhead
- Hamilton Avenue right-of-way (ROW)

FIGURE 8-1
Gowanus Canal Alternative Concept Option Alignments

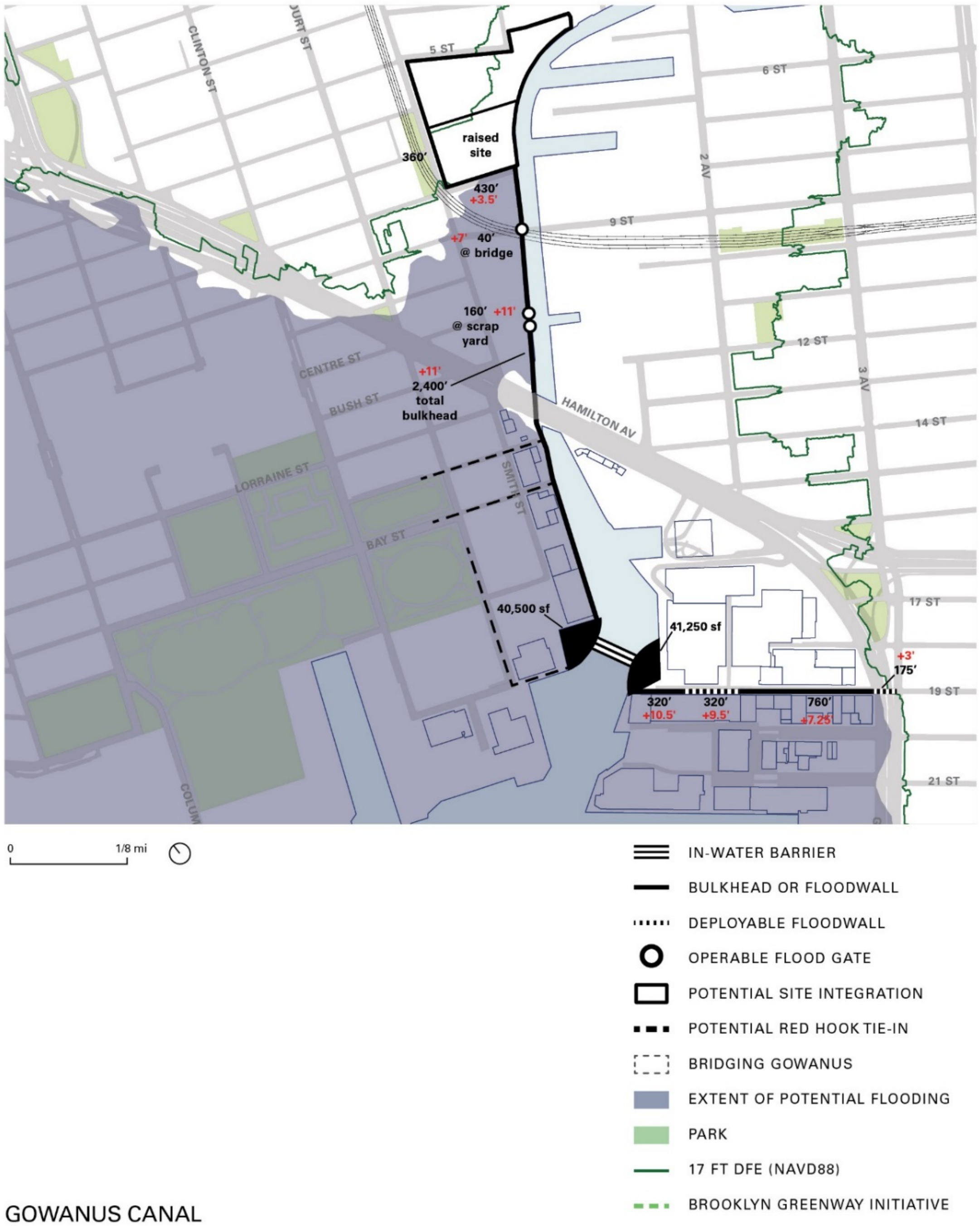
For this conceptual stage of development, concept options are presented in plan form. The types of upland defense that may be suitable for given locations along portions of the alignment are indicated. Key trade-offs, strengths, and weaknesses for each concept option are presented in this section. The complete Part II comparative evaluation is summarized in spreadsheets in Appendix K.

As noted previously in the report, the Red Hook Integrated Flood Protection System (IFPS) project has funding, thus the assumption is that it would precede any project in Gowanus. A potential Gowanus Canal flood defense system could tie in later. No Gowanus Canal concept option has an advantage over any other in its ability to tie-in. In the concept option plan diagrams that follow, dotted lines indicate where connections between a Gowanus Canal solution and the Red Hook IFPS might be made. Although the Red Hook alignment is yet to be determined, the recreational lands appear to be a good location for integrating the two systems. Another consideration, is that depending upon where the Red Hook IFPS runs, a Gowanus Canal alignment could potentially tie in further south and be shorter than shown for this study's stand-alone purposes.

8.1.1 19th Street Concept Option

The 19th Street option minimizes reliance on deployable components by running permanent floodwalls or operable gates along bulkheads to the degree possible. On the west side of the canal, the alignment extends north to Huntington Street where it could tie into a potentially elevated National Grid site, or run west to tie into the +17-foot North American Vertical Datum of 1988 (NAVD88) elevation at Smith Street. Operable gates would be installed at the 9th Street Bridge (below the design flood elevations [DFE]) and at active berths, including a scrap yard and Bayside Oil. The alignment extends south along the canal to approximately Court Street and Bryant Street opposite The Home Depot. A 150-foot-wide horizontal sector gate would span the Canal. The alignment then crosses to the east of the Canal and a mixture of permanent and deployable floodwalls would run along 19th Street, under the Gowanus Expressway viaduct, to the tie-in with +17-foot NAVD88 elevation at 3rd Avenue.

19th St option



Note: Heights for the flood defense components indicated in the plan above are averages for the indicated segments and not spot elevations.

FIGURE 8-2
19th Street Concept Option

Two variations of this alignment were considered. Rather than run along the Canal north of Hamilton Avenue, the flood defense scheme could instead run west along Hamilton Avenue (A) to tie into the +17-foot elevation. The implications for this variation are described in detail in the Hamilton Avenue ROW section. A second variation (B) could run the alignment down 20th Street, instead of 19th Street. However, 20th Street is not mapped all the way to the Canal's edge, and the flood defense would interfere with entrance to and the business activity within Sunset Industrial Park.

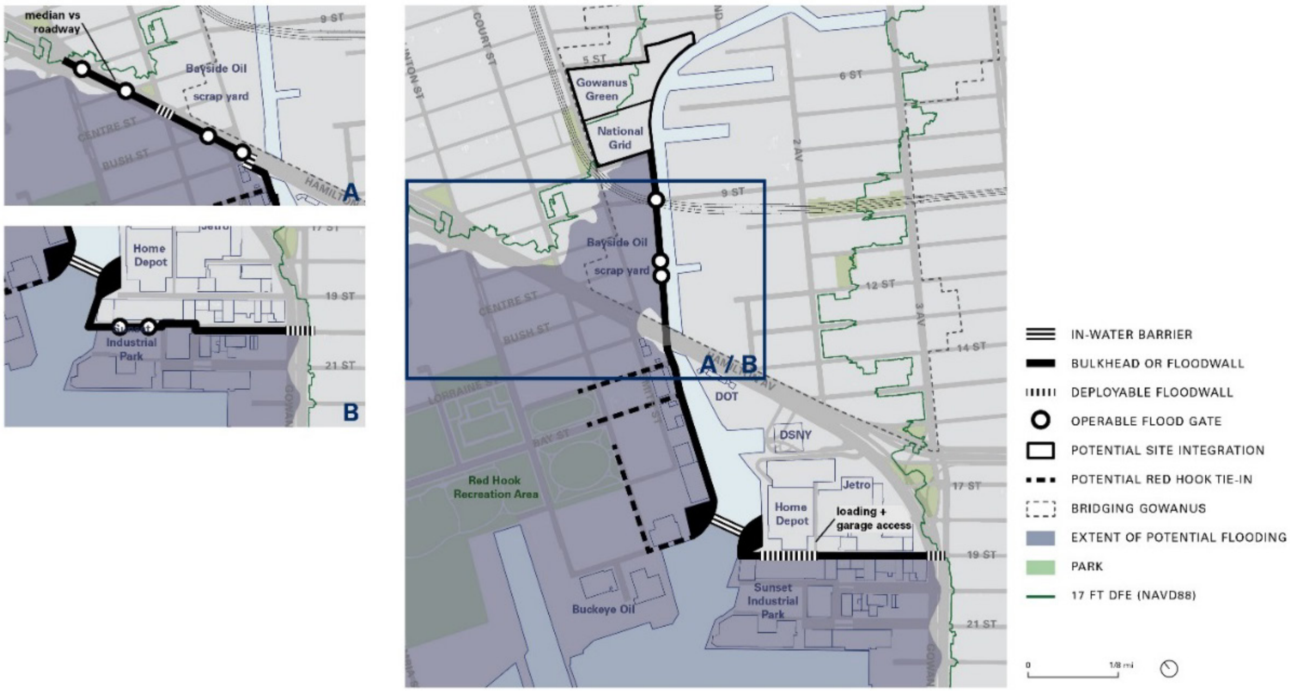
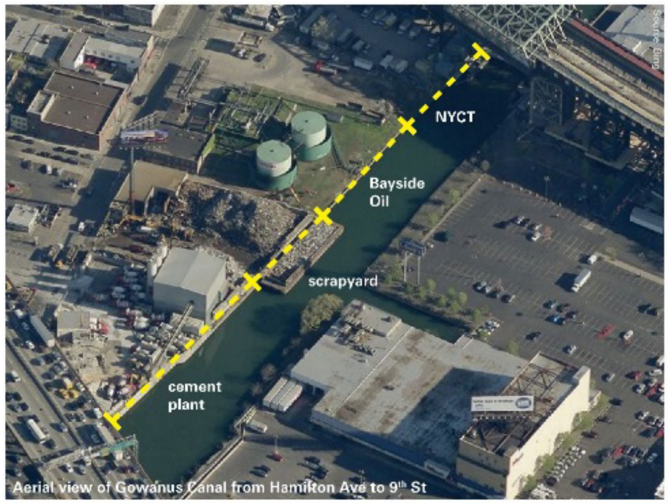


FIGURE 8-3
19th Street Concept Option Alignment Variations

As far as elevations, the area just north of 9th Street is a low point for exiting grade elevation. A sliding gate at the asphalt plant would be around 13 feet above grade and the floodwall along the Canal would transition from 13 feet above grade and down to grade as it approaches the Hamilton Avenue Bridge. The average bulkhead height along the western alignment is approximately 11 feet above existing grade.

+13'
above grade elevation to achieve DFE



Aerial view of Gowanus Canal from Hamilton Ave to 9th St

+13'
above grade elevation to achieve DFE

Smith St scrap yard: sliding gates to close across berth (160 ft)

Sliding or roll-across gate

FIGURE 8-4
Illustrative Concept Option Component: Slide Gate along Bulkhead to Maintain Berth Access

+0'
above grade elevation to achieve DFE

Gowanus / Smith St: raised bulkhead with sliding gates at berths (700 ft in total, from Hamilton Ave to 9th St)

Hamilton Ave at Gowanus Canal, looking north

FIGURE 8-5
Illustrative Concept Option Component: Raised Bulkhead along Canal

There are significant challenges associated with the 19th Street concept option. Its major strength is that it lessens the reliance on deployable/temporary components for much of the alignment. However, there would be significant impacts to commercial activities along 19th Street, where upland defenses would range in height from 10 feet above grade elevation near the Canal to 1 foot above grade as it approaches 3rd Avenue. Parking, loading spaces, and 19th Street access to the Sunset Industrial Park would all be lost. From an urban design perspective, an already industrial area could become dangerous. While lower 2-foot-tall segments would have minimal impact, 7-foot tall segments could have negative impacts on illumination and lighting with public safety and pedestrian implications. Limiting the number of openings along the floodwall would present obstacles to pedestrian circulation. Finally, maintenance of the roadway and utilities, as well as emergency access, would suffer.

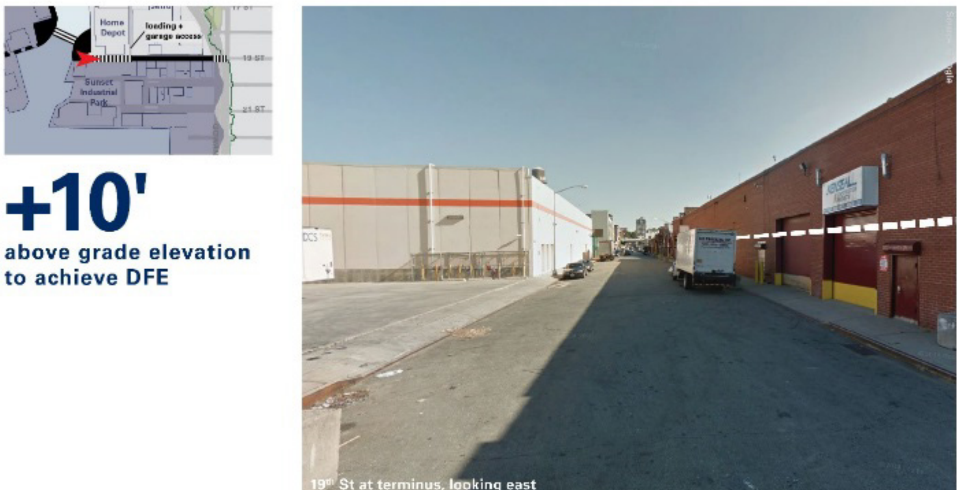


FIGURE 8-6
Floodwall Height along South Side of 19th Street

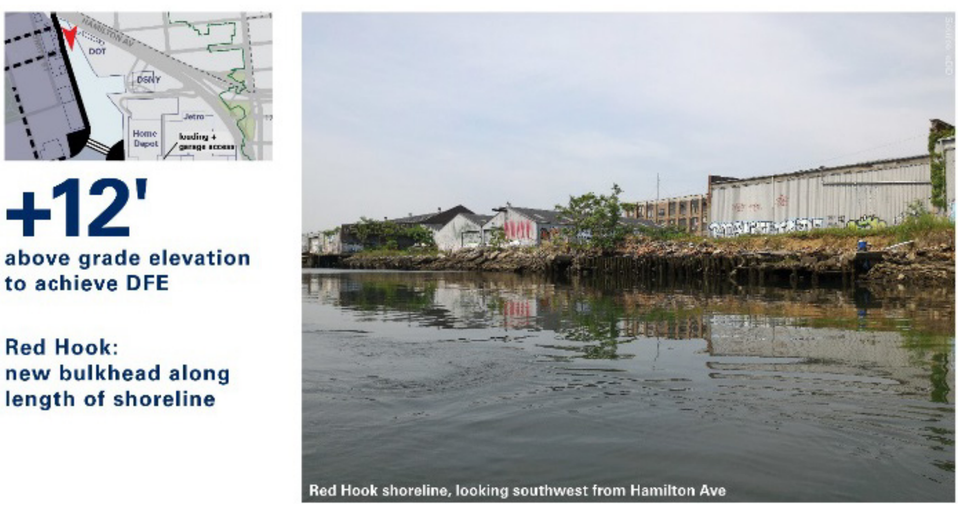


FIGURE 8-7
Raised Floodwall to Replace Existing Shoreline Condition

Based on precedent from similar systems in Europe, expensive and continuous operations and maintenance work would likely be required for his alignment due to the active nature of the waterway and vessels impacting the bulkhead/floodwall. Timing and potential early coordination with planned Superfund remediation work is important for this alignment. There might be cost savings and design coordination opportunities with the planned bulkhead replacement activities. It is understood that as currently planned, replacement bulkhead will be built to their current elevation. For this alignment to maximize construction and cost efficiency, it would be preferable to design new bulkheads in consideration their dual role as canal retaining wall and flood defenses. Otherwise, there would be significant costs to raise and reinforce bulkheads at a later date. In such a case, floodwalls behind the bulkheads might become more likely (and require easements from the private property owners), and the permitting and approval process would face additional complexities due to likely upland hazardous material remediation and require permitting and interface with Superfund-related activities that have already been remediated.

- **Minimizes reliance on deployables**
- **Could leverage Superfund remediation bulkhead replacement work**
- **O&M costs & challenges**
- **Adverse impacts to berths & businesses**
- **Major permitting considerations**

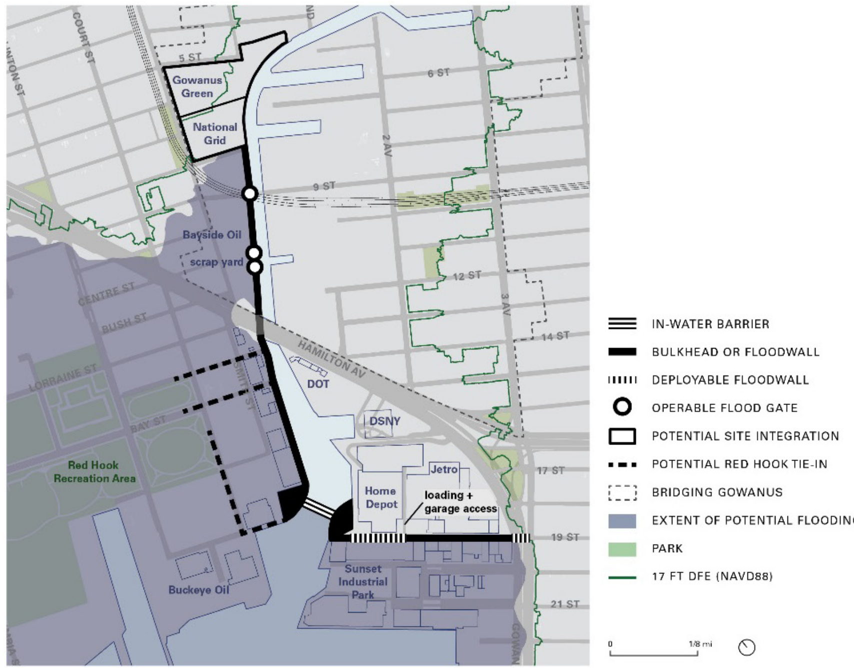


FIGURE 8-8
19th Street Concept Option's Key Strengths and Weaknesses

8.1.1.1 Protection of People and Jobs

For the 100-year flood event, the 19th Street option would protect around 128 acres. The residential populations protected by the 19th Street and the alternative options are almost the same, at around 1,600 people. The area protected by all of the Gowanus Canal concept options has a high concentration of businesses and jobs, particularly in the industrial sectors. The extra land protected south of Hamilton Avenue protected by the 19th Street option has a significant amount of commercial activity. The 19th Street concept option protects 445 businesses and 5,300 jobs, an additional 25 businesses and 400 jobs compared to the Hamilton Avenue ROW concept option.

For the more extreme 500-year flood event, a much larger areas of 207 acres would be protected by the 19th Street Concept Option. Largely driven by the inclusion of the 1,137-unit Gowanus Houses in the 500-year floodplain, these areas are much more densely populated than the areas protected from the 100-year flood event: more than 32 residents per acre compared to less than 14. The 19th Street option protects close to 6,700 residents, 300 fewer than the Hamilton Avenue alternative. This reflects the fact that the Hamilton Avenue alternatives provide greater protection north of Hamilton Avenue on the west side of the Canal which falls outside the 19th Street concept option's zone of protection.

The 19th Street option protects 7,900 jobs and 680 businesses within the 500-year flood plain, at a density slightly than in the 100-year protected area. As in the 100-year scenario, the difference between the 19th Street concept option and the Hamilton Avenue option are driven by the large industrial and retail sites south of Hamilton Avenue, such as the Marine Transfer Station and Asphalt Plant, as well as the Home Depot and Jetro Cash & Carry. The 19th Avenue option includes fewer buildings, but those buildings are larger, for a total of 6.9 million square feet.

8.1.1.2 Conceptual Engineering and Planning Cost Estimate

Engineering and construction risks were considered for this alignment, and a high level planning cost estimate for this alternative is provided for comparison purposes.

The predominant defense type outside of the in-water barrier is the bulkhead along the west side of the canal. Floodwalls are also incorporated and it is assumed that the soil is suitable to support this construction.

This alignment minimizes the potential utility conflicts assuming few utilities are currently located in the existing bulkhead corridor. Construction of significant underground infrastructure to support the concrete floodwalls is expected. It is assumed that this will be possible and that utility conflicts can be addressed and are accounted for with a utility allowance of 10 percent in the conceptual cost estimate.

Construction of the bulkhead will require access between the commercial businesses and the water. It is assumed that sufficient space will be made available via a temporary easement from the business owners. Wall construction will require staging along the streets and it is assumed that the streets can be closed to traffic during these periods. Some buildings are immediately adjacent to the canal which will likely require the bulkhead to be constructed from the water side at these locations. Access to the commercial businesses will need to be addressed and is likely a more significant impact east of the canal. A 10 percent access allowance factor is included in the cost estimate.

The preliminary conceptual cost estimate for the upland defense portion of the 19th Street concept option is approximately $57 million. This figure excludes any land acquisition, and risks and other factors as described above and similar to those described for the in-water barrier conceptual engineering, could escalate the figures. The total cost estimate for the complete 19th Street concept option, combing both the in-water storm surge barrier and the upland defenses is approximately $160 million. Appendix L provides the detailed build-up of the conceptual cost estimates.

8.1.1.3 FEMA Certification Considerations

The National Grid Site is considered as an option for the west limit of the system. The Federal Emergency Management Agency (FEMA) will only consider full system certification, so this site raising would need to be complete before certification is pursued. Use of this site as high ground rather than an earthen berm will require that the full site, not just a corridor, be raised and that proper compaction of the site can be shown.

Portions of this alternative are aligned along private commercial property. In order to obtain FEMA certification, this land would need to have a permanent easement to the City (or operating agency) with access. At both terminus points, the system ends at existing ground that is sufficiently high to provide an acceptable tie-in point for FEMA mapping purposes.

While the number of deployable measures are limited in this alternative, they are included. FEMA would require that the adopted Operation and Maintenance Plan detail all aspects of these features, including the flood warning system in place to allow sufficient time for implementation.

8.1.2 Hamilton Avenue: Bulkhead Concept Option

The Hamilton Avenue bulkhead concept option is similar to the 19th Street option as far as alignment, rationale, strengths, and weaknesses, but shorter in overall length. As with the 19th Street option, the Hamilton Avenue bulkhead concept options minimizes the reliance on deployable components, but at a cost for increased maintenance expense and more complex legal interactions with and worsened impacts to private property owners. For this alignment, the in-water barrier location moves to the Hamilton Avenue location where a 90-foot-wide mite gate would be erected. On the west side of the Canal, the alignment extends north to Huntington Street where it could tie into a potentially elevated National Grid site, or run west to tie into +17-foot NAVD88 elevation at Smith Street. Operable gates would be installed at the 9th Street Bridge (below the DFE) and at active berths, including a scrap yard and Bayside Oil. The alignment then runs along Hamilton Avenue to 3rd Avenue along the east side of the canal.

- **Minimizes reliance on deployables**
- **Could leverage Superfund remediation bulkhead replacement work**
- **O&M costs & challenges**
- **Adverse impacts to berths & businesses**
- **Major permitting considerations**

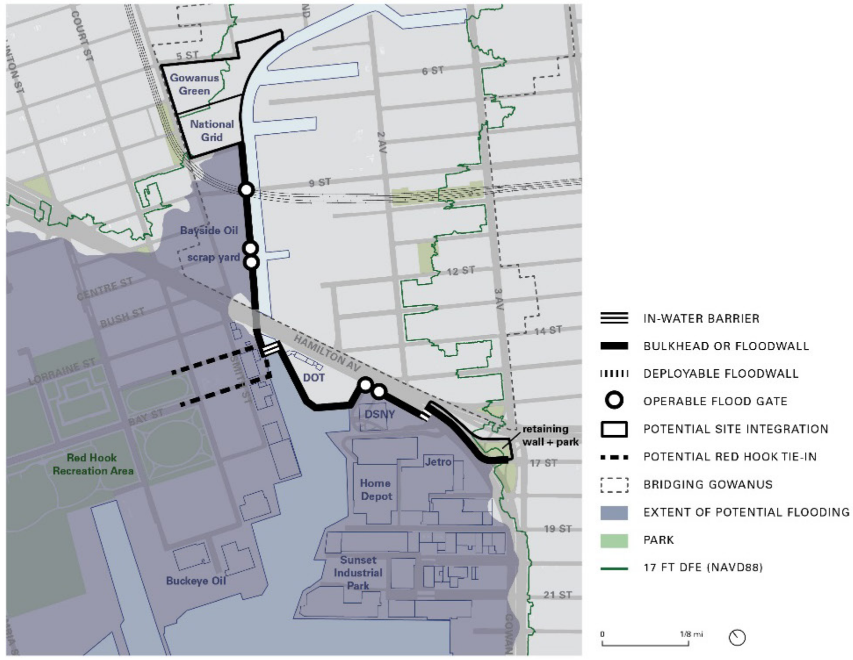


FIGURE 8-9
Hamilton Avenue Bulkhead Concept Option's Key Strengths and Weaknesses

There is potential to integrate with the existing retaining wall under the Gowanus Expressway near the 17th Street exit from Hamilton Avenue. Such integration might be a way to leverage existing infrastructure investment, reducing overall capital costs. The retaining wall was built in the 1930s or 1940s, and there is fill behind the stone façade. Steel and concrete support columns for the expressway were added later. It is anticipated that based on current loading capacity, the retaining wall would need to be reinforced/waterproofed, but that it would probably be able to be integrated into the upland defense system. Such reinforcement/waterproofing is likely to involve grout injection into the existing wall (and maybe to some of the fill material behind it as well) and then repointing of the stone cladding up to the required defense height. Any future detailed design will require coordination with New York State Department of Transportation (NYSDOT).

+0'

above grade elevation to achieve DFE

17th St exit ramp: tie into retaining wall under the expressway; flood defenses terminate at park

FIGURE 8-10
17th Street Exit from Hamilton Avenue: Natural Elevation Tie-in Point

FIGURE 8-11
Retaining Wall at Hamilton Avenue and 17th Street: Potential Existing Infrastructure Integration

There are a few variations for protecting the NYCDOT asphalt and City of New York Department of Sanitation (DSNY) marine transfer station (MTS) facilities on Hamilton Avenue. One option is to keep the defense line along Hamilton Avenue with operable driveway gates. Alternatively, the alignment could run along the bulkhead and including operable gates along the active berths. While in comparison to 19th Street, the number of curb cuts and therefore operable gates on Hamilton Avenue are fewer, the NYCDOT and DSNY facilities represent some of the most important connections and access must be ensured.

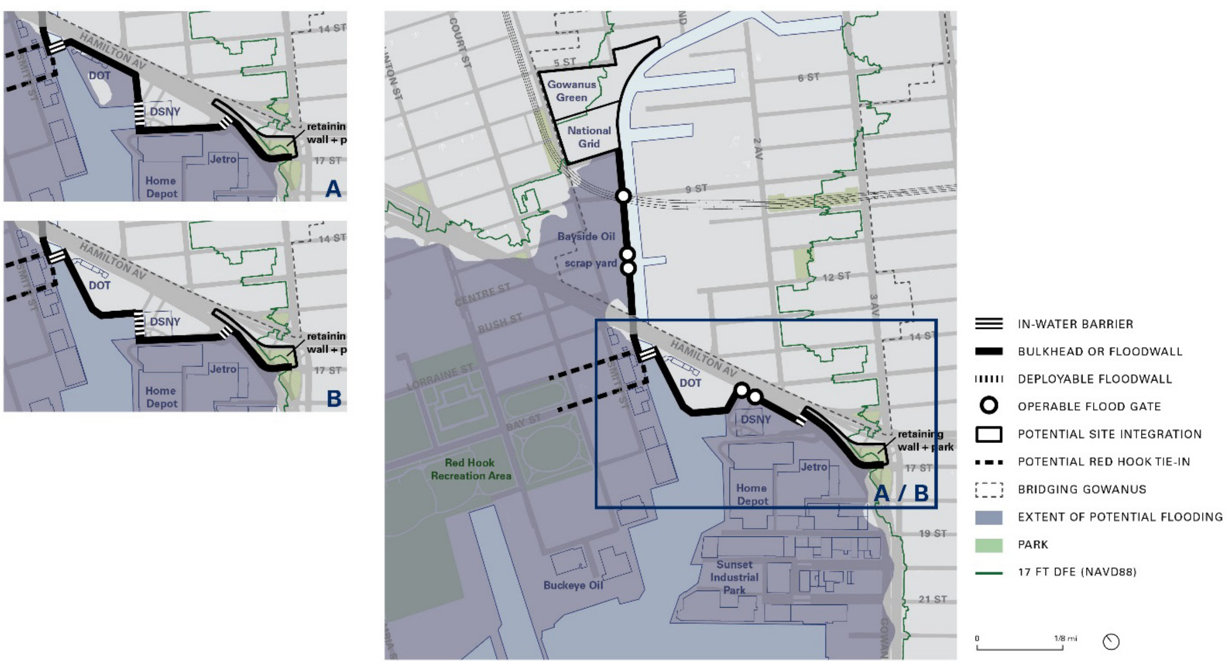


FIGURE 8-12
Alternative Protection Variations for DOT and DSNY Facilities

The protection of people and jobs for this concept option would be similar to those of the 19th Street or Hamilton Avenue ROW alternatives, depending upon the alignment variation.

The conceptual engineering assumptions are similar to those presented in the 19th Street Concept option. As discussed previously, an assumption of this alignment is that integration with the Gowanus Expressway retaining wall is possible. The costs for this option would be similar to those of the 19th Street and Hamilton Avenue Concept Options. The FEMA considerations are similar for this alternative as compared to the 19th Street option.

8.1.3 Hamilton Avenue: Right-of-Way Concept Option

The Hamilton Avenue ROW concept option is the third concept option for Gowanus Canal. To the west of the canal, the concept option runs along Hamilton Avenue to +17-foot NAVD88 natural elevation at Clinton Street. To the east of the Canal, the concept option runs along Hamilton Avenue to 3rd Avenue under the Gowanus Expressway.

On the west side of the canal, the alignment could run down the median under the elevated Gowanus Expressway viaduct. Such an alignment would likely comprise floodwall and operable gates. It would require changes to current traffic patterns, as turn lanes in the median might need to be relocated, and could raise safety concerns related to visibility of turning traffic and interface with pedestrian crossings.

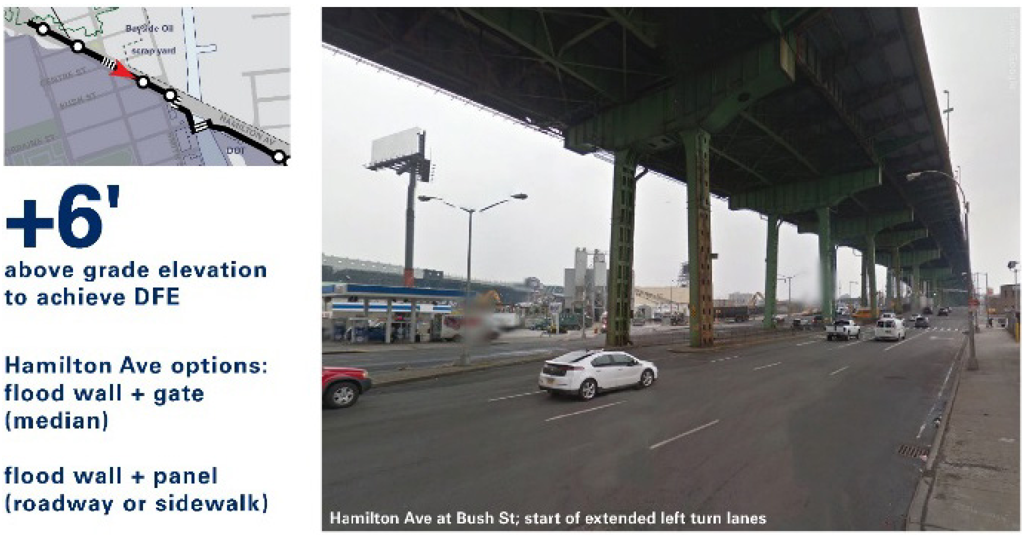


FIGURE 8-13
Hamilton Avenue at Bush Street: Concept Option in Median or Southern-most Traffic Lane

Alternatively, the alignment could run down the southern side of Hamilton Avenue or along the sidewalk. This alignment would likely comprise a floodwall with deployable post and panel segments. Current NYCDOT greenway plans propose turning the existing sidewalk and southernmost lane into a 23-foot-wide greenway. The upland defense could integrate with the greenway, becoming part of the buffer between the greenway and vehicular traffic. Of the two alternative upland defense alignments for this segment of the Hamilton Avenue ROW concept option, integration with the future greenway is probably the preferred alternative.

+5'
above grade elevation to achieve DFE

FIGURE 8-14
Retaining Wall at Hamilton Avenue and 17th Street: Potential Existing Infrastructure Integration

On the east side of the Canal, the upland defense alignment continues along the southern side of Hamilton Avenue before crossing Hamilton Avenue to the northeastern side and integrating with the retaining wall. The potential for integration with the existing retaining wall under the Gowanus Expressway near the 17th Street exit, described in the preceding concept option, also applies to the Hamilton Avenue ROW alignment. Demountable panels or operable gates are used for the Hamilton Avenue crossing. The variations for differing levels of protection of the NYCDOT asphalt plant and the DSNY MTS described for the Hamilton Avenue bulkhead concept option are possible.

Note: Heights for the flood defense components indicated in the plan above are averages for the indicated segments and not spot elevations.

FIGURE 8-15
Hamilton Avenue ROW Concept Option

In contrast to the two alternative Gowanus Canal concept options, the Hamilton Avenue alternative minimizes business disruption and maximizes public control, but in order to do this, relies on a defense system comprised heavily of deployable components that ensure access to seven intersections and numerous vehicular crossings as well as the asphalt plant and MTS driveways.

- **Erected in public ROW**
- **Least complex legal and planning process**
- **Minimal coordination and business disruption**
- **Reliance on deployables**
- **O&M costs & challenges**
- **? Possible tie-in to Brooklyn Greenway Initiative**

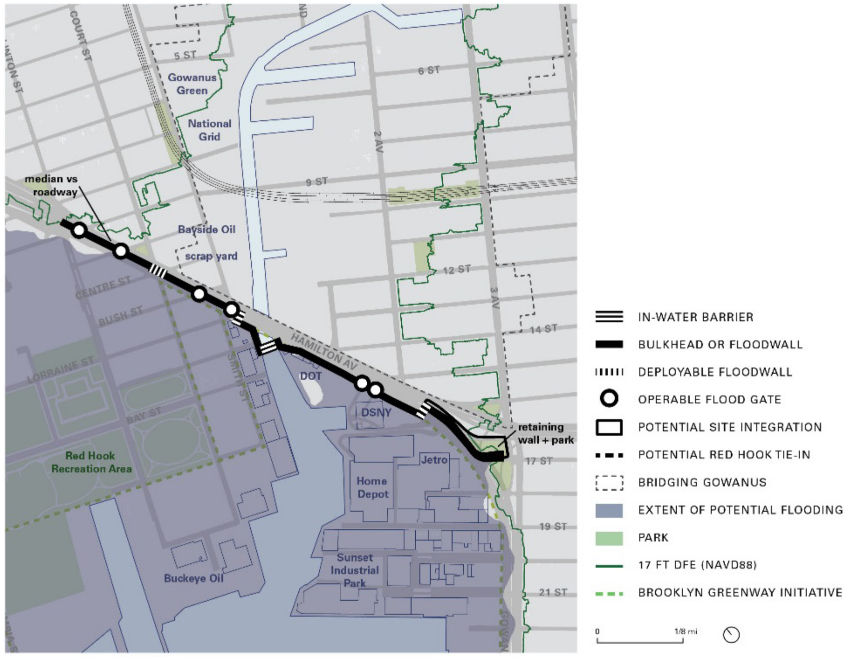


FIGURE 8-16
Hamilton Avenue ROW Concept Option's Key Strengths and Weaknesses

The Hamilton Avenue ROW option appears to be the best option because of its relatively simpler legal and planning process due to its erection in a public ROW, and the minimal coordination requirements and business disruption it would impose. As noted in the in-water storm surge barrier discussion in Section 6, this alignment would affect NYCDOT asphalt plant operations, taking the first 100 feet of bulkhead/berth in from the Hamilton Avenue Bridge out of active use and requiring access to the northwest corner of the NYCDOT parcel. In addition, access to the property directly adjacent to the west side of the Hamilton Avenue Bridge is required both for construction staging and for ongoing operation and maintenance access. Makaka Toys and a car service currently reside at this location, and the backside of the property is rented out for parking. Either an easement or property acquisition could be considered. The level of coordination and negotiation with the fewer number of property owners impacted by the Hamilton Avenue ROW concept option appears to be more manageable in comparison to the alternative concept options.

Operations and maintenance costs could be high, given the need for storage, labor, and mobilization activities in a storm event, and testing, operations. However, the operations and maintenance activities would avoid the need for expensive and continuous work along bulkhead floodwalls due to vessels impacting the bulkhead/floodwall that would be anticipated for the alternative concept options running along the Canal. Mobilization activities in a storm event are more complex for the Hamilton Avenue ROW and require more lead time than the permanent barrier solution in the other alternatives. The heavier reliance on deployable elements increases the potential for system failure, although all of the Gowanus Canal concept options require some deployables so this is less of a differentiating factor.

Erecting a barrier may potentially lead to a feeling of increased disconnect between the Red Hook and Gowanus neighborhoods, which would require mitigation through a design solution. However, much of the upland defenses, especially on the Red Hook side of the canal vary between 3 and 6 feet above existing grade, so adverse impacts to the pedestrian experience would not be as severe as some of the locations along the 19th Street option. One design solution might integrate the upland defense system with the proposed greenway to provide a buffer between the greenway and vehicular traffic. The incorporated floodwall and upland defense options could have architectural attributes. For example, rather than erecting a solid concrete floodwall, higher segments could be topped with three feet of aquarium glass. Murals or other artistic elements may also be incorporated to create a safer, more inviting environment.

8.1.3.1 People and Jobs Protected

For the 100-year flood event, the Hamilton Avenue ROW option would protect roughly 117 acres, slightly fewer than the 19th Street concept option. However, the residential populations protected are almost the same, at around 1,600 people. The Hamilton Avenue ROW option protects around 440 businesses and 4,900 jobs, 25 fewer businesses and 400 fewer jobs than the 19th Street concept option.

For the more extreme 500-year flood event, modeling results show that a much larger area of 192 acres would be protected. Largely driven by the inclusion of the 1,137-unit Gowanus Houses in the 500-year floodplain, these areas are much more densely populated than the areas protected from the 100-year flood event: more than 32 residents per acre compared to less than 14. The Hamilton Avenue ROW option provides greater protection north of Hamilton Avenue on the west side of the Canal, capturing almost 7,000 residents, 300 more than the 19th Street option.

The Hamilton Avenue ROW option protects around 7,500 jobs (400 fewer than the 19th Street concept option) and 650 businesses (30 fewer than the 19th Street concept option). As in the 100-year scenario, these differences are driven by the large industrial and retail sites south of Hamilton Avenue, such as the Marine Transfer Station and Asphalt Plant, as well as the Home Depot and Jetro Cash & Carry. With more small residential buildings, the Hamilton Avenue option protected area includes around 770 buildings and 6.5 million square feet of built area.

8.1.3.2 Conceptual Engineering and Planning Cost Estimates

Engineering and construction risks were considered for this alignment. A high level planning cost estimate of around $54 million for this alternative is provided for comparison purposes. This figure excludes any land acquisition, and risks and other factors as below and similar to those described for the in-water barrier conceptual engineering, could escalate the figures. The total cost estimate for the complete Hamilton Avenue ROW concept option, combing both the in-water storm surge barrier and the upland defenses is approximately $108 million. Appendix L provides the detailed build—up of the conceptual cost estimates.

The predominant defense type outside of the in-water barrier is the floodwall located at the Gowanus Expressway (underneath or integrated with the existing retaining wall). It is assumed that the soil is suitable to support the concrete floodwalls and that integrations with the existing retaining wall is possible.

Construction of significant underground infrastructure to support the concrete floodwalls is expected. While there are numerous utilities, it is assumed that utility conflicts can be overcome in the design. A utility relocation allowance of 20 percent was included in the cost estimate to account for this issue.

Construction of the floodwall will require staging and access under the Expressway. It is anticipated that some access to the expressway and Hamilton Ave will need to be rerouted. In addition, restrictions in equipment height used in construction will be required. These challenges are incorporated into an access allowance of 15 percent in the cost estimate.

8.1.3.3 FEMA Certification Considerations

Portions of this alternative could be aligned along private commercial property. In order to obtain FEMA certification this land would need to have a permanent easement to the City (or operating agency) with access. At both terminus points the system ends at existing ground that is sufficiently high to provide an acceptable tie-in point for FEMA mapping purposes.

This alternative contains a significant number of deployable measures. FEMA would require that the adopted Operation and Maintenance Plan detail all aspects of these features, including the flood warning system in place to allow sufficient time for implementation. Details of the manpower and time needed for the implementation would likely be required.

8.2 Preferred Concept Options Advanced to Project Analysis

8.2.1 Evaluation Screening Outcomes

A summary of the comparative screening is shown in **Figure 8-17**. The Hamilton Avenue ROW concept option advanced for further analysis as the "Preferred Concept Option" while the 19th Street concept option advanced as an "Alternate Concept Option" for purposes of completeness and comparison.

Overall, the Hamilton Avenue right-of-way (ROW) alignment appeared to offer the most promise of the three concept options evaluated. There are challenges to implementation and, where the project progresses, additional investigations and detailed feasibility studies will be required. However, as far as anticipated costs and benefits, potential ease of implementation from a permitting and regulatory perspective, and its relative ease of integration into the existing urban fabric with fewer disruptions to private property owners and the business community, the Hamilton Avenue alignment is a concept option that warrants future consideration. Based on the evaluation screening, discussions with NYCEDC and ORR, and feedback from City agencies, the Hamilton Avenue ROW alignment was selected as the preferred co for additional analysis.

	Criterion	19th St	Hamilton Ave bulkhead	Hamilton Ave right-of-way
Cost	Total cost	yellow	green	green
	Ability to leverage other investments	yellow	green	green
	O&M costs	red	red	yellow
Benefit	Protects jobs	green	yellow	yellow
	Protects homes	green	green	green
	Utilizes green infrastructure	gray	gray	gray
	Minimizes impact on public safety	yellow	yellow	red
Reliability	Extent of in-place vs deployable barriers	yellow	green	red
	Number of responsible parties	red	red	green
Implementation	Complexity of legal/planning approvals	red	red	green
	Disrupts access for residents & businesses	red	yellow	green
	Maintains view corridors	gray	gray	gray
	Maintains waterfront access	gray	gray	gray
	Improves neighborhood connections	yellow	yellow	yellow
	Reliance on third-party commitments	gray	gray	gray
	Potential tie-in to Red Hook IFPS	green	green	green

Alternate Concept Option (*for comparative purposes*) — 19th St

Preferred Concept Option — Hamilton Ave right-of-way

FIGURE 8-17
Summary of Part II Comparative Screening for Gowanus Canal Concept Options

Should a potential Gowanus Canal storm surge barrier system project advance beyond this conceptual study, a whole host of investigations and due diligence, ranging from utility and geotechnical surveys to environmental site investigations, would be required. There are also a number of topics that require interagency coordination or decisions that would also need further investigation and discussion. These include the following:

- The potential for integration with existing infrastructure. For example, the Hamilton Avenue retaining wall could offer an opportunity to leverage other public investment, and reduce the need to erect new infrastructure. Based on preliminary information from NYSDOT, the retaining wall on Hamilton Avenue by 17th Street could be integrated, provided that reinforcement and waterproofing were performed. Future coordination with NYSDOT will be required should this opportunity advance.
- Easements or land acquisition to support access and operations are likely to be required. For the Hamilton Avenue alignment, the two most critical sites are those adjacent to the east and west of the Hamilton Avenue Bridge. For the bulkhead alignment concept options where a floodwall or gate runs across a driveway or waterfront, easements would be required onto private parcels to ensure 24-hour access to operable gates and for maintenance activities. In places where defense systems run across private property, there are typically two gates, with the public agency operator having its own key and point of entry.
- The preferred level of protection for the NYCDOT asphalt plant and the DSNY Marine Transfer Station ultimately needs to be decided. There are variations of the concept options that could afford differing levels of protection and access. Maintaining the line of defense along Hamilton Avenue and ensuring site access via operable gates would be the most efficient from a cost and engineering perspective, if leaving either site outside the line of defense is a tolerable approach. Altering the line of defense to protect these sites would add to the overall design complexity and costs in order to minimize impact to the busy operations across active berths and the additional length of upland defense running along bulkhead conditions.
- Storage of demountable components is a consideration for any upland defense alignment that incorporates them. There might be space within the NYCDOT asphalt plant or the DSNY MTS that could accommodate storage of posts, panels, and other equipment. Alternatively, as noted above, the City might consider acquiring nearby property for storage and operations and maintenance activities.
- While of lesser relevance to the Hamilton Avenue ROW alignment than to the 19th Street or Hamilton Avenue bulkhead concept options, coordination with U.S. Environmental Protection Agency (USEPA), New York City Department of Environmental Protection (NYCDEP) and other parties involved with the Gowanus Canal Superfund remediation work should take place. For the Hamilton Avenue ROW alignment, the topic of focus is ensuring that the bulkhead improvements are designed to accommodate the in-water storm surge barrier. For the alternative concept options, the in-water barrier interface is still important, but the topic of focus expands to the ability to leverage ongoing USEPA bulkhead replacement efforts more broadly. As part of Superfund remediation work at Gowanus, property owners will be replacing or repairing their bulkheads. It is understood that the height of the improved bulkheads will remain the same as the current elevation. To the degree that coordination with USEPA and the planned remediation efforts could happen sooner than later, there might be opportunities to design and construct the bulkhead improvement such that they could more easily accommodate floodwalls or in-water barriers rather than having to undergo costly retrofits and reinforcement or rebuild efforts at a later date.
- The ultimate configuration of a Red Hook alignment, which would be constructed prior to any Gowanus Solution, will dictate where tie-ins between the two flood defense systems are ultimately placed. Early coordination efforts during the planning stages for the Red Hook IFPS can help to ensure that future Gowanus connections are considered.

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Part III:
Project Analysis

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9 Hydrodynamic Modeling Assessment

9.1 Modeling Objectives

Hydrodynamic modeling and high-level flushing and rainfall analyses were conducted as part of the study in order to:

1. Provide data on flood depth and extent for the existing “no barrier” condition, defined as the “baseline” condition, for surge events of varying return period. The outputs were used in order to determine baseline damages in the preliminary benefit-cost analysis.
2. Provide data on flood depth and extent for the preferred barrier option in the closed position at each location for surge events of varying return period. The outputs were used determine damages for each of the options and hence damages avoided, by comparison with baseline conditions in the preliminary benefit-cost analysis.
3. Undertake an assessment of the impact of the barrier on tidal exchange via flushing modeling by assessing changes in the residence time with and without the barrier in place.
4. Assess the likely impact of rainfall/surface water flooding on the land side of a closed barrier by performing a volume comparison that considers landside storm runoff for a range of rainfall events.

The avoided damages analysis was achieved via a combined regional surge modeling and local flood modeling approach interfaced at the project shoreline. In this way, the surge time series along the project shoreline were extracted from the regional surge model and fed to the local flood model that simulates surge propagation overland. The resulting flood depth and extent were used as inputs into the economic analysis model to determine the associated flood damages.

The flushing analyses were achieved using a local flow model nested within a sub-regional flow model and run coupled to an advection and diffusion (Transport) module while the rainfall/surface water analysis was addressed via a desktop assessment. Details of each of the approaches and graphic presentation of modeling results for all modeled scenarios are provided in Appendix F.

9.2 Modeling Scenarios

For the purpose of bracketing the likely cost variation of flood damages, surge/flood simulations for a range of return periods as summarized in **Table 9-1** were conducted. The various return period events were determined based on Federal Emergency Management Agency (FEMA)/New York City Panel on Climate Change (NPCC2) extreme water levels at the Battery. These water levels are compared with other sources in **Table 9-2**.

Since the NPCC2 study applied the same modeling methodology, storm and associated inputs of FEMA (2014) for the baseline set (without considering sea level rise), their results of return period-based extreme water levels (tide + surge + wave setup) are consistent with those of FEMA (2014) as shown in **Table 9-2**. These levels are higher than those given in United States Army Corps of Engineers’ North Atlantic Coast Comprehensive Study (NACCS) (2015).

For future extreme water level incorporating future sea level rise (SLR), the NPCC2 (2015) study conducted additional simulations using the 90th percentile SLR projections for 2020s, 2050s, and 2080s. The 90th percentile SLR scenario was considered a conservative approach in NPCC2.

For the present study, it is deemed appropriate to apply the 50 percent percentile SLR projection as a mid-range estimate to assess impacts of sea level change on project performance. This 50th percentile value is not provided in NPCC2 (2015) but has been linearly interpolated herein based on the published 10th (1.25 feet), 25th (1.83 feet), and 75th (4.17 feet) percentile values in NACCS (2015). The corresponding

50th percentile SLR value in 2100 is 3ft, which was adopted for use in conjunction with the 100-year return period extreme water level incorporating sea level rise.

For replicating the referenced flood exceedance levels at The Battery for the 1-year, 10-year, 100-year, and 500-year return periods for the existing condition, a scaling approach based on the Holland B parameter (generally varying between 0.5 and 2) in the parametric Holland model, which in terms determines the maximum wind speed in the Holland parametric model, was used. The simulation with the “correct” Holland B parameter value that results in the closest match with the referenced flood exceedance levels at the Battery was adopted and the same model setup used to conduct the barrier option runs.

For the SLR run, the selected SLR (3 feet in this case) was applied as a uniform uplift of the present-day offshore water level boundary conditions for the 100-year return period run.

In the ensuing model runs, the 1-year return period event was replaced by the 1.5-year return period to represent the damage initiating event as needed for the economic analysis of the flood damage.

Two barrier options were investigated for the Gowanus Canal Site. These are presented as the Barrier I and Barrier II options as shown in **Figure 9-1**. For the Gowanus Canal (Canal) study site, the Hamilton Avenue ROW concept option was identified as the most promising concept option based on screening, discussion with NYCEDC and feedback from City agencies. The 19th Street concept option was also modeled, for purposes of completion and comparison.

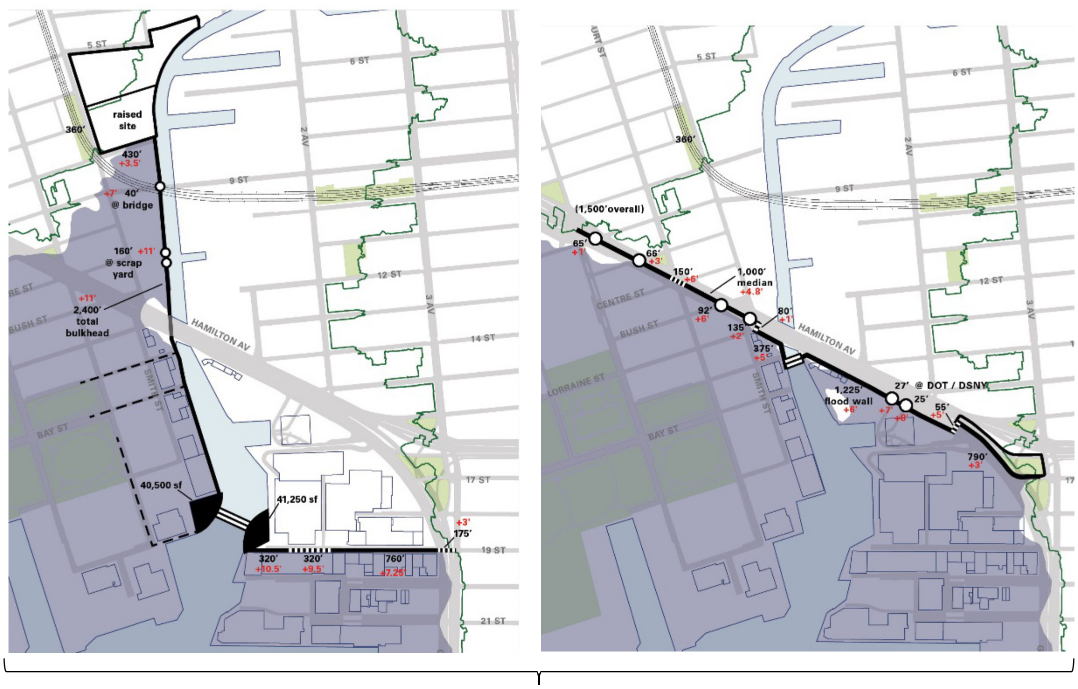

FIGURE 9-1
Barrier options, Gowanus Canal: Left: 19th Street Alignment (Barrier II); Right: Hamilton Avenue Alignment (Barrier I)

TABLE 9-1
Summary of Modelling Scenario Mix

Modeling Task	Condition	Purpose	Return period (year)	SLR Scenario for surge modeling
Surge/Flood modeling	Baseline – present day condition – no barrier	To provide data on flood depth and extent for use as input to the economic analysis model to determine baseline damages	1	No
			10	No
			100	No
			500	No
			100	Estimated 50th percentile, NPCC2 (2015), target year = 2100
	Barrier closed	1) With Flood model: to provide data on flood depth and extent maps for use as inputs into the economic analysis model based on flooding-dependent damage functions; and to determine damages for each of the options and hence damages avoided by comparison with baseline conditions.	1	No
			10	No
			100	No
			500	No
		2) For surge modeling: to assess the impact of the barrier on hydrodynamics outside/downstream.	100	Estimated 50th percentile, NPCC2 (2015), target year = 2100
Local flow/ Flushing modeling	Baseline – present day condition – no barrier	To assess impact on water quality based on mechanical water exchange	Spring neap tidal cycle, operational condition	No
	Barrier open – normal conditions		Spring neap tidal cycle, operational condition	No
	Barrier open – stormwater volume stored behind barrier after surge event		Spring neap tidal cycle, operational condition	No

TABLE 9-2
Comparison of Extreme Water Levels, The Battery (feet North American Vertical Datum of 1988 [NAVD88])

RP (year)	FEMA (2014)	NACCS (2015)		NPCC2 (2015)
	Gowanus	Mean	90% CL	
10	6.9	6.2	6.6	6.9
100	11.2	7.9	9.5	11.2
500	14.8	9.8	12.8	14.4

Note:
FEMA levels are stillwater elevations that account for tides, surge, and wave setup while NACCS (2015) and NPCC2 (2015) values are model outputs from coupled hydrodynamic-wave modelling and thus account for tides, surge, and wave setup as well.)

9.2.1 Flood Model

9.2.1.1 Flood Model Overview

The interface between the surge and the flood model occurs at the shoreline. The extent of the surge model is such that it includes an overlapping land area abutting the shoreline wherein the land topography is resolved schematically to minimize surge elevation rising vertically at the shoreline if it were represented as the land-water interface. The flow outputs at the shoreline were extracted from the surge model and fed into the flood model as boundary conditions. Flood Modeling was performed using Flood Modeller Suite.

9.2.1.2 Surge Inputs

Point locations for surge time series data were extracted from the Surge model and used as input locations for the Flood model. The time/stage storm surge data series associated with each surge data point location (See **Figure 9-2**) was applied to a polyline input boundary matching the adjacent shoreline and spread inland using the polyline as a boundary condition. A typical surge boundary time series is shown in **Figure 9-3**.

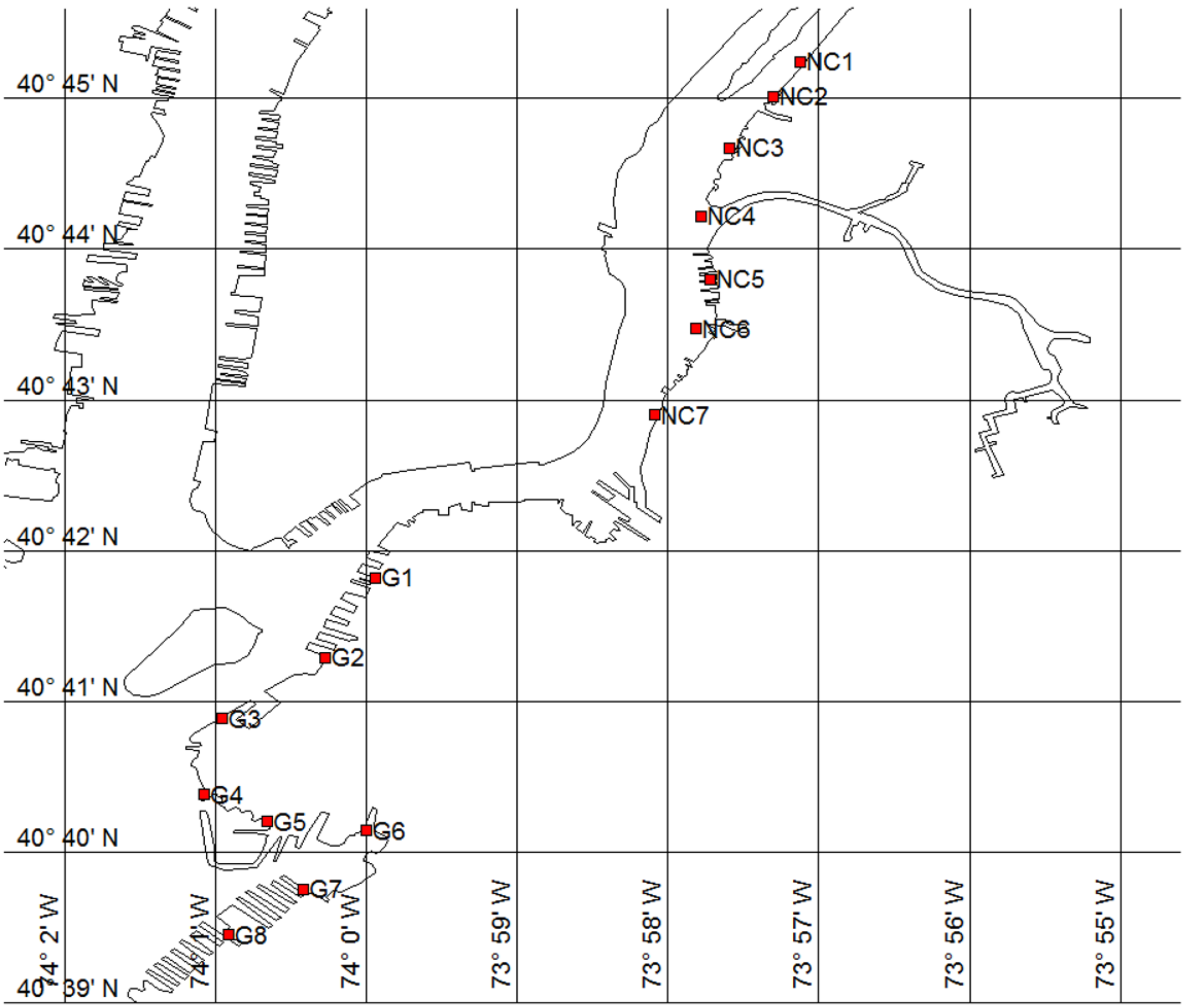

FIGURE 9-2
Gowanus Canal Surge Input Locations-Baseline Conditions (G series)

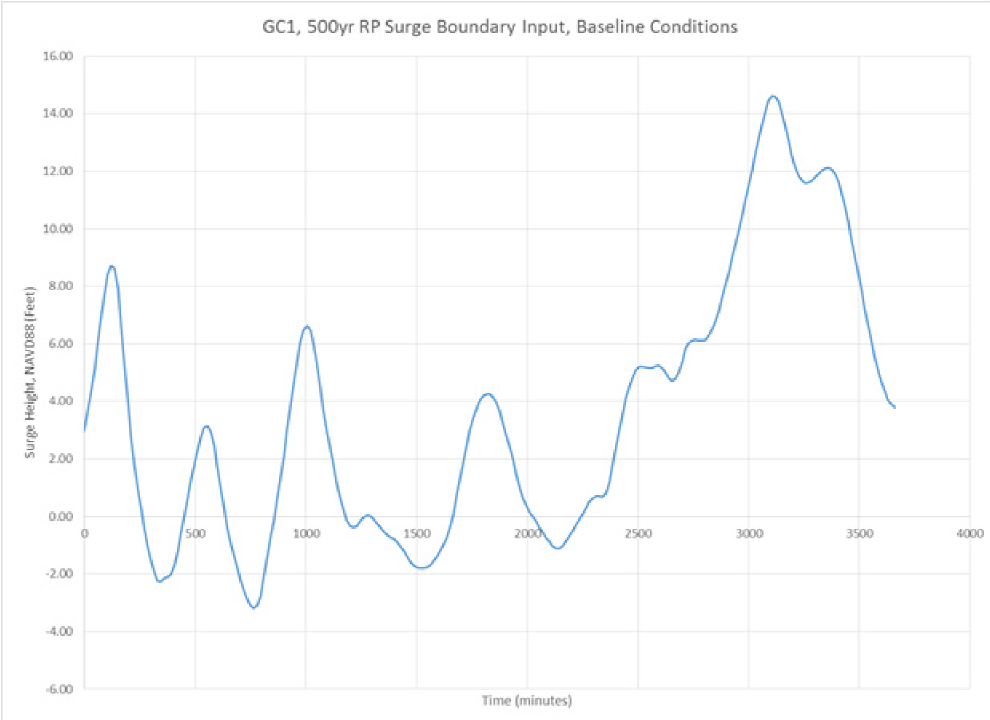

FIGURE 9-3
Typical surge boundary input as a time series plot, Gowanus Canal

9.2.1.3 Topography

A three-foot bare earth Digital Elevation Model (DEM) of New York City was used as the topographic basis for the flood modeling. This DEM was produced November 2011 from 2010 NYC LiDAR data to support the production of updated hurricane surge (SLOSH) inundation area and depth data for Office of Emergency Management (OEM) and New York State Office of Emergency Management (NYSOEM). The data is in feet, referenced to NAVD88. The clipped DEM used for the baseline simulation is shown in **Figure 9-4**.

NYC Department of Information Technology provided the source 2010 LiDAR (.las) tiled data which was collected April 14 to May 1, 2010, by Sanborn and reviewed for quality assurance and control by the Center for Advanced Research of Spatial Information lab at City University of New York Hunter College. Accuracy of the source LiDAR data is 9.24 cm RMSE vertical accuracy, 33 cm horizontal accuracy, and 8-12 points per square meter point density.

USACE' Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire, produced this data at the request of the USACE New England District to meet the hurricane SLOSH data production schedule. Only class 2 (bare earth) points from the source .las tiles were used for production. No additional quality assurance or control was performed on the final DEM other than that already performed on the source.

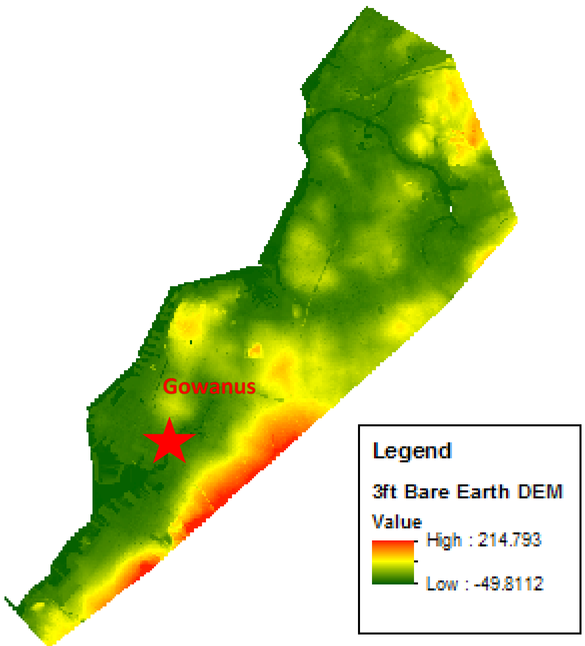

FIGURE 9-4
Bare earth DEM

The DEM contained elevations for the bridge deck for the Gowanus Expressway/I-278 Bridge that reflected the bridge deck, not the channel beneath, which required a patch over the waterway to override the bridge deck elevations with an elevation reflecting the channel. Other minor DEM modifications were made to reflect "holes" in the DEM with very low elevations. These are likely a reflection of the filtering technique used on the DEM, shadows in the aerial photography used for DEM development, or active construction sites at the time of photography that resulted in low elevations.

A computational grid of 10 feet by 10 feet, based on the original 3-foot bare earth grid, was used in the software for all flood model simulations.

9.2.1.4 Model Parameters

All Gowanus Canal FAST simulations used similar base model parameters. The baseline models were constructed using a 10-foot computational grid with a global starting water elevation set at the average elevation of the initial surge height in the time series input files. The default FAST Advanced Parameters were used, and the baseline simulations were individually run for durations sufficient to simulate the entire surge time series for each scenario. Simulations were run for baseline conditions (without barriers) and with the Barrier 1 and Barrier 2 configurations.

9.2.1.5 Model Validation

Surge inputs from Hurricane Sandy were input into the FAST model and the results compared against the FEMA Modeling Task Force (MOTF) Hurricane Sandy Impact Analysis field-verified MOTF Sandy Inundation extent. The comparison, **Figure 9-5**, shows that the FAST-simulated depth grid closely matches the recorded Hurricane Sandy inundation extents.

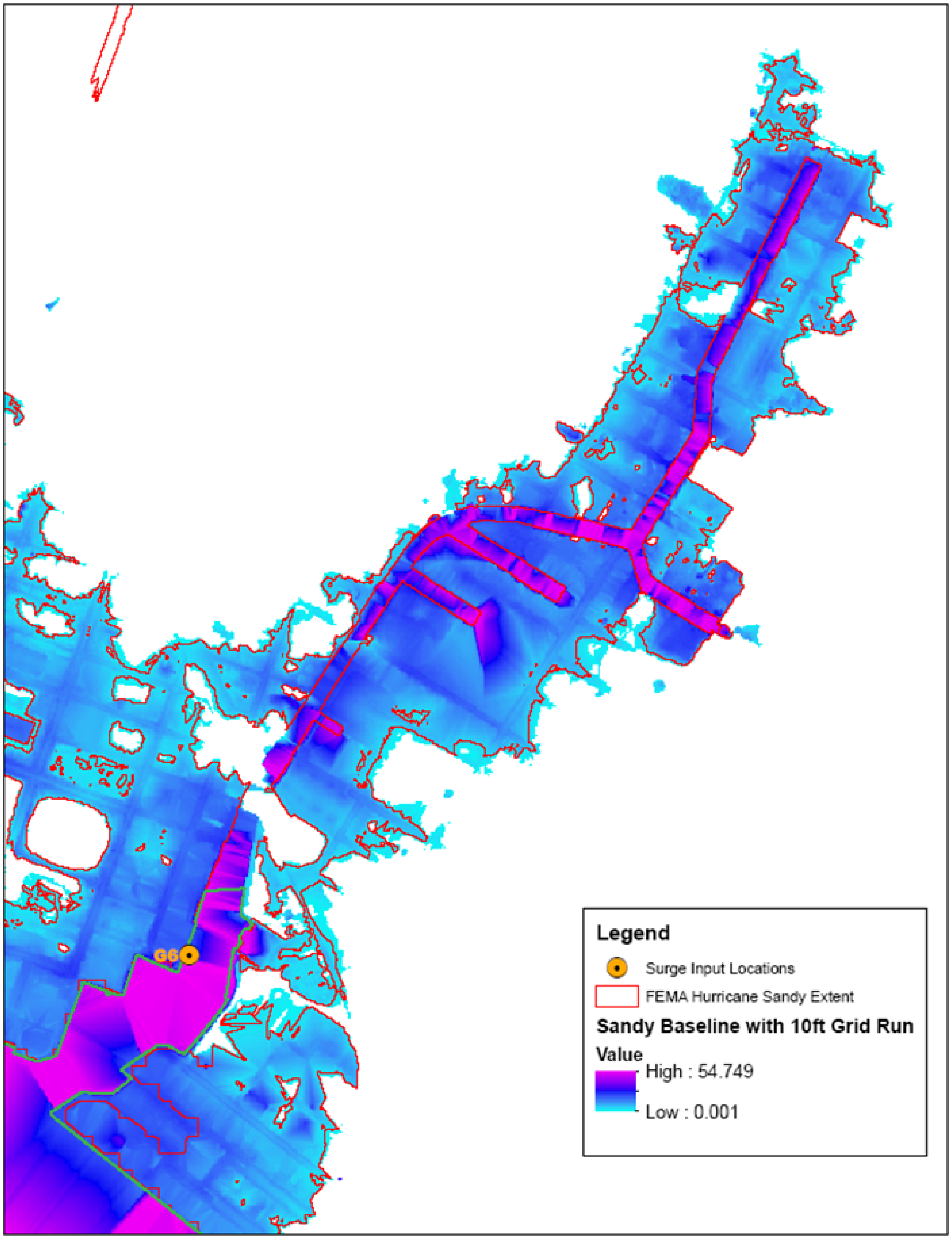

FIGURE 9-5
Comparison of the flood extent between Gowanus Canal Hurricane Sandy FAST simulation and FEMA inundation boundary

9.2.2 Flushing Model

9.2.2.1 Flushing Model Overview

As outlined in Section 3.1, the local flow model was driven by the boundary conditions provided by the sub-regional model as shown in **Figure 9-6**. The local flow model was then coupled to the Transport model (advection and diffusion module) to compute the time for full exchange of the water within the water body under normal tidal conditions, i.e., over a typical 2-week spring/neap cycle, termed the "flushing/residence time" of the water body.

During the simulations, the water body behind/upstream of the canal mouth/barrier locations was assigned an initial unit tracer concentration. Combined sewer overflows (CSO) discharges were included as point sources with time varying flows with an assigned constant unit tracer concentration. The residual level of the tracer concentration in the defined water boundary was tracked through time. This was assessed for both the baseline "no barrier" case and with the barrier in place (open) case to assess the impact of the barrier on the flushing time due to any flow restriction.

In addition, the local flow model was applied to the condition when the barrier was open immediately after the passage of a surge event to investigate the flushing of the ponded water behind the barrier accumulated over the barrier closure period.

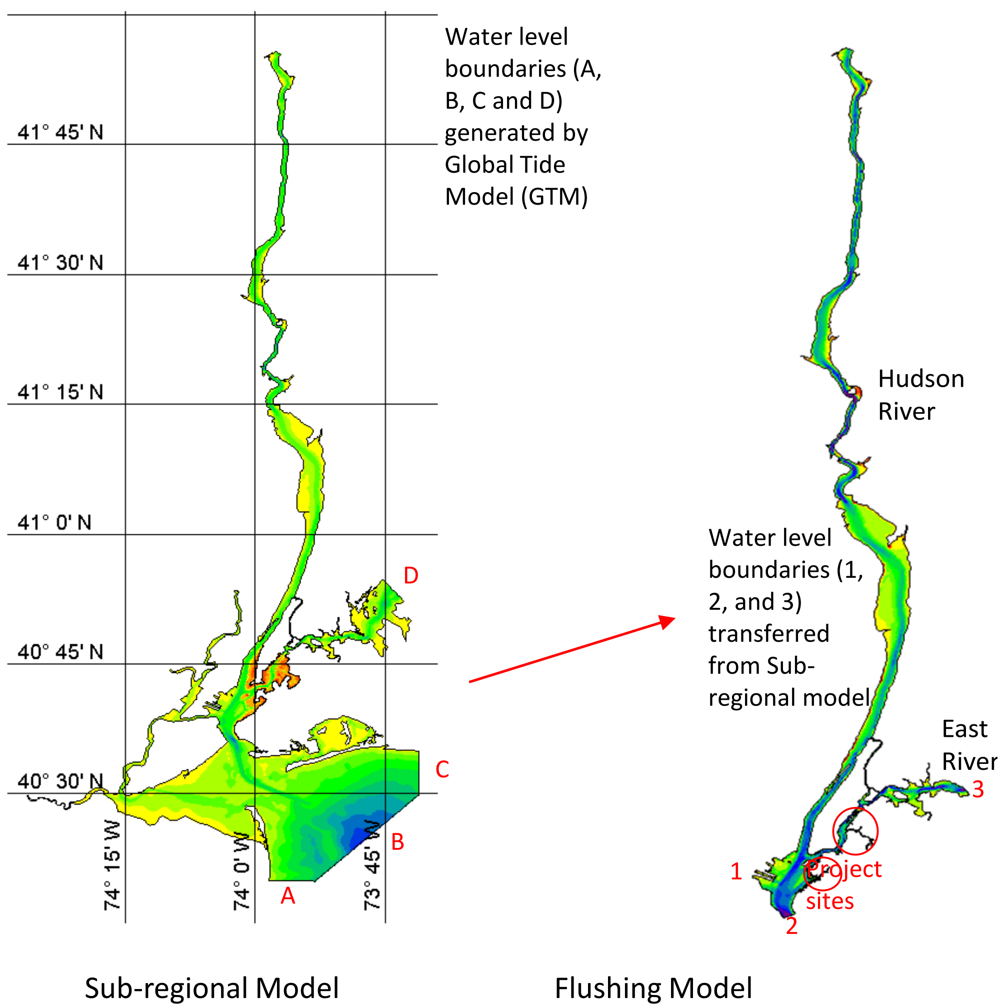

FIGURE 9-6
Boundary Transfer Protocol, Flushing Modeling

9.3 Modeling Outputs

9.3.1 Flood Modeling

Appendix F contains figures showing the flood model results for all the baseline conditions and each of the two barrier scenarios. **Figure 9-7** compares the flood extents for the 500-year event between the baseline condition and Barrier 1 (Hamilton Avenue ROW alignment) option.

In addition, overlay maps of the flood extent between the baseline and each of the barrier options are also contained in Appendix F. Both the barrier options provide an effective level of protection through the 500-year event as illustrated in **Figure 9-8** for the highest surge event of 500-year return period for Barrier Option I (Hamilton Avenue ROW).

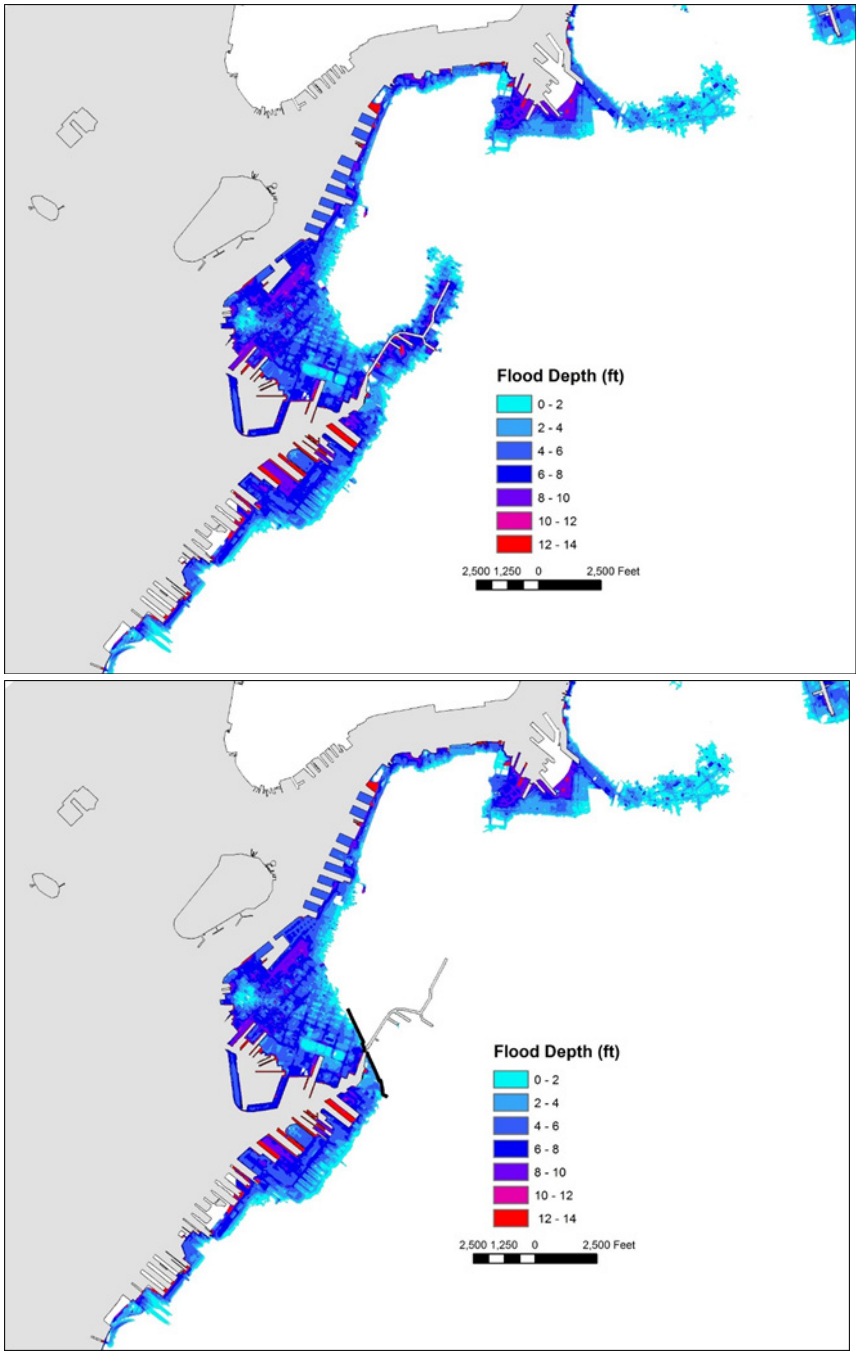

FIGURE 9-7
Comparison of flood extent, 500-year event: Top: baseline condition; Bottom: barrier option I (Hamilton Avenue ROW Alignment)

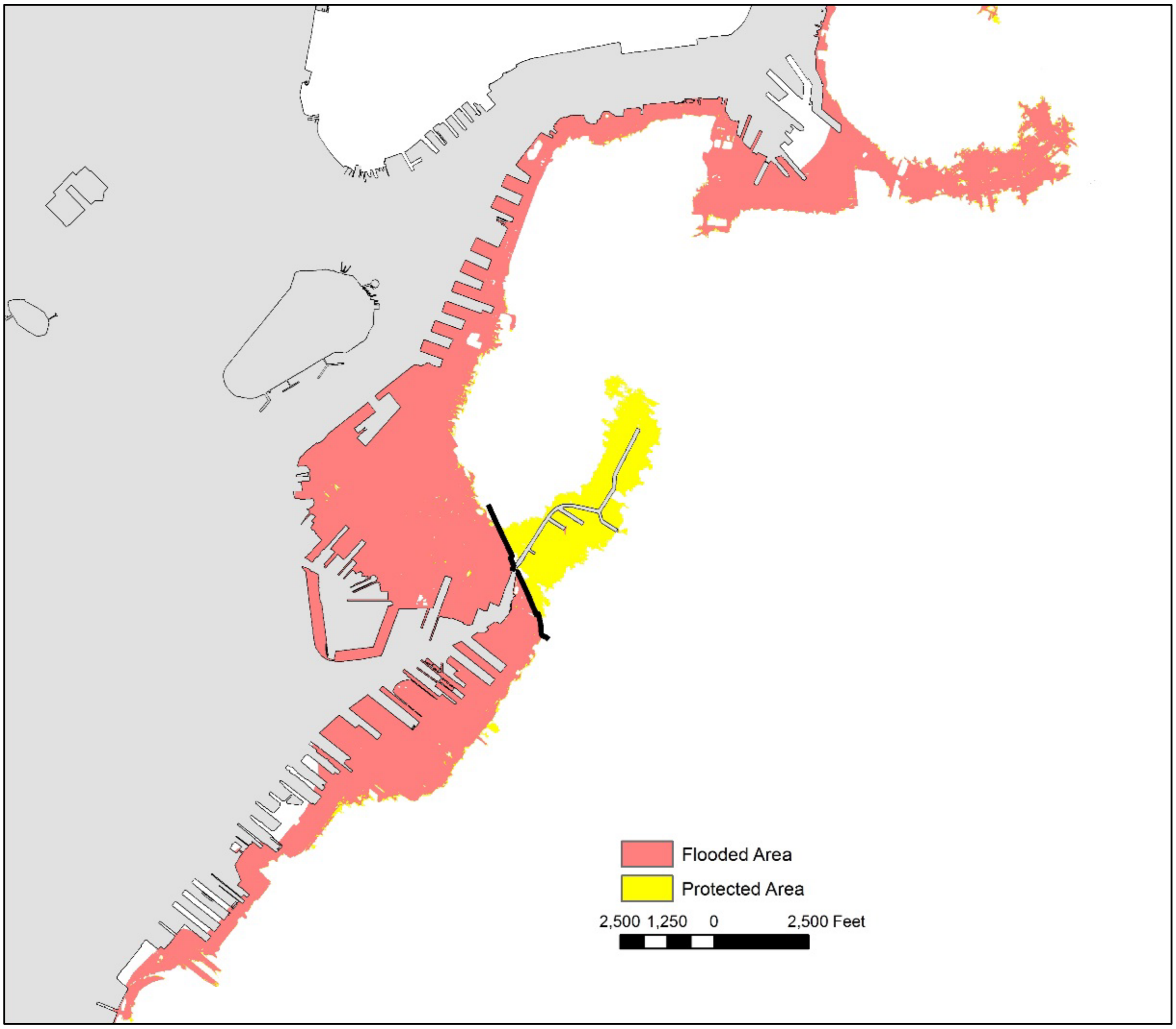

FIGURE 9-8
Protection Zone based on overlay of flood extents between the baseline condition and barrier option I (Hamilton Avenue Alignment)

9.3.2 Flushing Model

The results of the flushing model are presented in the form of flushing curves shown in **Figure 9-9**. For these runs, the barriers remain open throughout the 15-day simulation period. The green horizontal line denotes the e-folding time, which defined as the time required for the initial tracer concentration to reduce to a fraction of 1/e where e is the base of the natural logarithm (=2.7183). The light brown line denotes the 4-day time limit within which the residual tracer concentration level reaches 1/e of its initial level considered as good flushing.

It is seen that the barrier options do not affect the e-folding time adversely relative to the respective baseline conditions (same initial concentration areas).

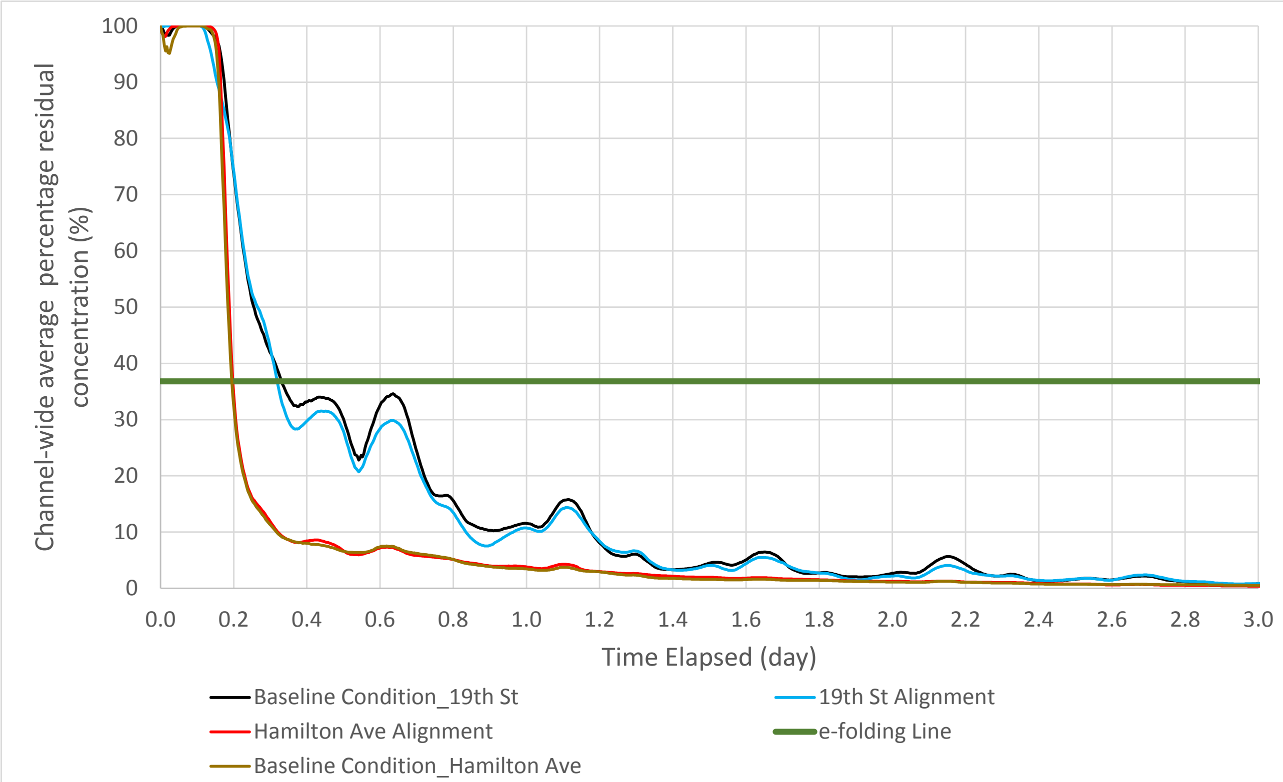

FIGURE 9-9
Comparison of Flushing Curves for Gowanus Canal

An additional set of runs were conducted whereby the barriers are open after the passage of the surge event during which time the water level behind the barriers has risen due to rainfall runoff. For these runs, a 4-foot rise in the channel water level was assumed and the barrier gate opens over a span of 8 minutes.

The results are again presented in the form of flushing curves as shown in **Figure 9-10**, which indicates that the drawdown is rapid for both options due to the initial flow momentum associated with barrier opening.

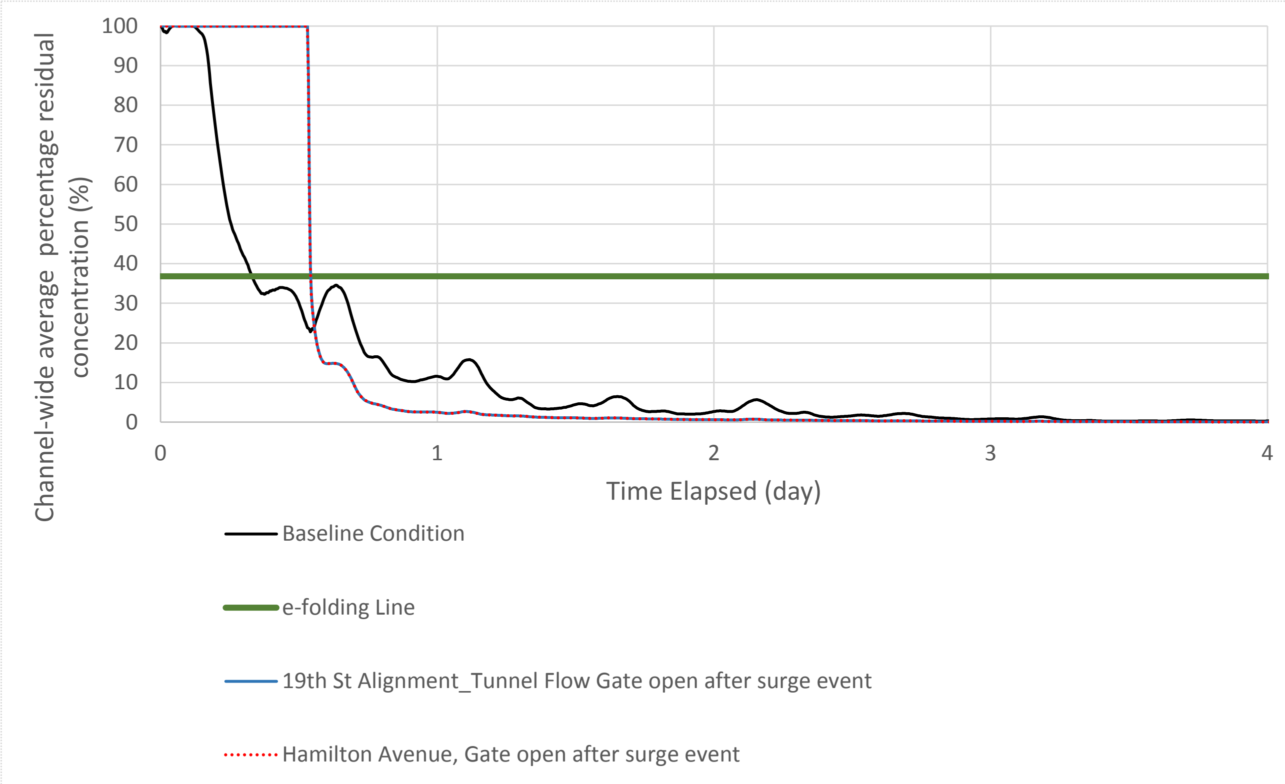

FIGURE 9-10
Drawdown of tracer concentration when barrier is open after the passage of surge event, Gowanus Canal

In summary, the introduction of in-water barriers at Gowanus Canal does not appear to cause a noticeable change in the e-folding time, which is already considered good due to the flow contribution from the flushing tunnel. Future analysis based on more refined studies may be required to confirm the above flushing assessment. For the case of barrier opening after the passage of a surge event, the modeled results indicate that the accumulation of rainfall runoff behind the barriers leads to a rapid drawdown of the accumulated tracer concentration as a result of the initial flow momentum associated with barrier opening.

The flushing study has qualitatively assessed potential impacts to the flushing capacity of Gowanus Canal. Detailed water quality modeling is recommended to be done as part of a future feasibility study both to appropriately size the in-water gate width and to analyze impacts to salinity, oxygen levels and pollutant loads.

9.4 Rainfall Impact Assessment

9.4.1 Overview

Landside rainfall impact analysis was performed to assess the potential for flooding problems behind the barrier when an event with a high storm surge (requiring the flood barrier to be closed for an estimated 12-hour period) is coupled with intense rainfall. For this high-level simplified analysis, a simple approach is taken by comparing the volume of rainfall discharged to each waterbody to the volume of storage available in each waterbody assuming different freeboards. The volume of rainfall is also reduced assuming that a portion of it is redirected to the respective water pollution control plants (WPCP). The approach is detailed and the results presented in the following sections.

9.4.2 Rainfall Volumes

In this analysis, direct rainfall runoff with 100 percent runoff and no infiltration was used to conservatively calculate the volume of rainfall being discharged to Newtown Creek from its tributary area.

Four return periods (RP) for rainfall intensity were considered based on the storm surge events analyzed in the numerical modelling study. These include 1-year, 10-year, 50-year, and 100-year. The rainfall intensity was determined using Technical Paper No. 40, Rainfall Frequency Atlas of the United States, May 1961 as summarized in **Table 9-3**. The 1-hour, 1-year storm event is similar in volume to the observed landside rainfall during Hurricane Sandy. Hurricane Irene was also analyzed with 7-inches of rainfall. Including the Hurricane Irene analysis, a total of 9 scenarios were considered.

TABLE 9-3
Rainfall Intensity in NYC

Rainfall Event (RP – year)	**Rainfall (Inches)**	
	1 Hour Storm Duration	**6 Hour Storm Duration**
1	1.2	2.0
10	2.2	3.6
50	2.8	4.5
100	3.0	5.5

The tributary areas summarized by NYC Department of Environmental Protection (NYCDEP) (2008 and 2011) equal 1,758 acres for the Gowanus Canal area. This areas include those serviced by CSOs, stormwater sewers, and areas of direct overland flow to the canals.

The rainfall was conservatively converted to runoff volume by directly and uniformly applying the rainfall to the tributary areas (rainfall x area). Rainfall volumes are summarized in **Table 9-4** for the Gowanus Canal watershed.

TABLE 9-4
Rainfall volumes for Gowanus Canal Watershed

Rainfall Event (RP – year)	**Volume (MG)**	
	Gowanus Canal	
	1 hour duration	**6 hour duration**
1	57	95
10	105	172
50	134	215
100	143	263

The seven inches of rainfall that relate to Hurricane Irene produce 334 MG at Gowanus Canal.

9.4.3 Resulting Rainfall Considering Losses to WPCP

An assumption was made for this analysis that the water pollution control plants (WPCP) would be operating at full capacity for a period of 12 hours with no power failure. This volume would reduce the total rainfall volume listed in **Table 9-4**. State Pollutant Discharge Elimination (SPDES) capacities for each WPCP are given by NYCDEP (2008 and 2011). Owls Head WPCP and Red Hook WPCP service portions of the Gowanus Canal watershed. The capacity considered for each WPCP was the SPDES capacity minus the dry weather flow.

Each WPCP covers multiple watersheds. Therefore, it was necessary to assume that only a portion of total water directed to each WPCP would be from Gowanus Canal watershed. It was assumed that this was proportional to the percentage of flow that is normally discharged into each waterbody from the WPCPs.

The total volumes handled by each facility and the proportion coming from each watershed based on the above assumption are summarized In **Table 9-5**.

TABLE 9-5
Volumes redirected to each WPCP

WPCP	SPDES Capacity (MGD)	Dry Weather Flow (MGD) from 2007	Total Volume (MG) for 12 hours	Watershed	% From Watershed	Volume (MG) from watershed
Red Hook	120	30	45	Gowanus Canal	43.1%	19
Owls Head	250	86	82	Gowanus Canal	3.5%	3

Notes:
MGD = million gallons per day

In summary, a total of 22 MG of rainfall would be redirected from the Gowanus Canal watershed.

Considering these losses the total volume of rainwater directed to each waterbody for the various cases considered are shown in **Table 9-6**. The 1-year, 1-hour storm event total represents the total rainfall similar to the rainfall volume that fell during Hurricane Sandy. A 7-inch total rainfall, similar to the rainfall volume produced by Hurricane Irene, produces 312 MG of net runoff volume at Gowanus Canal.

TABLE 9-6
Rainfall volumes discharged into Gowanus Canal

Rainfall Event (RP – year)	Volume (MG)	
	Gowanus Canal	
	1 Hour	6 Hour
1	35	73
10	83	150
50	111	193
100	121	240

9.4.4 Available Storage in Waterbodies

The volume of available storage in Gowanus Canal was calculated based on the surface area of the waterbodies. Assuming various freeboards the available storage is summarized in **Table 9-7**.

TABLE 9-7
Available Storage

Freeboard (feet)	Storage Volume (MG)
	Gowanus Canal
1	7
2	14
3	22
4	29

Figure 9-11 depicts the rainfall volumes (summarized in **Table 9-6**) compared to the storage volume at the four freeboards (summarized in **Table 9-7**) for Gowanus Canal. In these figures, the black horizontal lines represent available storage volume in the waterbody assuming different freeboards. The colored lines

represent the net rainfall volume discharging into Gowanus Canal behind the surge barrier for different recurrence intervals at different storm durations.

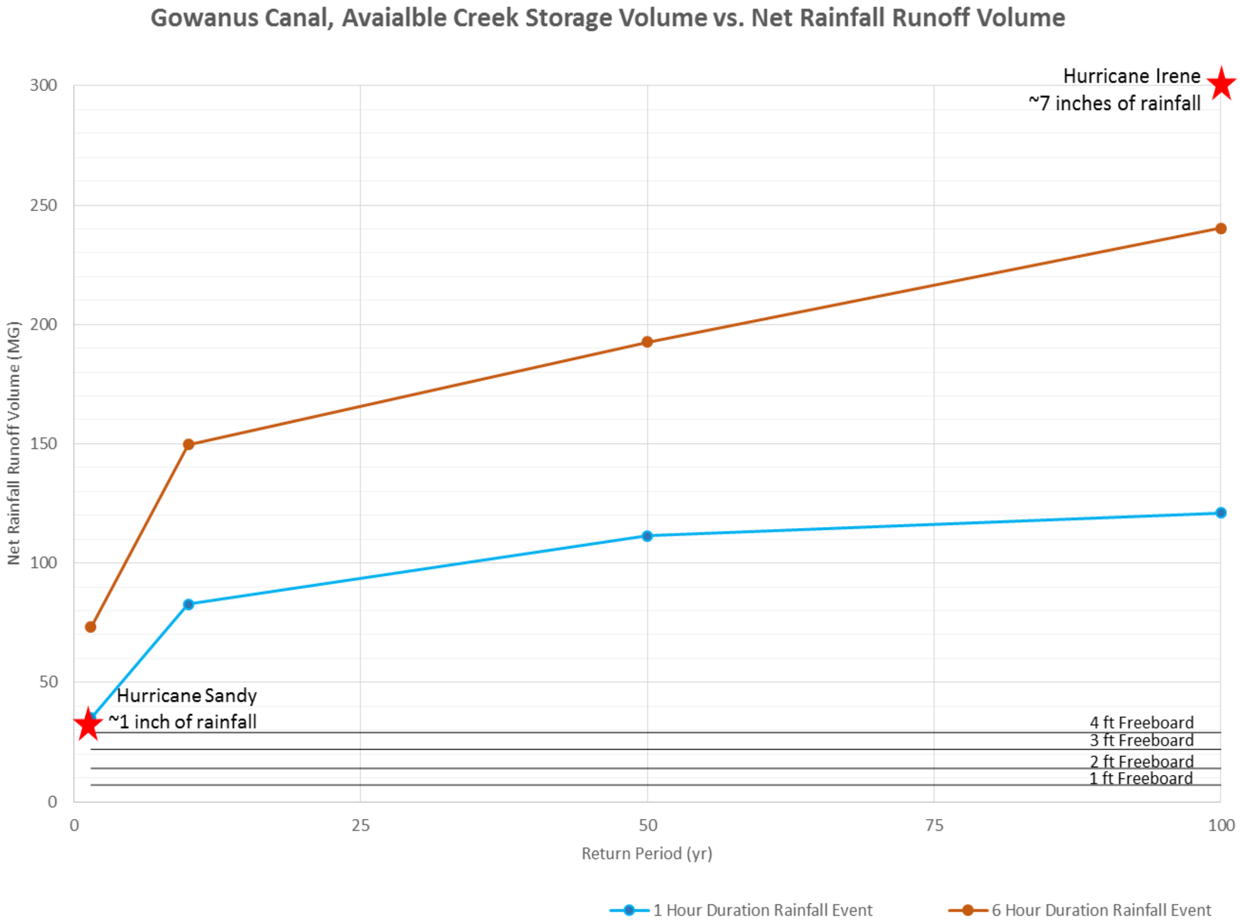

FIGURE 9-11
Gowanus Canal Rainfall Volume for Various Return Periods Compared to Available Storage

9.4.5 Conclusions

From the comparison in the above section, this simplified analysis shows that Hurricane Sandy's landside rainfall would likely not have caused flooding behind a closed barrier. Hurricane Irene, however, would likely have caused flooding. Longer and larger storms cannot likely be contained within the Canal. In this simplified analysis, storms larger than the 1-hour, 1-year event rainfall volume were not contained within the canal system.

It is recommended that any future studies should analyze potential rainfall impact behind the barrier in more detail to better define the flood risk behind a closed flood barrier and potential need for pumping stations at the barrier locations. Planned CSO and drainage improvements, some of which are understood to be planned as part of Superfund remediation works, as well as other LTCP improvements, would be anticipated to be accounted for in a detailed future study.

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10 Preliminary Benefit-Cost Analysis

10.1 National Economic Development (NED) Benefit-Cost Analysis

10.1.1 Overview and Approach

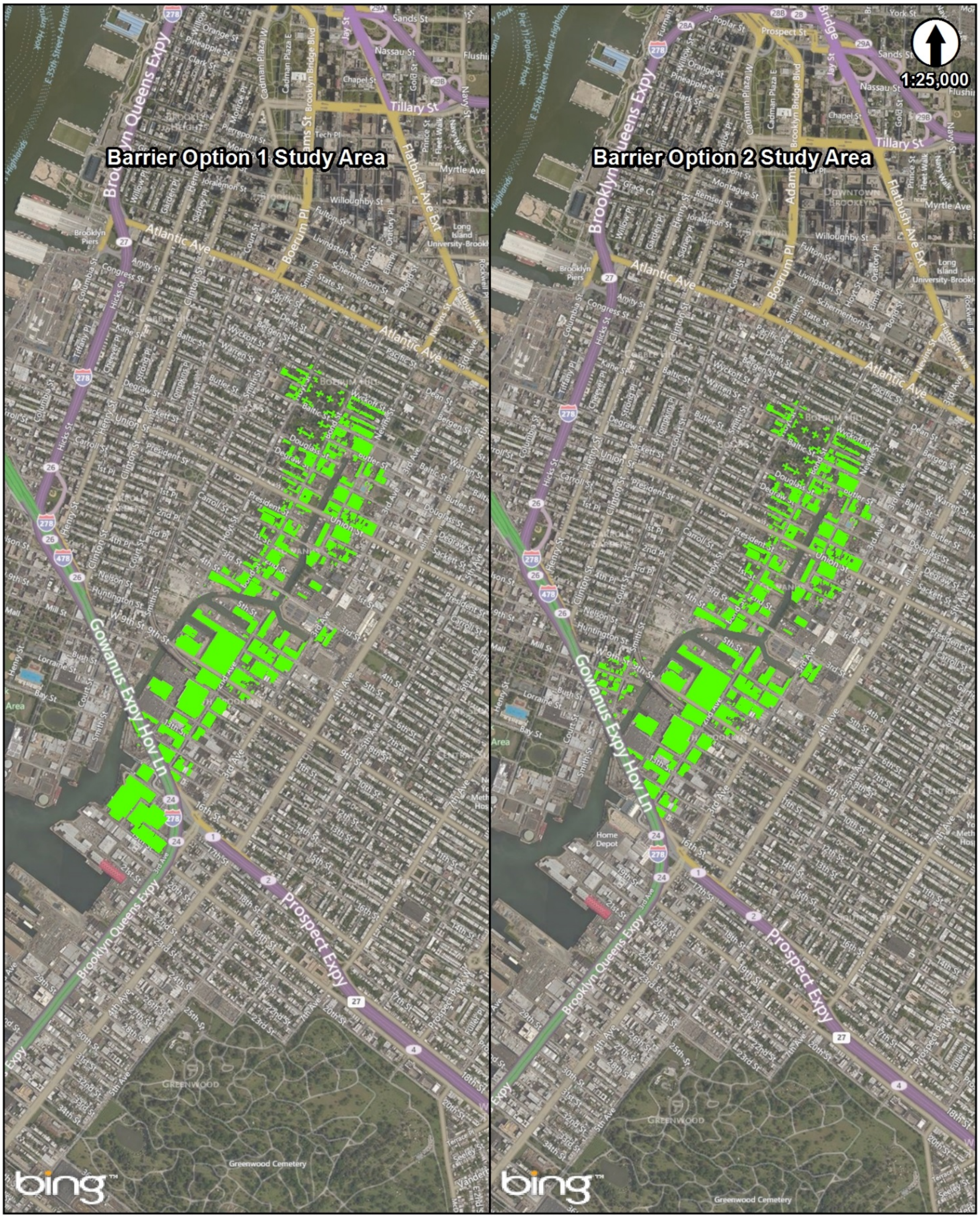
This section documents the economic analysis of flood risk to structures and building contents performed as part of the Gowanus Canal Storm Surge Barrier Study. The objectives of this effort were as follows:

- Estimate storm surge-related flood risk to structures and building contents and potential damages reduced by implementation of storm surge barrier conceptual design options in each study area.
- Estimate expected flood damages to structures and contents by methods generally consistent with United States Army Corps of Engineers (USACE) flood risk assessment guidelines albeit at a level of detail appropriate for a pre-feasibility study.
- Calculate the net benefits and benefit to cost ratios associated with alternative concept design options as modeled.
- Provide data on potential costs and benefits of options to facilitate informed decision making regarding advancement to more detailed study/design and potential for assistance through USACE programs.

10.1.1.1 Economic Flood Risk Study Area

The initial inventory area for each waterbody was defined based on the limits of the Federal Emergency Management Agency (FEMA) 2013 Preliminary Flood Insurance Rate Map's (Flood Insurance Rate Maps [FIRMs]) 500-year floodplain. However, the nature of the storm surge-induced flooding necessitated definition of the upstream and downstream limits of the study area along the East River. To determine these limits, the hydrodynamic modeling team was tasked with estimating the area that would be impacted by construction of any of the proposed protection projects, including both beneficial impacts to protected upland structures and any potential adverse impacts to structures waterward of the project.

Hydrodynamic modeling results for the baseline and with-barrier conditions identified that: 1) any of the modeled storm surge barrier concept options would provide protection from storm surge-induced flooding at all modeled storm events, effectively eliminating residual flood risk to structures protected by the barriers for the purposes of this preliminary analysis; and 2) no significant adverse effect on flood elevation to structures waterward of the barriers is expected. As such, the economic flood risk study area for this analysis was defined as the area encompassing those structures that would be protected by construction of each storm surge barrier option. **Figure 10-1** presents the Gowanus economic flood risk study areas in terms of structures that would be protected by the conceptual storm surge barrier options. At Gowanus Canal, the options differed in alignment, resulting in minor differences in the structures protected. The analysis at Gowanus Canal reflected these differences. The Gowanus economic flood risk study areas included 652 structures for Option 1 (19th Street concept option) and 700 structures for Option 2 (Hamilton Avenue right-of-way (ROW) concept option).



Left: Barrier Option 1, 19th Street concept option; right: Option 2, Hamilton Avenue ROW conception option.

FIGURE 10-1

Gowanus Canal Economic Flood Risk Study Areas

10.1.1.2 Methodology

Damage estimates were calculated using Version 1.4 of the USACE-certified Hydrologic Engineering Center Flood Damage Assessment model (HEC-FDA) (USACE, 2015). HEC-FDA integrates available hydrologic, hydraulic, geotechnical, and economic relationships to estimate flood risk in terms of expected annual damage (EAD). EAD is a measure of average annual impact, accounting for the risk of inundation across the full frequency curve, rather than for a single event.

Figure 10-2 illustrates the primary relationships that HEC-FDA uses in a typical application to generate estimates of EAD. As shown in the top left quadrant, hydraulic inputs are used to define the flow-exceedance relationship with uncertainty. The top right quadrant illustrates a rating curve that is defined by hydraulic modeling, and allows exceedance-flow and stage-flow to be related. As shown in the lower left quadrant, HEC-FDA combines hydraulic and economic inputs to define the stage-damage relationship. Finally, the lower right quadrant shows that these linked hydraulic and economic relationships allow computation of an exceedance-damage function. Integration of this function results in the EAD over the period of analysis.

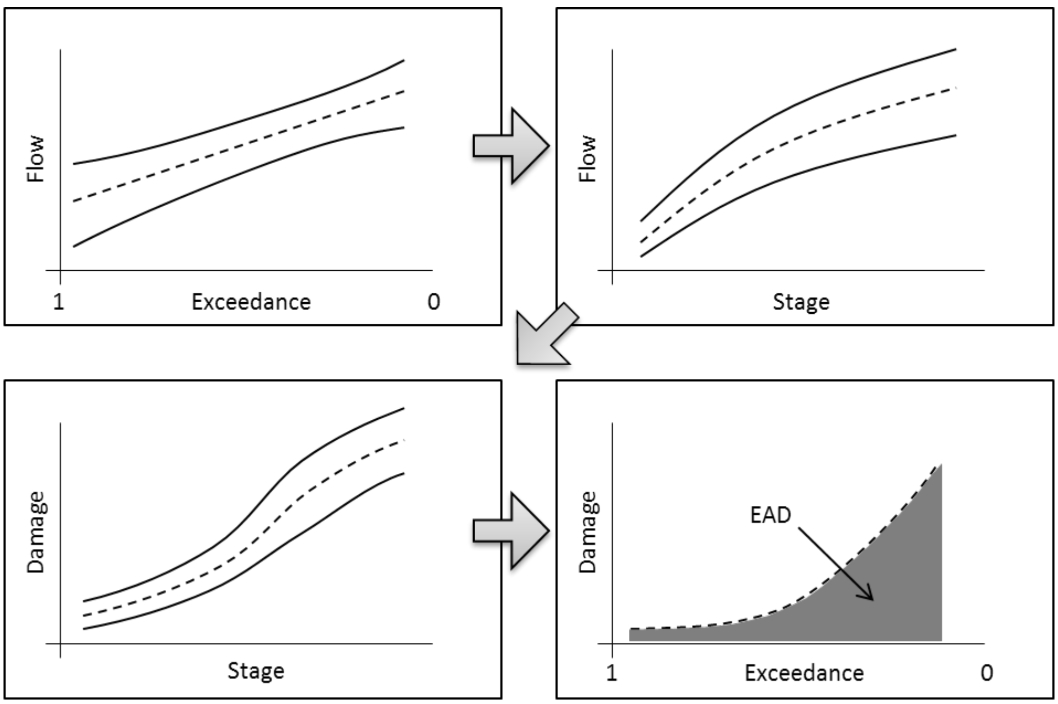


FIGURE 10-2
Summary of HEC-FDA Flood Risk Analysis Framework

As applied for this study, a separate HEC-FDA models was set up that corresponded to each of the economic flood risk study areas analyzed. Because the study area for each model was defined by the structures that would be completely protected by a project, estimated flood damages in the without-project condition (WOPC) were equivalent to the potential flood risk reduction benefits of project implementation. While simplified compared to a typical USACE feasibility study that would have a single study area and assess expected flood risk, flood risk reduction benefits, and residual damages in that defined area; this approach was considered appropriate to provide a preliminary assessment of flood risk in the study areas and to assess the potential for positive net benefits of a flood risk management option. The two HEC-FDA models for the Gowanus Canal are characterized as follows: the first reflecting Option 1 (19th Street concept option) protected structures, and the second reflecting Option 2 (Hamilton Avenue ROW concept option) protected structures.

The following subsections summarize the hydrodynamic and economic input parameters to the HEC-FDA flood risk modeling methodology as applied for this study.

10.1.1.3 Hydrodynamic Data

The hydrodynamic modeling team developed a WOPC inundation model using a two-dimensional inundation model that generated a set of floodplain depth grids for five modeled return-period events (the 1.5-, 10-, 50-, 100-, and 500-year events). Using a geographic information system (GIS), the average depth of flooding within the footprint of each structure was calculated for each return-period event. The HEC-FDA model relies on the inundation modeling results and user-specification of the uncertainty in the relationships between frequency and stage, as described below.

HEC-FDA requires input of depth-grid profiles for eight return period flood events. Typically, the eight events include the 2-, 5-, 10-, 25-, 50-, 100-, 250, and 500-year events. As noted above, the hydrodynamic modeling team provided results for five events, substituting the 1.5-year event for the 2-year event. The remaining three events (5-, 25-, and 250-year) were interpolated linearly. By using linear interpolation, the geographic extent of flooding does not change from the more-frequent to the less-frequent event; only the depth of flooding at each structure changes.

During development of an HEC-FDA model, “reaches” must be defined. A reach is an area in the floodplain whose structures experience similar flood characteristics or are similarly affected by the proposed alternatives. Each reach is then assigned a common reference point along the channel (index location) for the purpose of aggregating and reporting damages with consistent geographic extent for both the without-project and with-project conditions. In order to limit model complexity, only the minimum number of reaches are defined. Because the alternatives were assumed to provide 100 percent protection to any structure upstream and there was minimal elevation grade change throughout either waterbody, only one reach was needed in HEC-FDA for each study area.

As noted above, HEC-FDA requires an index location be specified for each reach. An index location is a channel cross-section for which a frequency-stage relationship can be defined. HEC-FDA uses the index location to aggregate damages for the entire reach. The hydrodynamic modeling team provided frequency-stage information for a number of locations. Due to the relatively flat nature of the channel at Gowanus, the choice of index location made little difference in the computed results. At Gowanus, the index was set just downstream of the Gowanus Expressway overpass.

HEC-FDA allows for the inclusion of uncertainty in the relationship between recurrence interval and depth at the index location in terms of either discharge or stage. Because the hydrodynamic modeling team provided depth-grids for specific return period events, rather than for specific discharges, this function was defined in terms of stage at each of the eight specific recurrence interval events using HEC-FDA’s built-in order statistics tool. Because the exceedance-probability function was entered based on stage, no additional definition of the relationship between discharge and stage was required.

HEC-FDA computed confidence limit curves around the exceedance-stage relationship based upon the period of record at the Battery gage (93 years). For illustrative purposes, **Figure 10-3** shows an example exceedance-stage relationship with uncertainty for Newtown Creek’s WOPC.

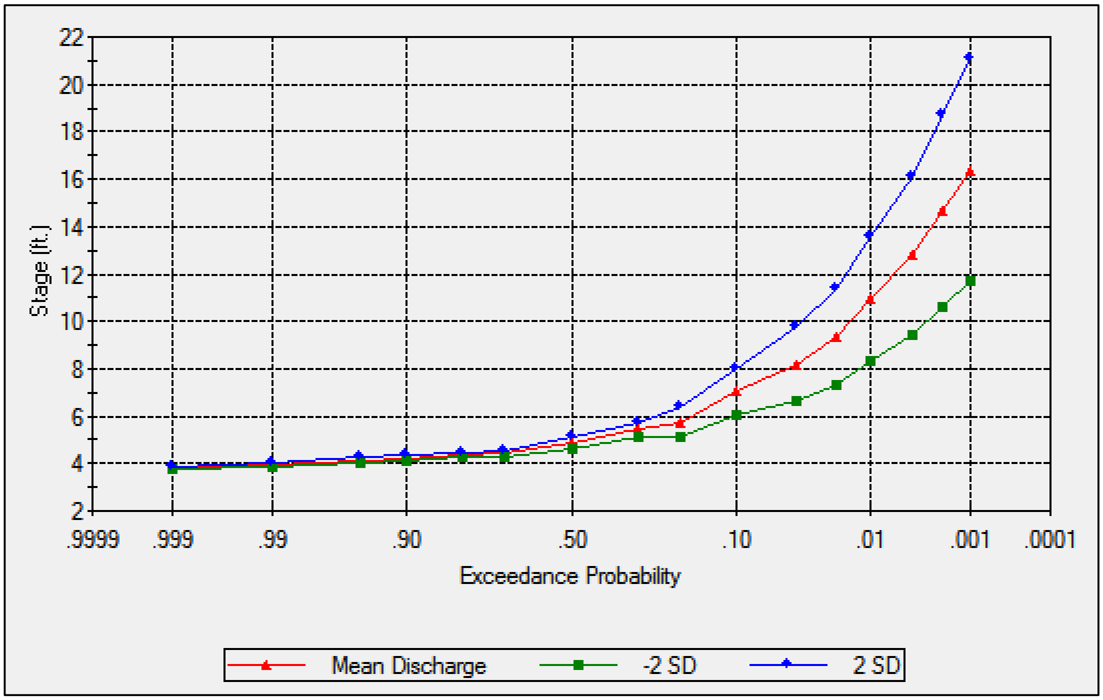


FIGURE 10-3
Example Exceedance-Stage Function with Uncertainty

HEC-FDA includes a levee component where the height of a levee (top-of-bank) and its geotechnical fragility curve may be entered for each reach. HEC-FDA assumes that the levee is located at the index location of the reach and controls failure or overtopping of the levee for the entire reach at that location. For the Gowanus Canal models, the HEC-FDA levee feature was used to control the initiation of flooding through the top-of-bank parameter, but no geotechnical risk was included. Per coordination with the hydrodynamic modeling team, it was assumed that no damages occur for the provided 1.5-year return-period event depth grid. As such, the top of bank at the index location for each model was set to the channel water surface elevation corresponding to the 1.5-year return-period event. This parameter prevented HEC-FDA from initiating damages until after the banks are expected to overtop.

10.1.1.4 Economic Data

The economics component of HEC-FDA is where the user specifies and describes the inventory at risk of damage from flooding. For this study, the inventory included structures and their contents, and the related damage categories of cleanup cost, emergency assistance cost, and debris removal. The following subsections describe development of the economic data for input into HEC-FDA.

10.1.1.5 Inventory and Valuation

The structure inventory formed the basis for the primary damage category in the models. Public data sets for building outlines and lot-level assessor's information (New York City's Primary Land Use Tax Lot Output database 14v2) were combined into an inventory of structures within the provided 500-year inundation extent. GIS and online mapping tools were used to sample 5 percent of structures within a "sample zone" identified based upon preliminary alignment information available at that point in the study (April 2015). The sample included collection of additional characteristics necessary for estimation of depreciated replacement value and an adjustment of the first floor elevation above grade.

Following data collection and post-processing, estimation of structure Depreciated Replacement Value (DRV) was completed using the Marshall & Swift Valuation Service (M&S) at a third quarter fiscal year 2015 price level.

The M&S process involves assignment of an M&S structure type, and selection of a replacement cost per square foot within that M&S type based on the construction material (i.e., masonry, wood, etc.) and the quality of the construction. Square footage is used in conjunction with the unit cost to estimate replacement cost. Next depreciation is estimated, converted to a multiplier, and the replacement cost is adjusted to account for depreciation. M&S also includes price adjustments for locale.

For this analysis, M&S was used to estimate DRV of the sampled inventory. Structures in the sample were categorized as either commercial, industrial, public, mixed, or residential. According to these classifications, typical unit costs were derived and applied to the unsampled inventory. The M&S local adjustment factor for Kings and Queens counties is approximately 1.4. Depreciation was based upon the observations of the sampled structures and applied according to the five structure categories. Content value was estimated using Content-to-Structure-Value ratios from FEMA's Hazards United States (HAZUS) model. Typically, residential occupancy types have a ratio of about 50 percent, and non-residential occupancy types had a ratio of 100 to 150 percent. Uncertainty in DRV was estimated for each of the five building categories based on the sampled buildings and variation in M&S unit costs by construction type and quality used in the valuation analysis. Uncertainty in the first floor elevation of each building was set at a typical value for all buildings: 0.5 feet. This parameter would likely decrease with a more complete survey that would occur in a feasibility-level analysis.

10.1.1.6 Depth-to-Percent Damage Functions

HEC-FDA relies upon depth-to-percent-damage functions (DDFs) to tabulate impacts to the economic inventory. This is accomplished by linking the economic inventory to a location in the floodplain via the water surface profile grid identification numbers. This reconnaissance-level analysis relied on published and available DDFs.

DDFs are published by USACE as well as by FEMA through its HAZUS model. The DDFs used in HAZUS are typically sourced from previous USACE studies or data published by the Flood Insurance Administration (FIA). An additional source of depth damage functions for this study came from USACE's recent report, the North Atlantic Coast Comprehensive Study (NACCS) (USACE, 2015).

HEC-FDA allows for specification of uncertainty about the DDF as either a triangular or a normal distribution. In this analysis, uncertainty about the DDFs was included only if the source curve included uncertainty. HAZUS DDFs do not include uncertainty, and none was estimated. USACE functions for residential structures and contents used a standard deviation of percent damage. For both Newtown and Gowanus, single-family residential DDFs were borrowed from the 2015 NACCS report. Most other DDFs were borrowed from those included in FEMA's HAZUS model. In total, 35 DDFs were included in the model to account for a variety of structure occupancy types in the study areas.

10.1.1.7 Associated Damage Categories

Associated with inundation damage to structures and their contents are flood cleanup costs, emergency costs, and structure-related debris removal costs. Incorporation of these damage categories into the economic flood risk analysis for this study is described in the following subsections.

- *Cleanup:* Cleanup costs occur in the aftermath of flood inundation where interior debris, sediment, and moisture must be dealt with before residences and businesses can return to normal operation. This cleanup damage category is related to cleaning costs for the interior of structures. In general, the cost is based on returning the interior of the structure to a dry and normal condition (removing sediment, vacuuming water, drying). Cleanup costs were applied on a dollar-per-first-floor-square-foot basis to the residential, commercial, public, and mixed-use building inventory. Cleanup costs were not applied to industrial buildings under the assumption that industrial buildings do not require the same level of cleanup and often do not employ third-party specialized services. A cleanup cost per square foot of $3.65, with a standard deviation of $0.94, was applied to all relevant structure types based on approved costs in prior USACE studies (USACE, 2009).

- *Emergency costs:* Emergency assistance costs following a flood are estimated based on published FEMA assistance payments. FEMA public assistance payments can take the form of housing assistance, other needs assistance, or public assistance. Housing assistance includes items such as temporary disaster housing grants, rental reimbursement, and temporary repair assistance. Other needs assistance covers disaster-related medical, dental, funeral, transportation, or other expenses not covered by insurance. Finally, public assistance covers the repair, replacement, or restoration of disaster-damaged publicly owned facilities or facilities of certain private non-profits. A previous USACE analysis of FEMA disaster expenditures across the nation resulted in an estimate of combined residential and public assistance payments of about $9,800 per flooded residential structure with a standard deviation of about 40 percent (USACE, 2009). This value was used to set up a damage function for residential structures, which was triggered at 1 foot of inundation.

- *Debris Removal:* Debris disposal can be a significant issue following most natural disasters, including floods. This analysis used FEMA's HAZUS model to inform estimates of exterior debris removal costs. The HAZUS flood debris model focuses on building-related debris from structural components and finishes, and does not address contents removal or additional debris loads, such as vegetation and sediment. HAZUS uses a default data set based on the 2010 Census to estimate quantity and type of debris. The model was run for each of the five hydrodynamic model depth grids to generate an estimate of total debris tonnage by event. These tonnages were converted to an estimate of debris removal cost based on a typical mass-to-volume ratio of 4 cubic yards per ton (FEMA, 2010) and a unit cost for removal of $100 per cubic yard (Lipton, 2013). These results were then translated into a stage-damage function for insertion into HEC-FDA.

  To illustrate the estimated debris load, the HAZUS 100-year storm event estimate for Gowanus was 1,700 tons, and the 500-year estimate was 5,400 tons, resulting in removal costs of $682,000 and $2.2 million, respectively.

- *Vehicle Damage* Vehicles present in the study area during a flood would be susceptible to direct damage from floodwaters. To estimate these direct vehicle damages, HAZUS data were used to develop an inventory of vehicles and input a depth damage function into HEC-FDA. HAZUS data sets included an estimate of count and value of vehicles per Census block for night and day, and for three types of vehicles (cars, light trucks, and heavy trucks).

  For this analysis, the night and day counts were averaged, and the total vehicle value was scaled down in proportion to the ratio of inundation extent (floodplain area) to the total area of intersecting Census blocks. This scaling accounted for the fact that the HAZUS data set included the value of all vehicles within the Census block, and this analysis was only concerned with the value of vehicles within the inundated area. Next, total vehicle value by type was converted to a vehicle value per structure in the FDA structure inventory. This simplified approach allowed the depths reported at each structure to be applied to vehicles in the floodplain. The HAZUS depth damage curve for each vehicle type was inserted into FDA and the estimated vehicle value at each structure was entered as well.

  The total estimated value of vehicles associated with structures in Gowanus was $42.2 million for cars, $19.5 million for light trucks, and $19.3 million for heavy trucks.

10.1.2 Project NED Benefits

After populating all necessary data components of the three HEC-FDA models as outlined above, each was run to calculate EAD. The HEC-FDA process applies Monte Carlo simulation, an iterative statistical sampling procedure that allows estimation of the expected value of damages based on the supplied input parameters and their uncertainty. For each iteration of the model, the Monte Carlo process selects a different set of values for each input variable from within the range of uncertainty, and repeats this process until a sufficient number of iterations have been completed that the EAD estimate ceases to change significantly with each additional iteration. For the Gowanus Canal FDA models, 10,000 iterations were sufficient to define the EAD.

The conversion of EAD to present value (PV) was based on the fiscal year 2015 Federal Interest Rate for Federal Water Resources Project Studies of 3.375 percent (USACE, 2014) and a 50-year period of analysis, which is typical for USACE analyses. The following sections summarize the results.

10.1.2.1 Key Assumptions

The bullets below summarize key assumptions in the HEC-FDA analyses for the Gowanus Canal.

- The study area for each (and each associated HEC-FDA model) includes only those structures that would be protected by the storm surge barrier alternatives. The EAD reported by HEC-FDA for the WOPC, therefore, is equivalent to the risk reduction benefits associated with a given alternative.
- Because the area is already built out, the analysis assumed a constant structure stock throughout the period of analysis, and did not consider changes in building stock due to redevelopment within the 50-year period.
- Only the WOPC hydrodynamic modeling results are used in HEC-FDA because the alternatives are assumed to provide full protection (100 percent risk reduction), and there is no residual risk to the structure inventory in the model.

10.1.2.2 Expected Annual Damages and Potential Benefits

The following subsection presents the results for the Gowanus Canal HEC-FDA models. The tables and text will refer to the results as EAD, though as described previously, these are equivalent to the benefits (damages reduced) for each alternative.

Table 10-1 presents the total number of structures in the Gowanus Canal protected area (study area), for each barrier option, and the estimated total value (structure DRV plus content value) for each. It also presents EAD as both an annualized and a PV. For Gowanus Barrier Option 1, EAD was estimated at $3.6 million and PV at $85.8 million. For Barrier Option 2, EAD was estimated at $3.1 million and PV at $74.0 million.

TABLE 10-1
Gowanus Canal Analysis Summary by Barrier Option

Alternative	Structures Protected	Total Value ($)	EAD Annualized $	EAD Present Value $
Barrier Option 1 (19th Street)	652	$782,705,000	$3,576,100	$85,804,300
Barrier Option 2 (Hamilton Avenue ROW)	700	$695,864,000	$3,086,200	$74,048,800

Table 10-2 presents a more detailed overview of the Gowanus structure inventories for the two barrier options, including DRV and content value by structure category. As shown in **Table 10-1** and **Figure 10-1**, Barrier Option 1 includes 48 fewer protected structures than Barrier Option 2. However, unlike Barrier Option 2, Barrier Option 1 includes protection of a small number of structures on the downstream side of the Gowanus Expressway. These structures have a higher-than-average value per structure and, as such, the total value of the inventory protected by Barrier Option 1 is greater than the inventory value protected by Barrier Option 2, despite fewer total structures protected.

TABLE 10-2
Gowanus Structure Inventory Value by Barrier Option

Type	Count	Structure Value	Content Value	TOTAL
Barrier Option 1 (19th Street Concept Option)				
Commercial	75	$146,723,000	$141,857,000	$288,580,000
Industrial	182	$149,648,000	$155,158,000	$304,806,000
Mixed	38	$10,252,000	$10,252,000	$20,505,000
Public	22	$15,544,000	$16,328,000	$31,872,000
Residential	335	$91,295,000	$45,647,000	$136,942,000
TOTAL	**652**	**$413,463,000**	**$369,242,000**	**$782,705,000**
Barrier Option 2 (Hamilton Avenue ROW)				
Commercial	81	$112,202,000	$107,219,000	$219,421,000
Industrial	191	$139,129,000	$144,670,000	$283,799,000
Mixed	50	$13,755,000	$13,755,000	$27,511,000
Public	15	$8,144,000	$8,928,000	$17,072,000
Residential	363	$98,708,000	$49,354,000	$148,061,000
TOTAL	**700**	**$371,938,000**	**$323,926,000**	**$695,864,000**

Table 10-3 presents impacts broken out by damage category, in terms of EAD and PV, by barrier option. The industrial structure category makes up the majority of the damages, followed by commercial, then residential structures. Gowanus Barrier Option 1 (19th Street Concept Option) exhibits higher EAD by about $490,000 than Gowanus Barrier Option 2 as modeled.

TABLE 10-3
Gowanus Impacts by Damage Category and Barrier Option

Type	EAD ($)	PV ($)	% of Total
Barrier Option 1 (19th Street Concept Option)			
Industrial	$1,499,800	$35,986,100	41.9%
Commercial	$1,241,900	$29,798,000	34.7%
Vehicle Damage	$422,500	$10,137,200	11.8%
Residential	$146,700	$3,520,400	4.10%
Public	$106,280	$2,550,100	2.97%
Commercial - Cleanup	$55,300	$1,326,900	1.55%
Debris Removal	$48,400	$1,161,500	1.35%
Mixed-Use	$37,300	$895,500	1.04%
Emergency Costs	$8,500	$204,200	0.24%
Public - Cleanup	$4,300	$103,700	0.12%
Residential - Cleanup	$4,200	$99,600	0.12%
Mixed-Use - Cleanup	$900	$21,400	0.02%
TOTAL	**$3,576,100**	**$85,804,300**	**100%**
Barrier Option 2 (Hamilton Avenue ROW Concept Option)			
Industrial	$1,408,600	$33,798,500	45.6%
Commercial	$891,200	$21,382,600	28.9%
Vehicle Damage	$422,500	$10,137,400	13.7%
Residential	$153,600	$3,686,400	4.98%

TABLE 10-3

Gowanus Impacts by Damage Category and Barrier Option

Type	EAD ($)	PV ($)	% of Total
Public	$64,320	$1,543,300	2.08%
Debris Removal	$35,700	$857,100	1.16%
Mixed-Use	$48,500	$1,163,900	1.57%
Commercial - Cleanup	$44,500	$1,067,000	1.44%
Emergency Costs	$9,000	$215,200	0.29%
Residential - Cleanup	$4,500	$108,500	0.15%
Public - Cleanup	$2,700	$64,100	0.09%
Mixed-Use - Cleanup	$1,000	$24,700	0.03%
TOTAL	**$3,086,200**	**$74,048,800**	**100%**

Tables 10-4 and **10-5** present estimated structure and contents damages by event for the five events included in the hydrodynamic model for each barrier option. Note that these are event-specific damages, not EAD. The column headings for each event also note the average depth of flooding for structures that were damaged in the event. For Barrier Option 1, damages at the 100-year event were estimated at $56.6 million, and damages at the 500-year event were estimated at $202 million. For Barrier Option 2, damages at the 100-year event were estimated at $43.1 million, and damages at the 500-year event were estimated at $162 million. Average depth of flooding for damaged structures was 0.6 feet at the 10-year event and 1.8 feet at the 500-year event.

TABLE 10-4

Gowanus Barrier Option 1 (19th Street Concept Option) Structure and Content Damage by Event

Damage Category	1.5-year		10-year		50-year		100-year		500-year	
	Count	Damage ($1,000)	Count	Damage ($1,000)	Count	Damage ($1,000)	Count	Damage ($1,000)	Count	Damage ($1,000)
Commercial	0	$0	5	$869	19	$12,162	42	$25,609	71	$92,960
Commercial - Cleanup	0	$0	1	$18	11	$497	23	$1,139	61	$3,800
Individual	0	$0	26	$2,196	70	$15,172	94	$26,777	168	$74,092
Mixed-use	0	$0	0	$0	0	$0	7	$361	35	$4,361
Mixed-use - Cleanup	0	$0	0	$0	0	$0	2	$8	27	$132
Public	0	$0	3	$113	5	$433	8	$910	20	$9,857
Public - Cleanup	0	$0	1	$6	4	$31	4	$33	17	$307
Residential	0	$0	2	$22	16	$299	89	$1,781	308	$14,776
Residential - Cleanup	0	$0	0	$0	1	$3	4	$7	132	$480
Residential - Emergency Costs	0	$0	0	$0	1	$10	4	$21	132	$1,112
TOTAL*	**0**	**$0**	**36**	**$3,224**	**110**	**$28,606**	**240**	**$56,648**	**602**	**$201,875**

Note:
The total count for damaged structures may be less than the total structures reported in previous tables. This is because some structures may not have experienced sufficient flood depth to initiate damage even though they were within the geographic extent of inundation.

TABLE 10-5
Gowanus Barrier Option 2 (Hamilton Avenue ROW Concept Option) Structure and Content Damage by Event

Damage Category	1.5-year		10-year		50-year		100-year		500-year	
	Count	Damage ($1,000)	Count	Damage ($1,000)	Count	Damage ($1,000)	Count	Damage ($1,000)	Count	Damage ($1,000)
Commercial	0	$0	5	$869	16	$6,506	41	$15,466	77	$65,501
Commercial - Cleanup	0	$0	1	$18	10	$308	21	$563	67	$2,519
Individual	0	$0	26	$2,196	73	$13,089	101	$24,019	177	$67,270
Mixed-use	0	$0	0	$0	0	$0	7	$361	45	$5,130
Mixed-use - Cleanup	0	$0	0	$0	0	$0	2	$8	34	$150
Public	0	$0	3	$113	5	$433	8	$844	13	$4,190
Public - Cleanup	0	$0	1	$6	4	$31	5	$34	10	$113
Residential	0	$0	2	$22	18	$314	92	$1,809	332	$15,310
Residential - Cleanup	0	$0	0	$0	1	$3	4	$7	135	$488
Residential - Emergency Costs	0	$0	0	$0	1	$10	4	$21	135	$1,140
TOTAL*	**0**	**0**	**36**	**$3,224**	**112**	**$20,693**	**249**	**$43,134**	**644**	**$161,810**

Note:
The total count for damaged structures may be less than the total structures reported in previous tables. This is because some structures may not have experienced sufficient flood depth to initiate damage even though they were within the geographic extent of inundation.

10.1.3 Project Costs

Conceptual project costs were developed for each of the barrier options. The costs include in-water barrier construction costs (including a base allocation for stormwater pump station), upland defense construction costs, associated contingencies, and O&M costs over 50 years, and at this conceptual stage convey a 15 to 30 percent level of accuracy. Costs were based upon benchmarking to similar-sized precedent projects and used industry unit cost factors as a starting point that were reviewed checked for sensibility to the New York City (City) infrastructure construction market. Detailed discussion of the conceptual capital cost development, assumptions, contingencies, risks, and uncertainties was presented in Sections 7 and 8. Costs were developed at fiscal year 2015 price level and use the same 3.375 percent USACE interest rate used in the benefit calculations. Interest during construction (IDC) was included based on an assumed construction period of 24 months for all options. Construction spending was assumed to occur at a constant rate over the period. Costs are presented in **Table 10-6**. Detailed cost build-ups, including assumptions and unit cost factors for capital and O&M costs, are included in **Appendix L**.

TABLE 10-6
Gowanus Canal Options Cost Summary

Cost Component	Option 1: 19th Street	Option 2: Hamilton Avenue ROW
In-Water Barrier	$103,025,433	$53,838,503
Upland Defenses	$56,890,761	$53,785,985
O&M: Upland	$1,646,680	$1,645,498
O&M: In-Water	$16,077,489	$13,372,390
Construction Period (month)	24	24
IDC (3.375%)	$5,198,958	$3,498,928
Total	**$182,839,321**	**$126,141,303**

10.1.4 Net NED Benefits and Benefit-Cost Ratio

For USACE planning studies, the plan that maximizes positive net benefits (benefits less costs) is considered the NED plan and is typically the plan that the USACE would recommend for implementation. The NED plan is not necessarily the same as the plan that has the highest benefit-to-cost ratio. This approach reflects the federal objective, which seeks to maximize contribution to the net value of the national output of goods and services.

Table 10-7 presents the net benefits for the two Gowanus Canal barrier options. At Gowanus Canal, the *Hamilton Avenue ROW* option—the preferred concept option—provides the greatest net benefits, although in both cases at Gowanus Canal, net benefits are negative.

For USACE planning projects, the BCR typically must exceed 1.0 in order to be eligible for project authorization. Additionally, the BCR of a project can influence construction budget prioritization at the national level. **Table 10-7** present the BCR resulting from the analysis for each option. At Gowanus Canal, neither option resulted in a BCR above 1.0. Option 2, Hamilton Avenue, had the higher BCR of 0.59, but it did not exceed 1.0.

The following section presents sensitivity analysis considerations related to reduction in uncertainty in the results for future analyses.

TABLE 10-7
Gowanus Canal BCR Analysis Summary

Gowanus Options	Cost ($PV)	Benefits ($PV)	Net Benefits ($PV)	BCR
Option 2: Hamilton Avenue ROW	$126,141,000	$74,048,800	-$52,092,503	0.59
Option 1: 19th Street	$182,839,000	$85,804,300	-$97,035,021	0.47

10.1.5 Sensitivity and Uncertainty

On the benefits side of the analysis, the study team identified structure valuation as an area where more detailed analysis during a feasibility study would reduce uncertainty in the benefits analysis. Even including the M&S regional adjustment factor of approximately 1.4, M&S had substantially lower typical unit costs for construction as compared to preliminary construction cost market research in the vicinity of the project area. Unit costs for construction are the basis for estimating structure replacement value, and subsequently, depreciated replacement value.

As an example of this underestimation, the M&S replacement cost for a “white box” industrial building, even after incorporating a local adjustment factor for the City, is just $67 per square foot. Market research with local experts for actual projects in the City yielded estimates of $150 to $180 per square foot. Similarly, while the M&S valuation for residential development is under $120 per square foot, local developers estimate actual hard and soft costs at around $275, and a cost estimator for a high-end development suggested more than $335. The local market research identified that construction unit costs in the vicinity of the project area averaged about twice as large as the costs used in this analysis (average adjustment factor of 2.2 for Industrial and Residential properties).

For the purposes of a brief sensitivity analysis, the benefits associated with structure and content damages were approximately doubled, in order to see the effect of the BCR at Gowanus Canal. This resulted in a hypothetical BCR for the 19th Street option of 0.93, and a hypothetical BCR for the Hamilton Street option of 1.15 (see **Table 10-8**).

TABLE 10-8
Gowanus Canal BCR Analysis Summary with Variation in Structure Valuation Methodology

Gowanus Options	M&S BCR	Sensitivity BCR
Option 2: Hamilton Avenue ROW	0.59	1.15
Option 1: 19th Street	0.47	0.93

On the cost side, as highlighted in Section 7, construction cost escalation could arise due to uncertainty around barrier width and depth, upstream storage capacity and surface water pumping requirements, service diversions, development parcel integration, land or easement acquisition requirements and potential legal challenges, and any upland environmental remediation that might be necessitated. Conversely, construction cost estimates could decrease upon completion of a Red Hook Integrated Flood Protection System. With partial project funding secured, the Red Hook project will precede any storm surge barrier at Gowanus Canal. Depending upon the constructed alignment and opportunities for project tie-ins, the extent of upland defenses required on the western side of a Gowanus Canal project could be reduced, potentially saving millions of dollars.

A number of other items were identified for more detailed consideration in a future analysis or feasibility study, including:

- Additional consideration of the allocation of costs for surface water flood mitigation requirements (interior drainage, pumps, etc.), assumptions as to without project conditions for local flooding, and the effects of these issues on project benefits.
- A more detailed evaluation of optimal level of protection for in-water and upland defense structures and the implications of varied barrier system elevations and configurations on project benefits.
- Refinement of debris and cleanup cost damage categories during a feasibility study through site-specific cost and damage estimates, as well as inclusion of additional damage categories that may require a separate modeling effort, such as local and regional traffic impacts.

10.2 Expanded Project Benefits

Numerous benefits, beyond the avoided damages calculated in the preceding section, would result from the construction of a storm surge barrier system to protect the areas surrounding the Gowanus Canal. Evaluating these benefits is necessary to obtain funding, and each funding source recognizes specific types of benefits and often requires quantification of these benefits according to specific methodologies. While USACE—concerned with the national economy—will only fund a project if the value of the avoided damages to structure and contents is greater than the cost of building and maintaining the infrastructure, other funders, such as the Department of Housing and Urban Development, allow for more social and environmental factors to be weighed against costs. City and community leaders may take a more expansive view of benefits in assessing a project’s worth. Some of these expanded project benefits are quantified or described here, including those that may warrant further investigation as part of a future feasibility study. For purposes of translation, where applicable, these benefits are related back to the corresponding USACE planning account under which they would be grouped.

10.2.1 Protected Existing Populations, Housing, and Buildings (OSE)

A Gowanus Canal storm surge barrier will ensure socially vulnerable communities are protected. While nearly all land adjacent to Gowanus Canal is used for industry, the flood zone extends far upland to include the homes of approximately 7,000 residents. Many of these residents share demographic characteristics that indicate a particular vulnerability to the challenges posed by storm surge and other hazards. Nearly half live in the Gowanus Houses, a New York City Housing Authority development with more than

1,100 apartments. The Protected Area also contains Mary Star of the Sea, a 100-unit building for low-income seniors. Half of all families in the Protected Area earn less than $60,000 a year, and more than 40 percent earn under $40,000 annually, indicating higher levels of poverty than the City as a whole, where approximately 36 percent of families earn less than $40,000 a year. Including the Gowanus Houses, approximately 90 percent of all residential units are in buildings constructed before 1961, when the New York City Zoning Resolution led to the construction of buildings more resistant to flood damage.

Closer to the Canal, residential development is occurring on specific sites where the underlying manufacturing zoning has been modified. The Lightstone Group's 365 Bond Street development is currently under construction and will create 700 rental units within a block of the Canal, including 140 affordable units. Gowanus Green is a planned 774-unit, 70 percent affordable development by the Fifth Avenue Committee, Hudson Companies, Jonathan Rose Companies, and the Bluestone Group, on a City-owned site adjacent to the Canal.

10.2.2 Protected Growing Communities and Future Development (OSE)

Beyond the existing and currently planned developed, a Gowanus Canal storm surge barrier system has the potential to protect a significantly larger future population. Although no action is confirmed, efforts by City Councilman Brad Lander could lead to a rezoning of much of the neighborhood. Under a theoretical scenario analyzed by the City Council Land Use Division for the purposes of calculating value increments, a rezoning could create almost 10 million square feet of residential development rights, adding more than 20,000 residents to the area if fully built out and occupied at the same density as the existing housing stock; the vast majority of this new population would be within the 100-year flood zone.

Any new buildings will be built to flood-resistant standards and elevated one foot above the 100-year flood elevation, but their residents and owners would still reap the benefits of a storm surge barrier. First, a barrier system built to a 17-foot elevation would provide a higher level of protection than the minimum required by the New York City Building Code (see below). Next, a barrier system would allow residents to remain in place during a storm without fear of adjacent streets and other infrastructure being flooded. Finally, a barrier system would ensure the continued operation of the entire neighborhood during storms. Many important neighborhood assets, such as retail along Smith and Court Streets, face significant flood risk, and protecting them would benefit neighborhood residents regardless of whether their own buildings are damaged.

10.2.3 Protection Beyond Current Standards (OSE)

While Appendix G of the New York City Building Code requires flood-resistant construction for new or substantially improved buildings in the 100-year flood zone, the storm surge barrier system would offer additional flood protection because it incorporates added freeboard and an adjustment for a rise in sea level. The 2015 New York City Panel on Climate Change report projects that, due to climate change, the 100-year flood in the 2050s may reach an elevation up to 2.5 feet higher than today's 100-year flood. A building built to code today would flood under these circumstances, but a storm surge barrier built to the 17-foot design elevation would still offer protection. Similarly, today's standards do not protect against the less frequent but more severe 500-year flood event, with a 15-foot elevation, while the flood barrier would.

While the avoided damages modeling results in Section 10.1.2.2 do take into account the protection of existing structures from these lower-frequency but higher-intensity events, they do not include any avoided damages to structures that are not yet built.

10.2.4 Reduced Flood Insurance Costs (RED)

As a result of a Gowanus Canal storm surge barrier system, property owners will experience reduced flood insurance costs. In New York City, flood insurance is available through the public National Flood Insurance Program (NFIP) as well as through private insurers. NFIP premiums are based on FIRMs, which are produced by FEMA and intended to reflect the risk of flooding. Properties within an NFIP Community—a community that has adopted certain land use and construction standards to prevent flood damage—are eligible for NFIP coverage, and all properties with a federally backed mortgage and within the FEMA Special Flood Hazard Area (SFHA) (an area inundated by a flood having a 1 percent annual chance of being equaled or exceeded) are required to carry NFIP policies. Assuming the Gowanus Canal storm surge barrier system is certified by FEMA, the FIRMs would be updated to reflect the reduced risk of flooding within the zone of protection. This would mean that 1) no properties within the zone of protection would be required to carry flood insurance because they would no longer be within the SFHA; and 2) properties with voluntary NFIP coverage would have lower premiums than they would without the barriers.

Coverage beyond NFIP policy limits must be purchased in the private flood insurance market, either individually or as part of a manuscript policy. Private insurers do not need to rely solely on FIRMs and can establish their own rate-setting methods, so a change in FIRMs would not necessarily result in a reduction in private flood insurance premiums. On the other hand, private insurers would not necessarily require a change in FIRMs in order to recognize the reduction in flood risk due to the storm surge barriers. With or without FEMA certification and a resulting FIRM update, if the private insurance market is efficient, the reduction in flood risk should lead to a decrease in flood insurance premiums.

It is important to note that flood insurance is meant to cover some of the same damages quantified in Section 10.1.2.2, so adding these benefits together would be duplicative. However, the timing of these benefits is not the same: damage costs are modeled based on expected probabilities but are only incurred when flooding actually happens, while flood insurance costs are incurred regardless of actual flooding.

The 2014 NFIP Policy Database contains a sample of data on approximately 39,000 policies within the City. Of these, 64 were located within the area protected from the 100-year flood event, as summarized in **Table 10-9**.

TABLE 10-9
2014 NFIP Policies in Protected Area, 100-Year Flood Zone

	Properties	Policies	Take-up Rate	% Pre-FIRM	Avg. 2014 Premium & Fee	Total 2014 Premium & Fee	Pres. Value 50 Yrs., 3.375%[1]
1-4 Family	95	27	28%	96%	$1,600	$48,000	$1,060,000
Multifamily	17	2	12%	100%	$1,500	$160,000	$70,000
Non-Residential	184	35	19%	77%	$4,100	$312,000	$3,460,000
ALL	**1,161**	**64**	**22%**	**95%**	**$3,000**	**$520,000**	**$4,590,000**

As discussed above, a flood protection system, if certified by FEMA, could remove any mandatory NFIP requirements within the Protected Area, and any future flood insurance costs could be realized as savings. Assuming property owners do forego flood insurance coverage, the total premium and fee amounts in **Table 10-9** represent a lower bound of annual NFIP savings, and NFIP is only one source of flood insurance.

Actual NFIP savings may be significantly higher for the following reasons:

1. **Incomplete Data.** Due to incomplete or irregular addresses recorded in the NFIP Policy Database, there may be additional NFIP policies within the zone of protection that were not captured in this analysis.
2. **Premium and Fee Increases.** This analysis does not take NFIP premium and fee increases into account. As shown in **Table 10-10**, premium and fee increases are particularly drastic between 2014 and 2015 as

[1] The current discount rate for water resources projects that is required for use on USACE projects per USACE Economic Guidance Memorandum EGM15-01. A 7 percent discount rate, used for FEMA-funded mitigation projects per Office of Management and Budget's Circular A-94, Section 8.b.1, yields a PV of $7.2 million for all properties.

a result of the 2012 Biggert-Waters Flood Insurance Reform Act and the 2014 Homeowners Flood Insurance Affordability Act. Although increases will certainly continue, the size of increases is unknown and, therefore, they are not included in this analysis.

TABLE 10-10
2014-2015 Average NFIP Increases, Zone AE[2]

	Premium Increase	Total Increase
Post-FIRM	9%	23%
Pre-FIRM Primary Residence	14%	15%
Pre-FIRM Non-Primary Residence	24%	37%

1. **Takeup and Coverage Rates.** In 2014, NFIP takeup rates among properties in the Protected Area SFHA was about 20 percent. As awareness of flood vulnerability increases, this rate, as well as total coverage amounts, may also increase, leading to greater total costs and, therefore, greater potential savings.
2. **Future Development.** Flood insurance for future developments are also not considered here.

While the total premium and fee amounts in **Table 10-10** represent a lower bound of annual NFIP savings if property owners forego flood insurance, some owners may choose to maintain coverage despite the flood protection system. These owners would face greatly reduced NFIP rates, reflecting their reduced risk. For instance, in the NFIP Rating Example presented in **Appendix M**, the with-project NFIP premium and fee of $2,400 is 70 percent less than the without-project full-risk premium and fee of $8,000. Because the final premium depends on individual owner decisions and very specific building characteristics, it is not feasible to estimate these potential savings for all properties in the zone of protection.

Beyond NFIP policies, many buildings have coverage through private insurers, whose premiums and rating systems are proprietary. Private insurance is particularly significant among multi-family and non-residential buildings, which contain approximately 75 percent of the residential units and 95 percent of the built area within the zone of protection. A lack of public information about private flood insurance means that costs, takeup rates, and coverage amounts from the private market are unknown at this time.

10.2.5 Avoided Mandatory Floodproofing Costs (RED)

Appendix G of the New York City Building Code requires that all new or substantially improved buildings within the FEMA 100-year flood zone comply with flood-resistant construction standards. This places restrictions on allowable uses, and requires certain construction strategies in building areas below the base flood elevation: no residences are allowed, and all areas must be either wet- or dry-floodproofed, depending on the type of building. This can add to the upfront costs for constructing a building with a floodproofed or elevated ground floor, and can reduce net operating income through the loss of rentable area as well as requirements to maintain floodproofing components. A storm surge barrier could reduce these costs by compelling FEMA to map the Protected Area out of the 100-year flood zone.

Under the existing manufacturing zoning, little development is anticipated within the Protected Area. However, under the theoretical scenario analyzed by the City Council Land Use Division, a rezoning could create nearly 10 million square feet of residential development rights. Using a 20-story, 230,000-square-foot residential building as an example, floodproofing costs may amount to approximately $0.53 per square foot; therefore, avoided floodproofing costs may amount to about $5 million across the rezoning area.

[2] FEMA. 2015. "April 1, 2015, Program Changes."

10.2.6 Protected Jobs and Businesses (RED)

The erection of a Gowanus Canal storm surge barrier system can add flood protection to the measures the City is taking to preserve the viability of the Gowanus industrial economy. Over the past decades, the City and the Gowanus community have made the preservation of industrial jobs, businesses, and land a public policy priority. From 2002 to 2013, the City spent more than $880 million from its expense and capital budgets in support of industrial sectors, and the Economic Development Corporation, Industrial Development Agency, and Brooklyn Navy Yard Corporation all have major programs to support these businesses. [3] In November 2015, City Hall and City Council renewed their commitment to industrial businesses as they announced the $115 million Industrial Action Plan. Recognizing the value of industry and the compatibility of light industry with a residential neighborhood, one of the key recommendations of the Bridging Gowanus community plan was to preserve the neighborhood's mixed-use character, including a requirement for all new buildings to build or preserve light manufacturing space, art/artisan workspace, or nonprofit organization workspace.[4]

Like other industrial areas, Gowanus is home to businesses that are critical to the performance of the local economy and jobs that are accessible to New Yorkers who typically face barriers to employment. Businesses in the Protected Area employ more than 1,000 people in these sectors.[5] In 2014, a report by the New York City Independent Budget Office (IBO)[6] found that industrial firms are more likely than others to hire employees without college degrees, while a report by the City Council Land Use Division[7] found that more than 80 percent of employees in industrial sectors are people of color and more than 60 percent are foreign-born. While the IBO report did find that industrial workers without college educations earn more than their counterparts in non-industrial sectors, this difference comes largely from the construction sector. Within the Protected Area, average earnings in industrial sectors ($67,000) are higher than those in non-industrial sectors ($61,000), and average industrial earnings compare favorably with those of other sectors with high proportions of workers without college degrees: Retail Trade, with average earnings of $49,000, and Accommodation and Food Services, with average earnings of $56,000.

Rare among industrial areas, Gowanus has a strong arts community, and synergy between creative and industrial activities has made Gowanus a local hub for the design and production of apparel, jewelry, printed products, and films. While cross-subsidy from new residential development, as suggested by the Bridging Gowanus plan, may help invigorate local industry, it will not address the construction, insurance, and operating costs of businesses operating in this flood-prone area. Industrial businesses face financial challenges throughout the City, even with City support. Therefore, if the City seeks to preserve industry in Gowanus, either under the current zoning or under a rezoning plan, a storm surge barrier can be another investment to alleviate challenges faced by businesses in these important sectors.

Across all sectors, the 350 businesses and 2,600 employees in the Protected Area generate more than $2 billion in direct annual economic output and earn nearly $670 million in compensation. Applying economic multipliers, this direct economic activity generates nearly 15,200 jobs, $1.1 billion in earnings, and $3.2 billion to total output (see **Table 10-11**).

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[3] NYC IBO. 2014. "City Support for the Industrial Sector."

[4] Pratt Center for Community Development. 2015. "Bridging Gowanus Draft Planning Framework."

[5] Unless otherwise noted, "industrial sectors" includes Construction, Manufacturing, Transportation and Warehousing, Utilities, and Wholesale Trade.

[6] NYC IBO. 2014. "A Profile of New York City's Industrial Workforce."

[7] NYC Council Land Use Division. 2014. "Engines of Opportunity."

TABLE 10-11
Economic Impact of Businesses in Protected Area

	Employees (FTE)	Employee Earnings	Output
Direct	2,600	$668 M	$2,054 M
Indirect	3,000	$234 M	$654 M
Induced	2,600	$170 M	$488 M
Total	**15,200**	**$1.073 M**	**$3,196 M**
Multiplier	*1.58*	*1.61*	*1.56*

10.2.7 Additional Potential Benefits

Although not quantified here, there are additional potential benefits to the storm surge barrier system that should be studied in detail as part of a complete feasibility study, including the following:

1. **Avoided loss of life and injuries.** Hurricane Sandy proved that even in New York City, storms can be deadly. Forty-three New Yorkers lost their lives during Sandy, and tens of thousands were injured.[8] The benefit of avoiding loss of life and injury can be converted to dollar amounts using FEMA life safety values.
2. **Avoided evacuation costs.** Much of the Protected Area is in Hurricane Evacuation Zone 2, the second tier of areas to be evacuated in the case of a hurricane. Evacuation presents a particular challenge for those with limited mobility, such as children and older residents, who combined make up nearly 20 percent of the population within the Protected Area.
3. **Avoided relocation costs.** Damaged buildings and infrastructure can force residents and business to temporarily relocate, incurring extra costs. This benefit can include not only direct relocation costs, but also loss of productivity and mental health effects.
4. **Avoided business interruptions.** In addition to damage to physical structures and goods, flooding can cause business interruptions that lead to losses of profits for owners and wages for some classes of workers, as well as spillover effects from these losses. Hurricane Sandy caused approximately $5.7 billion of net losses in economic activity,[9] including direct, indirect, and induced impacts. A more detailed feasibility study should deploy localized economic models to obtain an estimate of lost economic activity.
5. **Pedestrian/bicycle improvements**. Depending on the final design, there may be an opportunity to create pedestrian and/or bicycle improvements along Hamilton Avenue. This path could connect a portion of the Brooklyn Waterfront Greenway that currently passes through inhospitable City streets. This benefit can be converted to dollar amounts based on public health and safety benefits as well as reduced travel times.
6. **Green infrastructure secondary benefits.** There may be opportunities to incorporate green infrastructure or create habitat as part of a Gowanus Canal storm surge barrier system. These components could generate ecological benefits or human recreational benefits that could be quantified and monetized through benefit transfer analysis, habitat equivalency analysis, and willingness to pay models.

[8] City of New York. 2013. "Hurricane Sandy After Action Report."

[9] City of New York. 2013. "New York City CDBG-DR Action Plan."

11 Implementation and Phasing

11.1 Implementation Overview

A variety of federal, state, and New York City (City) permits and approvals may be necessary to implement a Gowanus Canal (Canal) storm surge barrier system as examined in this feasibility study. Detailed discussion of the anticipated regulatory framework is provided in **Appendix I**. This section summarizes the process and timeframe for implementation of the project.

In general, it is assumed that any future implementation of storm surge protection would be developed and implemented by United States Army Corps of Engineers (USACE), with the City as the local participant. Therefore, the framework associated with USACE project development, review, and implementation provides the overriding framework for the development and approval of any future proposed storm surge infrastructure. Implementation procedures for New York State or City actions and approvals would be completed in coordination with the federal process. The actual implementation of the project is assumed to be aligned with completion of the federal Superfund remediation. For analysis purposes, this is assumed to be a 10-year horizon such that project implementation would not begin until at least 2025. As shown in **Figure 11-1**, there are two possible scenarios for project implementation.

Pathway A presents a likely sequence if the Gowanus Canal storm surge barrier project is integrated in the NY NJ Harbor and Tributaries Feasibility Study. Under Pathway A, the potential measure would be evaluated in the feasibility study that is expected to begin its prescribed 3-year timeline in 2016, with a 2019 completion date. Should a waiver be acquired, the feasibility study duration could exceed the 3-year timeframe. From the feasibility study, the project would be reviewed by the Civil Works Review Board, and a Final Chief's Report and the National Environmental Policy Act (NEPA) record of decision (ROD) would be prepared and circulated with final sign-off anticipated in 2022. Project authorization, preconstruction engineering and design, and congressional authorization are expected to take about 3 years, with authorization estimated at 2025 to coincide with conclusion of the Superfund remediation. Project construction would be expected to begin about 2 years thereafter, in 2027, to provide time for procurement and any baseline testing and evaluation of pre-construction conditions accounting for a stabilized condition after the Superfund remediation. Under Pathway A, the project could be completed before 2030.

Pathway B presents a process that would be based on an independent project implemented by the USACE (although coordinated with other storm surge protection projects such as the adjacent Red Hook project that are also under consideration). Under this scenario, there are additional steps to get the process started, most notably, it is expected that by 2019 the NY NJ Harbor and Tributaries Feasibility Study would have identified the recommended project or projects for implementation, the Gowanus Canal storm surge barrier would not have been a part of the recommended project, and the Gowanus Canal study area would not be protected by the recommended regional project. USACE would start by requesting Investigation Funding from Congress. With funding in place by 2020, it is assumed that the feasibility study would be initiated in 2021 and completed by 2024. From this point on, the process is the same as described above. Under Pathway B, the project could be completed by approximately 2034. These timing assumptions are best case. Funding decisions, from initiation to authorizations, could, in reality, take significantly longer to achieve.

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Implementation Plan -- Gowanus Canal Overview*

City/USACE/NEPA/City ULURP

*Assumes Full Appropriations Authorizations and Budgeting

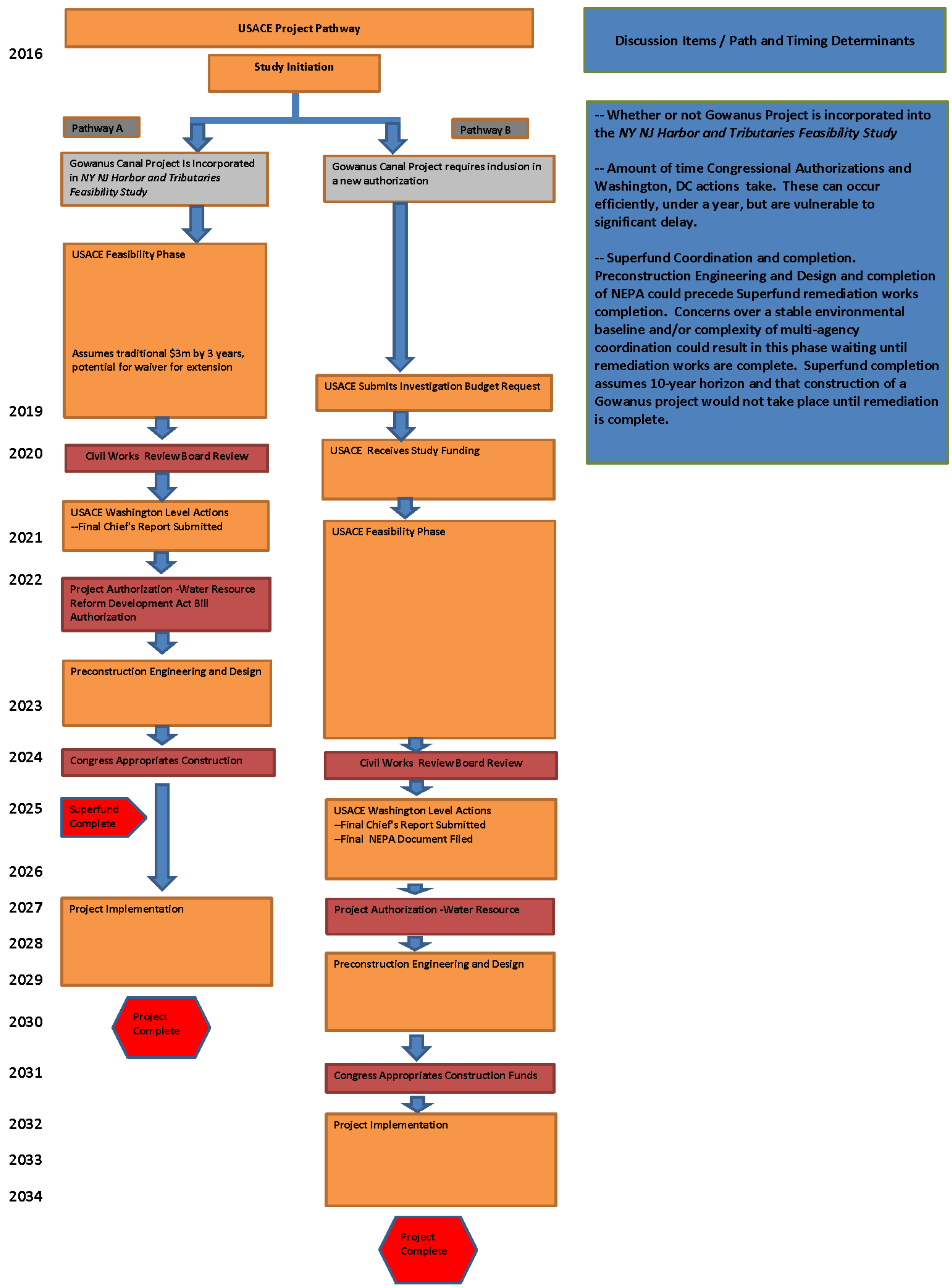

FIGURE 11-1
Gowanus Canal Implementation Plan Scenarios

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11.2 Detailed Phasing and Implementation Steps

Within each of the larger phases of project implementation, a significant number of steps and coordination points will be required. **Figures 11-1a, 11-1b, and 11-1c** provide a more detailed breakdown of the overall framework, including anticipated New York City actions that would need to be integrated and timed to match the federal process.

In fact, even before the formal USACE process gets under way (approximately in the period from 2016 to 2020), the City should be actively preparing and coordinating with USACE during the initial lead up to USACE's start of the feasibility study (or during the feasibility study if the project is included in the NY NJ Harbor and Tributaries Feasibility Study). These steps could include business and resident stakeholder outreach, political consensus building, studying funding opportunities such as an assessment district, early action opportunities such as willing seller land acquisition, inter-agency coordination, and ongoing USACE coordination (i.e., providing ongoing support to the benefit-cost assessment that underpins project feasibility) and discussions around level of risk reduction and the potential for an LPP in the event the City's policy objective for design high and level of risk reduction exceeds that of USACE's recommended project.

11.2.1 Study Initiation

During this initial phase, USACE will undertake preliminary problem identification assessment that will yield first whether the project is included in the NY NJ Harbor and Tributaries Feasibility Study or if separate authorization for feasibility studies would be required specific to the Gowanus storm surge barrier project.

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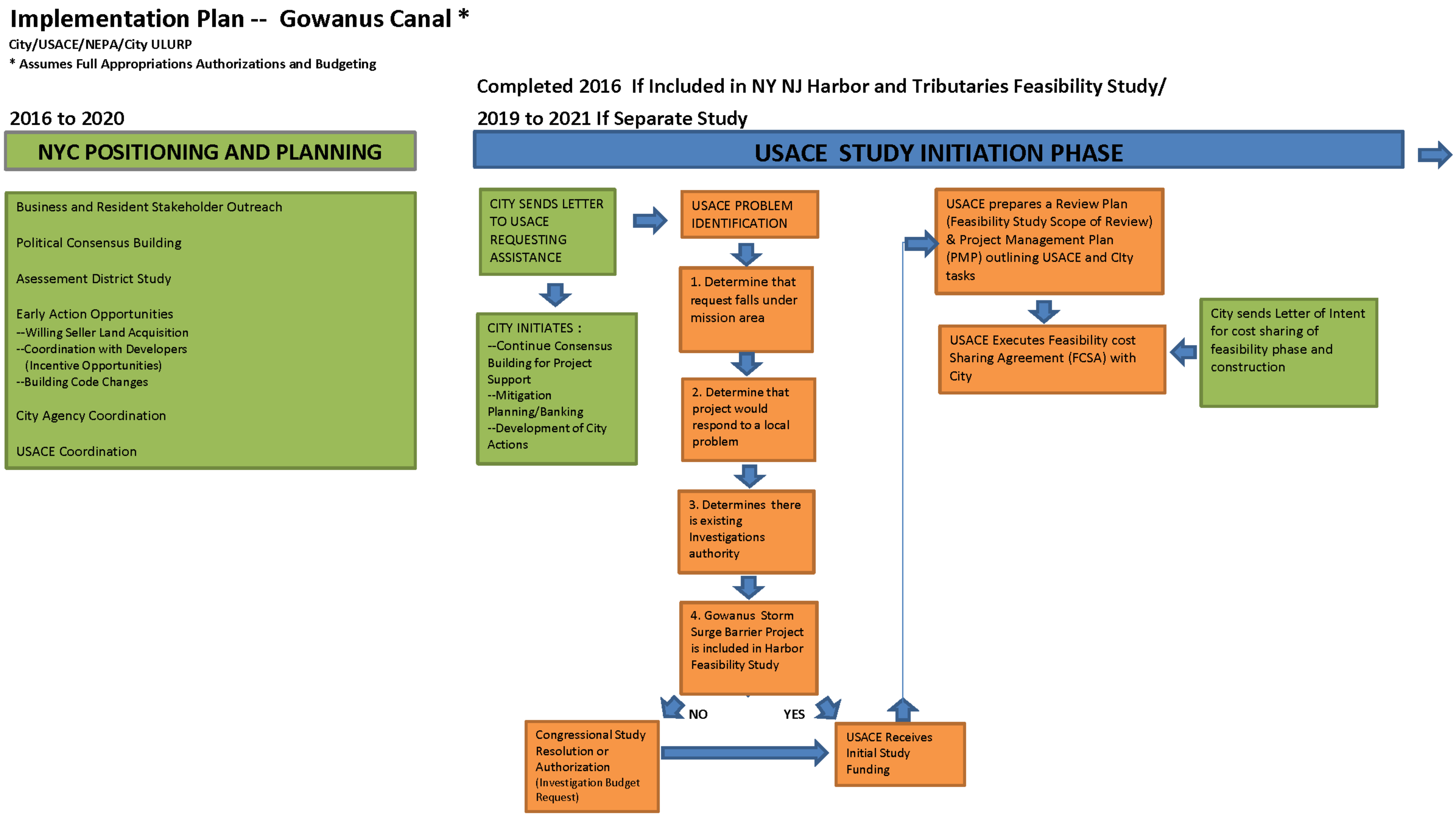

FIGURE 11-1A
Gowanus Canal Study Initiation

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As shown in **Figure 11-1a**, the City would need to formally request assistance from USACE for the study initiation phase to begin. During this time, it would be expected that the City would continue its early coordination and consensus building. With USACE's preliminary investigations under way, the City should begin to consider defining what local actions would be necessary to support the project. The City could also begin to define areas for mitigation banking in anticipation of future requirements that may result from the environmental impact study (EIS) findings.

At the end of this phase, USACE would prepare a Review Plan (Feasibility Study Scope of Review) and Project Management Plan (PMP) outlining USACE and City tasks. The City would commit to its intent to share costs of the feasibility study and future construction, and both the City and USACE would sign a cost-sharing agreement.

The timeframe for this would be for finalization in 2016, reflecting ongoing discussions with the relevant parties, if the project is included in the larger NY NJ Harbor and Tributaries Feasibility Study, and from approximately 2019 to 2021 as an independent USACE study.

11.2.2 Feasibility Study

As shown in **Figure 11-1b**, the feasibility study is closely integrated with the supporting NEPA review process, including project scoping, alternatives development, evaluation and assessment, and identification of the preferred alternative (See Task 3 detailed description of the NEPA process and EIS content). The City's role is to participate in the scoping process and to define any locally preferred alternatives.

This phase of the process concludes with USACE preparing and issuing the Final Feasibility Report/NEPA Document and, after a 30-day period, the District Engineer signs the final report and submits to Washington, D.C., to begin the Civil Work Board phase of the project.

The timeframe for this phase is between 2016 and 2019 if the project is included in the larger NY NJ Harbor and Tributaries Feasibility Study, and from 2021 to 2024 as an independent USACE study.

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Implementation Plan -- Gowanus Canal

2016 to 2019 If Included in NY NJ Harbor and Tributaries Feasibility Study/
2021 to 2024 If Separate Study

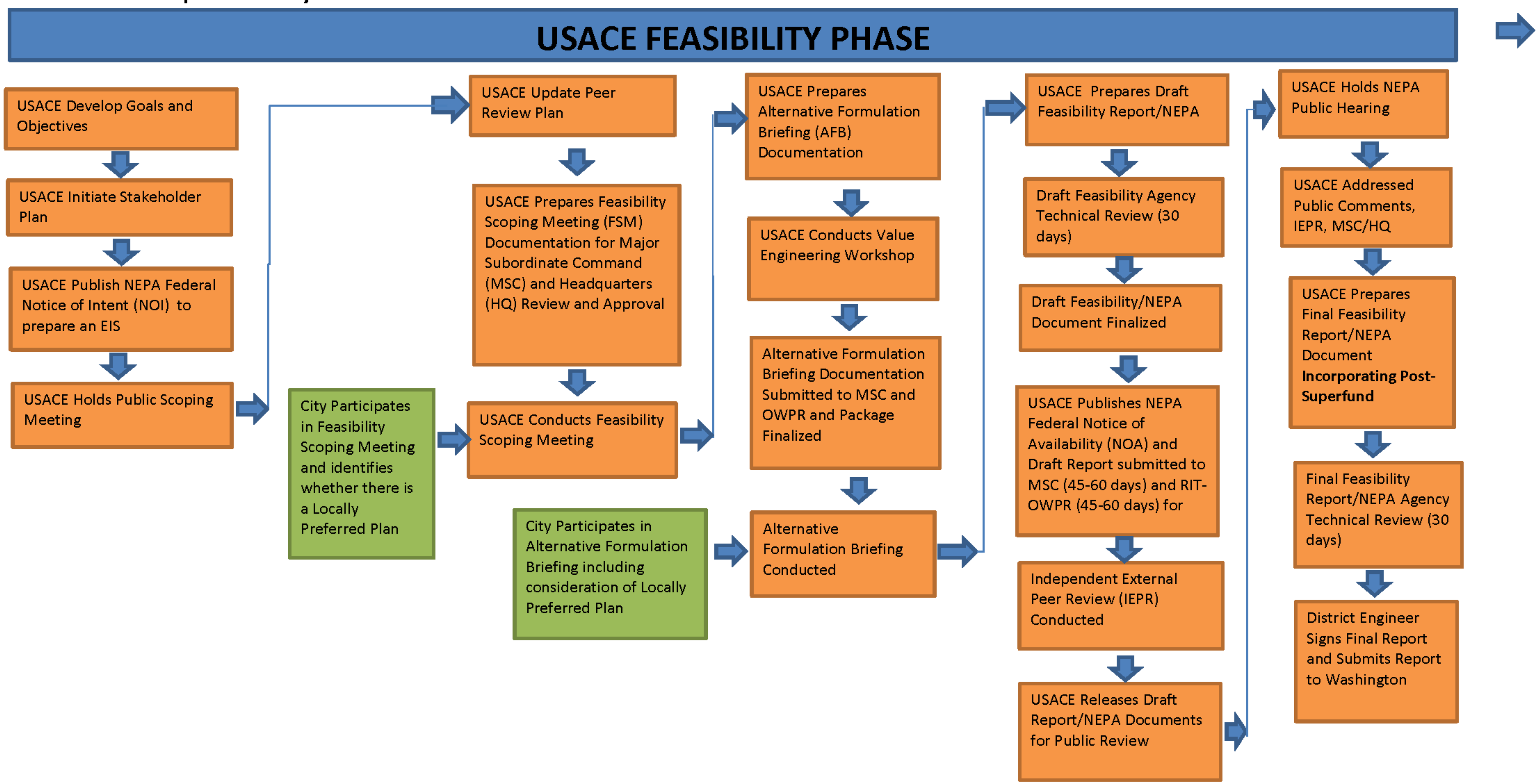

FIGURE 11-1B
Gowanus Canal Feasibility Phase

11.2.3 Washington, D.C./Civil Works Review

Completion of the Final Feasibility Report initiates a USACE Headquarters-based review period that incorporates project review by the Civil Works Review Board (see **Figure 11-1c**). The final NEPA documents are prepared with responses to comments generated and Headquarters prepares Final Chief's Report, which is submitted to Congress, the Office of the Assistant Secretary of the Army for Civil Works (ASA/CW), and the Office of Management and Budget. This phase concludes with project authorization through a Water Resource Reform Development Act bill.

During this period, it is anticipated that the City would be establishing and initiating local actions such that it could begin local approval processes (i.e., the Uniform Land Use Review Procedure [ULURP]) to be timed with USACE authorization to proceed. Specifically, this would include pre-ULURP activities such as finalizing the City's proposed actions, coordination with borough and community board officials, and undertaking City Planning's BluePrint process as necessary for any proposed land use actions.

This phase is expected to take about 2 years and would be completed by 2022 under the NY NJ Harbors and Tributaries Feasibility Study or 2027 for the independent study. Under the longer independent study timeframe, the anticipated 2025 completion of the Gowanus Superfund project would occur during this stage.

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Implementation Plan -- Gowanus Canal

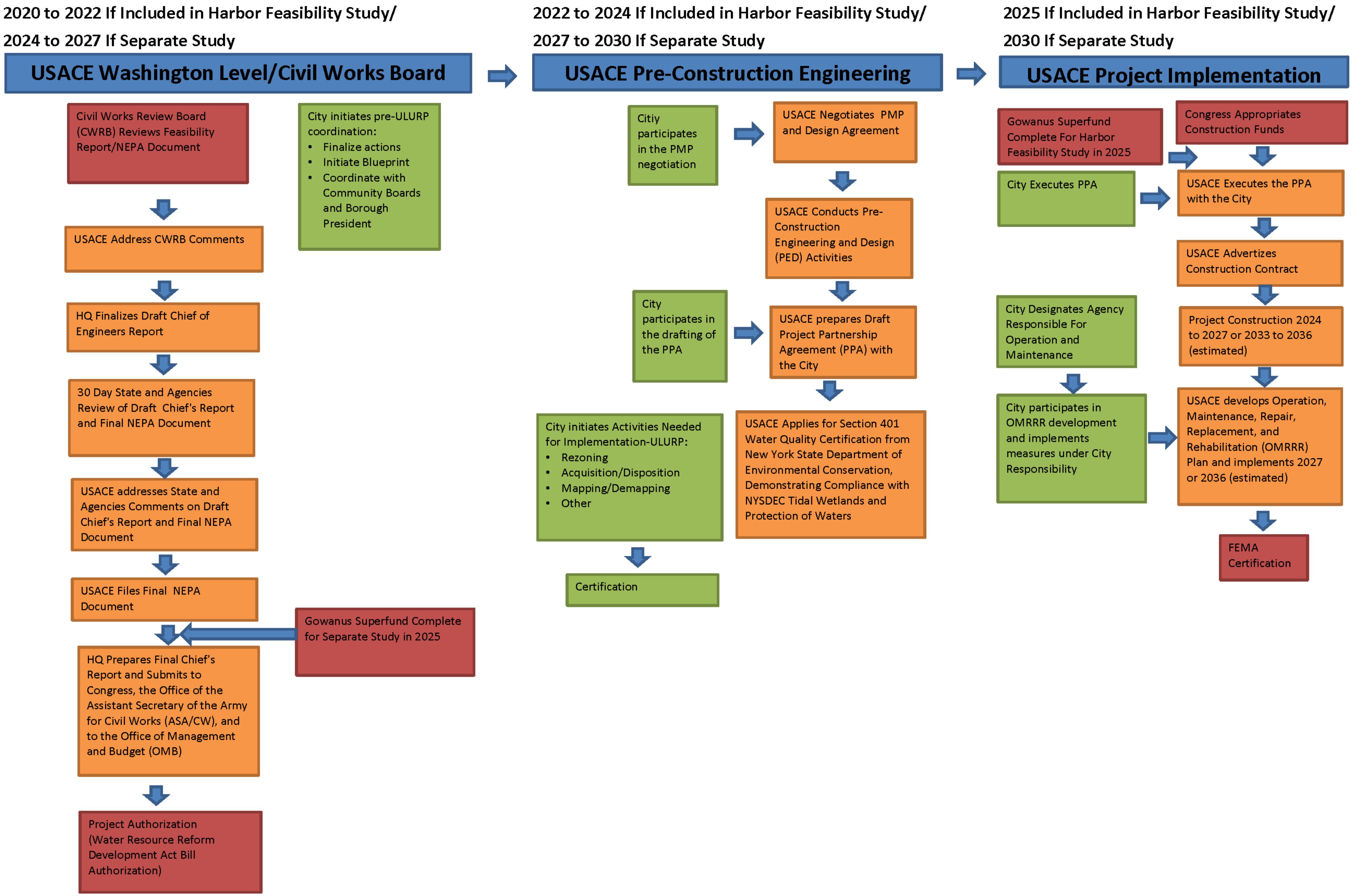

FIGURE 11-1C
Gowanus Canal Review

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11.2.4 USACE Preconstruction Engineering and design

Once authorized, USACE begins the preconstruction engineering phase by completing the PMP and Design Agreement with New York City. As the engineering and design nears completion, USACE prepares a Draft Project Partnership Agreement (PPA) with the City and upon execution, initiates its application for Section 401 Water Quality Certification from the New York State Department of Environmental Conservation (NYSDEC), which includes demonstrating compliance with NYSDEC Tidal Wetlands and Protection of Waters.

At this time, it would be expected that New York City would use the completed NEPA process as the fulcrum to initiate City actions requiring environmental review, most notably the ULURP process that will enable to the City to proceed with any future rezoning, land acquisition or disposition, and any street closures and demapping actions.

As shown in **Figure 11-1c**, it is expected that this phase will take about 2 years, with a potential completion date of 2024 with the Harbor Study and 2029 as an independent project.

11.2.5 Project Implementation

With the Draft PPA and NYSDEC certification, USACE would then obtain congressional authorization for the project and, with that in place, finalize and sign the PPA with the City. Under the scenario where the Gowanus project is included in the NY NJ Harbor and Tributaries Feasibility Study, the anticipated 2025 completion of the Gowanus Superfund project would occur during this stage. USACE then advertises and secures the construction contracts and the project can get under way. The project has an anticipated construction schedule of about 2 years. USACE and the City develop an Operation, Maintenance, Repair, Replacement, and Rehabilitation (OMRRR) Plan for implementation upon construction completion.

With the PPA executed, New York City must designate the agency responsible for O&M, and the City participates in OMRRR development and implements measures under City responsibility.

With the project complete, FEMA can then certify changes to the flood elevation maps based on the new protection measures.

Project Implementation is expected to take about 3 to 4 years total, concluding by 2028/2029 under the Harbor Study pathway or 2033/2034 under the independent project pathway.

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12 Funding Approach

12.1 Local Funding and Governance

The estimated capital costs for the storm surge barrier system are $108 million[1] and under United States Army Corps of Engineers (USACE) funding guidelines, New York City (City) would be responsible for 35 percent of capital costs, or $38 million. The City would also be responsible for operations and maintenance O&M costs, with an annualized estimate of $634,000; the PV of this annualized cost[2] is $15 million. Thus, the total cost to the City of protecting this area—which generates almost 15,200 jobs, $1.1 billion in earnings, and $3.2 billion in total output (**Table 12-1**)—is just more than $50 million. Establishment of an assessment district is a funding approach the study team explored for the Gowanus

12.1.1 Funding Scenario: Assessment District

Many of the benefits of a storm surge barrier system accrue to private property owners and, therefore, the City would be justified in trying to capture some of this value to meet its obligations for 35 percent of capital funding and all O&M costs. Furthermore, the Gowanus community has expressed an interest in raising local infrastructure funds through a value capture tool, in view of the fact that the Bridging Gowanus plan recommended a tax increment financing district.[3] A conceptual model of a more general assessment district suggests that this tool is a promising source of funds for O&M because districtwide net benefits would far exceed the required assessment, and average assessment rates would be well under 1 percent of assessed value. However, raising a significant share of capital costs would likely not be justified based on the benefits accrued and would represent relatively high financial burdens. The conceptual model was also used to test the sensitivity of the assessment rate to certain assumptions.

12.1.1.1 Base Case Model[4]

The funding potential of a special assessment district was tested under three different scenarios:

1. Size the assessment to fund all of the operations and maintenance costs;
2. Size the assessment to fund all of the local capital costs (i.e., 35 percent of total capital costs); and
3. Size the assessment to fund all of the O&M costs and local capital costs.

The results of this analysis (**Table 12-1**) show that full funding of O&M costs for a barrier system could be achieved through an assessment of properties equal to 0.61 percent of total assessed value. Funding the City's portion of capital costs would require an assessment more than four times the size.

TABLE 12-1
Assessment District Funding Scenarios

	Scenario 1: Fund All O&M Costs	**Scenario 2: Fund All Capital Costs**	**Scenario 3: Fund O&M and Capital**
Total Assessment	$10.5 M	$40.8 M	$51.3 M
Year 1 Assessment	$760,000	$3.28 M	$4,050,000
Total Assessed Value	$124,000,000	$124,000,000	$124,000,000
Year 1 Avg. Assessment Rate	**0.61%**	**2.64%**	**3.25%**

[1] This assumes the Hamilton Avenue alignment.

[2] Over a 50-year period with a 3.375 percent discount rate, the current rate for USACE water resources projects per USACE Economic Guidance Memorandum EGM15-01.

[3] Pratt Center for Community Development. 2015. "Bridging Gowanus Draft Planning Framework."

[4] The base case includes all properties in the Protected Area; assumes no future development or property value increases; applies a standard assessment rate to each property's non-exempt assessed value; assumes a 7 percent discount rate for property owners and a 6 percent interest rate for debt, with a 30-year term and 1.2 debt service coverage ratio; and counts as benefits only avoided property damages, not avoided business interruptions or other benefits.

The Protected Area contains properties with a wide range of types and values. This model assumes all properties contribute to an assessment district as a fixed percentage of their assessed value. **Table 12-2** contains the estimated assessment for sample properties, along with total estimated real estate taxes for comparison.

TABLE 12-2
Estimated Assessments for Sample Properties

Sample Property	***Est. FY15 Real Estate Tax***	**Scenario 1: Fund All O&M Costs**	**Scenario 2: Fund All Capital Costs**	**Scenario 3: Fund O&M and Capital**
3-unit, 3-story building	*$2,968*	$93	$401	$493
90-unit, 7-story building	*$499,504*	$23,651	$102,359	$126,010
100,000-square-foot warehouse	*$123,045*	$7,044	$30,484	$37,528

In order to contextualize the cost of an assessment, it must be compared to the value it creates for property owners, which, in this model, is assumed equal to the value of avoided flood damages. Results in **Table 12-3** suggest that the value of flood protection to property owners is far greater than the cost of an assessment district that funds O&M, so such a district appears justified. However, the value of avoided damages is on par with an assessment to fund capital costs, so it is likely not justified to seek all capital funds from such a district.

TABLE 12-3
Assessment District Return on Investment

	Scenario 1: Fund All O&M Costs	**Scenario 2: Fund All Capital Costs**	**Scenario 3: Fund O&M and Capital**
Total Assessment	$10.5 M	$40.8 M	$51.3 M
Total Benefits[5]	$42.6 M	$42.6 M	$42.6 M
Benefit/Assessment Ratio	4.1	1.0	0.8

12.1.1.2 Sensitivity Analysis

The assessment paid by each property owner will be sensitive to the total value of all properties in the district. To evaluate this sensitivity, the base case assumptions were varied in line with plausible alternative district inventories, including a fully built-out Protected Area,[6] a smaller protected area that includes only properties within the 100-year flood zone, and a district that exempted all residential area. Results in **Table 12-4** suggest the financial burden of an assessment district and, therefore, its feasibility, will depend on key decisions regarding the total inventory of assessable properties.

[5] Includes all NED benefits; if only structures and content damages and cleanup costs are considered, the benefit/assessment ratios are 3.4, 0.9, and 0.7.

[6] Projection assumes the theoretical rezoning scenario studied by the City Council Land Use Division, with manufacturing districts rezoned as R8A north of 3rd Street. Within this rezoning scenario, it assumes all parcels are fully built to 1 FAR commercial and 6.2 FAR residential and assessed at the same average rate as the existing inventory.

TABLE 12-4
Assessment District Sensitivity Analysis

	Base Case	**Full Build Out**	**100-Year Flood Zone**	**Excluding Residential**
Total Assessed Value	*$124 M*	$372 M	$78 M	$104 M
Year 1 Assessment Rate:				
Scenario 1: O&M	*0.61%*	0.20%	0.98%	0.73%
Scenario 2: Capital	*2.64%*	0.88%	4.22%	3.16%
Scenario 3: Capital and O&M	*3.25%*	1.09%	5.20%	3.90%

12.2 Areas for Further Study

While this initial evaluation suggests that the benefits created by a storm surge barrier system justify at least some value capture from local properties, the establishment of an assessment district would require more detailed studies to address the following issues:

- **Legal process.** Presently, the only common form of assessment district in the City is a business improvement district (BID), which typically funds security, sanitation, marketing, and other services in a business district, but may also issue debt to fund infrastructure. BIDs require support from local property owners and must be approved through a community process, culminating in legislation by City Council. A BID model could be implemented without authorization from the State of New York, but would require strong community support and would have a limited assessable inventory if it excluded residential properties. It is also possible to form other types of assessment districts, designed for specific purposes, but these would require legislation at the state level.
- **Distribution of benefits and financial burden.** This model shows that districtwide assessment costs compared favorably with districtwide avoided damages, but on the level of individual properties, this relationship likely will not hold. Many of the properties that are at greatest risk of flood damage and, therefore, would benefit the most from flood protection, do not have high assessed values. These properties would not be major contributors to the district if all properties were assessed at the same rate. Conversely, many new, high-value buildings will face little risk of flood damage, yet would contribute significantly to the assessment. The City must work with property owners toward a shared understanding that the actual benefits of flood protection extend beyond avoided building damage. Other benefits include avoided evacuations and business interruptions as well as neighborhood-level effects, such as retail corridors remaining in service, and these benefits apply to newer, more flood-resistant buildings as well. Based on a more complete understanding of benefits, a value capture tool would need to balance the proportionality of assessment to benefit and the desirability of a districtwide strategy, as well as the property owners' capacity to absorb additional costs.
- **Relationship to other public policy goals.** Related to the distribution of financial burden, the City will need to balance funds raised for flood protection with funds raised or development regulations imposed to further other public policy goals, including industrial preservation and housing affordability.

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13 Conclusions

13.1 Study Findings

The Gowanus Canal is a channelized water body surrounded by the Gowanus neighborhood. The low-lying lands on either side of the Canal are subject to flood hazard, as waters from Gowanus Bay are brought inland by the Canal. Hurricane Sandy demonstrated these areas' vulnerability, with more than 150 acres of land along the Canal inundated by the storm.

- A storm surge barrier system could successfully limit risk at Gowanus Canal up through the 500-year storm event, based on a +17-foot NAVD88 design flood elevation, and enable New York City (City) to achieve three essential goals:
  - Protecting Socially Vulnerable Residents. The Protected Area[1] surrounding the Canal is home to 7,000 residents, many of whom are low-income inhabitants and face other challenges indicating social vulnerability, and most of whom live in older buildings not built to flood-resistant standards. Furthermore, if the area were rezoned to allow more residential development as has been proposed by local elected officials, this population would grow considerably, particularly within the 100-year flood zone.
  - Protecting Jobs and Businesses. Gowanus is a unique mixed-use neighborhood, with more than 100 traditional and innovative industrial businesses and a thriving arts community in close proximity to residences. Although overall density of commercial activity is low, there are still more than 2,500 jobs in the Protected Area—including those in industrial sectors—performing critical functions within the local economy and providing employment opportunities for those with low educational attainment or limited English language proficiency, as well as minorities and immigrants.
  - Protecting Critical Infrastructure: The Protected Area includes the F and G train subway lines, which run above ground long 9th Street between Smith Street and 4th Avenue, but have vulnerable entrances, the elevated Gowanus Expressway viaduct that runs over Hamilton Avenue, operable bascule bridges crossing the Gowanus Canal at Hamilton Avenue, 9th Street, 3rd Street, Carroll Street and Union Street, as well as a handful of water treatment/power stations, fuel and waste stations and food manufacturing facilities.
- Any project at Gowanus Canal will present challenges, require significant investment, and require close coordination with agencies, regulatory bodies, and the community to explain the risks and the tradeoffs at stake in adopting a solution.
- The preferred concept option is the Hamilton Avenue ROW alignment.
  - It minimizes disruption to business activities by avoiding active berths and driveways to the extent possible. Operable gates ensure access to essential facilities, such as the New York City Department of Transportation (NYCDOT) Asphalt Plant and the City of New York Department of Sanitation (DSNY) Marine Transfer Stations (MTS).
  - It has a relatively simpler legal and planning process as it is erected almost entirely in the public ROW, and includes potential for integration with existing infrastructure under the Gowanus Expressway.
  - There is potential to integrate with the future greenway along Hamilton Avenue that may run along the southernmost lane and for which the upland defenses could provide a buffer from vehicular traffic.

[1] Unless otherwise noted, "Protected Area" includes all properties that would be inundated during a 500-year flood event without the project, but would not be inundated with the project, as identified through hydrodynamic modeling of a barrier along the Hamilton Avenue alignment.

- It is anticipated that it could convey a positive return on investment for the City and its partners, though the Protected Area is limited geographically and a more detailed study is required for a definitive answer. The preliminary Benefit-Cost Ratio (BCR) at this conceptual stage was found to range between 0.59 and 1.15. The range reflects the project benefit's sensitivity to the replacement structure values used in quantifying avoided damages and the variation in construction estimation data sets such as Marshall & Swift (M&S) as compared to local construction market intelligence.
    - Capital costs are estimated at $108 million.
    - Operations and maintenance (O&M) costs are estimated to be $626,000 on an annualized basis or $15 million on a 50-year present value basis.
    - The present value of expected annual damages (EAD) for the 50-year period of analysis, the benefits, are $74 million or $3.1 million annualized.
    - Net benefits are estimated at ($52) million based on one data set. However, the value of avoided damages relies significantly on the real estate construction values used and could be substantially greater.
    - Construction estimation data sets, such as M&S, understate the value of avoided damages. A future detailed feasibility study should include research and verification of market construction values for New York City.
    - Greatest uncertainty and cost risk are likely to come from barrier gate sizing, stormwater pumping or storage requirements, utility and service diversions, environmental remediation separate from Superfund works, Red Hook tie-in requirements, land acquisition, and legal challenges. These are areas that should be further investigated at a complete feasibility study stage beyond this initial study.
    - The benefits reflected in the BCR are limited to avoided damages. The future feasibility study stage should expand the criteria to capture and monetize the broader set of benefits.
- The major weakness of the Hamilton Avenue ROW alignment is its reliance on deployable components and the associated O&M requirements, although any Gowanus Canal storm surge barrier system will require some deployable components due to the existing urban fabric and activities being performed.
    - Mobilization activities in a storm event are more complex and require more lead time than a permanent barrier solution.
    - Nearby equipment storage areas would need to be identified.
- Easements or land acquisition to support access and operations are likely to be required. The two most critical sites are those adjacent to the east and west of the Hamilton Avenue Bridge. The first 90 to 100 linear feet of berth at the asphalt plant would be behind the barrier and lost to barge use.

- The alternate concept option is the 19th Street alignment.
    - It has major adverse impacts on commercial and industrial activities in the area, including operable gates across active berths, and significantly alters movement along 19th Street. Parking, loading spaces, and 19th Street access to Sunset Industrial Park would be lost.
    - It has a more complex legal and planning process and will require easements along private waterfront parcels and additional coordination with the Superfund remediation works.
    - Despite substantially larger estimated capital costs, the 19th Street alignment is not anticipated to convey proportionally greater benefits. The preliminary BCR at this conceptual stage was found to range between 0.47 and 0.93.
        - There is very little difference in the zones of protection provided by the 19th Street and Hamilton Avenue ROW concept options, and, even using larger locally adjusted construction

values to calculate the avoided damages, this alternate concept option fails to achieve a BCR approaching or exceeding one.

- Capital costs are estimated at $160 million.
- O&M costs are estimated at $739,000 on an annualized basis or $17.7 million on a 50-year $ present value basis.
- The present value of expected annual damages (EAD) for the 50-year period of analysis, the benefits, are $86 million or $3.6 million annualized.
- Net benefits are estimated at ($97) million, but could be substantially greater in value when local construction market values are factored into the analysis.

- A storm surge barrier project at the Canal could help community members realize substantial savings through both reduced flood insurance premiums and avoided mandatory floodproofing costs.
- The ultimate configuration of a Red Hook alignment, which would be constructed prior to any Gowanus Solution, will dictate where tie-ins between the two flood defense systems are ultimately placed. Early coordination efforts during the planning stages for the Red Hook IFPS can help to ensure that future Gowanus connections are considered.
- As part of coordination and initial planning between the City and USACE for a full feasibility study, a policy decision will be required to set the design flood elevations (DFE) and the level of risk reduction for the project to achieve.
  - This study assumed a conservative +17-foot NAVD88 DFE.
  - Federal policy may dictate that funded projects be built to a DFE lower than that assumed in this study. This could impact minimum design elevations and funding limits.
  - City preference for greater risk reduction may require a LPP, in which the City is financially responsible for capital costs beyond the USACE plan. Alternatively, the City might consider a gradual approach, expanding the barrier and increasing the height over time.
- There are limited opportunities to incorporate habitat enhancement as part of a storm surge barrier system. Crevices and habitats might be designed into a barrier structure or bulkhead surfaces supplemented with material to promote bivalve or crab colonization.
- A high-level flushing analysis found that in-water barriers do not appear to worsen tidal exchange at Gowanus Canal. The flushing tunnel provides sufficient flow to offset any marginal effects from the barrier.
- The preliminary rainfall and storage capacity analysis performed found that longer duration storms likely cannot be contained within Gowanus Canal.
  - In this simplified analysis, storms larger than the 1-hour, 1-year event rainfall volume were not contained within the canal system.
  - Storm water pump stations will almost certainly be required as part of a storm surge barrier system. Conceptual cost estimates built up for this study have made an allowance for an additional storm water pump station for all concept options.
  - A detailed surface water and drainage study will need to be performed as part of a complete feasibility study.
- Given the industrial history of the study area, especially heavy industrial and automotive uses, future environmental site investigations will need to be performed as part of a feasibility study to determine whether hazardous material remediation may be required along the alignment. Primary contaminants of concern include petroleum, metals, solvents, coal tar, and creosote.

- A complex regulatory arena, comprising federal, state, and City reviews and approvals, will need to be navigated as part of any future project implementation.
- Future studies, investigations, and analyses that are anticipated to be scoped into a detailed feasibility study in order to refine cost and benefit estimates include, but are not be limited to:
  - Elevation spot checks of LIDAR data as part of storm surge modeling.
  - Comprehensive drainage and water quality modeling, including combined probability analysis of storm surge and rainfall events.
  - Sampling and detailed environmental site investigations on parcels along the storm surge barrier alignment.
  - Utility investigations and as-needed service diversions or relocations studies.
  - Real estate studies and plans.
  - Expanded benefits quantification and monetization such as avoided relocation costs, avoided business interruptions, preserved services and protected infrastructure, and green infrastructure secondary benefits

13.2 City Actions and Next Steps

Although United States Army Corps of Engineers (USACE) would likely not complete construction and implementation of a project until after the completion of Superfund remediation in 10-plus years, there is much that the City can do in the meantime to prepare for a storm surge barrier system. Many of these actions apply not only to a Gowanus Canal storm surge barrier system, but could also apply to other flood control projects throughout the City; therefore, they should be pursued independent of the timeline or feasibility of this project. Some actions will help to secure funding while other actions can increase the likelihood of obtaining USACE funding, foster local support, and improve flood management tools.

13.2.1 Establish Flood Protection Funding and Financing Mechanisms

The estimated capital costs for the storm surge barrier system are $108 million[2] and, under USACE funding guidelines, the City would be responsible for 35 percent of capital costs, or $38 million. The City would also be responsible for O&M costs, with an annualized estimate of $634,000; the PV of this annualized cost[3] is $15 million. Thus, the total cost to the City of protecting this area—which generates nearly 15,200 jobs, $1.1 billion in earnings, and $3.2 billion of total output—is just more than $50 million.

The City can take actions now to limit the total public expenditure necessary to fund the construction and O&M of a barrier system. By creating a special assessment district for the properties that benefit from flood protection, the City can raise at least some portion of its funding obligations.

13.2.2 Refine Cost Estimating Methodology with USACE

The avoided damages methodology applied in this study relies on the M&S valuation system, consistent with other USACE flood control projects, but likely underestimates actual avoided damages. This could result in an underestimation of the project’s net benefits and BCR, and reduced potential for federal funding. It is critical that the City, in consultation with USACE, develop a cost estimating methodology that is in line with federal guidelines but also captures the true cost of construction in the City.

This study’s preliminary investigation into the differences between the M&S replacement costs and data from local developers found significant variation between estimated values. Substituting market-based cost estimates for the M&S replacement costs resulted in an increase to the avoided damages benefit and ultimately lifted the Hamilton Avenue ROW concept option’s BCR above 1.0.

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[2] This assumes the Hamilton Avenue alignment.

[3] This assumes the Hamilton Avenue alignment.

Beyond the fact that the M&S valuation system employed for USACE purposes may underestimate total replacement costs, there are a number of factors that suggest that actual replacement costs may be greater than would be recognized by USACE:

- **National and Local Cost Escalation.** Nationally, construction costs are escalating at rates significantly faster than inflation; NYC construction costs are escalating at a rate faster than the national average.[4] For a project that is still decades away from implementation, this escalation will have a significant impact on valuation.
- **Public Processes.** The prevalence of public reconstruction funding can introduce regulations and bureaucracy that increase costs directly and through project delays.
- **Post-Disaster Premiums.** Demand for construction labor and materials spikes after a disaster; M&S guidelines suggest that materials and labor can increase 30 to 50 percent following natural disasters.

It is understood that the NYC Emergency Management is presently undertaking an interagency effort to document and understand actual costs to the City from Hurricane Sandy, including replacement costs, service disruption impacts, and other factors. These values may be a potential data source for more accurate benefits calculations that could be incorporated into a detailed feasibility study.

13.2.3 Build Support

While construction of a barrier may still be decades in the future, it is not too early to begin building support among local stakeholders and congressional representatives.

13.2.4 Establish Administrative Processes

As climate change continues to increase the risk of floods, it will become increasingly important to efficiently approve, permit, and implement flood defense projects. Other flood defense projects currently under way, such as East Side Coastal Resiliency and Red Hook Integrated Flood Protection, which will be implemented far in advance of a Gowanus Canal storm surge barrier; it is important that lessons learned from those projects are institutionalized. The Gowanus Canal barrier system would be different from these other projects because it contains an in-water barrier, which presents unique challenges of implementation and operation.

13.2.5 Acquire Strategic Parcels or Easements

Certain strategic parcels will be necessary for barrier construction and maintenance. Establish a real estate plan that identifies where such parcels and land are anticipated to be required and monitor those parcels. Swift action by the City to acquire parcels or easements may lead to much smoother and less costly future implementation of the project.

13.2.6 Define Approach to Surface Water Flood Mitigation

While a Gowanus Canal storm surge barrier system can protect a vast area from storm surge, it will not alleviate flooding from stormwater. The Department of Environmental Protection must continue to refine its approach to stormwater management and implement solutions that are integrated with storm surge defense projects.

[4] NYC Building Congress. 2015. "New York City Construction Costs on the Rise."

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Part IV:
Supporting Analysis and Background Documents

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