US Army Corps of Engineers®
New York District

# Appendix B
# Engineering Appendix

# DRAFT

# New York – New Jersey Harbor and Tributaries Coastal Storm Risk Management Feasibility Study

**September 2022**

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## Glossary

| Term/Acronym | Expanded | Definition |
|---|---|---|
| **ADCIRC model** | ADvanced CIRCulation model | Computational model for predicting wind, wave, and storm surge conditions of tropical and extratropical cyclones |
| **AdH Model** | Adaptive hydraulics model | a high fidelity computational tool capable of simulating estuarine and riverine flows, hydrodynamics in reservoirs, and lakes, flows due to dam and levee breaches, continental scale flows, flows due to compound flooding, non-hydrostatic free surface flows, and all associated transport phenomenon. |
| **ADM** | USACE Agency Decision Milestone | |
| **AEP** | annual exceedance probability | the probability that at least one event in excess of a particular magnitude will occur in any given year |
| **Aesthetic valuation** | | A judgement of value based on appearance of an object or emotional response. |
| **AMM** | USACE Alternatives Milestone Meeting | |
| **ASA(CW)** | Assistant Secretary of the Army (Civil Works) | an office of the United States Department of the Army responsible for overseeing the civil functions of the United States Army |
| **ATR** | Agency Technical Review | |
| **BCR** | benefit to cost ratio | |
| **CBRA** | Coastal Barrier Resources Act | |
| **CERCLA** | Comprehensive Environmental Response, Compensation, and Liability Act | |
| **CFR** | Code of Federal Regulations | |
| **closure criterion** | | The forecast water level for which operation of the storm surge barrier is authorized. For this study, this is assumed to be +7 feet NAVD 88 |
| **closure elevation** | | The observed water level at which the mechanical procedure to close storm surge barrier gates is executed |

| Term/Acronym | Expanded | Definition |
|---|---|---|
| **CSO** | Combined Sewage Outfalls | |
| **CSRM** | coastal storm risk management | |
| **CZMA** | Coastal Zone Management Act | |
| **Deepwater ecoystems** | Coastal ecosystems with bed elevation between -2m and -20m below Mean Sea Level (MSL) | |
| **DOI** | Department of Interior | an executive department of the U.S. Government responsible for the management and conservation of most federal lands and natural resources |
| **DRSAA** | Disaster Relief Supplemental Appropriations Act | |
| **EFH** | Essential Fish Habitat | |
| **EIS** | Environmental Impact Statement | |
| **EJ** | Environmental Justice | |
| **elevation** | | The height of an object relative to an established datum such as mean sea level |
| **EOP** | Environmental Operating Principles | |
| **EPA** | Environmental Protection Agency | |
| **EQ** | environmental quality | |
| **ERDC** | U.S. Army Engineer Research and Development Center | |
| **ESA** | Endangered Species Act | |
| **Estuarine Ecosystems** | Coastal ecosystems with salinity from 0.5 to 28 ppt | |
| **ESI** | Environmental Sensitivity Index for shorelines from the National Oceanic and Atmospheric Administration | |
| **FCSA** | Fiscal cost share agreement | |
| **FEMA** | Federal Emergency Management Agency | |
| **FIRM** | Fire Insuranve Rate Map | |
| **Freshwater Ecosystems** | Coastal ecosystems with low salinity < 0.5 ppt | |
| **FWOP** | future without project | |
| **FWOPC** | future without project condition(s) | |
| **FWP** | future with project | |
| **FWPC** | future with project condition(s) | |
| **GIS** | Geographic Information System | |

| Term/Acronym | Expanded | Definition |
|---|---|---|
| **HEC-FDA** | Hydraulic Engineering Center Flood Damage Reduction Analysis | USACE software used to assess economic benefits of flood protection projects |
| **height** | | A measurement from one fixed point to another fixed point |
| **HFFRRF** | high-frequency flood risk reduction features | |
| **HR** | Hudson River | |
| **HTRW** | Hazardous, Toxic, and Radioactive Waste | |
| **HUC** | Hydrologic Unit Code | |
| **IFF** | induced flooding mitigation feature[1] | Features used to offset the impacts of increased water levels due to the presence of a storm surge barrier |
| **IMPLAN** | IMpact analysis for PLANning | A software and database program that estimates input-output models based on data and assumptions of social accounting and multipliers. |
| **Intertidal Ecosystems** | Coastal ecosystems with bed elevation between Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) | |
| **IPCC** | Intergovernmental Panel on Climate Change | |
| **IPR** | In-Progress Review | |
| **IWR** | Institute for Water Resources | |
| **JB** | Jamaica Bay | |
| **Marine Ecosystems** | Coastal ecosystems with low salinity >= 28 ppt | |
| **MBTA** | Migratory Bird Treaty Act | |
| **MHHW** | Mean Higher High Water | The average of the higher high water height each tidal day observed over AdH simulation period |
| **MLLW** | Mean Lower Low Water | The average of the lower low water height each tidal day observed over AdH simulation period |
| **MMPA** | Marine Mammal Protection Act | |

[1] Formerly also referred to as induced flooding features.

| Term/Acronym | Expanded | Definition |
|---|---|---|
| **MSA** | Magnuson-Stevens Fishery Conservation and Management Act | |
| **MSL** | mean sea level | |
| **NACCS** | North Atlantic Coast Comprehensive Study | |
| **NAVD88** | North American Vertical Datum of 1988 | The vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-United States leveling observations |
| **NED** | national economic development | |
| **NEPA** | National Environmental Policy Act | |
| **NJ** | New Jersey | |
| **NJDEP** | New Jersey Department of Environmental Protection | |
| **NLT** | no later than | |
| **NMFS** | National Marine Fisheries Service | |
| **NNBF** | Natural and nature-based feature | Landscape features that are used to provide engineering functions relevant to flood risk management, while producing additional economic, environmental, and/or social benefits Examples of NNBF include beaches and dunes; vegetated environments such as maritime forests, salt marshes, freshwater wetlands and fluvial flood plains, and seagrass beds; coral and oyster reefs, barrier islands, among others |
| **NOAA** | National Oceanic Atmospheric Administration | |
| **Nonstructural Measure** | | Permanent or contingent (deployable, or temporary) measures applied to a structure and/or its contents that prevent or provide resistance to damage from flooding. |
| **NPS** | National Park Service | |
| **NWS** | National Weather Service | |
| **NY** | New York (State) | |
| **NYBEM** | New York Bight Ecological Model | |
| **NYC** | New York City | |
| **NYDOS** | New York Department of State | |
| **NYNJHAT** | New York New Jersey Harbor and Tributaries | |

| Term/Acronym | Expanded | Definition |
|---|---|---|
| **NYNJHAT** | New York New Jersey Harbor and Tributaries Study | |
| **NYSDEC** | New York State Department of Environmental Conservation | |
| **OFC** | Other first costs | |
| **OHSIM** | Oyster Habitat Suitability Index Model | |
| **OMRR&R** | Operations, Maintenance, Repair, Rehabilitation & Replacement | |
| **OSE** | other social effects | |
| **PDT** | project delivery team | |
| **PED** | preconstruction, engineering, and design | |
| **ppt** | parts per thousand | |
| **RECONS** | Regional ECONomic System | a model designed to provide estimates of regional economic impacts and contributions associated with Corps projects, programs, and infrastructure across Corps Civil Works business lines |
| **RED** | Regional economic development | |
| **REMI** | Regional Economic Model, Inc. | Input/output regional economic model |
| **RRF** | risk reduction feature[2] | features to reduce the residual coastal flood risk prior to closure of a given SSB |
| **RSLC** | relative sea level change | |
| **S&A** | State and Agency (Review) | |
| **SAV** | submerged aquatic vegetation | |
| **SBM** | shore-based measure | On-land perimeter measures such as levees, floodwalls, dunes, promenades, etc., that are constructed to impede coastal storm surge |
| **SSB** | storm surge barrier | In-water measure consisting of navigable and auxiliary gates which can be opened and closed to impede storm surge or tides from entering an area vulnerable to coastal flooding. |

[2] Formerly also referred to as residual risk feature.

| Term/Acronym | Expanded | Definition |
|---|---|---|
| **Still Water Overtopping** | | the amount of water flowing over the crest of a coastal structure such as a seawall, a dike, a breakwater, due to still water only |
| **STP** | Sewage Treatment Plant | |
| **Structural Measure** | | Permanent measures that prevent or provide resistance to damage from flooding. Also called "grey infrastructure." |
| **Subtidal Ecosystems** | Coastal ecosystems with bed elevation between Mean Lower Low Water (MLLW) and -2m below Mean Sea Level (MSL) | |
| **SWL** | Still Water Level | Average water surface elevation at any instant, excluding local variation due to waves and wave set-up, but including the effects of tides, storm surges and long period seiches |
| **TEU** | Twenty-foot Equivalent Unit | a unit of cargo capacity generally used for container ships and container handling facilities |
| **trigger elevation** | | |
| **TSP** | Tentatively Selected Plan | |
| **US** | United States | |
| **USACE New York District** | U.S. Army Corps of Engineers North Atlantic Division New York District | |
| **USACE North Atlantic Division** | U.S. Army Corps of Engineers North Atlantic Division New York District | |
| **USFWS** | U.S. Fish & Wildlife Service | |
| **USGS** | U.S. Geological Survey | |
| **VN** | Verrazano Narrows | |
| **VT** | Vertical Team | USACE internal project team consisting of members across all three levels of USACE: district, division, and HQ |
| **Wave Overtopping** | | the amount of water flowing over the crest of a coastal structure such as a seawall, a dike, a breakwater, due to wave action |
| **Wave Runup** | | Wave run-up is the maximum onshore elevation reached by waves, relative to the shoreline position in the absence of waves |
| **WPCP** | Water Pollution Control Plant | |

| Term/Acronym | Expanded | Definition |
|---|---|---|
| **WRDA** | water resources development act | a series of acts, usually biannual, which authorize funding for a variety of studies and projects, including beach nourishment, clean water, and flood control programs |
| **WSE/WSEL** | Water surface elevation | |
| **WWTP** | Wastewater Treatment Plant | |

# 1 Project Overview

## 1.1 Introduction

The North Atlantic Coast Comprehensive Study (NACCS) was conducted to address the flood risks of vulnerable coastal populations in areas that were affected by Hurricane Sandy within the boundaries of the North Atlantic Division of the U.S. Army Corps of Engineers (USACE). The New York/New Jersey Harbor and Tributaries (HAT) area was identified as a "focus area" within the NACCS study. This Engineering Appendix to the New York/New Jersey Harbor and Tributaries Feasibility Study (HATS) contains the technical narrative to explain the analyses, engineering and design work completed to layout and evaluate potential structural and non-structural solutions to manage coastal storm risk in the study area.

The engineering analyses have been conducted under USACE's SMART planning principles. SMART planning documents propose an approximate 10% level of design development, documentation of risks and efforts to mitigate risks, and decisions made to expedite the opportunity for public and agency comment on the study's recommendation. Detailed design decisions are typically deferred to the Planning, Engineering, and Design phase. In this context, this Engineering Appendix provides an overview of the analyses supporting the Coastal Storm Risk Management (CSRM) measures proposed as part of the five feasibility study alternatives.

## 1.2 Background and History

In 2012, Hurricane Sandy caused considerable loss of life, extensive damage to property, and massive disruption to the North Atlantic Coast. The effects of this storm were particularly severe because of its tremendous size and the timing of its landfall (during high tide on the Atlantic Coast). Twenty-six states were impacted by Hurricane Sandy, and disaster declarations were issued in thirteen states. New York and New Jersey were the most severely impacted states, with the greatest damage and most fatalities in the New York Metropolitan Area. For example, storm surges of 12.65 feet and 9.4 feet above normal high tide were reported at Kings Point on the western end of Long Island Sound and the Battery at the southern tip of Manhattan, respectively. Flood depths due to the storm tide were as much as 9 feet in Manhattan, Staten Island, and other low-lying areas within the New York Metropolitan Area. The storm exposed vulnerabilities associated with inadequate CSRM measures and lack of mitigating measures to deal with flood risk for critical transportation and energy infrastructure. Devastation in the wake of Hurricane Sandy revealed a need to address the vulnerability of populations, infrastructure, and resources at risk throughout the entire North Atlantic coastal region. At the time of the publication of this report, Hurricane Sandy is the second costliest hurricane in the nation's history and the largest storm of its kind to hit the U.S. East Coast.

In response to Hurricane Sandy and other historical storms that have severely impacted New York and New Jersey, causing loss of life and extensive economic damages, USACE is investigating measures to manage future flood risk in ways that support the long-term resilience and sustainability of the coastal ecosystem and surrounding communities, and reduce the economic costs and risks associated with flood and storm events for the New York-New Jersey Harbor and Tributaries (NYNJHAT) study area. The alternative concepts proposed would help the region manage flood risks that are expected to be exacerbated by relative sea level rise (RSLC).

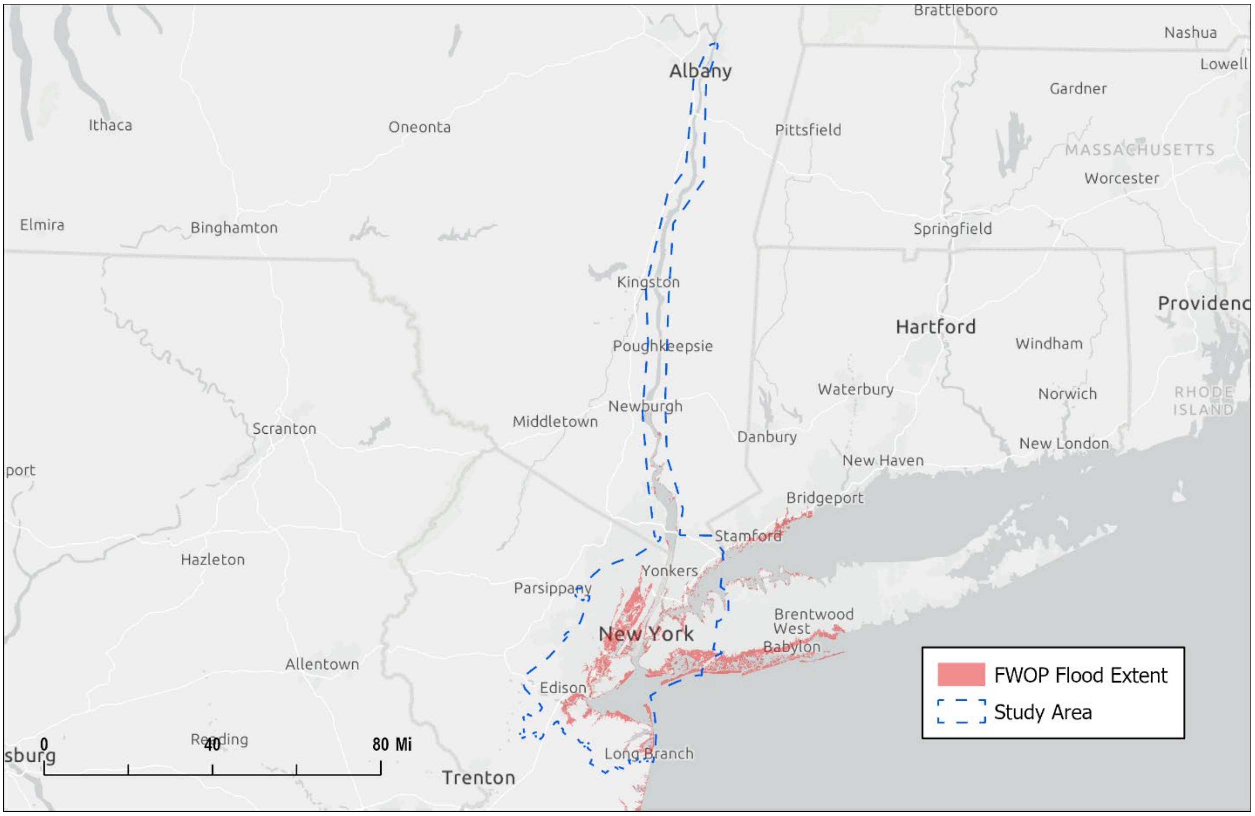



**Figure 1-1: Flood Risk for the study area (1% AEP Flood Extent including Intermediate SLR up to the year 2095)**

## 1.3 Study Alternatives

The study area covers more than 2,150 square miles and comprises parts of 25 counties in New Jersey and New York. During coastal storms, storm surges are generated on the open coast and propagate through New York Harbor or through the Long Island Sound with the potential to flood the extensive low-lying areas surrounding the metropolitan area. The feasibility study includes five principal alternatives that can function as flood risk reduction systems; the Alternatives are listed in Table 1-2. The reader is referred to the main body of the feasibility study report for a detailed description of the planning framework and formulation of the array of alternatives to establish flood risk reduction for the region.

### 1.3.1 Service Life and Functional Requirements

The project will perform to meet the design criteria related to flood risk reduction in this document for a 50-year period spanning the years between 2045 and 2095. The project is to be designed for the 1% Annual Exceedance Probability (AEP) still water level (SWL). The project shall account for sea level rise, regional subsidence, and local settlement occurring for 50 years, assuming project construction completion in 2045. After such a time, to achieve the same level of risk reduction, the plan would likely have to be adapted.

The following functional requirements of the structural CSRM measures have been identified consistent with the overall objectives of the NYNJHAT Study:

1) The CSRM measures shall provide a reliable structural measure as part of the NYNJHAT Study alternatives to reduce the risk of coastal storm damage to the region behind it for the 1% AEP coastal storm event (including intermediate Sea Level Rise (SLR) up to the year 2095).
2) The measures seek to avoid or minimize adverse impacts on existing infrastructure, land use, and the natural and built environment.

### 1.3.2 Study Alternatives' Structural Components and Description

The six alternatives for the NYNJHAT Study (no action, and five project alternatives) presented in the body of the main feasibility report represent scales of solutions: system-wide, basin-wide, or site-specific CSRM solutions. During project scoping, the basic outline of each of these alternatives was set and then refined during the feasibility study phase. Each study alternative, other than the no-action alternative and Alternative 5, originally consisted of a flood risk reduction system that combined storm surge barriers and Shore-Based Measures (SBM). Alternative 5 only included shore-based measures. Storm surge barriers are the large in-water, gated, navigable barriers which are unique civil works on their own. Shore-based measures are the typical flood risk reduction features on land that, when combined, form a reach of the CSRM system. In other words, SBMs are the collective of all structural CSRM measures other than storm surge barriers.

Over the course of the feasibility study, two additional categories of measures were added to address two specific types of flood risk. These flood risks are:

1) Induced Flood Risk: This refers to an increase in flood levels as a result of the proposed project. For example, the presence of a structural measure that is part of an alternative (e.g., storm surge barrier) is an effective impediment to the storm surge but can cause peak storm surge levels on the ocean side of the storm surge barriers to marginally increase as compared to the condition without the storm surge barrier being present.
2) Residual Flood Risk: Residual flood risk in general is the flood risk that remains considering that the project reduces the flood risk but does not completely eliminate flood risk. In the NYNJHAT Study context, it also specifically refers to the flood risk that remains for the coastlines "behind" the storm surge barriers. Storm surge barriers will only be closed for extreme events (an operating closure criterion will be set for each storm surge barrier – more details discussed in section 4.3), and flood risk remains for the coastal areas served by the storm surge barrier up to the elevation of the closure criterion. As such, flood risk associated with a more frequent coastal flood event remains for low-lying coastal areas behind a storm surge barrier because the storm surge barrier may not be operated for such events.

As a result of the identification of these processes and the need to address them, Induced Flooding mitigation Features (IFFs) and Risk Reduction Features (RRFs) were introduced to address the two respective flood risk conditions identified above. Where storm surge barriers are proposed (Alternatives 2, 3A, 3B, and 4), complementary RRFs (to manage the risk of frequent flooding) and IFFs (to manage induced flooding) are also proposed, which aim to provide an integrated solution. As a result, the NYNJHAT Study Feasibility Report includes the terms SBM, IFFs, and RRFs when describing structural CSRM measures at the shoreline or on land and includes the term "storm surge barrier" when describing the large in-water structures with gated navigable openings. A brief description of the most frequent used terms and acronyms and the flood risk associated with each is provided in Table 1-1 below.

**Table 1-1: NYNJHAT Study Terminology**

| Acronym | Term | Description | Design Event |
|---|---|---|---|
| **SSB** | Storm Surge Barrier | SSBs are in-water structures with an opening (or openings) to allow for the passage of flow and vessels during normal day-to-day conditions. These openings are gated and can be closed such that the structure effectively impedes the storm surge and provide flood risk reduction for the region upstream of the barrier. | 1% AEP flood level |
| **SBM** | Shore-Based Measure | SBMs are designed to provide flood risk reduction for 100-year Return Period (RP) storm events (1% Annual Exceedance Probability (AEP)) in 2095 for areas that are not protected by storm surge barriers. The alignments of SBMs for each study alternative were developed by USACE during plan formulation, with further modifications and refinements made over the course of the feasibility study phase where appropriate. | 1% AEP flood level |
| **IFF** | Induced Flooding mitigation Feature | IFFs are equal and equivalent to SBMs and are only distinguished as IFFs because they provide flood risk reduction for areas subject to induced flooding. | 1% AEP flood level |
| **RRF** | Risk Reduction Feature | Where storm surge barriers are proposed (Alternatives 2, 3A, 3B, and 4), complementary measures to manage the risk of frequent flooding are also proposed. RRFs mitigate residual flood risk under the assumption that the storm surge barrier (SSB) closure criterion is El. +7 ft NAVD88. | Up to the +7 ft NAVD88 flood level |

Each alternative consists of various CSRM Measures both structural and non-structural, but it is recognized that the non-structural measures are fairly limited compared to the overall scale of the structural measures. The following table provides a high-level overview of each of the alternatives considered, and Figure 1-2 through Figure 1-6 present each of the alternatives and highlights the location of the SSBs, SBMs, IFFs and RRFs. Additional detail on these measures is provided within this appendix and its supporting materials (e.g., see Annex D of the SBM Sub-Appendix).

### Table 1-2: NYNJHAT Study Alternatives – Structural Measure Overview

| Alt. | Areas that see flood risk reduction as a result of the Alternative | Structure Type | Location Description of Features and Measures |
|---|---|---|---|
| **1** | None. | | No Action Alternative. |
| **2** | Most of the NYNJHAT Study area. | SSBs | Outer Harbor (OH) and Throgs Neck (TN); |
| | | SBMs | Tie-ins to TN SSB and tie-ins to OH SSB |
| | | IFFs | Along shorelines at the western end of the Long Island Sound. IFFs include additional SSB structures. |
| | | RRFs | Within the newly created basin between the OH and TN SSB. |
| **3A** | A large portion of the NYNJHAT Study area. | SSBs | Arthur Kill (AK), Verrazzano Narrows (VN), Throgs Neck (TN), Jamaica Bay (JB), Sheepshead Bay (SB), Gerritsen Creek (GRC). |
| | | SBMs | Tie-ins to the JB SSB, tie-ins to VN SSB, tie-ins to AK SSB and tie-ins to TN SSB. |
| | | IFFs | Along shorelines at the western end of the Long Island Sound, IFFs at Breezy Point and IFFs in the Lower Bay along the Staten Island and Jersey shoreline. IFFs include additional SSB structures. |
| | | RRFs | Within the newly created basin between the AK, VN and TN SSB and within Jamaica Bay, upstream of the JB SSB. |
| **3B** | Inland NJ areas (incl port, oil terminals and Newark airport) and west side of Staten Island as result of SSBs. In addition, areas with relative high flood risk in NYC. | SSBs | AK, Kill van Kull (KVK), JB, Flushing Creek (FC), SB, GRC, Newtown Creek (NC), Gowanus Canal (GC). |
| | | SBMs | Tie-ins to the JB SSB, tie-ins to the AK SSB, tie-ins to KvK and tie-ins to the FC SSB. In addition, SBMs in the Red Hook neighborhood tied into the GC SSB and SBMs in Long Island City tied into the NC SSB. SBMs along the shorelines of Jersey City, the south side and west side of Manhattan and SBMs along the Harlem River. |
| | | IFFs | At Breezy Point and IFFs in the East River and Harlem River. |
| | | RRFs | Within the newly created basin between the AK and KVK SSB and within Jamaica Bay, upstream of the JB SSB. |

| Alt. | Areas that see flood risk reduction as a result of the Alternative | Structure Type | Location Description of Features and Measures |
|---|---|---|---|
| **4** | Only the areas with higher flood risk or smaller tributary basins in NYNJHAT study area. | SSBs | Hackensack River (HR), NC, GC, JB, FC, SB, GRC |
| | | SBMs | Tie-ins to the JB SSB, tie-ins to the HR SSB and tie-ins to the FC SSB. In addition, SBMs in the Red Hook neighborhood tied into the GC SSB and SBMs in Long Island City tied into the NC SSB. SBMs along the shorelines of Jersey City, the south side and west side of Manhattan and SBMs along the Harlem River |
| | | IFFs | At Breezy Point and IFFs in Newark Bay and the lower reaches of the Passaic and Hackensack River. |
| | | RRFs | Within Jamaica Bay, upstream of the JB SSB. |
| **5** | No SSBs and only SBMs for the areas with higher flood risk in NYNJHAT study area. | SSBs | None |
| | | SBMs | SBMs along the shorelines of Jersey City, the south side and west side of Manhattan, SBMs along the Harlem River and SBMs in the Meadowlands |
| | | IFFs | None |
| | | RRFs | None |

### *1.3.2.1 Alternative 1*

Alternative 1 is the no-action alternative. Alternative 1 does not incorporate any structural measures.

### *1.3.2.2 Alternative 2*

Alternative 2 incorporates SBMs in combination with the Outer Harbor storm surge barrier connecting Sandy Hook, New Jersey to Rockaway Point on the Rockaway Peninsula, as well as the storm surge barrier at Throgs Neck. To mitigate the residual flood risk, RRFs are proposed along the shorelines of the Lower and Upper Bay, the Arthur Kill region, the Raritan River, Jamaica Bay, the Hackensack River and Passaic River, and the Lower Hudson and East Rivers. Induced flooding is expected to occur in the western end of the Long Island Sound as a result of the presence of the Throgs Neck storm surge barrier; thus, IFFs are proposed in this region. A schematic overview of the structural CSRM measures for this Alternative is shown in Figure 1-2.

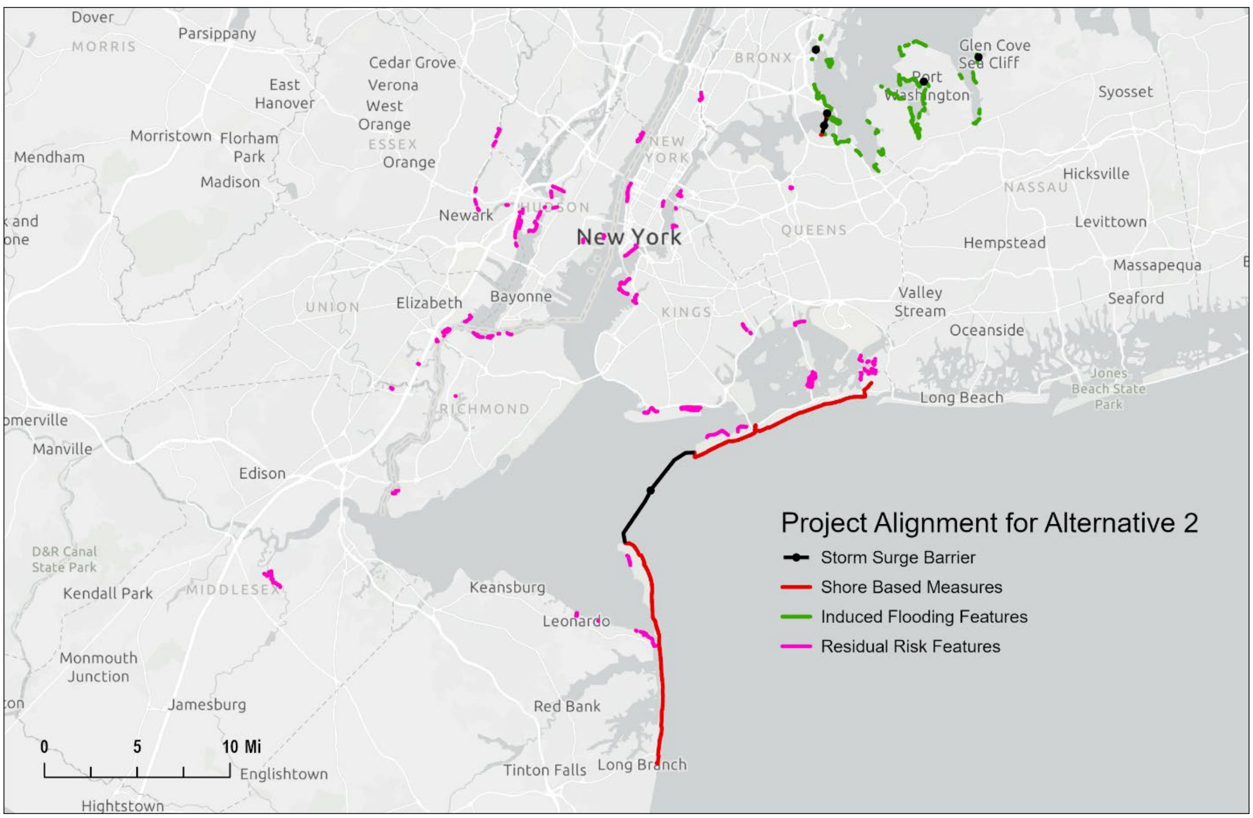



**Figure 1-2: Alternative 2 Structural CSRM Measures**

### *1.3.2.3 Alternative 3A*

Alternative 3A integrates SBMs with the storm surge barriers at Verrazzano-Narrows, Arthur Kill, Throgs Neck, and Jamaica Bay. To mitigate the residual flood risk, RRFs are proposed along the shorelines of the Upper Bay, the Arthur Kill region, Jamaica Bay, the Hackensack River, Passaic River, and the Lower Hudson and East River. Induced flooding is expected to occur along the Lower Bay, the Raritan River and the western end of Long Island Sound as a result of the presence of the above-stated storm surge barriers; thus, IFFs are proposed in these regions. The schematic concept for this Alternative is shown in Figure 1-3.

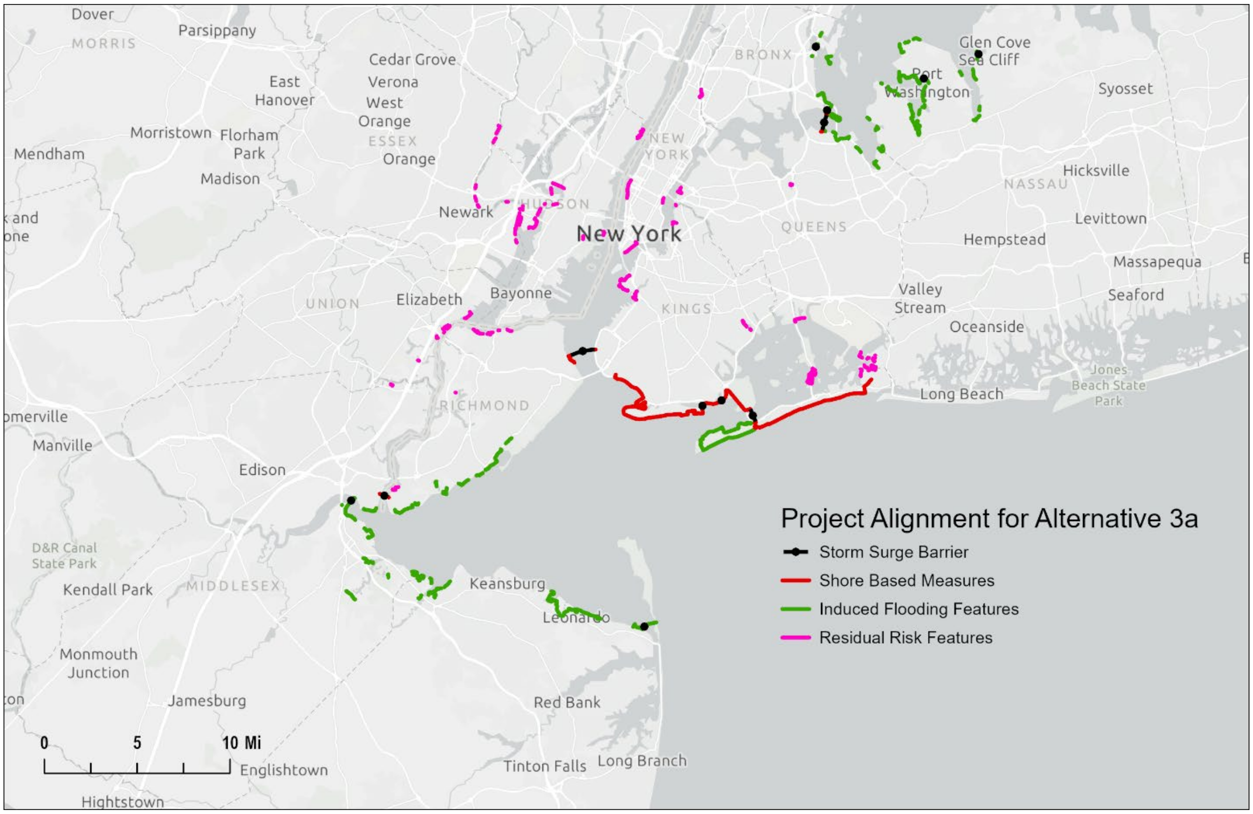



**Figure 1-3: Alternative 3A Structural CSRM Measures**

### *1.3.2.4 Alternative 3B*

Alternative 3B integrates SBMs along with the Arthur Kill, Kill Van Kull, Jamaica Bay, Newtown Creek, Gowanus Canal, and Flushing Creek storm surge barriers. The required SBMs include risk reduction of the New Jersey Upper Bay and Hudson River shoreline from Liberty State Park to Hoboken; New York City West Side shoreline from the Brooklyn Bridge to Pier 78; East Harlem shoreline from Carl Schurz Park to Washington Heights; the Red Hook shoreline; and the Long Island City-Astoria shoreline from WNYC Transmitter Park to Ed Koch Queensboro Bridge. To mitigate the residual flood risk, RRFs are proposed along the shorelines of Newark Bay, the Arthur Kill region, Jamaica Bay, and the Hackensack and Passaic Rivers. Induced flooding is expected to occur in portions of the East River and Harlem River and on the flood side of the Jamaica Bay storm surge as a result of the presence of the above-stated storm surge barriers; thus, IFFs are suggested to be placed in these regions. A schematic concept for this Alternative and the referenced reaches is shown in Figure 1-4.

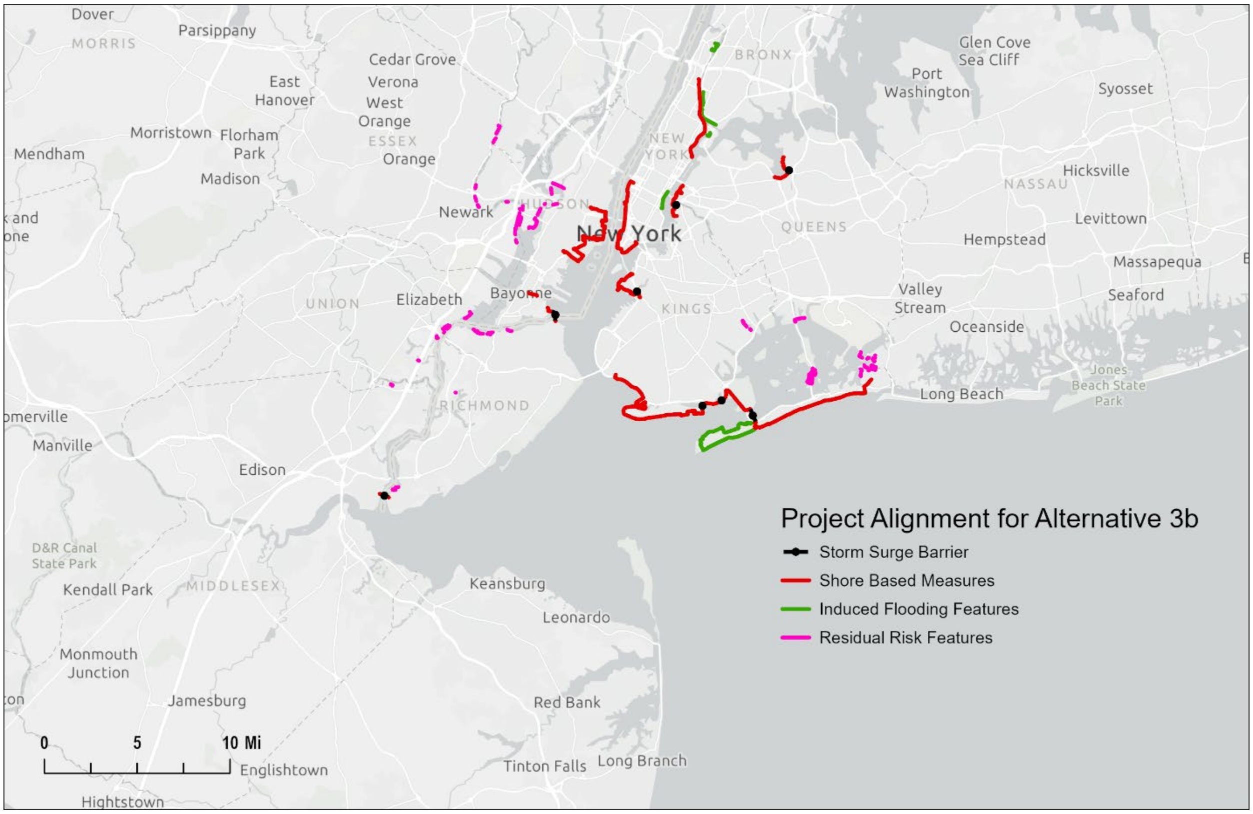



**Figure 1-4: Alternative 3B Structural CSRM Measures**

#### *1.3.2.5 Alternative 4*

Alternative 4 incorporates SBMs along with the storm surge barriers at Jamaica Bay, Newtown Creek, Gowanus Canal, Flushing Creek, and Hackensack River. These SBMs are located at the Hackensack River and along the Hudson River shoreline from Liberty State Park to Hoboken; New York City West Side shoreline from Brooklyn Bridge to Pier 78; Long Island City shoreline; the Red Hook shoreline; the Flushing Creek shoreline; and the East Harlem Shoreline from Carl Schurz Park to Washington Heights. To mitigate the residual flood risk, RRFs are proposed along the shorelines of Jamaica Bay. Induced flooding is expected to occur in Newark Bay and portions of the Arthur Kill and Kill van Kull, and on the flood side of the Jamaica Bay storm surge barrier; thus, IFFs are suggested to be placed in these regions. A schematic concept for this Alternative is shown in Figure 1-5.

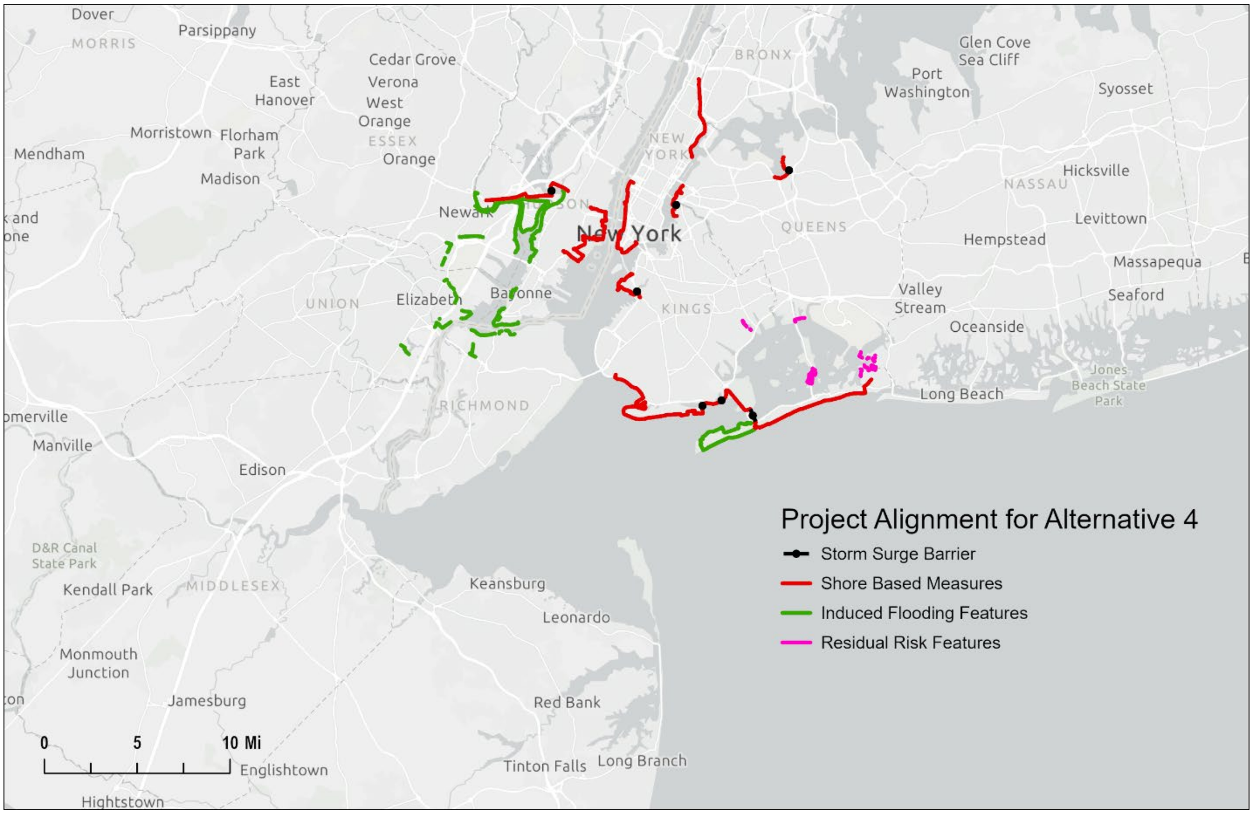



**Figure 1-5: Alternative 4 Structural CSRM Measures**

### *1.3.2.6 Alternative 5*

Alternative 5 presents a perimeter risk reduction concept which excludes storm surge barriers that traverse waterways or waterbodies. SBMs would be implemented at the New Jersey Upper Bay and Hudson River shoreline; New York City West Side shoreline; East Harlem shoreline; and the Hackensack Perimeter Lower, Middle and Upper Areas. Due to the absence of storm surge barriers, IFFs and RRFs are not part of this alternative. A schematic concept for this Alternative is shown in Figure 1-6.

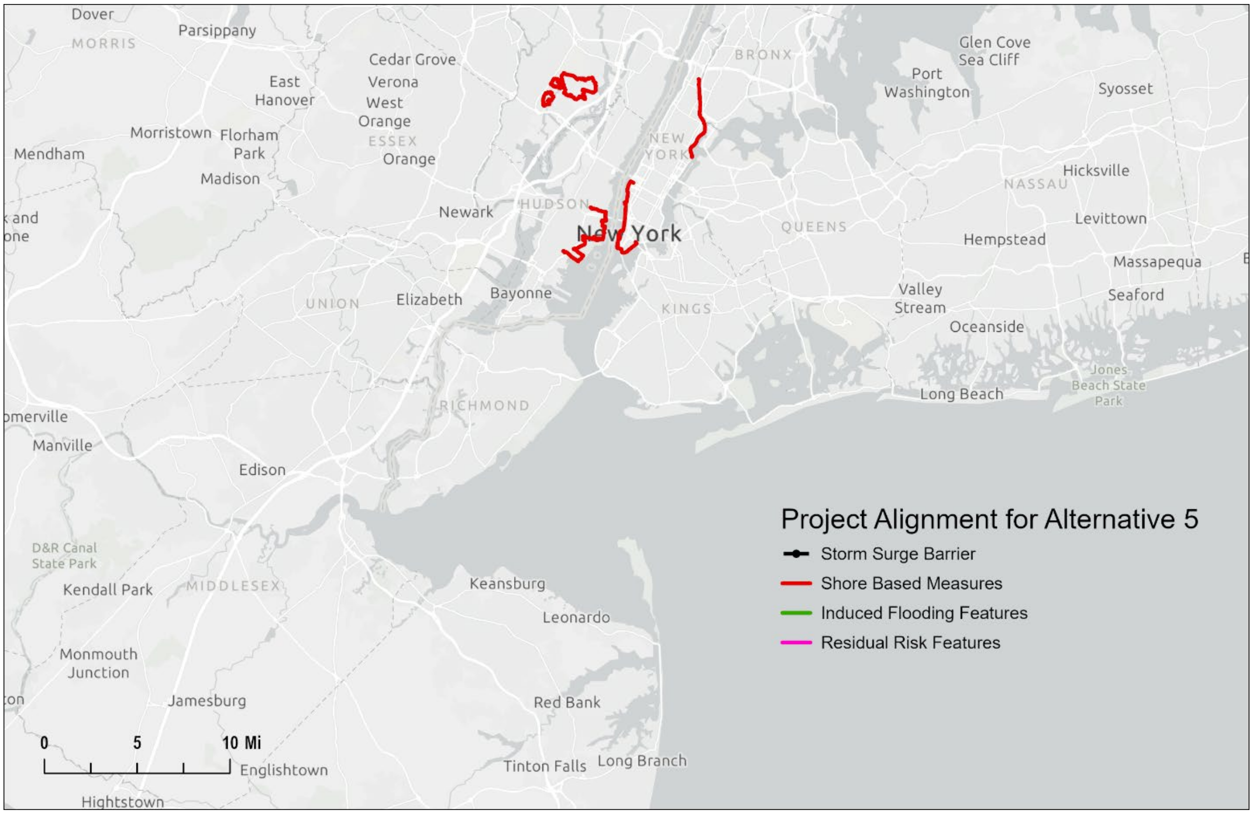



**Figure 1-6: Alternative 5 Structural CSRM Measures**

## 1.4 Organization

### 1.4.1 Scope

The scope of the Engineering Appendix is to describe the structural elements of each study alternative, introduce the storm surge barriers and navigable gates, and the shore-based measures (the location of the alignments and selection of shore-based measures for each alignment). Furthermore, the content of this appendix includes a narrative on the design development of these structural measures and provides quantity take-offs and/or sufficient engineering detail such that cost estimates can be developed. This information is then used in aggregate to develop cost estimates for the NYNJHAT Study project alternatives, which is documented separately in the Cost Engineering Appendix.

### 1.4.2 Organization of Engineering Analyses

The analysis and documentation of the engineering studies and analyses completed in support of NYNJHAT Study are extensive given the scope of the study and size of the study area. The Engineering Appendix to the Feasibility Study report discusses the engineering and design work conducted to layout and evaluate potential structural and non-structural solutions to manage coastal storm risk in the study area. The engineering appendix is limited to a description of structural measures and non-structural measures only, albeit that it is recognized that the study alternatives include more measures (i.e., Natural and Nature Based Features). Due to the large size and complexity of the study, a decision was made to limit the information presented in the engineering appendix to the principal engineering concepts that form the structural basis of the alternatives and provide specific detail on the measures and the data that is used to inform the cost engineering analyses in sub-appendices.

Specifically, the engineering appendix is organized around the distinction between storm surge barriers and shore-based measures as the principal structural CSRM measures. As such, the engineering appendix includes a high-level overview of engineering studies and analyses in support of the NYNJHAT Study as laid out in Table 1-3. The reader is referred to the storm surge barrier sub-appendix for a detailed description of the design development of the storm surge barriers that are part of the study alternatives, and the reader is referred to the shore-based measures sub-appendix for a detailed description of the design development of the shore-based measures that are part of the study alternatives. The Engineering Appendix includes a description of the Tentatively Selected Plan (TSP) and a plan set such that a clear technical depiction of the TSP is provided (Sub-Appendix B3). Additional sub-appendices are included as supporting material to document the Interior Drainage analyses (Sub-Appendix B4) and the non-structural plan (Sub-Appendix B5). Numerical hydrodynamic modeling studies in support of the NYNJHAT Study that investigated both storm surge conditions and normal hydrometeorological conditions are included in Sub-Appendix B6 and Sub-Appendix B7, respectively.

**Table 1-3: NYNJHAT CSRM Feasibility Study Engineering Appendix and Sub-Appendices**

| Appendix | Sub-Appendix | ID | Contents/Subject |
|---|---|---|---|
| **Engineering Appendix** | | | Engineering appendix to the Feasibility Study Report documenting preliminary designs of all structural measures that are part of this coastal storm risk management study. |
| | SBM sub-appendix | B1 | The Structural Coastal Storm Risk Management (CSRM) shore-based measures evaluated as part of the Study. |
| | SSB sub-appendix | B2 | Conceptual Design for Storm Surge Barriers that are part of the study alternatives, with emphasis on a conceptual design of three reference storm surge barriers (Verrazzano Narrows, Jamaica Bay and the Hackensack River SSB)[1] |
| | TSP Plan Set | B3 | Technical drawing plan set and sections to document the TSP. |
| | Interior Drainage Sub-Appendix | B4 | Analysis of Interior Drainage with project conditions. |
| | Individual Structure Risk Management Sub-Appendix | B5 | Documentation of investigation and analysis of non-structural measures and/or ring-walls/ring-levees. |

| Appendix | Sub-Appendix | ID | Contents/Subject |
|---|---|---|---|
| | ERDC CSTORM Model Report Sub-Appendix | B6 | To evaluate four of the five alternatives, storm surge and wave modeling was performed by the ERDC Coastal and Hydraulics Laboratory (CHL). |
| | ERDC AdH Model Report Sub-Appendix | B7 | To evaluate the study alternatives, hydrodynamic and salinity modeling was performed for normal hydrological conditions by the ERDC CHL. |

*Note 1: Throughout the engineering appendix there is frequent reference to the "reference storm surge barriers", this refers to the three SSBs for which a conceptual design has been developed, see Box 1.*

**Box 1. Three (3) Selected Reference Storm Surge Barriers under the NYNJHAT Study**

**It is recognized that storm surge barriers are complex civil works, and that this complexity translates into large contingencies on the cost estimates of such structures. This is especially the case if the level of design is very conceptual, which is typical during the feasibility phase of a project. Since the NYNJHAT Study alternatives include multiple storm surge barriers, there was a need to increase the level of analysis and provide more detail on these structures such that contingencies could be lowered. To that end, feasibility level designs for three selected reference storm surge barriers: Verrazzano Narrows, Jamaica Bay, and Hackensack River were completed, consistent with the objective of achieving a Class 4 cost estimate. Using the Class 4 cost estimates for the three selected reference SSBs, the PDT then scaled and extrapolated the costs for the other storm surge barriers under consideration. More specific details on this methodology and cost estimates are provided in the Cost Engineering Appendix.**

### 1.4.3 Reader's Guide

This engineering appendix describes the preliminary design of structural and non-structural measures at a high level and describes the components of the TSP. Specifically, this appendix includes the following items. This appendix includes a brief description of the project area, the existing conditions, and the with project conditions. Both existing conditions and with project conditions descriptions are inclusive of the water level, storm surge, and wave conditions (see section 2). For a more detailed elaboration on the history of the project area and past storms, the reader is referred to the main text of the feasibility study report. Section 3 details the design development of the SBMs and Section 4 details the design development of the SSBs, whereas Section 5 provides an inventory of all structural CSRM measures for each NYNJHAT Study alternative. The analysis of nonstructural measures and the potential for inclusion within the plan is detailed in section 7. The TSP is described in section 8, and recommendations and considerations for next phases of the study and the Pre-construction Engineering and Design (PED) Phase is provided in section 9.

# 2 Existing and With Project Conditions

## 2.1 General Setting

Information that describes the existing conditions in the study area was reviewed and used in the engineering evaluation and analysis for the feasibility level design of the study alternatives. A review of meteorological, hydraulic, and oceanographic conditions at the study site was performed to provide a basis for the preliminary design development. Amongst others, the following key items were investigated and are described in more detail within this section:

- Inlet Hydraulics and/or discharge regimes
- Storm surge elevations
- Wave climatology
- Local wind conditions
- Bathymetry

Existing conditions for the study site were developed primarily from available data produced by USACE and data available in the public domain. These data included:

- Coastal Hazards System (CHS); this includes NACCS storm surge and wave modeling
- Numerical modeling of normal hydrometeorological conditions with the use of the Adaptive Hydraulic (AdH) model prepared by U.S. Army Engineer Research and Development Center (ERDC) (USACE, 2015)
- Geological maps and profiles for the project vicinity and/or existing borings when readily available
- Existing navigation requirements: vessel traffic patterns and vessel sizes, from which minimum practical channel widths for the gated navigable passage were preliminarily established

Hydrodynamic modeling completed for this study was performed in meters, relative to mean sea level (MSL) in the current National Datum Tidal Epoch (NTDE). Water elevations are converted to feet, North American Vertical Datum of 1988 (NAVD88) using National Oceanic Atmospheric Administration (NOAA) VDatum. Vdatum is a vertical datum transformation software tool that provides conversions between various tidal datums fields and MSL as well as between MSL and NAVD88. The overview of data presented herein is general and aims to provide characteristics for the entire study area. More detailed and, where available, site-specific conditions are provided in the Storm Surge Barrier Sub-Appendix and the SBM Sub-Appendix.

## 2.2 System of Units and Reference

U.S. customary units shall be used. The vertical datum for the project shall be NAVD88, Geoid 12B. All elevations throughout the report are referenced to NAVD88 Geoid12B unless otherwise stated. The horizontal datum shall be the North American Datum of 1983 (NAD83) State Plane.

## 2.3 Natural Environment

### 2.3.1 Hydrological Characteristics

The characteristics of the hydrodynamic circulation of the New York Harbor area, Newark, Hudson River, East River and Throgs Neck's connection to the Long Island Sound are well documented in previous studies. Aerts et al. provides a brief but clear description of the hydrological characteristics of the area of interest (Aerts, Botzen, & De Moel, 2013). The description is provided hereafter but shortened for brevity, with parameters converted to U.S. customary units.

Numerous descriptive and modeling studies have described the hydrology and hydrodynamic circulation of the Hudson estuary, the NY Harbor area, and the NY Bight (for an overview, see Blumberg, Khan and St. John, 1999). The New York Harbor is located at the mouth of the Hudson River, which discharges to the ocean via New York Bay and the Verrazzano Narrows. This area is bounded by Brooklyn in the east and Staten Island in the west. The second connection of the Hudson River/New York Bay to the Atlantic Ocean is via the East River and Long Island Sound. Long Island Sound is an estuary of about 100 miles with a mean depth of 65ft.

The highest freshwater inflow to the NY Bay area is provided by the Hudson River. The river has a length of 315 miles that originates at "Lake Tear of the Clouds" in the Adirondack Mountains and drains a watershed of about 14,000 square miles. The long-term annual mean discharge is about 21,900 cfs, with a peak discharge in April (mean monthly flow ~42,400 cfs). Minimum flows occur in August (discharge ~6,700 cfs). The Hudson River has an average depth of 30-50 ft (Geyer and Chant, 2006), and is influenced by the ocean tide, which can propagate upstream about 180 miles. Other freshwater sources are from water treatment plants and storm-water runoff. (Rozenzweig, et al., 2007). Blumberg et al. estimated a runoff of 4,025 cfs from 110 wastewater treatment plants in their hydrodynamic modeling framework (Blumberg, Khan, & St. John, 1999). Additional runoff can be produced by rainfall and storm water discharges.

The harbor receives a significant sediment load from the Hudson River with an average of 1 million tons per year (HydroQual, 2007). Siltation problems occur in the lower Hudson estuary where the river widens as it empties into New York Harbor and the Lower New York Bay. Furthermore, on the southern coast of Long Island, a westward migration of sand and a northward migration along the New Jersey coast contribute further sedimentation problems to the NY Bay area, which requires periodic dredging to maintain the depth of navigation channels.

The following hydrologic description of the Hackensack River is based on the report titled *Hackensack River Basin, New Jersey – Reconnaissance Report* (USACE, February 1989).The Hackensack River Basin is situated in the northeasterly part of the State of New Jersey and the most southerly section of New York State, west of the Hudson River. The Hackensack River and its tributaries are located primarily in Bergen County, New Jersey, with portions in Hudson County, New Jersey, and Rockland County, New York. Tidal flooding occurs along the Hackensack River and its tidal tributaries, specifically in the Hackensack Meadowlands 1ocated in Bergen County, New Jersey. The Hackensack River Basin drains 197 square miles. The river originates in the northern Palisades in Rockland County, NY, and runs 50 miles to its mouth in

Newark Bay. The river is tidal and navigable from the mouth for 21.5 miles upstream; at this point, there is a tidal barrier.

The Hackensack River estuary is of the coastal plain type, formed when rising ocean levels inundated a former glacial lakebed and the river that fed it. The depth is shallow when compared to the width, and the river depth increases gradually going downstream towards Newark Bay. The Hackensack is well mixed vertically and laterally but has a horizontal salinity gradient from its mouth to the upstream areas. The ratio of tidal prism to freshwater inflow is high. The river is tidal as far upstream as river mile 21.5.

The same report also provides a peak discharge vs. frequency curve for USGS gaging station #01378500: Hackensack River at New Milford, N.J. This station is approximately 15 miles upstream, yet the discharge in the Hackensack River is largely correlated to water release from the Oradell reservoir. 10%, 2% and 1% AEP river discharges correspond to 3,800 cfs, 5,800 cfs, and 6,870 cfs, respectively.

The Passaic River formed as a result of drainage from a massive proglacial lake that formed in Northern New Jersey at the end of the last ice age, approximately 13,000 years ago. The Passaic River is approximately 80 miles long and located in northern New Jersey. The river in its upper course flows in a highly circuitous route, meandering through the swamp lowlands between the ridge hills of rural and suburban northern New Jersey. In its lower portion, it flows through the most urbanized and industrialized areas of the state, including along downtown Newark. Annual exceedance probability of river flows has been determined using USGS *StreamStats* tool (USGS, 2018). 10%, 2%, and 1% AEP peak flow river discharges correspond to 19,100 cfs, 27,400 cfs, and 31,500 cfs, respectively.

### 2.3.2 Astronomical Tides

Daily tidal fluctuations in the project study area are semi-diurnal, with a full tidal period that averages 12 hours and 25 minutes; hence there are nearly two full tidal cycles per day. The mean tidal range in the ocean is approximately 4.5 feet in the New York Bight. The rise and fall of the tide in the ocean and the Long Island Sound leads to tidal flow throughout the New York Harbor and its major tributaries and causes a corresponding rise and fall of water levels in all connected water bodies.

The southern end of the study area, from the inlet at Sandy Hook Bay to Lower New York Bay, experiences a mean tide range in the 5.0-foot mean range. Associated barriers in proximity of said area are: The Outer Harbor Barrier, Jamaica Bay, Verrazzano Narrows, Arthur Kill, and Kill van Kull. North of Lower New York Bay, the mean tide range in the Upper Bay decreases slightly such that at The Battery in Lower Manhattan, the mean range is about 4.5 feet. Going north along the Hudson River, the tidal range decreases steadily and is about 3.8 ft at Turkey Point, NY. The study area near The Bronx at Long Island Sound experiences much larger tide ranges of over 7 ft at Kings Point in proximity of the Throgs Neck barrier. Due to water flows from the east to the west, and vice versa, tide ranges in the comparatively long and narrow Long Island Sound estuary may amplify, which explains the significant difference to the comparatively smaller tide ranges near the Sandy Hook inlet.

Information on tidal water levels is obtained from NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) website (National Oceanic and Atmospheric Administration, n.d.). Tidal data for each location are derived from the NOAA gauges provided in Table 2-1 and used for the preliminary design.

**Table 2-1: Tidal Gauges of Interest within the Study Area**

| Location | Closest Tide Gauge | Station Number |
|---|---|---|
| **Upper Harbor** | The Battery | 8518751 |
| **Eastern end of Long Island Sound** | Kings Point | 8516946 |
| **Lower Bay** | Sandy Hook | 8531680 |
| **Kill van Kull** | Bergen Reach West | 8519483 |
| **Hackensack River** | Amtrak RR Swingbridge, Hackensack River, NJ | 8530696 |

The tidal datums for each of these gauges are provided in tables included within the Storm Surge Barrier Sub-Appendix.

### 2.3.3 Sea Level Change

Research by climate science experts predicts continued or accelerated climate change for the 21st century and possibly beyond, which would cause a continued or accelerated rise in global mean sea level. The resulting local relative Sea Level Change (SLC) will very likely impact the proposed projects under the NYNJHAT Study alternatives. As a result, the planning and engineering analyses considered how sensitive and adaptable the engineered systems are to climate change. Sea level change values for preliminary design of all CSRM measures are based on the USACE moderate scenario (ER 1100-2-8162) and were obtained for three tidal gauge stations: Sandy Hook, The Battery, and Kings Point. These values are provided in Table 2-2.

**Table 2-2: Sea Level Change per USACE's Moderate Scenario, in feet**

| Year | Station 8561680, Sandy Hook | Station 8518750, The Battery | Station 8516945, Kings Point |
|---|---:|---:|---:|
| **1992 (base year)** | 0 | 0 | 0 |
| **2045** | 0.94 | 0.76 | 0.66 |
| **2095** | 2.29 | 1.93 | 1.74 |

Sea level change values from the station nearest to the proposed storm surge barriers will be applied to obtain design water levels for both operational and extreme conditions. The Sandy Hook Station data will be utilized for the Outer Harbor, Arthur Kill, Verrazzano Narrows, and Jamaica Bay storm surge barrier. The Battery station data will be utilized for the Kill van Kull and Hackensack River storm surge barrier and the Kings Point station data will be utilized for the Throgs Neck storm surge barrier. For the preliminary design of the SBMs, the highest value of relative SLC (value from Sandy Hook) was used to conservatively account for SLC.

Figure 2-1 shows the USACE SLC projection curves for a range of possible future climate scenarios based on historical trends at The Battery, NY. The historical trends up to the middle of the current tidal epoch (1992) are shown as gray lines. They include the monthly average MSL and a long-term linear trend. While the monthly means show seasonal and year-to-year variability, the long-term trend indicates about a foot of SLR over the last century. Tidal datums including Mean Sea Levels are typically computed over 19-year periods referred to as a "tidal epoch," and projections of future trends with SLR are made based on the expected trend of the 19-year average. Analysis of recent trends show some acceleration in the trend of observed sea level rise. As a result, the observed Sea Level Rise since 1992 till present (2022) appears to track somewhat higher than the USACE Intermediate projection curve. The 50-year economic analysis period (2045-2095) and the 100-year planning horizon (2045-2145) are highlighted in the figure.

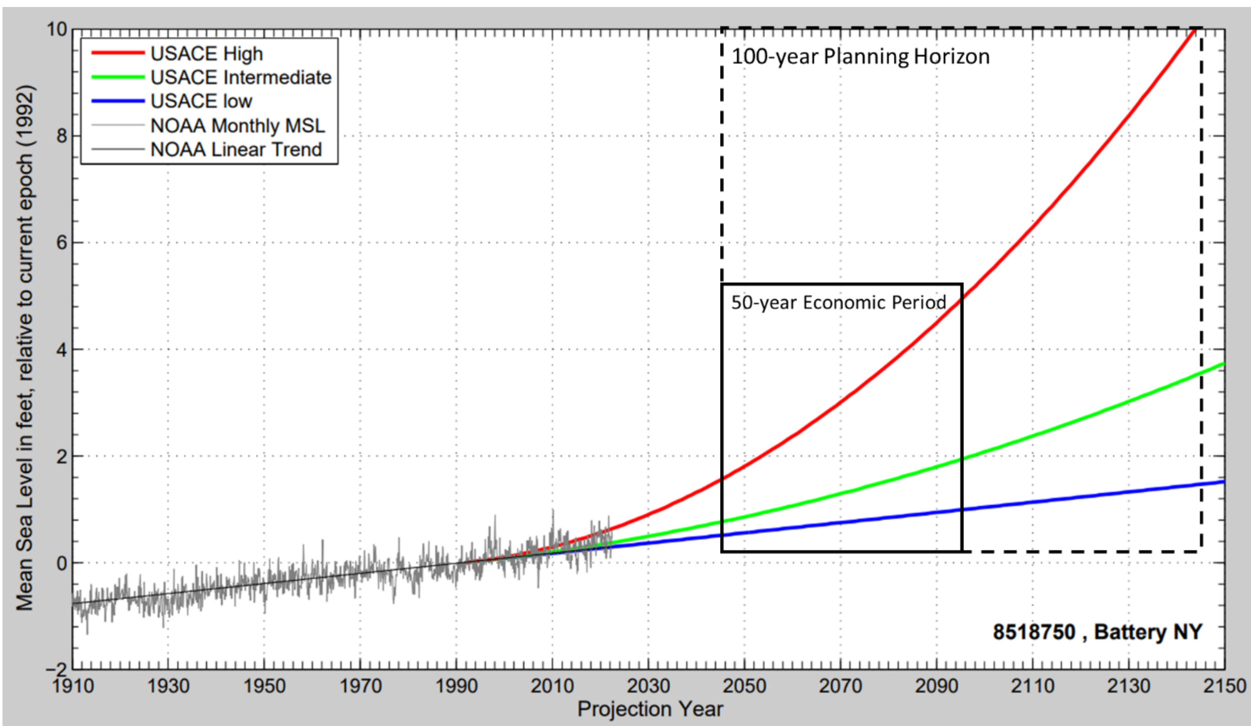



**Figure 2-1: Historical and Projected SLR Trends at the Battery, NY, through the 100-year Planning Horizon for NYNJHAT Study**

### 2.3.4 Tidal Flows and Current Magnitudes

Tidal flow characteristics are obtained from modeling studies performed by ERDC (USACE ERDC, 2019). The report detailing the study and outcomes is included as a Sub-Appendix (Sub-Appendix B7 – ERDC AdH Model Report Sub-Appendix). USACE-ERDC analyzed the NYNJHAT Study alternatives and the impacts on normal tidal conditions and circulation. This modeling effort focused mainly on the impacts of the larger storm surge barriers discussed herein (the three reference SSBs, VN, JB, and HR, as well as OH, KvK, AK and TN). A data summary is provided here and is based on the statistical analysis of model output for the 1995 calendar year for a cross-section spanning the storm surge barrier sites. The values presented in Table 2-3 show tidal fluxes and are model results rounded to the nearest thousand cfs and averaged between ebb and flood flows for base conditions, i.e., without the storm surge barriers in place.

**Table 2-3: Tidal Flow**

| Location | Mean Tidal Flow (m3/s) | Mean Tidal Flow (cfs) | Maximum Tidal Flow (m3/s) | Maximum Tidal Flow (cfs) |
|---|---|---|---|---|
| **Verrazzano Narrows** | 16,100 | 568,000 | 36,400 | 1,286,000 |
| **Throgs Neck** | 5,800 | 204,000 | 13,000 | 459,000 |
| **Arthur Kill** | 1,200 | 43,000 | 3,200 | 113,000 |
| **Outer Harbor** | 39,400 | 1,391,000 | 115,900 | 4,092,000 |
| **Kill van Kull** | 2,400 | 83,000 | 7,700 | 274,000 |
| **Jamaica Bay** | 3,700 | 129,000 | 10,300 | 363,000 |
| **Hackensack River** | 900 | 32,000 | 2,500 | 87,000 |

The values presented in Table 2-4 show tidal currents at predetermined output locations and are depth averaged model results for base conditions, i.e., without the storm surge barriers in place. Values are also provided in knots for ease of reference and in support of interpretation by the navigation community and marine engineering discipline.

**Table 2-4: Tidal Currents**

| Location | Output point | Mean Tidal Current Magnitude (knts) | Mean Tidal Current Magnitude (ft/s) | Maximum Tidal Current Magnitude (knts) | Maximum Tidal Current Magnitude (ft/s) |
|---|---|---|---|---|---|
| **Verrazzano Narrows** | S2 | 1.1 | 1.9 | 2.9 | 4.9 |
| **Throgs Neck** | V4 | 1.0 | 1.7 | 2.7 | 4.5 |
| **Arthur Kill** | S1 | 0.6 | 1.0 | 1.8 | 3.0 |
| **Outer Harbor (Sandy Hook Channel)** | V1 | 1.3 | 2.2 | 4.7 | 8.0 |
| **Outer Harbor (Ambrose Channel)** | V2 | 1.1 | 1.8 | 4.2 | 7.0 |
| **Outer Harbor (Rockaway Inlet)** | V3 | 0.8 | 1.4 | 3.2 | 5.4 |
| **Kill van Kull** | T1 | 0.5 | 0.9 | 2.5 | 4.3 |
| **Jamaica Bay** | S3 | 0.8 | 1.3 | 2.7 | 4.5 |
| **Hackensack River** | R1 | 0.8 | 1.3 | 2.4 | 4.1 |

The same report also presents an analysis of tidal flows, current magnitudes, and changes in tidal prism for the conditions with a project alternative in place. The reader is referred to the ERDC report (USACE ERDC, 2019) for details on the "with project" assessment.

### 2.3.5 Extreme Hydraulic Conditions

Storm surge is the increased water level above the predicted astronomical tide due to storm winds over the ocean and the resultant wind stress on the ocean surface. The principal factor that creates flood risk for the study area is storm surge that propagates into the back bays through the twelve inlets distributed along the New Jersey coast. The magnitude of the storm surge is calculated as the difference between the predicted astronomic tidal elevation and the actual water surface elevation at any time. Wind blowing over the ocean surface is capable of generating storm surge; however, the largest and most damaging storm surges develop as a result of either tropical cyclones (hurricanes and tropical storms) or extra-tropical cyclones ("nor'easters"). Although the meteorological origins of the two types of storms differ, both can generate large, low-pressure atmospheric systems with intense wind fields that, in the northern hemisphere, rotate counterclockwise. The relatively broad and shallow continental shelf along the east coast is a physical characteristic that allows for the generation of relatively large storm surges to develop, compared to, for example, the US Pacific coast. Extreme Hydraulic conditions, both water level and waves, are based upon storm surge modeling results completed for the NACCS Study (USACE, 2015). Annual exceedance probability statistics for water level and wave characteristics can be obtained on the Coastal Hazards System (CHS) website (USACE ERDC, 2022).

#### *2.3.5.1 Extreme Water Levels*

Figure 2-2 provides an overview of extreme Still Water Levels (SWL), inclusive of SLR per USACE's intermediate scenario, throughout the study area. Table 2-5 provides an overview of the extreme water levels for a select number of points throughout the study area and exemplifies the spatial variability that is observed in extreme water levels with the same Average Recurrence Interval (ARI). The utilized Advanced Circulation Model (ADCIRC) nodes/output stations are listed in the second column.

**Table 2-5: ARI Still Water Levels in ft, NAVD88 (50% confidence limit) from NACCS ADCIRC output, inclusive of Sea Level Rise in 2045 and 2095. Specific output nodes referenced in table.**

| General regions within the Study Area | NACCS ID | ARI | 1992 | 2045 | 2095 |
|---|---|---|---|---|---|
| New York Bight / Atlantic Ocean | 3900 | 100 | 11.4 | 12.6 | 13.3 |
| | | 500 | 15.1 | 16.2 | 17.0 |
| | | 1000 | 16.7 | 17.9 | 18.6 |
| Jam Bay / Rockaway Inlet | 3592 | 100 | 11.9 | 13.1 | 13.8 |
| | | 500 | 15.4 | 16.5 | 17.3 |
| | | 1000 | 16.9 | 18.0 | 18.8 |

| General regions within the Study Area | NACCS ID | ARI | 1992 | 2045 | 2095 |
|---|---|---|---|---|---|
| **The Battery, NY** | 11781 | 100 | 12.4 | 13.4 | 14.3 |
| | | 500 | 16.5 | 17.5 | 18.4 |
| | | 1000 | 18.4 | 19.3 | 20.3 |
| **Throgs Neck / Eastern End of Long Island Sound** | 4347 | 100 | 13.4 | 14.2 | 15.3 |
| | | 500 | 16.9 | 17.7 | 18.8 |
| | | 1000 | 18.6 | 19.5 | 20.5 |
| **Arthur Kill / Pert Amboy** | 11650 | 100 | 13.9 | 15.0 | 15.8 |
| | | 500 | 18.2 | 19.3 | 20.1 |
| | | 1000 | 20.1 | 21.3 | 22.0 |
| **Hackensack River** | 11816 | 100 | 14.4 | 15.3 | 16.3 |
| | | 500 | 17.5 | 18.4 | 19.4 |
| | | 1000 | 18.7 | 19.7 | 20.6 |
| **East River** | 13898 | 100 | 11.8 | 12.7 | 13.7 |
| | | 500 | 15.6 | 16.5 | 17.5 |
| | | 1000 | 17.3 | 18.3 | 19.2 |

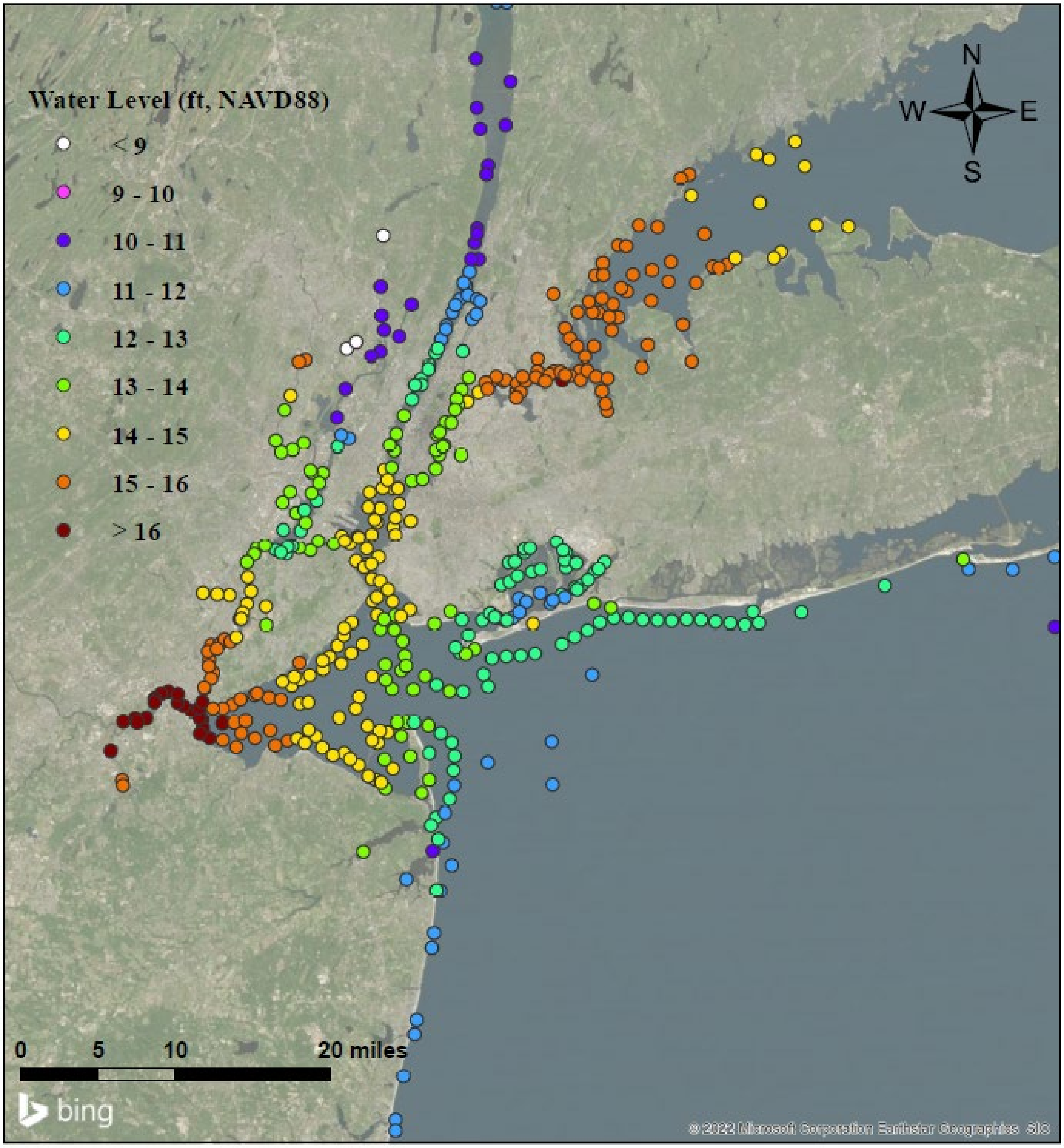



**Figure 2-2: 100-Year ARI Still Water Levels Including Sea Level Rise up to Year 2095 at select NACCS Save Points within the Project Area.**

### *2.3.5.2 Extreme Wave Heights and Period*

Figure 2-3 presents the 100-year ARI wave heights on open waters throughout the study area. 100-Year extreme wave heights are naturally higher on the open ocean (exceeding 20 ft), while for more sheltered waters with limited fetch 100-year ARI wave heights are in the moderate range (3 to 4 ft). Table 2-6 shows the wave characteristics for 100-year, 500-year and 1,000-year ARI storm conditions for a select number of points throughout the study area and exemplifies the spatial variability that is observed in extreme wave heights with the same average recurrence interval (ARI). The ADCIRC nodes/output stations for each location are listed in the second column.

The variation in significant wave height throughout the study area is accompanied by a variation in wave period. Wave periods associated with the 100-year ARI wave heights range from 14 seconds in the Atlantic Ocean and Lower Harbor to 4 to 5 seconds in the Hudson and East River.

**Table 2-6: ARI Significant Wave Characteristics, Significant Wave Height in Feet and Period in Seconds (50% confidence limit)**

| General regions within the Study Area | NACCS ID | ARI | Hs | Tp |
|---|---|---|---|---|
| **New York Bight / Atlantic Ocean** | 3900 | 100 | 16.1 | 14.1 |
| | | 500 | 16.8 | 14.5 |
| | | 1000 | 17.1 | 14.6 |
| **Jam Bay / Rockaway Inlet** | 3592 | 100 | 4.8 | 5.7 |
| | | 500 | 5.1 | 5.8 |
| | | 1000 | 5.2 | 5.9 |
| **The Battery, NY** | 11781 | 100 | 5.9 | 6.0 |
| | | 500 | 6.9 | 6.5 |
| | | 1000 | 7.3 | 6.8 |
| **Throgs Neck / Eastern End of Long Island Sound** | 4347 | 100 | 4.3 | 5.6 |
| | | 500 | 4.5 | 5.8 |
| | | 1000 | 4.6 | 5.9 |
| **Arthur Kill / Pert Amboy** | 11650 | 100 | 3.8 | 5.4 |
| | | 500 | 4.4 | 5.8 |
| | | 1000 | 4.6 | 5.9 |
| **Hackensack River** | 11816 | 100 | 3.2 | 5.3 |
| | | 500 | 3.6 | 5.6 |
| | | 1000 | 3.7 | 5.7 |
| **East River** | 13898 | 100 | 3.7 | 5.4 |
| | | 500 | 4.1 | 5.7 |
| | | 1000 | 4.3 | 5.8 |

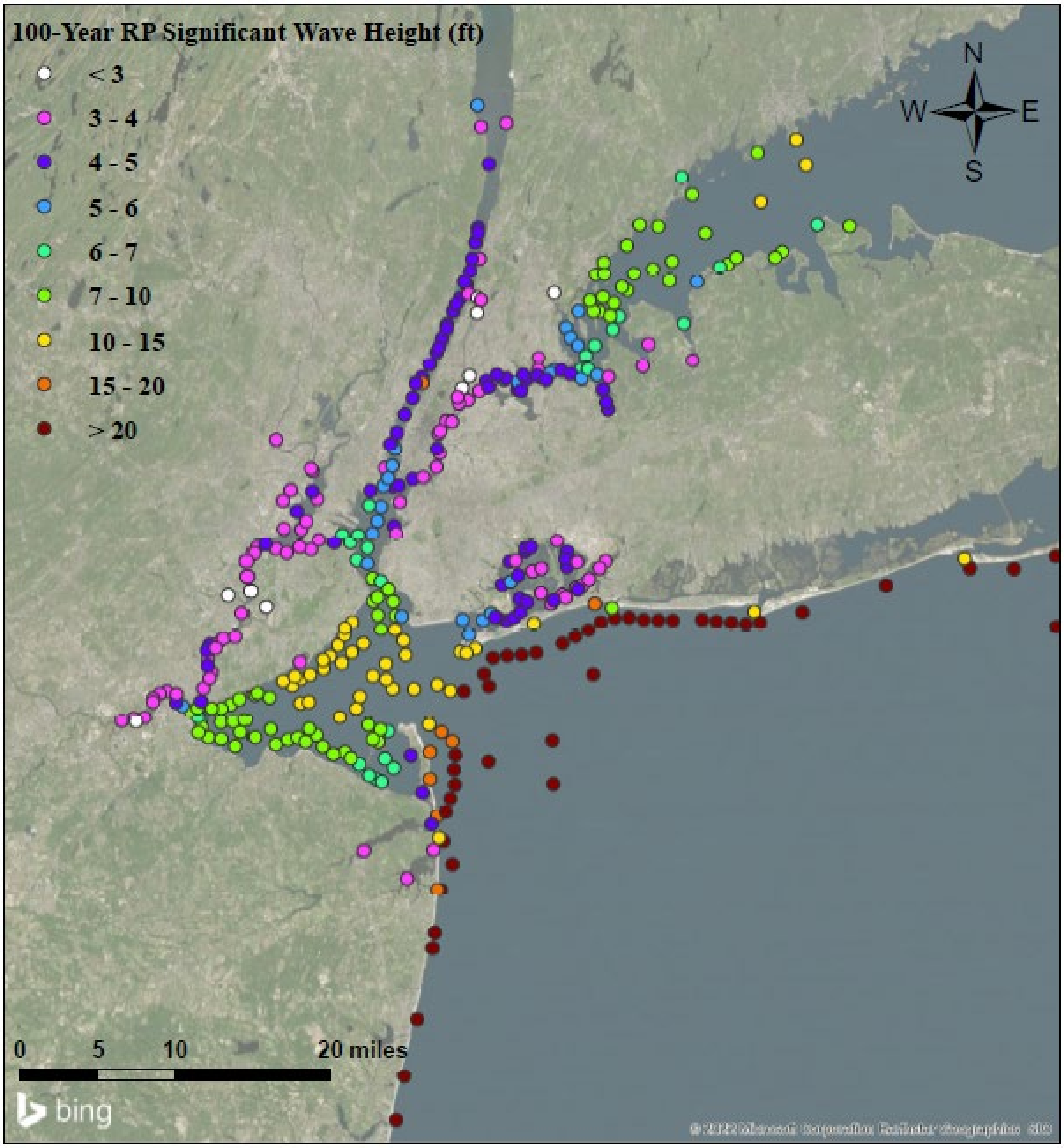



**Figure 2-3: 100-Year ARI Significant Wave Heights at Select NACCS Save Points within the Project Area.**

### 2.3.6 Extreme Hydraulic with Project Conditions

As introduced in Section 1, the presence of a structural measure that is part of an alternative (e.g., storm surge barrier) is an effective impediment to the storm surge but can cause peak storm surge levels on the ocean side of the storm surge barriers to increase compared to the condition without the storm surge barrier being present. Four of the NYNJHAT Study alternatives include storm surge barriers and to evaluate the effects of these alternatives on surge, currents, and nearshore waves, numerical modeling was performed by ERDC using the Coastal Storm Modeling System (CSTORM-MS). Model grids used in this study were adapted from those developed as part of the North Atlantic Coast Comprehensive Study (NACCS). In addition, out of the 1050 synthetic tropical storms developed for the NACCS, 20 storms were selected for use as proxy storms for representing the annual exceedance probabilities curves for water levels within the study area. More details about the four CSRM alternatives that were modeled along with the CSTORM model development and setup, selected proxy storms, simulation results, and modeling conclusions drawn from this study are discussed in Sub-Appendix B6 (ERDC CSTORM/ADCIRC Model Report Sub-Appendix).

### 2.3.7 High Frequency Flooding

High-frequency flooding, also known as nuisance flooding, recurrent flooding, or sunny-day flooding, are flood events caused by tides and/or minor storm surge that occur more than once per year. High-frequency flooding mostly affects low-lying and exposed assets or infrastructure, such as roads, public storm-, waste-, and fresh-water systems (Sweet, Dusek, Marcy, Carbin, & Marra, 2018) and is likely more disruptive (a nuisance) than damaging. However, the cumulative effects of high-frequency flooding may be a serious problem to residents who live and work in these low-lying areas. The number of high-frequency flood days is accelerating in the study area as a result of RSLC (Figure 2-4) (Orton, et al., 2019).

Flooding from rainfall and inadequate stormwater systems can be related to high-frequency flooding but interior drainage improvements are not within the scope of this study. It is common for municipalities in the study area to have gravity-based stormwater systems that are unable to drain when the tide level exceeds the elevation of the storm drain. In such events, water ponds at the drain and surrounding low-lying areas may get inundated as well, all as a result of high-frequency flooding. The frequency and impact of pluvial flooding will increase as the probability of high tide levels increases with RSLC. Some municipalities are addressing this problem by installing one-way flow valves on outfalls or within drainage pipes or by constructing pump stations that mechanically aid in draining rainwater during high tail water conditions. Under this study, specific emphasis has been put on the heigh frequency flood risk that remains with a storm surge barrier, and connected perimeter flood risk reduction system, in place. In the NYNJHAT Study context this is referred to as residual flood risk. Storm surge barriers will only be closed for extreme events (an operating closure criterion will be set for each storm surge barrier in Sub-Appendix B2), and flood risk remains for the coastal areas served by the storm surge barrier up to the elevation of the closure criterion. As such, flood risk associated with more frequent coastal flood event remains for low lying coastal areas behind a storm surge barrier because the storm surge barrier may not be operated for such events. As a results of the identification of this process and the need to address it, RRFs were introduced. Where storm surge barriers are proposed (Alternatives 2, 3A, 3B, and 4), complementary RRFs are also proposed to provide an integrated CSRM solution. More detail is provided in section 3.

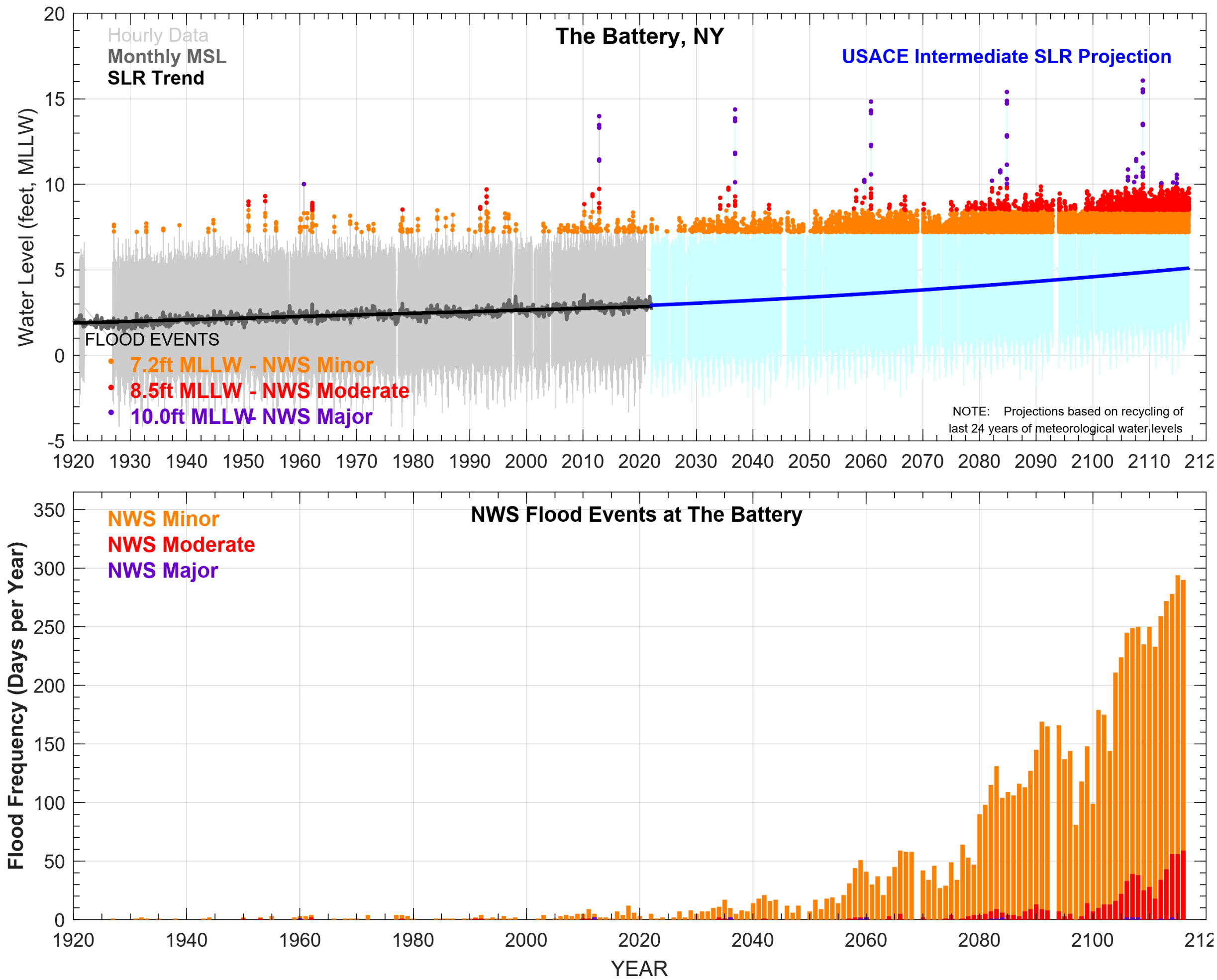



**Figure 2-4: Estimate of Flood Frequency (Days per Year that NWS Minor, Moderate and Major Floods occur) at The Battery, NY, using a repetition of historic observed water level data superimposed on the USACE Intermediate SLC projection**

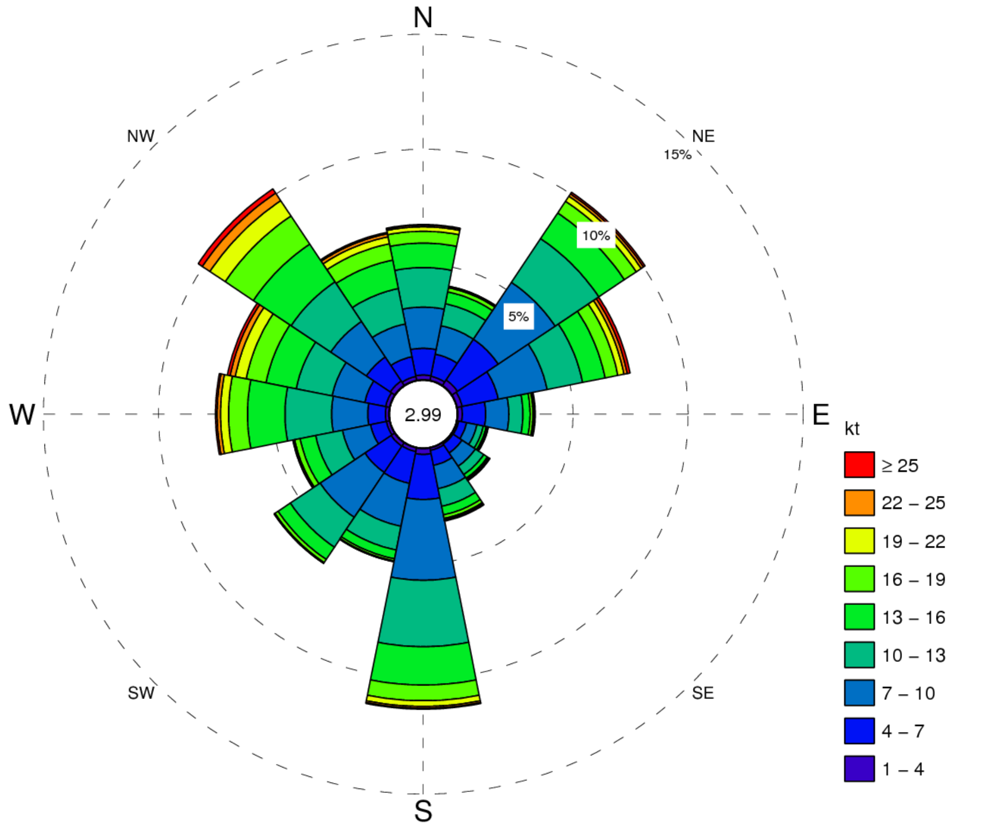
### 2.3.8 Wind

Wind data for each location are derived from the wind gauges in closest vicinity to the storm surge barrier location and are provided in Table 2-7. The wind rose and statistical data for La Guardia is provided in Figure 2-5 and can be regarded as fairly typical for the study area.

**Table 2-7: Wind Stations**

| Closest Wind Stations | Station Identification | General regions within the Study Area |
|---|---|---|
| **John F. Kennedy International Airport** | KJFK | Jamaica Bay, Lower Bay |
| **LaGuardia Airport** | KLGA | Upper Bay, East River, Throgs Neck |
| **Linden Airport, NJ** | KLDJ | New Jersey Shorelines and Arthur Kill |

Wind Speed (Annual)
Station KLGA – NYC/La Quardia, NY
Period 01–Jan–1980 to 25–Jun–2018




Direction FROM is shown
Center value indicates calms below 1 kt
Total observations 370824, calms 11096
About 0.582% of observations missing

Percentage of Occurrence

| Wind Speed, kt | N | NNE | NE | ENE | E | ESE | SE | SSE | S | SSW | SW | WSW | W | WNW | NW | NNW | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | 6.73 | 4.16 | 10.08 | 7.66 | 3.36 | 1.38 | 1.98 | 3.23 | 11.31 | 5.03 | 6.29 | 4.28 | 7.53 | 7.17 | 10.26 | 6.55 | 97.01 |
| ≥ 25 | | | | 0.13 | | | | | | | | | | 0.12 | 0.22 | | 0.83 |
| 22 – 25 | | | 0.12 | 0.14 | | | | | | | | | 0.15 | 0.22 | 0.40 | 0.14 | 1.44 |
| 19 – 22 | 0.19 | | 0.26 | 0.27 | | | | | 0.25 | | | | 0.35 | 0.49 | 0.80 | 0.31 | 3.25 |
| 16 – 19 | 0.52 | 0.18 | 0.62 | 0.56 | 0.12 | | | 0.16 | 0.68 | | 0.16 | 0.24 | 0.82 | 0.88 | 1.47 | 0.72 | 7.35 |
| 13 – 16 | 1.06 | 0.52 | 1.34 | 1.00 | 0.31 | 0.13 | 0.19 | 0.38 | 1.66 | 0.39 | 0.64 | 0.69 | 1.63 | 1.34 | 1.97 | 1.26 | 14.52 |
| 10 – 13 | 1.71 | 0.97 | 2.28 | 1.57 | 0.61 | 0.28 | 0.44 | 0.78 | 2.89 | 1.05 | 1.56 | 1.18 | 2.03 | 1.59 | 2.07 | 1.56 | 22.58 |
| 7 – 10 | 1.79 | 1.26 | 2.97 | 2.16 | 1.00 | 0.46 | 0.69 | 1.03 | 3.51 | 1.90 | 2.34 | 1.24 | 1.57 | 1.44 | 1.86 | 1.45 | 26.69 |
| 4 – 7 | 1.16 | 0.98 | 2.13 | 1.60 | 1.02 | 0.34 | 0.47 | 0.66 | 1.96 | 1.41 | 1.37 | 0.70 | 0.77 | 0.92 | 1.25 | 0.87 | 17.63 |
| 1 – 4 | 0.20 | 0.17 | 0.28 | 0.22 | 0.19 | | | 0.10 | 0.25 | 0.16 | 0.18 | 0.13 | 0.14 | 0.17 | 0.23 | 0.17 | 2.72 |

**Figure 2-5: Percentage of Occurrence for Wind Speed in knots for La Guardia Airport (Station KLGA) for a 38-year period**

### 2.3.9 Precipitation

Precipitation criteria are detailed in the Interior Drainage Sub-Appendix (Sub-Appendix B4).

## 2.4 Physical Environment

### 2.4.1 Bathymetry and Topography

Bathymetric Data was obtained from the NOAA DEM (NOAA, 2015) as well as from USACE-NAN channel survey conditions and USACE's compiled digital elevation model data sets (Figure 2-6 and Figure 2-7). The bathymetric data was used to generate channel cross-section profiles and assess existing flow areas and modified flow areas based on the conceptual design and geometry of the storm surge barriers. In addition, for the proposed storm surge barriers that intersect with federally authorized navigation channels, channel dimension information was derived from: 1) Controlling Depth Reports and Surveys (USACE, 2018), 2) USACE Project Maps, Rivers & Harbors, Navigation Projects (USACE, 1986) and, 3) Nautical Charts (NOAA, 2017). Topography data in the form of Digital Elevation Models and LiDAR (U.S. Geological Survey, 2014) was used to assess the needed size of a CSRM intervention, e.g., the floodwall height above existing grade.

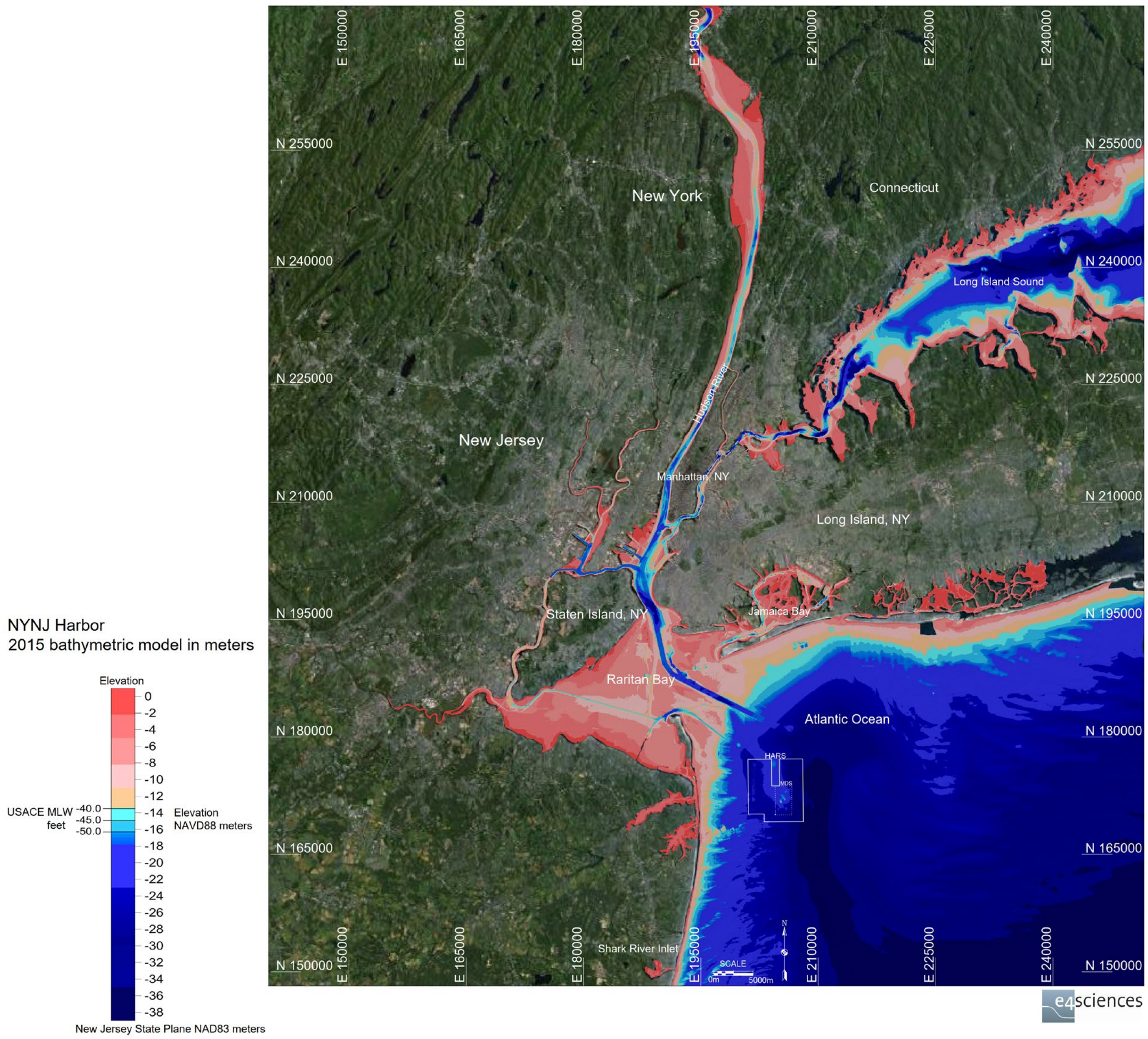



**Figure 2-6: NYNJ Harbor Bathymetric Model Overview**

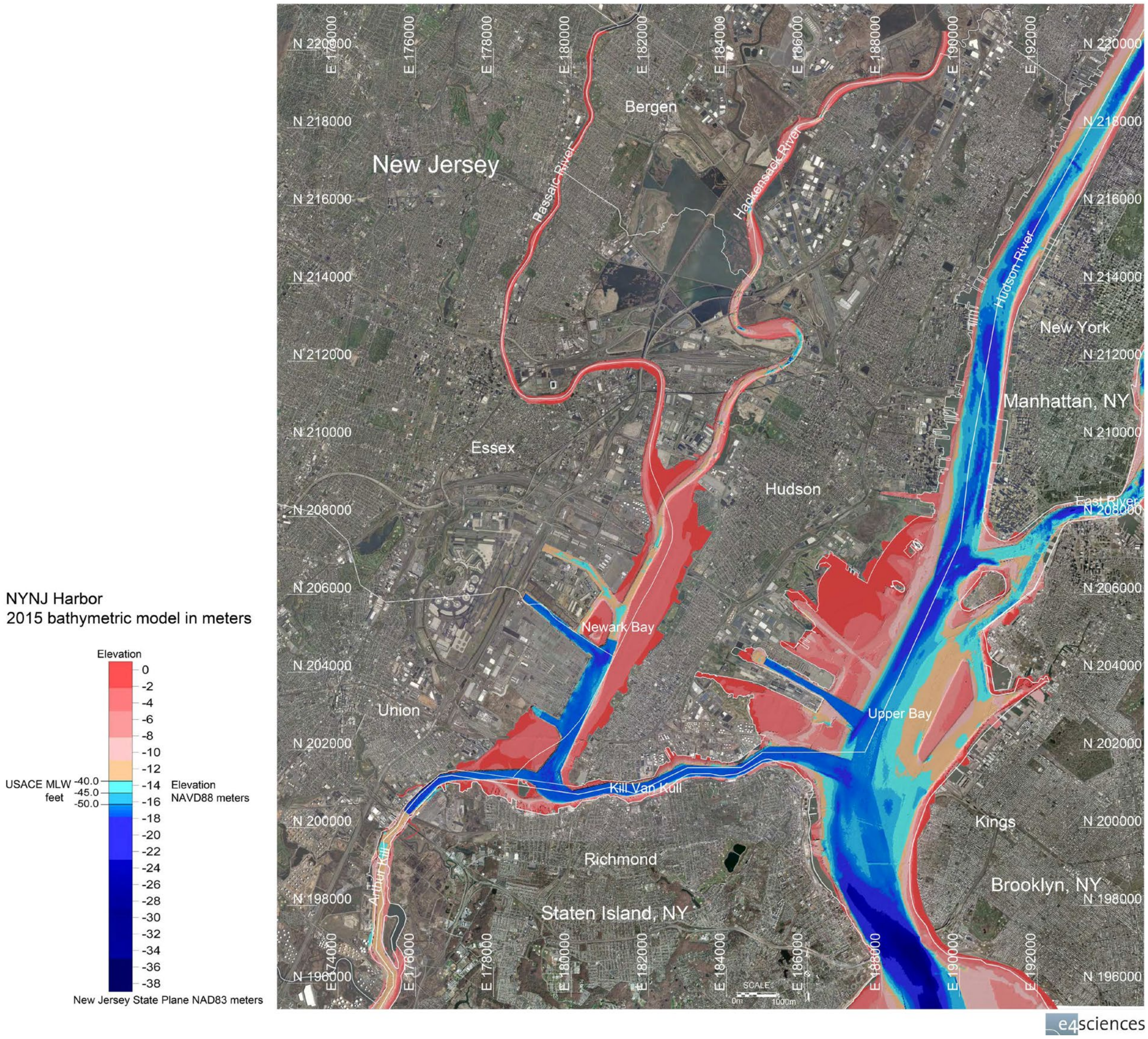



**Figure 2-7: NYNJ Harbor Bathymetric Model Detail of Upper Harbor and Newark Bay**

## 2.4.2 Utilities

Buried utilities, including pipelines and cables, are present within the study area and in many instances in close vicinity to the proposed storm surge barriers discussed herein[3]. Storm surge barriers are sited with consideration of avoiding utility conflicts to the extent practical. Further exploration will be needed to identify marked and unmarked utilities; for selected storm surge barrier locations, utilities will have to be located precisely and potentially relocated prior to construction. For the SBMs, no detailed utility or facility inventory or relocation analyses were

[3] The exception is the Throgs Neck storm surge barriers, based on preliminary desktop analyses

completed. It is recognized that in the dense urban areas within the study areas, numerous utility corridors exist above and below ground. At the feasibility stage the assumption has been made that these conflicts will need to be resolved at a later stage and that associated cost at this stage can be captured on a per linear foot basis (see Cost Engineering Appendix). Further site investigations are recommended at later stages of the study and future phases of the project to address utility conflicts and relocations.

### 2.4.3 Geology and Geotechnical Conditions

The CSRM measures on the south and east of the project area are generally located in a geological, structural, and topographic province known as the Atlantic Coastal Plain. In this area, the Coastal Plain consists of unconsolidated deposits of sands, silts, and clays that gently dip seaward. The coastal plain deposits are typically overlain with younger glacial deposits of till, outwash material, and moraine deposits. More recent deposits of fill, stream material, and reworked sediments may overlie the glacial deposits. In the west regions of the project area, proposed CSRM measures are located along waterways within the Newark Basin, a partial rift which has been filled with sand, silt, and clay sediment eroded from the surrounding basin walls and hills of the Piedmont region. Proposed CSRM measures within the northern regions of the project area are located along waterways within the Manhattan Prong geologic formation. This area typically consists of metamorphic bedrock overlain by recent alluvial deposits of sand, silt, and clay.

No site-specific geotechnical investigation or analysis was completed as part of this study. It should be emphasized that proposed CSRM measures are not site-specific but are expected to be used throughout the study area as part of any of the NYNJHAT Study alternatives. Geotechnical parameters based on existing reports and studies that fall within the study area were used and are assumed to result in a reasonable representation of potential soil conditions throughout the study area. For additional details, see Sub-Appendix B1 (Shore-Based Measures Sub-Appendix). For the three reference storm surge barriers, the soil parameters were based on site specific conditions if such data was available as detailed in Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix). For the other storm surge barriers, no geotechnical analyses were performed, and foundation and structure costs are assumed to be scalable based on the design of the reference storm surge barriers. More detail on this approach is provided in the Cost Engineering Appendix.

### 2.4.4 Future Without Project Conditions

The Future Without Project Conditions (FWOP) are described in the main text of the feasibility report (Section 2). In the engineering context, it is important to note that some of the funded, currently-in-construction projects provide flood risk reduction; however, these projects or the associated flood risk reduction benefits are not necessarily displayed on the mapping products included with this Appendix (unless specifically noted otherwise). Furthermore, some of the proposed alignments under the NYNJHAT Study tie into, or are directly adjacent to, such future projects, and continued coordination will be needed post-TSP and into the PED phase.

# 3 Shore-Based Measures

## 3.1 SBM, IFF, and RRF Alignments

The alignments of each of the NYNJHAT Study alternatives were developed during the early plan formulation phase of the study (see also section 0). Refinements and alterations to the SBM alignments were made over the course of the feasibility study but were generally minor. RRF alignments and IFF alignments were added to each study alternative, where applicable, during the feasibility study since those were not defined in the early plan formulation stage. The locations for IFFs and the IFF alignments were based on the analysis of the effects of induced flooding for each of the study alternatives. A detailed description of this analysis provided in Sub-Appendix B6 (ERDC CSTORM/ADCIRC Model Report Sub-Appendix) and can be summarized as follows. In locations where 1% AEP water levels are estimated to increase by more than half a foot, compared to the 'without project' condition, the area is marked for a potential need for induced flood mitigation. Through a desktop level evaluation of each of these areas, it is assessed whether SBMs are already present within this location (in this instance the SBM will mitigate for induced flood risk) or, if no SBMs are present, whether additional SBMs, in this instance referred to as IFFs, are needed to provide for flood risk reduction. The need for such measures depends on the evaluation of the inundated area, and generally any developed, non-natural, inundated area has been assigned an IFF alignment. Additional information on induced flooding and placement of the IFFs can be found in Sub-Appendix B1 (Shore-Based Measures Sub-Appendix).

A similar methodology was applied to establish the RRF alignments. Where storm surge barriers are proposed (Alternatives 2, 3A, 3B, and 4), complementary RRFs to manage the risk of more frequent flooding are proposed for developed, non-natural areas. The RRF alignments mitigate residual flood risk under the assumption that the storm surge barrier (SSB) closure criterion is El. +7 ft NAVD88. The need for RRF alignments to provide for flood risk reduction was evaluated through a desktop level evaluation of each of the coastal areas upstream of the storm surge barriers subject to inundation at the +7 ft NAVD88 flood level. Developed, non-natural, inundated areas have generally been assigned RRF alignments. Additional information on the RRFs and RRF placement can be found in Sub-Appendix B1 (Shore-Based Measures Sub-Appendix). Specifically, RRFs are only considered in the basins enclosed by the six large storm surge barrier complexes (OH, TN, VN, AK, JB, and KvK). The residual flood risk for the coastal areas upstream of the other storm surge barriers is mitigated by a lower closure elevation (i.e., more frequent operation of the SSB) or the flood risk is minimal for the elevation of +7 ft NAVD88 due to natural relief (see also section 4.3 and Table 4-1). A more detailed description of closure criteria for the SSBs is provided in Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix).

## 3.2 Methodology for Development of SBMs as part of NYNJHAT Study Alternatives

A limited series of reasonable and conceptually generic structural measures to provide flood risk reduction that can be used throughout the NYNJHAT Study area, and that are applicable to all NYNJHAT Study alternatives, were developed. As noted earlier, these structural measures are referred to as SBMs and include typical structures like floodwalls and levees (see Figure 3-1 and

Figure 3-2 as examples). The purpose of the study is to develop generalized SBMs that are comprehensive enough to be applicable and suitable for the entire study area, yet not too detailed or site specific such that they could only be applied at one location.

**Figure 3-1: Floodwall Construction in New Orleans (USACE, New Orleans District)**

**Figure 3-2: Levee in New Orleans (USACE, New Orleans District)**

A selected set of structural measures based on the NACCS report (USACE, 2015), including a Seawall, Levee, Floodwall, Deployable Floodwall, Tide Gate, Road Raising, and Beach and Dune Restoration were refined and expanded upon using the methodology for design development described hereafter. The methodology is characterized as a desktop study where a high-level assessment and analysis is performed with limited data and which, in large part, relies on evaluation of aerial photography, site photos, readily available public data and on professional engineering judgment. The general process combined both the evaluation of the applicability of SBMs for each alignment as well as the evaluation of the need for minor realignments to accommodate the SBMs and minimize conflict. The methodology is further described in Sub-Appendix B1 (Shore-Based Measures Sub-Appendix).

Following the methodology, and with the objective of developing generalized SBMs that are comprehensive enough to be applicable and suitable for the entire study area, yet not too detailed or site specific such that they could only be applied at one location, the list of structural SBMs for the NYNJHAT Study is provided below. It can be noted that in the lists provided below, different versions of floodwalls and levees are included. These variations were needed to accommodate the different locations where these measures are placed. In low-lying areas, relatively large floodwalls and levees (as measured from ground elevation to the top of the SBM) are needed to provide flood risk reduction, while further inland or in areas of moderate to higher elevations, the size of the intervention needed is smaller.

Lastly, for completeness, it is once more reiterated that measures used for IFFs are SBMs; the IFF nomenclature only highlights the fact that such measures address the induced flooding risk.

<u>SBMs:</u>

- Floodwalls
    - Medium Floodwall
    - Large Floodwall
    - Extra Large Floodwall
- Levees
    - Medium Levee
    - Large Levee
- Elevated Promenade
- Floodwall with Park Integration
- Seawall
- Reinforced Dune
    - Reinforced Dune – Natural Dune Cover for natural shoreline application
    - Reinforced Dune – Partial Dune Cover for urban application
- Deployable Flood Barriers
    - Flip-up Barrier
    - Pedestrian, Vehicular and Railroad Gates
- Tide Gate

For RRFs, the structural measures were based on an earlier completed feasibility study within the study region – *FINAL Integrated Hurricane Sandy General Reevaluation Report and Environmental Impact Statement Atlantic Coast of New York, East Rockaway Inlet to Rockaway Inlet and Jamaica Bay, Appendix A1* (USACE, 2018). In the 2018 report, High-Frequency Flood Risk Reduction Features (HFFRRFs) for the Jamaica Bay area were developed for areas at risk of high frequency flooding. Those measures have a reveal height (the height between top of wall and ground level) ranging from 3 ft to 8.5 ft. The HFFRRFs in the Jamaica Bay Feasibility Study provide the same function as the RRFs under the NYNJHAT Study. Since the RRFs have a similar reveal height and are applied in the same region, the HFFRRFs designs were adopted and used as the starting point for the design of the RRFs under the NYNJHAT study. The RRFs are listed below.

<u>RRFs:</u>

- Floodwalls
    - Low Floodwall
    - Standard Floodwall
    - High Floodwall
- Berm
    - Low Berm
    - Medium Berm

    - High Berm
    - Hybrid Berm
- Bulkhead
    - Shallow Bulkhead
    - Deep Bulkhead
- Revetment with Floodwall
- Tide Gate
- Deployable Flood Barriers
    - Pedestrian and Vehicular Gates
- Road Ramp
- Road Raising

All RRFs are typically small measures placed on land or at the coastal edge, with the exception of the tide gate which is placed at crossings of small streams and creeks. However, in a few specific instances, RRFs are proposed to cross existing waterways that are navigable. For these locations a navigable gate was selected as an assumed cost-effective alternative to many miles of land-based RRF features along the water's edge to reduce the risk of residual flooding. These navigable gates are considered secondary features, i.e., not storm surge barriers that provide the primary flood risk reduction function and due to their similarity with storm surge barriers, are discussed in section 4 and section 4.6, specifically.

The following section first provides a brief explanation of the evaluation of existing shoreline conditions and the compatibility and selection of SBMs under this study. Thereafter the development of the preliminary designs of the SBMs and RRFs is briefly discussed. For additional detail, the reader is referred to Sub-Appendix B1 (Shore-Based Measures Sub-Appendix).

## 3.3 Placement of SBMs and RRFs and Existing Shoreline Considerations

With the use of publicly available data and satellite images, existing shoreline features for all the study areas were assessed and classified into the categories shown in Table 3-1. Based on the existing features that prevail throughout the study area and the prototypical SBM designs developed for the NYNJHAT study, the table presents the general applicability of the SBMs by existing shoreline feature type.

It should be reiterated that no site-specific topographic survey, bathymetric survey, condition survey, or geotechnical analysis have been completed. Instead, in accordance with USACE's SMART planning principles, the development of the feasibility-level SBMs was based on qualitative data and desktop-level analysis, which resulted in broad generalizations of existing conditions. The implications of such assumptions. along with recommendations for further data collection and refined analysis to support the design are described in Section 9.

**Table 3-1: Existing Shoreline Features and General Applicability of SBMs**

| Existing Shoreline Type | Floodwall | Levee/Berm | Elevated Promenade | Floodwall with Park Integration | Bulkhead | Seawall/Revetment with Floodwall | Reinforced Dune – Natural Dune Cover, Partial Dune Cover | Deployable Flood Barrier - Flip-up Barrier | Deployable Flood Barrier – Pedestrian, Vehicular, Railroad Gates | Tide Gate | Road Ramp | Road Raising |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Natural Shoreline** | √ | √ | | | | | | | | | | |
| **Revetment** | | | √ | | | √ | | | | | | |
| **Parks/ Uplands** | | √ | | √ | | | | | | | | |
| **Street End/ Crossings** | √ | | | | | | | | √ | | √ | √ |
| **Urban Waterfront Development** | √ | | √ | | √ | | | √ | | | | |
| **Industrial Waterfront Development** | √ | | | | √ | √ | | | | | | |
| **Promenade** | √ | | √ | | | | | √ | | | | |
| **Bulkhead** | | | | | √ | | | | | | | |
| **Beach** | | | | | | | √ | | | | | |
| **Streams, Creeks, Waterways or Canals** | | | | | | | | | | √ | | |

## 3.4 SBM and RRF Designs

Based on available data and desktop analyses, preliminary designs commensurate with a feasibility study level were developed for the SBMs that are proposed to be part of the NYNJHAT Study alternatives. The list of SBMs developed for this study is provided in section 3.2 and a detailed description of the design development of each individual SBM is included in Sub-Appendix B1 (Shore-Based Measures Sub-Appendix). The following pages include an overview of SBMs and RRFs most commonly included within the NYNJHAT Study alternatives, and the design sections that have been developed for each (see Figure 3-3, Figure 3-4, Figure 3-5, Figure 3-6, Figure 3-7, and Figure 3-8). The reader is referred to Sub-Appendix B3 (TSP Plan Set) for a complete overview of technical sections, elevation views, and plan views of the SBMs and RRFs.

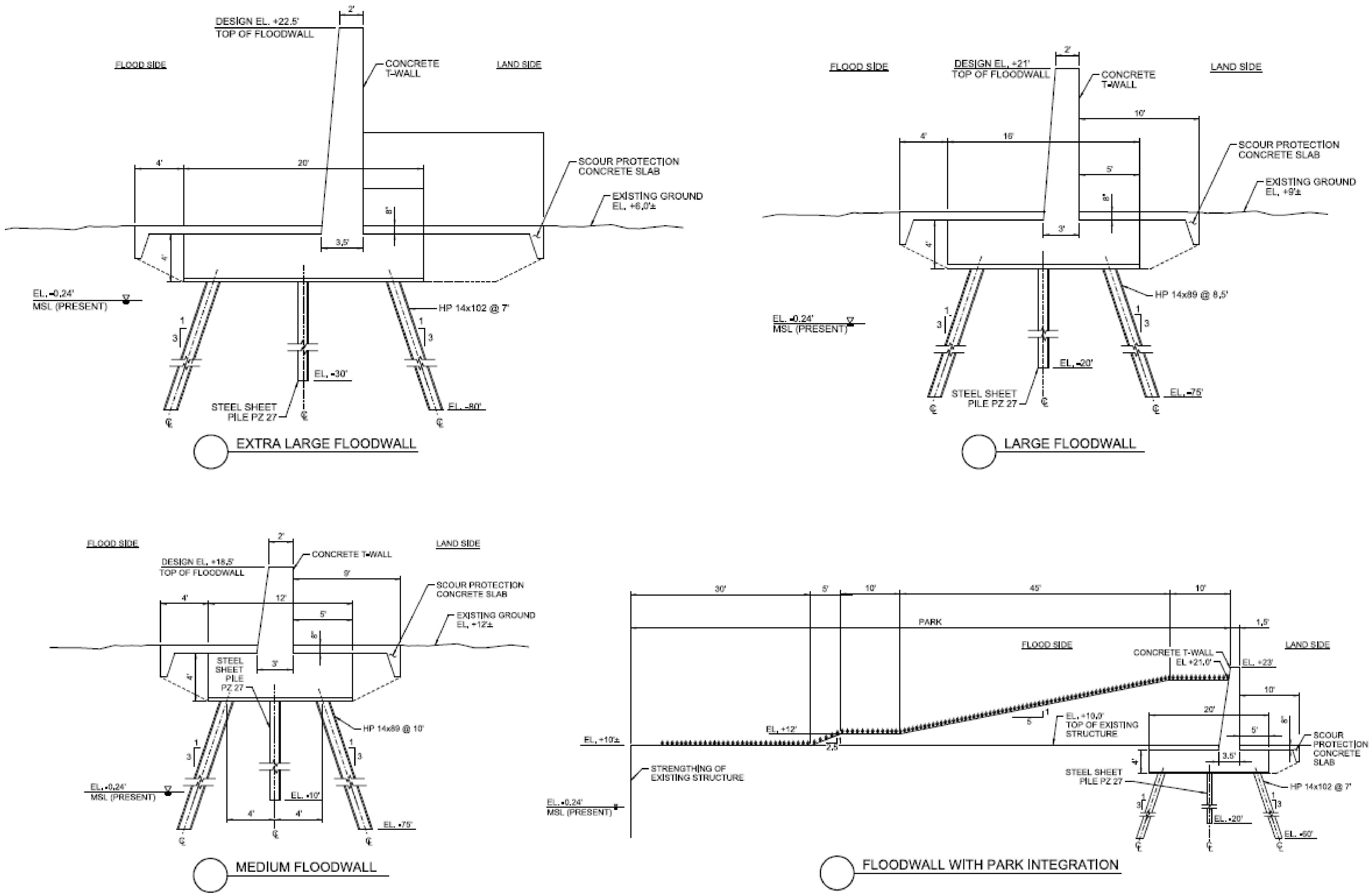
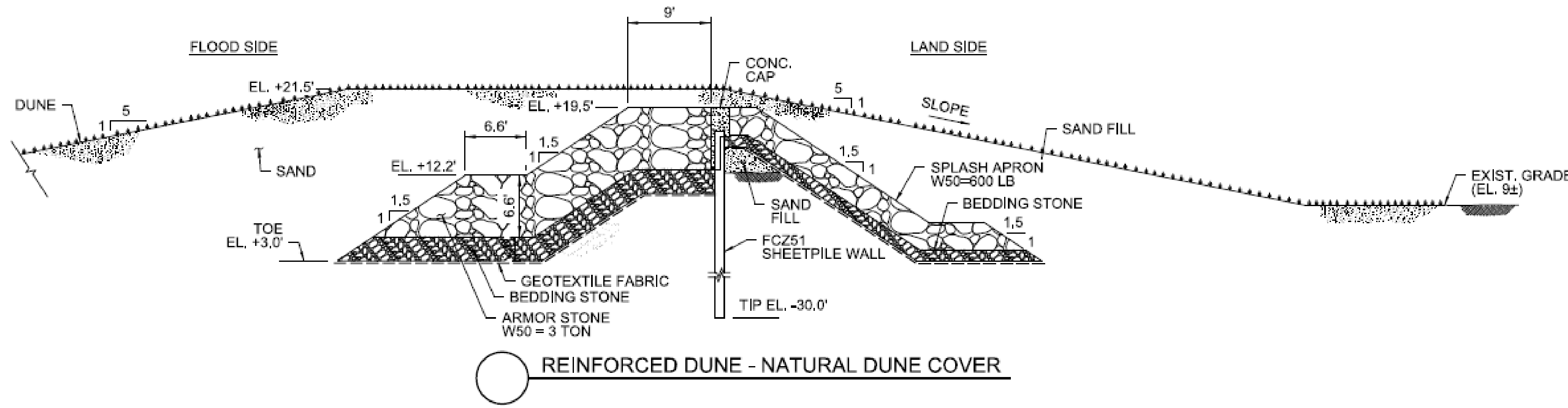
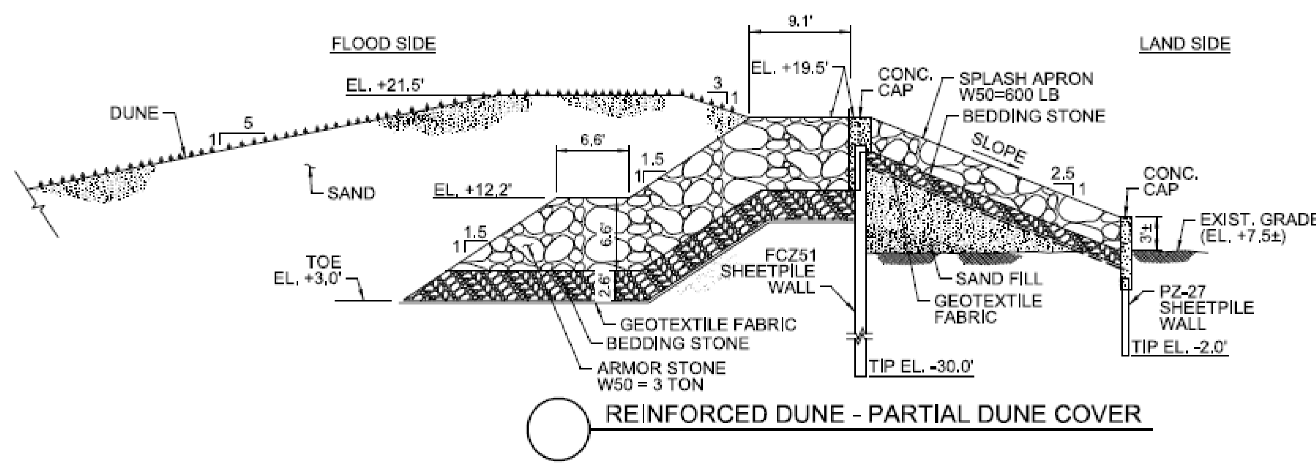



**Figure 3-3: Preliminary Designs for SBMs (Floodwalls), Not to Scale**



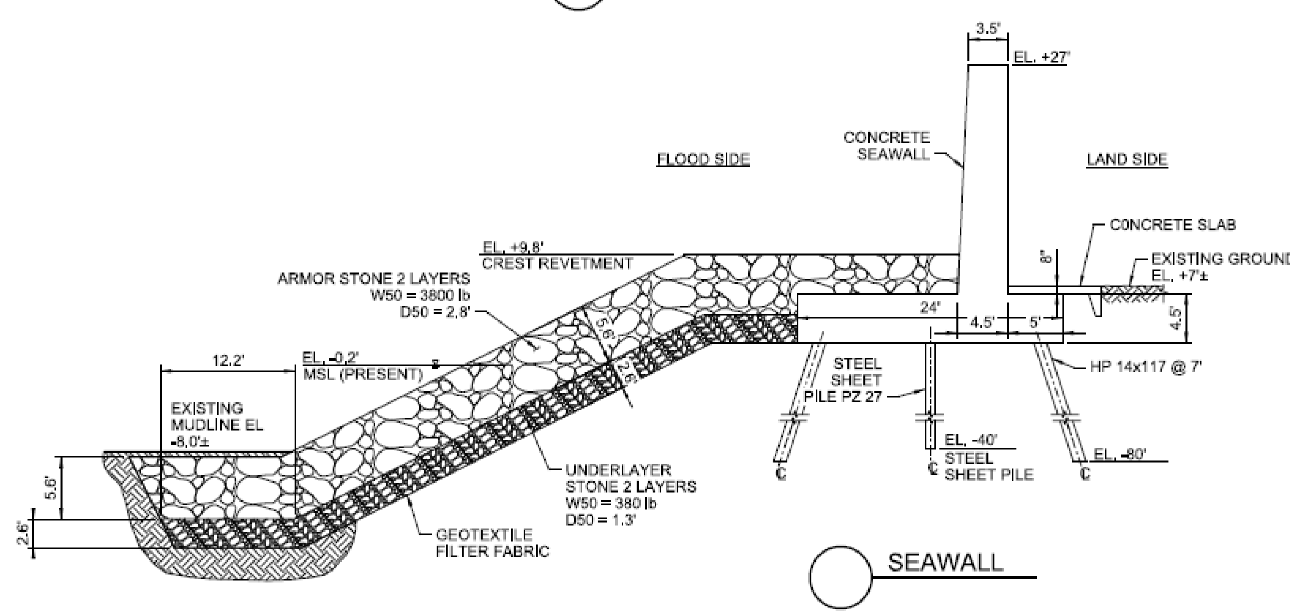




**Figure 3-4: Preliminary Designs for SBMs (Reinforced Dunes and Seawall), Not to Scale**

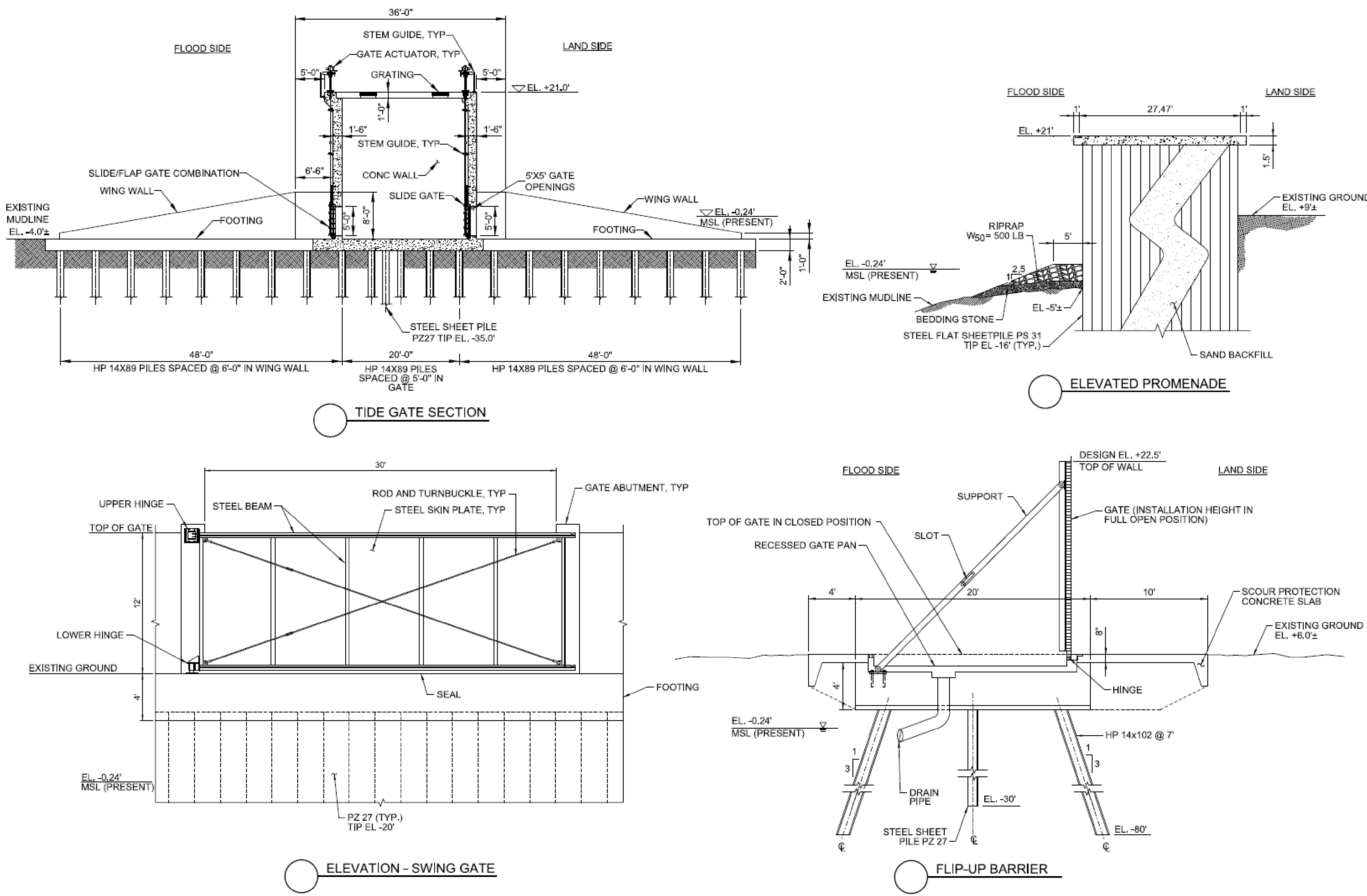
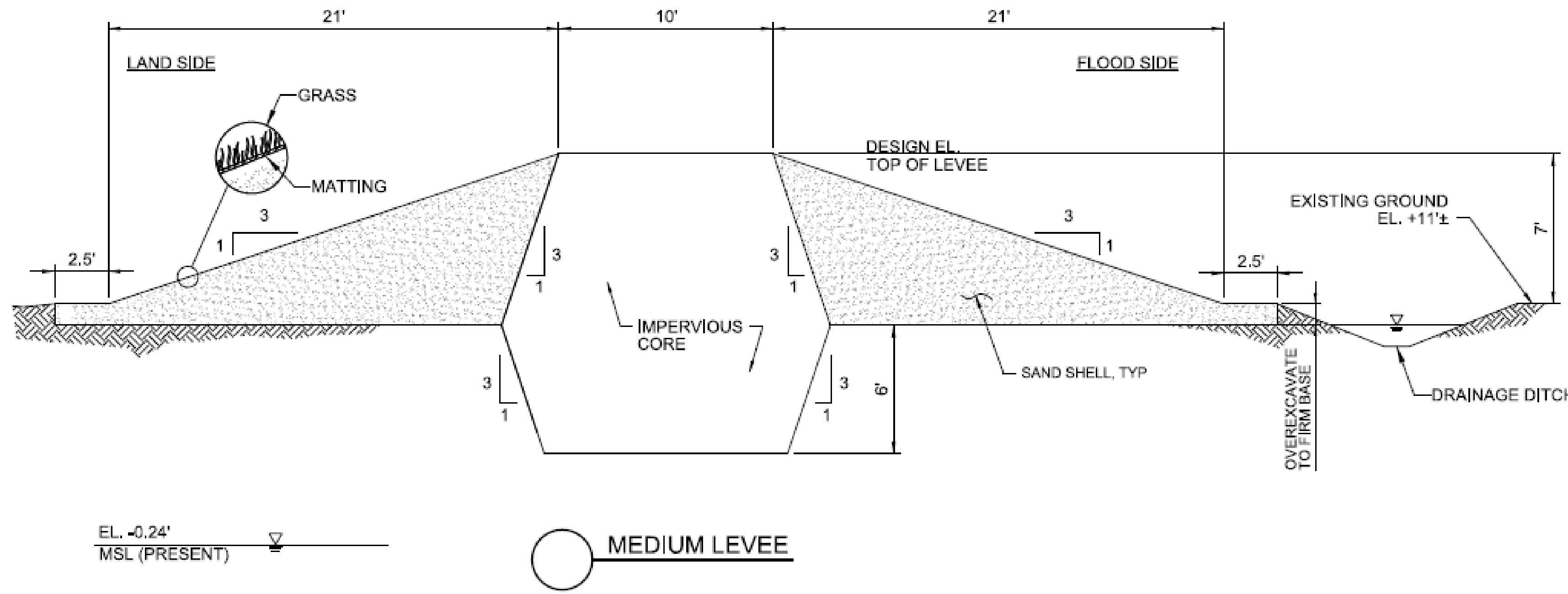



**Figure 3-5: Preliminary Designs for SBMs (Tide Gate, Elevated Promenade, Swing Gate and Flip-up Barrier), Not to Scale**



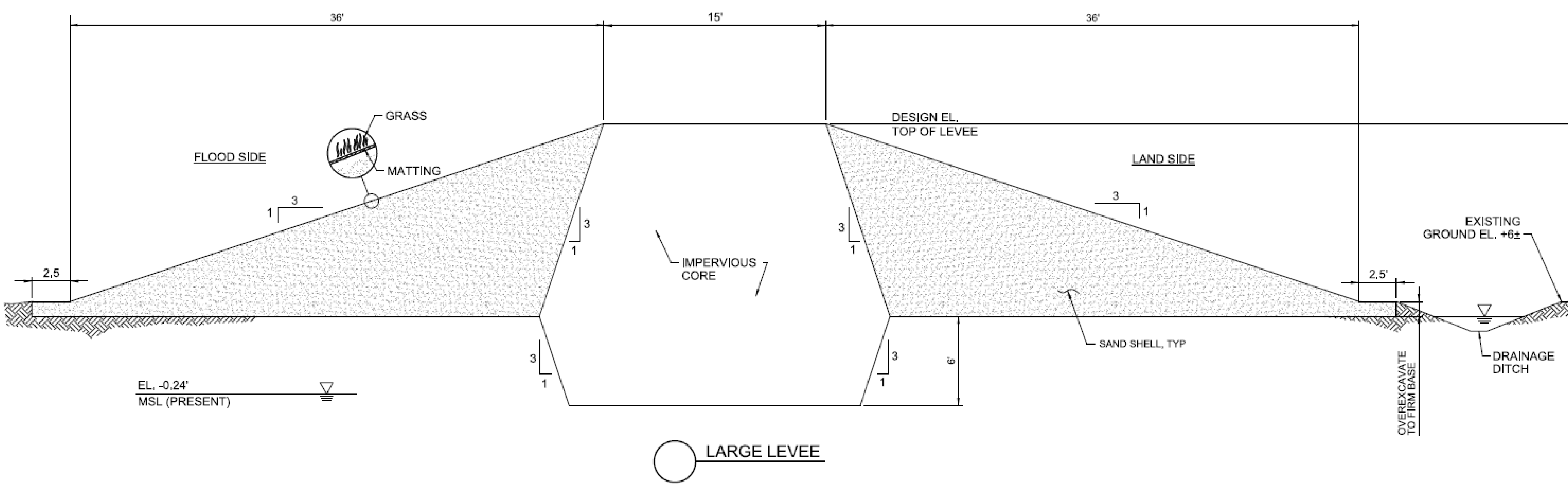




**Figure 3-6: Preliminary Designs for SBMs (Levees), Not to Scale**

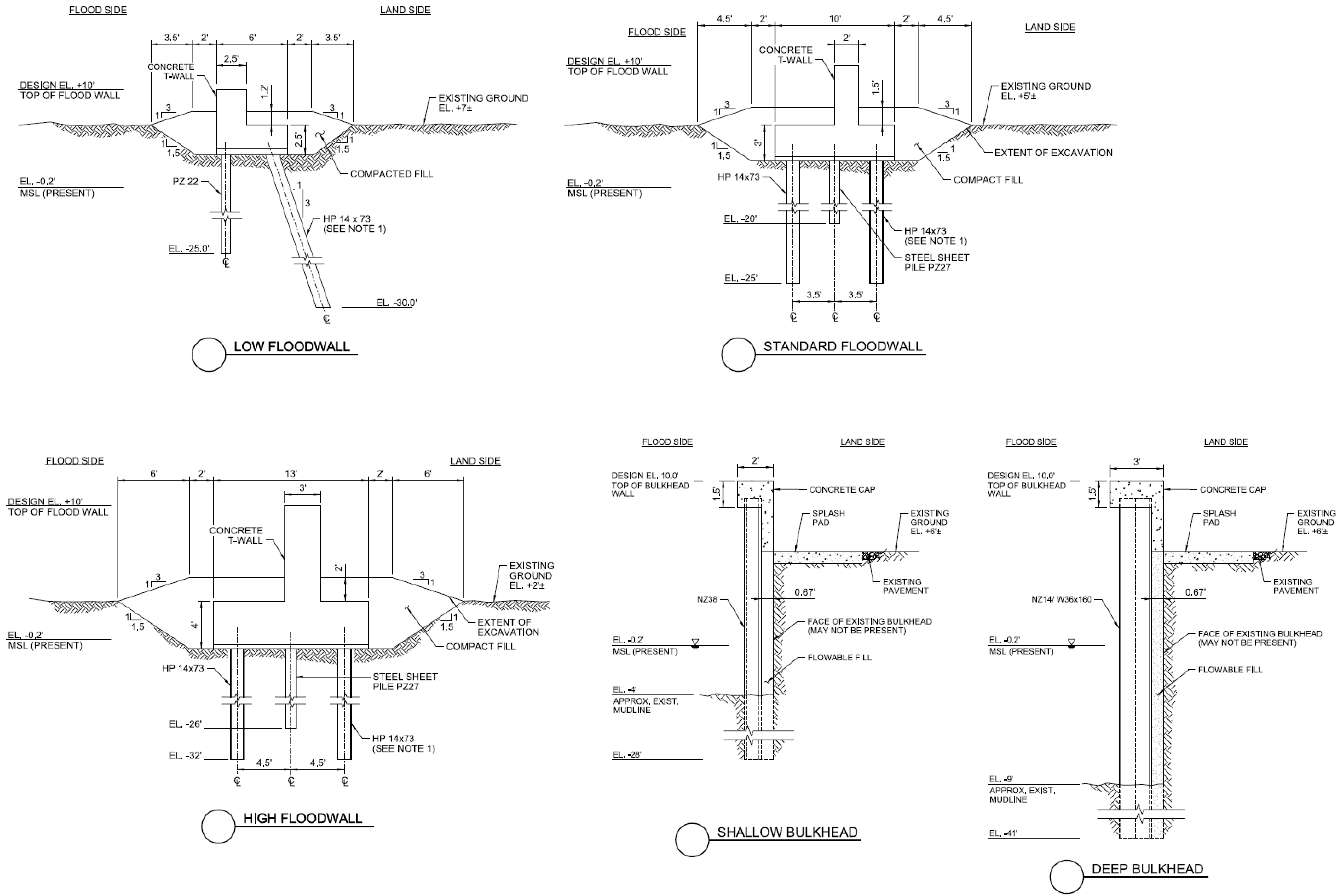



**Figure 3-7: Preliminary Designs for RRFs (Floodwalls and Bulkheads), Not to Scale**

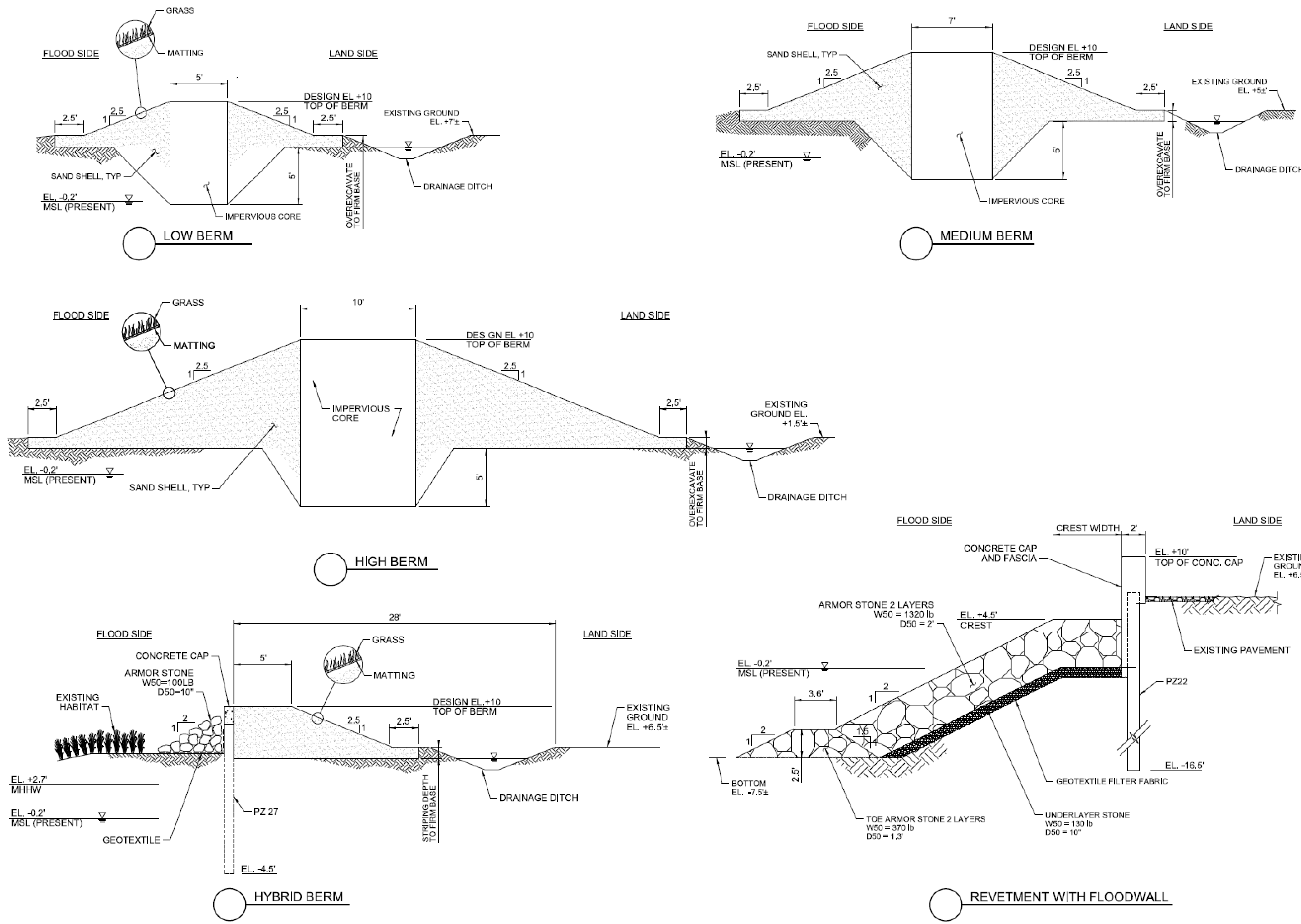



**Figure 3-8: Preliminary Designs for RRFs (Levees, Berm and Revetment with Floodwall), Not to Scale**

# 4 Storm Surge Barriers

## 4.1 Introduction

A typically employed solution for reducing flood risk is to raise the level of existing perimeter flood risk reduction systems. This solution can be challenging to implement in geometrically constrained urbanized areas where waterfront spaces have multiple uses and serve a variety of stakeholders such that social and economic impacts could be considerable. In large bays, estuaries, natural harbors, and port entrance channels, storm surge barriers constructed as integral part of flood risk reduction systems can be a cost-effective alternative to reduce the risk of flooding for the area. As such, the NYNJHAT Study includes evaluation of storm surge barriers, in combination with shore-based flood risk reduction systems.

## 4.2 General Description of a Storm Surge Barrier with Navigable Passage

Mooyaart and Jonkman (2017) provide general design considerations and an overview of navigable storm surge barriers based on data and design documentation review of a select set of constructed storm surge barriers throughout the world. They also provide a general description of a storm surge barrier where a typical layout contains three elements: a gated section, a dam section, and a navigable passage. A navigable passage can either be established with a lock or with a gated navigable opening. The difference is that a lock passage is usually closed during normal operational conditions and only opens for the passage of vessels; a gated navigable passage is open for free navigation passage and only closed during the occurrence of a storm surge event. Figure 4-1 below provides a schematic plan view of a navigable storm surge barrier. The navigable passage is schematically shown as a gated navigable opening, not as a lock, since the storm surge barriers studied under the NYNJHAT Study require minimal interruptions of maritime traffic except during storm surge events. Figure 4-1 schematically shows a total of three (3) auxiliary flow gates; however, the storm surge barriers discussed herein may have fewer or many more. Both navigation and tidal flow exchange can be provided through the navigable passage opening.

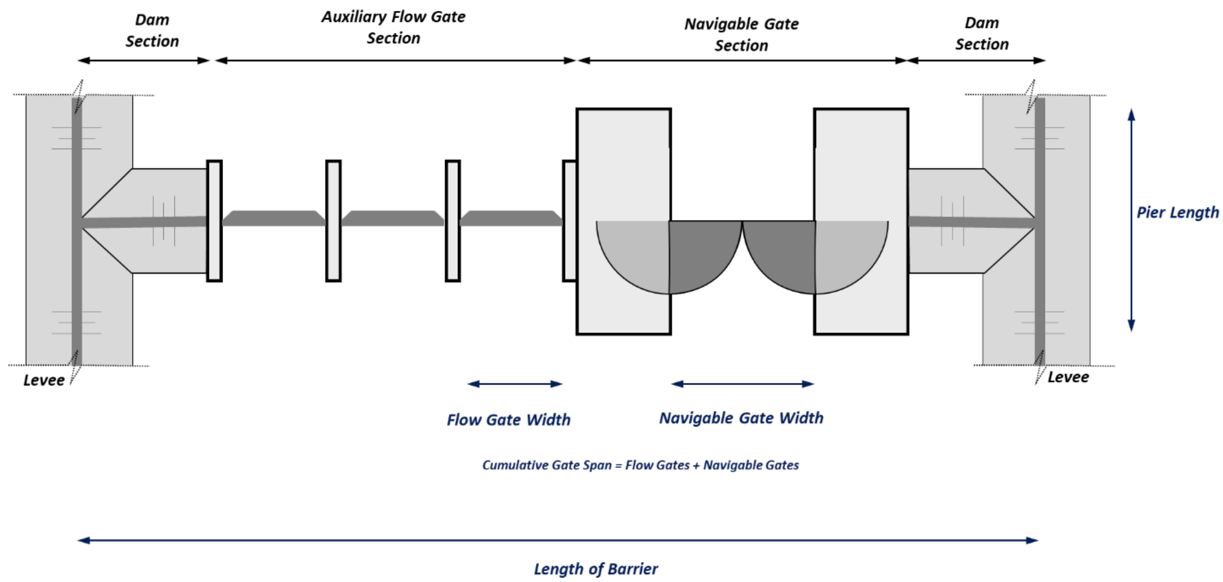



**Figure 4-1: Schematic Plan View of a Storm Surge Barrier**

It is recognized that each navigable storm surge barrier is a unique civil works projects and constructed storm surge barriers vary substantially in size and complexity. Two examples are provided below for reference (Figure 4-2 Figure 4-3).

**Figure 4-2: Seabrook Storm Surge Barrier Gate Complex, New Orleans, LA, containing a sector gate for the navigable passage and 2 auxiliary flow openings with vertical lift gates**

**Figure 4-3: The Maeslant Storm Surge Barrier, The Netherlands, a Floating Sector Gate for the Navigable Passage. Photo showing test closure (source: https://beeldbank.rws.nl, Rijkswaterstaat)**

## 4.3 Navigable Storm Surge Barriers in the NYNJHAT Study Alternatives

The locations of the storm surge barriers discussed herein are for the most part, determined by the extent and location of the perimeter flood risk reduction systems. Over the course of the feasibility study, IFF alignments were added to each study alternative, where applicable. The locations for IFFs and the IFF alignments were based on the analysis of induced flooding for each of the study alternatives and is detailed in the SBM Sub-Appendix. In some instances, induced flooding was mitigated by extending the shore-based measures across a water body, and in those locations a storm surge barrier was added to a study alternative as an IFF. Ultimately, 18 storm surge barrier structures were defined as part of the study alternatives (see Table 4-3) to mitigate flood risk for the 1% AEP coastal flood event. These 18 storm surge barriers, also referred to as “primary navigable barriers”, are shown in Figure 4-4.

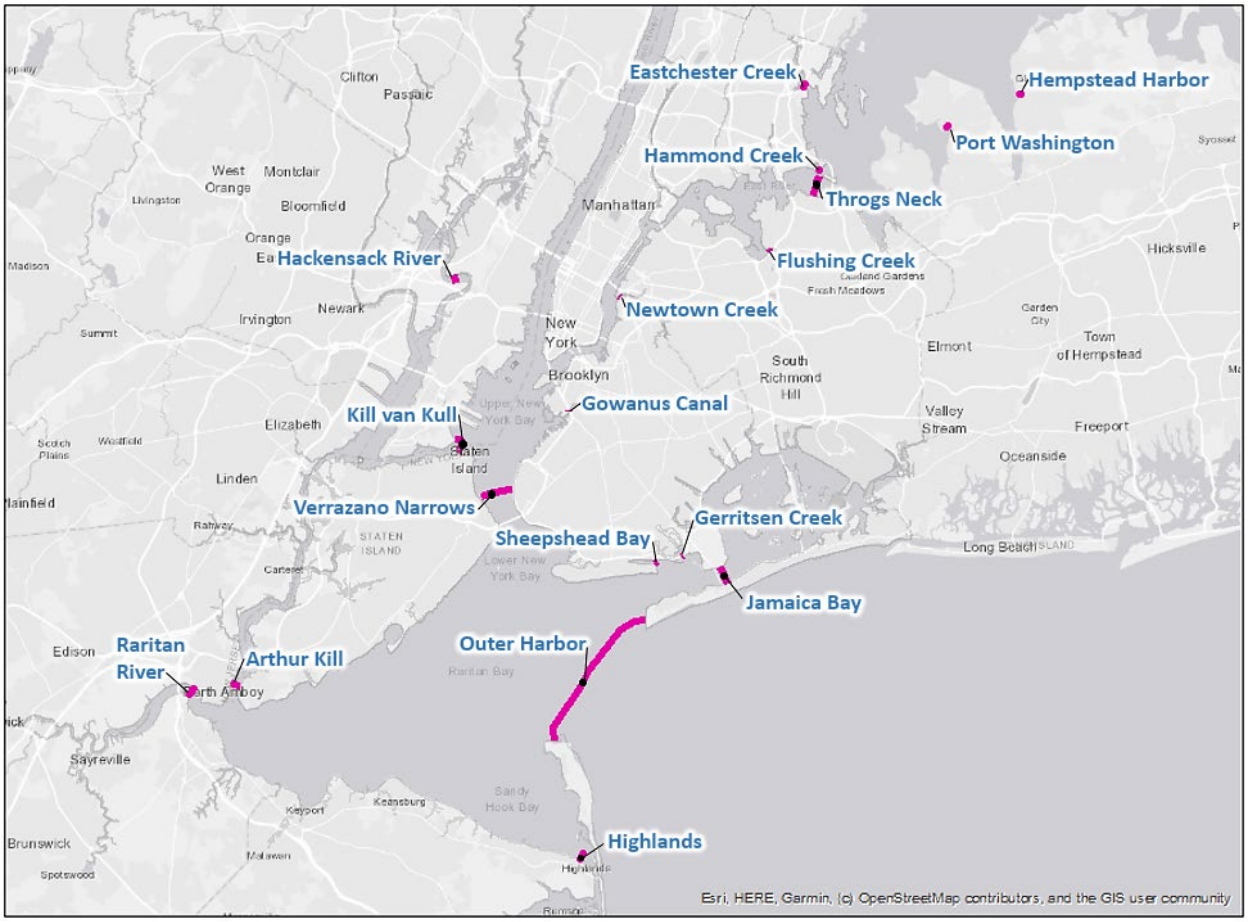



**Figure 4-4: Plan Overview of All SSBs Included Within the NYNJHAT Study Area**

**Table 4-1: Storm Surge Barriers (Primary Navigable Barriers) for NYNJHAT Study Alternatives**

| Name of Storm Surge Barrier | Abbrev. | Alt. 2 | Alt. 3A | Alt. 3B | Alt. 4 | Alt. 5 | RRFs in Basin | Strict constrained operation (CO) or moderately constrained operation (MCO) |
|---|---|---|---|---|---|---|---|---|
| **Storm Surge Barriers** | | | | | | | | |
| **Outer Harbor** | OH | Yes | | | | | Yes | SCO |
| **Throgs Neck** | TN | Yes | Yes | | | | Yes | SCO |
| **Verrazzano Narrows** | VN | | Yes | | | | Yes | SCO |
| **Arthur Kill** | AK | | Yes | Yes | | | Yes | SCO |
| **Jamaica Bay** | JB | | Yes | Yes | Yes | | Yes | SCO |
| **Kill van Kull** | KVK | | | Yes | | | Yes | SCO |
| **Hackensack River** | HR | | | | Yes | | No | MCO |
| **Newtown Creek** | NC | | | Yes | Yes | | No | MCO |
| **Gowanus Canal** | GC | | | Yes | Yes | | No | MCO |
| **Flushing Creek** | FC | | | Yes | Yes | | No | MCO |

| Name of Storm Surge Barrier | Abbrev. | Alt. 2 | Alt. 3A | Alt. 3B | Alt. 4 | Alt. 5 | RRFs in Basin | Strict constrained operation (CO) or moderately constrained operation (MCO) |
|---|---|---|---|---|---|---|---|---|
| **Sheepshead Bay** | SB | | Yes | Yes | Yes | | No | MCO |
| **Gerritsen Creek** | GRC | | Yes | Yes | Yes | | No | MCO |
| **Induced Flooding mitigation Features** | | | | | | | | |
| **Eastchester Creek** | EC | Yes | Yes | | | | No | MCO |
| **Port Washington** | PW | Yes | Yes | | | | No | MCO |
| **Hempstead Harbor** | HH | Yes | Yes | | | | No | MCO |
| **Hammond Creek** | HC | Yes | Yes | | | | No | MCO |
| **Highlands** | HL | | Yes | | | | No | MCO |
| **Raritan River** | RR | | Yes | | | | No | MCO |

For the larger storm surge barrier structures that accommodate deep-draft navigation or intersect major shipping routes, the operational frequency is expected to be considerably constrained. This is indicated by the keyword Strict Constrained Operation (SCO) in the last column in Table 4-1 which means that the storm surge barrier gates will only be closed for the more severe coastal storm events such that navigation is not negatively impacted. In the alternatives where these six storm surge barriers (OH, TN, VN, AK, KvK, JB) are proposed (Alternatives 2, 3A, 3B, and 4), complementary RRFs to manage the risk of more frequent flooding are proposed for developed non-natural areas, as indicated in Table 4-1. Shorelines protected by these 6 SSBs would still face residual risk from flooding events that may be too minor to trigger an SSB closure. The RRF alignments mitigate residual flood risk under the assumption that the SSB closure criterion is El. +7 ft NAVD88. As such, the need for RRFs is directly correlated to the assumed inability to operate these major storm surge barriers frequently. The residual flood risk for the coastal areas upstream of the other storm surge barriers is mitigated by a lower closure elevation, i.e., operation is only moderately constrained (MCO). Thus, more frequent operation is assumed to be possible for these storm surge barriers and no complementary RRFs are needed.

## 4.4 Storm Surge Barrier Conceptual Design Development

The purpose of a storm surge barrier is to impede storm surge when closed yet to maintain tidal flow exchange between the ocean and the upstream water body, e.g., bay, basin, or river, during normal conditions when the gates are open. All storm surge barriers that are part of the NYNJHAT Study alternatives have a navigable passage to allow for vessels to pass, and have additional auxiliary flow gates, provided sufficient space is available, to maintain tidal flow exchange. The auxiliary flow gates serve to maximize the water exchange through the opening and minimize impacts on the inner basin environmental conditions during normal hydrodynamic and meteorological conditions. At the tie-in locations of the storm surge barrier to the shore-based system, i.e., shallow waters, a dam section is included that can range on the order of 10 ft to 1000 ft long. This dam section will be the transition between the operable storm surge barrier gate structure and the shore-base or land-based flood risk reduction system.

### 4.4.1 Gated Navigable Passage

Once a location has been set, the overall geometry of the storm surge barriers was then dictated by the existing bathymetry, geometry of the navigable passage(s) and the auxiliary flow gates given the existing bathymetric profile and the design criteria. The structure crest elevation is set based on the design overtopping criterion (200 l/s/m) and the overtopping analysis is provided in Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix). The determination of the minimum practical dimensions of the navigable passages of the storm surge barriers follows from the analysis of maritime traffic and authorized channel dimensions (for federal navigation projects), also presented in Sub-Appendix B2. A couple of remarks and observations specific to the storm surge barrier conceptual design development as presented in Sub-Appendix B2 are highlighted here. The OH SSB includes three navigable passages, one each at the intersection with the federal channel. The VN SSB includes two navigable passages to accommodate the high volume of maritime traffic and the JB SSB includes two navigable passages to accommodate the separation of inbound and outbound traffic. It can further be noted that the dimensions of the navigable passage for the Ambrose Channel are larger than any gated opening in constructed storm surge barriers (Maeslant Barrier in The Netherlands spans approximately 1,200ft). A summary table with the key characteristics for each SSB structure is presented at the end of this section (see Table 4-2).

Following the minimum design dimensions, a suitable gate type has preliminarily been selected for each opening in the SSB. Based on data and characteristics of constructed storm surge barriers and the gate types used, the suitability of gate types for the navigable passage of each SSB was evaluated. Based on the evaluation that is provided in Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix), the conventional sector gate with vertical axis and floating sector gate were most commonly selected as the gate type for the navigable passages (see Table 4-2).

### 4.4.2 Auxiliary Flow Gates

For the auxiliary flow gates, a standard gate span of 150ft is preliminarily selected based on the review of constructed lift gates; 150ft is considered to be a reasonable assumption, where this width falls within the gate spans for constructed storm surge barriers. Some SSB locations have spatial constraints, and at those locations lift gates with smaller spans are incorporated within the conceptual design. Due to the variations in depth along the storm surge barrier alignment, it is expected that varying gate heights will be needed. Varying gate heights will allow the design to follow the natural bathymetric contours of the area while maintaining a large open cross-section for flow. To minimize construction complexity and allow for optimization through the economies of scale, the gate sill elevations are preliminarily assumed to vary in increments of 5ft. The sill elevation of the auxiliary flow gates is preferably located above the existing bed elevation such that the potential for sedimentation or siltation at the bottom of the sill is minimized. Future data collection will be needed to obtain site-specific bathymetric profiles, and additional analyses are needed to evaluate the effect the storm surge barrier has on the hydrodynamics and morphology of the estuarine system.

To reduce the gate size, weight, and overall complexity of the hoisting mechanisms, it is proposed to include a solid, non-moveable wall above the gate. For water-control structures, this is commonly referred to as a headwall. The auxiliary flow gate only passes flow, and as such the gate does not need to be raised much higher than the Mean Higher High Water (MHHW) elevation, plus a clearance needed for clear sight lines and maintenance operations. For example, for the VN SSB, the headwall spans between the elevation +8ft and the top of the structure. While a headwall requires a fourth seal between structure and gate, since all four sides need to be sealed instead of three, the headwall reduces the overall height of the gates substantially[4]. For example, for the Verrazzano Narrows storm surge barrier, a gate height of 49ft would be needed to close an opening between a sill elevation of -30ft to a design elevation of +19ft, while, with the use of a headwall, the gate height would be 38ft (sill elevation at -30ft and top of gate at elevation +8ft).

Following the determination of the gate sizes needed for the auxiliary flow openings, a suitable gate type was selected. Based on the evaluation that is provided in Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix), the vertical lift gate is preliminarily selected for the majority of the conceptual designs of the storm surge barrier discussed herein.

### 4.4.3 Overview of SSB Characteristics

An overview of all SSBs and their key characteristics, including dimensions and gate types for the navigable passage and auxiliary flow openings, is provided in Table 4-2. For a more detailed description of each SSB, the reader is referred to Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix).

[4] e.g., the Eastern Scheldt storm surge barrier (The Netherlands) includes a headwall type feature.

**Table 4-2: NYNJHAT Study Storm Surge Barrier Characteristics**

| Storm Surge Barrier Location | Federal Channel | Existing Depth (ft) | Authorized Channel Depth [ft, NAVD88] | Navigable Passage Opening Width [ft] | Navigable Passage Depth of Opening [ft NAVD88] | Navigable Passage Depth of Opening [ft MLLW] | Navigable Passage Gate Type | Auxiliary Flow Openings and Gates Number of Auxiliary Flow Openings | Auxiliary Flow Openings and Gates Gate Type | Total Length[4] [ft] | Crest Elevation [ft NAVD88] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Verrazzano Narrows** | Ambrose Channel | 70-75 | -56 | 1,400[2] | -58 | -55 | Floating Sector Gate | 15 | Vertical Lift Gate | 6,500 | 19 |
| | Secondary Navigation Channel | 20-25 | -43 | 200[1] | -45 | -42 | Sector Gate | | | | |
| **Throgs Neck** | Throgs Neck | 40-55 | -38 | 450[2] | -40 | -37 | Floating Sector Gate | 18 | Vertical Lift Gate | 4,700 | 19 |
| **Arthur Kill** | Arthur Kill Channel | 35 | -38 | 600[1,3] | -40 | -37 | Floating Sector Gate | 2 | Vertical Lift Gate | 2,300 | 19 |
| **Outer Harbor** | Ambrose Channel | 75-80 | -56 | 1500[2] | -58 | -55 | Floating Sector Gate | 148 | Vertical Lift Gate | 34,700 | 29 |
| | Sandy Hook | 60-70 | -38 | 800[1,3] | -40 | -37 | Floating Sector Gate | | | | |
| | Rockaway Inlet | 20-30 | -23 | 200[1] | -25 | -22 | Sector Gate | | | | |
| **Kill Van Kull** | Kill Van Kull | 50-55 | -53 | 800[1,3] | -55 | -52 | Floating Sector Gate | 5 | Vertical Lift Gate | 3,300 | 19 |
| **Jamaica Bay** | Rockaway Inlet | 20-30 | -21 | 200[1] | -25 | -22 | Sector Gate | 15 | Vertical Lift Gate | 3,800 | 18 |
| **Hackensack River** | Hackensack River | 20-25 | -18 | 100[1,3] | -23 | -20 | Sector Gate | 5 | Vertical Lift Gate | 1,800 | 19 |
| **East Chester Creek** | East Chester Creek | 10-20 | -8 | 200 | -16 | -12 | Sector Gate | 1 | Vertical Lift Gate | 1,400 | 19 |
| **Flushing Creek** | Flushing Bay and Creek | 10-20 | -15 | 135 | -21 | -17 | Vertical Lift Gate | 2 | Vertical Lift Gate | 500 | 18 |
| **Newtown Creek** | Newton Creek | 20-25 | -23 | 130 | -20 | -18 | Sector Gate | 0 | N/A | 400 | 17 |
| **Gowanus Canal** | Gowanus Creek | 10-15 | -18 | 100 | -22 | -20 | Miter Gate | 0 | N/A | 200 | 16 |
| **Sheepshead Bay** | Sheepshead Bay | 30-35 | -6 | 100 | -20 | -18 | Sector Gate | 2 | Vertical Lift Gate | 800 | 17 |
| **Gerritsen Creek** | N/A | 20-25 | N/A | 115 | -19 | -17 | Vertical Lift Gate | 2 | Vertical Lift Gate | 400 | 17 |
| **Port Washington[5]** | N/A | 10-20 | N/A | 60 | -16 | -14 | Sector Gate | 2 | Vertical Lift Gate | 700 | 19 |
| **Hempstead Harbor (Glen Cove) [5]** | Glen Cove Creek | 10 | -10 | 60 | -11 | -9 | Sector Gate | 0 | N/A | 300 | 19 |
| **Hammond Creek [5]** | N/A | 5-15 | N/A | 60 | -15 | -13 | Sector Gate | 0 | N/A | 300 | 19 |
| **Highlands[5]** | Shrewsbury River | 20-25 | -15 | 100 | -20 | -18 | Sector Gate | 8 | Vertical Lift Gate | 4,000 | 18 |
| **Raritan River[5]** | Raritan River | 15-20 | -28 | 100 | -30 | -27 | Sector Gate | 8 | Vertical Lift Gate | 1,900 | 19 |

*Notes:*

1. *Practical width of navigable passage based on one-way traffic*
2. *Practical width of navigable passage based on two-way traffic*
3. *Practical width of navigable passage limited based on existing authorized channel dimensions*
4. *Total Length of barrier measured from SBM to SBM and rounded up to the nearest 100 ft increment*
5. *SSB is part of an IFF alignment*

## 4.5 Design for Three Reference Storm Surge Barriers

It is recognized that storm surge barriers are complex civil works, and that this complexity translates into large contingencies on the cost estimates of such structures. This is especially the case if the level of design is very conceptual, which is typical during the feasibility phase of a project. Since the NYNJHAT Study alternatives include multiple storm surge barriers, there was a need to increase the level of analysis and provide more detail on these structures such that contingencies could be lowered. To that end, feasibility-level designs for three selected reference storm surge barriers (Verrazzano Narrows, Jamaica Bay, and Hackensack River) were completed consistent with the objective of achieving a Class 4 cost estimate. The geometric characteristics as determined through analysis and as summarized in Table 4-2 was used as a starting point to provide further definition to the conceptual design of the VN, JB, and HR SSB. Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix) includes a detailed description on the design development of each of these structures. In addition, the supporting materials to Sub-Appendix B2 include a plan set for both the VN and HR SSB. The conceptual design and plan set of the JB SSB is part of Sub-Appendix B3 (the TSP Plan Set).

## 4.6 Conceptual Design Development of Navigable Gates as RRFs

As noted in section 0, at a few specific instances, RRFs are proposed to cross existing waterways that are navigable. For the locations as shown in Table 4-3, a navigable gate was assumed to be a cost-effective alternative to land-based RRF features along the water's edge to reduce the risk of residual flooding. These features are also referred to as the secondary navigable barriers because these features do not provide for flood risk reduction during the 1% AEP event. Instead, these features provide flood risk reduction for high-frequency flooding events corresponding to the function of all RRFs. As such, the crest elevation for these RRF navigable barriers has been set equal to the crest elevation of all land-based RRFs, at +10ft NAVD88.

For three locations, an RRF navigable gate is proposed as part of a NYNJHAT Study alternative, at the same location where an SSB is proposed as part of a different alternative. For example, as part of Alternative 3B and Alternative 4, an SSB is proposed at the entrance to Newtown Creek, and as part of Alternative 2 and 3A, an RRF navigable gate is proposed at the same location. This occurs at three locations: the Hackensack River, Newtown Creek, and Gowanus Canal.

**Table 4-3: Summary of RRF Navigable Barriers (Secondary Navigable Barriers) per NYNJHAT Study Alternative**

| Name of Navigable Barrier | Abbrev. | Alt. 2 | Alt. 3A | Alt. 3B | Alt. 4 | Alt. 5 |
|---|---|---|---|---|---|---|
| **Hackensack River RRF** | HR RRF | Yes | Yes | Yes | | |
| **Newtown Creek RRF** | NC RRF | Yes | Yes | | | |
| **Gowanus Canal RRF** | GC RRF | Yes | Yes | | | |
| **Sandy Hook Bridge RRF** | SHB RRF | Yes | | | | |
| **Head of Bay Gate RRF** | HB RRF | Yes | Yes | Yes | Yes | |
| **Old Howard Beach East Gate RRF** | OHBE RRF | Yes | Yes | Yes | Yes | |
| **Old Howard Beach West Gate RRF** | OHBW RRF | Yes | Yes | Yes | Yes | |

The conceptual design for the RRF navigable gate at these three locations (HR, NC, and GC) was based on the concept SSB design, and gate types were assumed to be the same. The change in design was the crest elevation (RRF crest at +10 ft NAVD8) and omission of the headwall. Thus, the gate heights were reduced for the RRF navigable gate compared to the SSB design. For feasibility and conceptual design purposes, all other geometric characteristics were assumed to remain the same. For the other four RRF navigable barriers, a relatively simple conceptual design was developed that consisted of a conventional sector gate for the navigable passage and a lift gate for the auxiliary flow opening. For a more detailed description of each RRF navigable gate, the reader is referred to Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix).

# 5 Inventory of CSRM Measures per NYNJHAT Study Alternative

## 5.1 Introduction

Following the data and analyses presented in section 3 and 4, the structural measures of all NYNJHAT Study alternatives have been defined. An inventory of all structural measures (SBMs, IFFS, RRFs, and SSBs) is provided within this section to aid in the description of each of the Study Alternatives and as an aid in the preparation of cost estimates. The reader is referred to Sub-Appendix B1 (Shore-Based Measures Sub-Appendix) Annex D for detail maps of each of the alternatives. The following sections first provide an overview of the SBMs, followed by an overview of the SSBs.

## 5.2 Quantities and Inventory of Shore-Based Measure

The preliminary designs for the SBMs and RRFs developed for the NYNJHAT Study are provided in section 3. Due to the large area covered by the NYNJHAT Study and the varying coastal edge conditions associated with the design of the SBMs, the designs are preliminary in nature, yet sufficient to establish a quantity take-off of construction materials. The preliminary designs, in combination with the refinement of alignments, allows for an inventory of all structural SBM, IFF, and RRF measures under the NYNJHAT Study. The inventory is separated into two data sets:

1) Quantity take-off per SBM and RRF, and
2) Inventory of number and length of SBMs, IFFs, and RRFs per alternative.

These two data sets are then used to complete cost estimates for the study alternatives and allow for a comparison amongst the alternatives. The reader is referred to the Cost Engineering Appendix and the Economics Appendix for that information.

### 5.2.1 Quantity Take-offs

Quantity take-offs were developed for each prototypical SBM based on the preliminary design and sections provided (see section 0). The quantity per linear foot of the medium floodwall SBM is shown in Table 5-1 as an example. Additional appurtenances were described qualitatively when applicable, and additional notes regarding the items covered within each quantity take-off are provided within the supporting materials of Sub-Appendix B1 (Shore-Based Measures Sub-Appendix).

**Table 5-1: Quantity per Linear Foot of Medium Floodwall**

| Item | Quantity Per Linear Foot | Unit |
|---|---|---|
| **Reinforced Concrete for Flood Wall and Splash Aprons** | 3.00 | CY |
| **PZ-27 Sheetpile Wall** | 0.27 | TN |
| **HP 14x89 Piles (89' long)** | 17.80 | LF |
| **Excavation** | 3.15 | CY |
| **Repair Disturbed Pavement** | 0.11 | SY |

*Additional appurtenances: The items below are outside of he core construction quantities but should still be considered in the cost estimate:*

*Ladders/Stairs with handrail to provide access to flood side and aid inspection*
*Transitions between feature types*
*Utility relocation, drainage features, aesthetic features, real estate, right-of-way, easement, environmental mitigation*

### 5.2.2 Inventory of SBMs, IFFs, and RRFs per Alternative

The NYNJHAT Study alternatives were described in Section 1 and in the body of the Feasibility Study Report. Depending on the existing site conditions, each SBM/IFF alignment and RRF alignment may comprise one or more SBMs and RRFs, respectively. Based on the SBM type and the proposed length for each SBM included within each reach, an inventory was developed per alternative on a reach basis. This reach-based inventory, combined with the quantity take-offs, was used to develop cost estimates for the construction cost of each reach.

In addition, the reach-based information was aggregated to generate overviews of CSRM measures per NYNJHAT Study alternative. An inventory of SBMs, IFFs, and RRFs for each Alternative are included in Table 5-2 through Table 5-4. This tables includes the measure lengths in miles for all SBMs, IFFs, and RRFs, and measure counts for the deployable features (e.g., flip-up barriers, pedestrian gates, tide gates, etc.). Measure counts were added specifically for the deployable features and tide gates since cost estimates were generated based on an individual structure basis instead of a typical per linear foot basis. Diagrams depicting the tabulated information are provided in Figure 5-1. Navigable barriers that are part of the RRFs are separately addressed in section 5.3.

**Table 5-2: Summary Table of SBMs – Length and Count of Measures for Each Alternative**

| Alternative | 2 | 3A | 3B | 4 | 5 |
|---|---|---|---|---|---|
| **Medium Floodwall** | – | 2.0 | 4.0 | 5.3 | 1.0 |
| **Large Floodwall** | 0.6 | 3.3 | 10.8 | 11.9 | 3.7 |
| **Extra-large Floodwall** | – | – | 3.1 | 2.7 | 2.6 |
| **Medium Levee** | – | 2.8 | 3.7 | 5.6 | 0.6 |
| **Large Levee** | 0.3 | 1.5 | 4.9 | 5.0 | 15.3 |
| **Elevated Promenade** | – | 2.6 | 8.5 | 8.5 | 5.6 |
| **Floodwall with Park Integration** | – | – | 0.6 | 0.6 | 0.3 |
| **Seawall** | – | 2.4 | 5.9 | 5.9 | 1.1 |
| **Reinforced Dune with Natural Dune Cover** | 10.2 | 0.8 | 0.8 | 0.8 | – |
| **Reinforced Dune with Partial Dune Cover** | 13.2 | 6.9 | 6.9 | 6.9 | – |
| **Flip-up Barrier** | – | – | 0.3 (Count: 4) | 0.3 (Count: 4) | 0.3 (Count: 4) |
| **Pedestrian Gate** | – | 0.0 | 0.3 (Count: 53) | 0.3 (Count: 54) | 0.3 (Count: 49) |
| **Vehicular Gate** | 0.1 (4) | 0.2 | 0.7 (Count: 64) | 0.7 (Count: 63) | 0.4 (Count: 36) |
| **Railroad Gate** | – | – | 0.1 (Count: 4) | 0.1 (Count: 4) | 0.1 (Count: 5) |
| **Tide Gate** | – | 0.1 | 0.1 (Count: 1) | 0.1 (Count: 3) | 0.1 (Count: 2) |
| **Total (mi)** | 24.2 | 22.7 | 50.6 | 54.7 | 31.1 |

**Table 5-3: Summary Table of IFFs – Length and Count of Measures for Each Alternative**

| Alternative | 2 | 3A | 3B | 4 | 5 |
|---|---|---|---|---|---|
| **Medium Floodwall** | – | – | 0.04 | 2.3 | – |
| **Large Floodwall** | 1.1 | 4.3 | 2.5 | 21.3 | – |
| **Extra-large Floodwall** | 3.0 | 3.8 | 0.8 | 4.1 | – |
| **Medium Levee** | – | – | – | – | – |
| **Large Levee** | 5.8 | 18.1 | 2.4 | 4.5 | – |
| **Elevated Promenade** | 0.5 | 1.3 | 0.5 | – | – |
| **Floodwall with Park Integration** | – | – | – | – | – |
| **Seawall** | 11.8 | 15.7 | 0.6 | 3.7 | – |
| **Reinforced Dune with Natural Dune Cover** | 0.2 | 3.4 | 3.1 | 3.1 | – |
| **Reinforced Dune with Partial Dune Cover** | – | 4.5 | 1.7 | 1.7 | – |
| **Flip-up Barrier** | – | – | – | – | – |
| **Pedestrian Gate** | – | 0.01 (Count: 4) | – | – | – |
| **Vehicular Gate** | 0.04 (Count: 5) | 0.2 (Count: 19) | 0.1 (Count: 10) | 0.5 (Count: 51) | – |
| **Railroad Gate** | – | – | – | – | – |
| **Tide Gate** | 0.3 (Count: 12) | 0.3 (Count: 15) | – | 0.1 (Count: 3) | – |
| **Total (mi)** | 22.5 | 51.5 | 11.8 | 41.4 | – |

**Table 5-4: Summary Table of RRFs – Length and Count of Measures for Each Alternative**

| Alternative | 2 | 3A | 3B | 4 | 5 |
|---|---|---|---|---|---|
| **Medium Floodwall** | 5.5 | 4.8 | 2.4 | 0.5 | – |
| **Large Floodwall** | 5.4 | 5.3 | 4.1 | 1.1 | – |
| **Extra-large Floodwall** | 1.0 | 1.0 | 1.0 | 0.3 | – |
| **Medium Levee** | 1.9 | 1.6 | 1.6 | 1.5 | – |
| **Large Levee** | 2.9 | 0.7 | 0.7 | – | – |
| **Elevated Promenade** | 0.8 | 0.8 | 0.4 | 0.3 | – |
| **Floodwall with Park Integration** | 0.1 | 0.02 | 0.02 | – | – |
| **Seawall** | 3.7 | 3.4 | 3.4 | 3.4 | – |
| **Reinforced Dune with Natural Dune Cover** | 8.9 | 5.3 | 1.2 | 0.2 | – |
| **Reinforced Dune with Partial Dune Cover** | 3.9 | 2.4 | 2.4 | 0.2 | – |
| **Flip-up Barrier** | 0.03 (Count: 9) | 0.03 (Count: 9) | – | – | – |
| **Pedestrian Gate** | 0.3 (Count: 17) | 0.2 (Count: 16) | 0.04 (Count: 4) | 0.02 (Count: 2) | – |
| **Vehicular Gate** | 0.1 (Count: 5) | 0.1 (Count: 4) | 0.04 (3) | – | – |
| **Railroad Gate** | 0.9 | 0.9 | 0.9 | 0.9 | – |
| **Tide Gate** | 0.01 (Count: 2) | 0.01 (Count: 2) | 0.01 (Count: 2) | 0.01 (Count: 2) | – |
| **Total (mi)** | 36.2 | 27.1 | 18.7 | 8.5 | – |

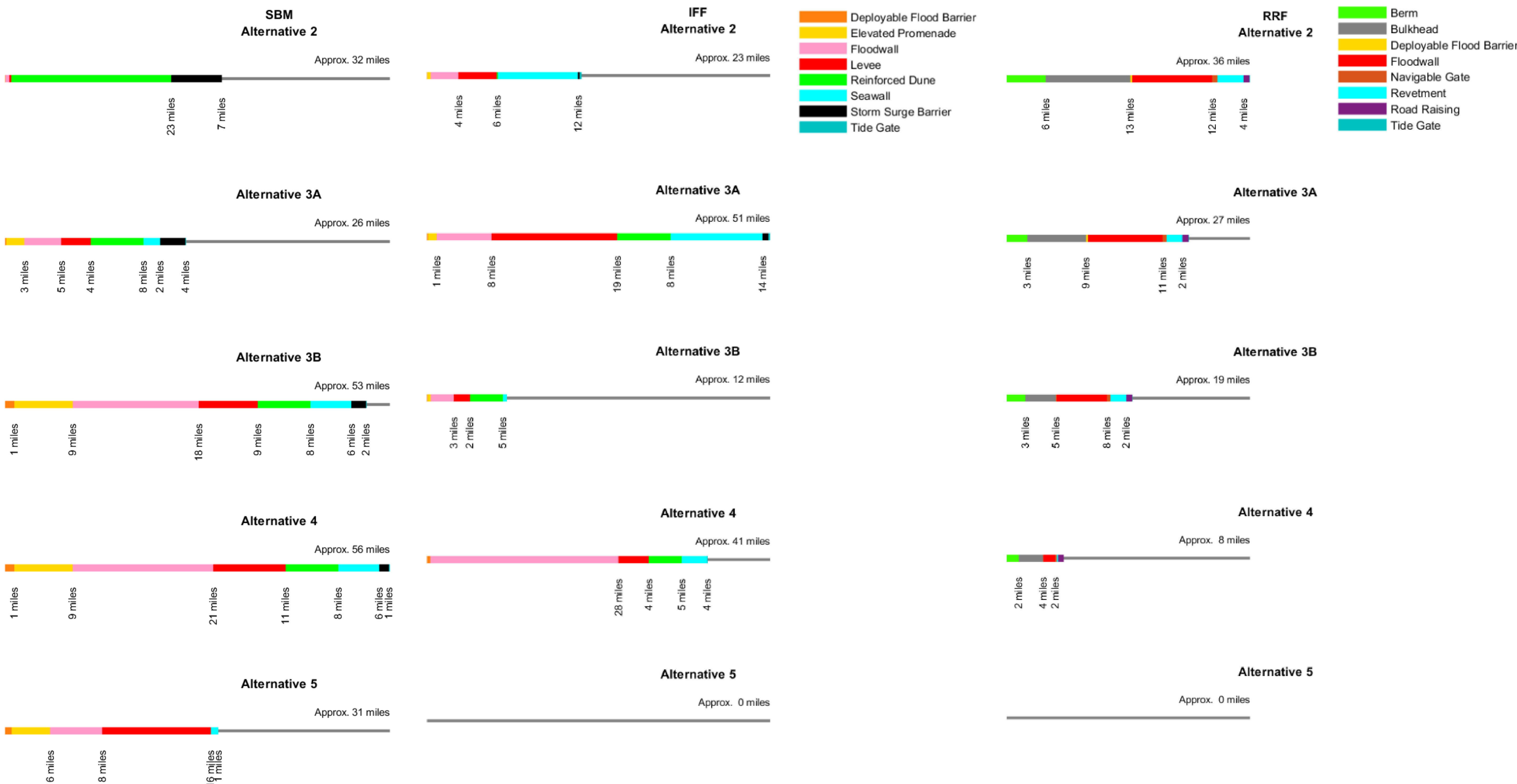



**Figure 5-1: Diagrams Depicting SBMs, IFFs, RRFs, and SSBs for each NYNJHAT Study Alternative**

## 5.3 Inventory of Storm Surge Barriers

The table below provides an overview of all navigable structures and the inclusion of each in study alternatives. The SSBs are marked as primary barriers as they are designed to provide flood risk reduction for the 1% AEP event, while the secondary navigable barriers are RRFs and designed to mitigate for the flood risk associated with a water-level elevation of +7ft NAVD88. For a more detailed description of the geometric characteristics of each SSB and RRF navigable barrier, the reader is referred to Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix). Construction cost estimates for all structures are included in the Cost Engineering Appendix (Appendix C).

**Table 5-5: Summary of Navigable Barriers per NYNJHAT Study Alternative**

| Name of Feature | Abbrev. | Alt. 2 | Alt. 3A | Alt. 3B | Alt. 4 | Alt. 5 |
|---|---|---|---|---|---|---|
| **Storm Surge Barriers (Primary Navigable Barriers)** | | | | | | |
| **Outer Harbor** | OH | Yes | | | | |
| **Throgs Neck** | TN | Yes | Yes | | | |
| **Verrazzano Narrows** | VN | | Yes | | | |
| **Arthur Kill** | AK | | Yes | Yes | | |
| **Jamaica Bay** | JB | | Yes | Yes | Yes | |
| **Kill van Kull** | KVK | | | Yes | | |
| **Hackensack River** | HR | | | | Yes | |
| **Newtown Creek** | NC | | | Yes | Yes | |
| **Gowanus Canal** | GC | | | Yes | Yes | |
| **Flushing Creek** | FC | | | Yes | Yes | |
| **Sheepshead Bay** | SB | | Yes | Yes | Yes | |
| **Gerritsen Creek** | GRC | | Yes | Yes | Yes | |
| **Storm Surge Barriers as IFFs (Primary Navigable Barriers)** | | | | | | |
| **Eastchester Creek** | EC | Yes | Yes | | | |
| **Port Washington** | PW | Yes | Yes | | | |
| **Hempstead Harbor (Glen Cove)** | HH | Yes | Yes | | | |
| **Hammond Creek** | HC | Yes | Yes | | | |
| **Highlands** | HL | | Yes | | | |
| **Raritan River** | RR | | Yes | | | |
| **Navigable Barriers as RRF (Secondary Navigable Barriers)** | | | | | | |
| **Hackensack River RRF** | HR RRF | Yes | Yes | Yes | | |
| **Newtown Creek RRF** | NC RRF | Yes | Yes | | | |
| **Gowanus Canal RRF** | GC RRF | Yes | Yes | | | |
| **Sandy Hook Bridge RRF** | SHB RRF | Yes | | | | |
| **Head of Bay Gate RRF** | HB RRF | Yes | Yes | Yes | Yes | |
| **Old Howard Beach East Gate RRF** | OHBE RRF | Yes | Yes | Yes | Yes | |
| **Old Howard Beach West Gate RRF** | OHBW RRF | Yes | Yes | Yes | Yes | |

# 6 Interior Drainage

An analysis of interior drainage features associated with the SSBs and SBMs is provided in the Sub-Appendix B4 (Interior Drainage Sub-Appendix) and summarized below. The SSBs include large pump stations as well as RRFs along the waterbody upstream of the SSBs, which provide flood risk management for high-frequency events that may occur prior to SSB closure, and IFFs, which are low-level structures to limit potential induced flooding from the closure of the SSB. Typical SBM interior drainage features include gravity outfalls along the lines of protection and outfall chambers for the existing Combined Sewer System (CSS), which will allow diversion of combined flow to new pump stations.

## 6.1 Interior Drainage Overview

The purpose of the interior drainage analysis was to provide estimates of interior drainage costs to support the economic analysis for both SSBs and SBMs. This involved two primary efforts:

- Identify preliminary pump station requirements associated with proposed SSBs based on typical projects constructed in the region.
- Estimate interior drainage costs for SBMs based on typical projects in the projects in the region.

Any project that incorporates a barrier to storm surge flooding will also form a barrier to drainage of runoff in some conditions. The SSBs limit the discharge from the river or estuary to the ocean while the barrier is closed, and the SBMs typically cut off interior stormwater drainage or overland flow. The SSBs will have pump stations, RRF, and IFF to limit interior flooding. The SBMs typically include flap gates on new and existing drainage pipes to prevent storm surge from backing up through the drainage system and CSS pump stations.

USACE policy for interior drainage planning and design as documented in Engineer Manual (EM) 1110-2-1413 *Hydrologic Analysis of Interior Areas* (1987) includes “Minimum Facility” interior drainage features integral to the line of protection (LOP) plus any additional facilities that are incrementally cost justified. Such assessments are highly complex, time consuming, and frequently considered part of the optimization phase of study, and are not necessary to meet the objectives of the current study. The current assessment incorporated a review of the interior drainage features for prior projects in the area that have similar rainfall and runoff characteristics in order to scale the various interior drainage features. The types of features in these prior projects, such as pump sizes at storm surge barriers, are considered representative of what would be expected as part of plans recommended as part of this study.

## 6.2 Storm Surge Barrier Interior Drainage

### 6.2.1 General Approach

The implementation of barriers and gates to reduce the risk of flooding from storm surges requires the addition of pump stations to prevent excessive flooding behind the line of protection when the barriers and gates are closed. The amount of pumping required is driven by many factors, including the peak runoff rate, total runoff volume, the timing of runoff relative to the storm surge, and the amount of flood storage available upstream of the SSB. The assessment of pump capacity evaluated prior projects' relationship between a project's pump capacity and the storage area upstream of the gate, the peak flow in the river, and the tributary drainage area (as a representation of both the volume and timing of runoff).

### 6.2.2 SSB Pump Station Costs

The pumping requirements for various surge barriers proposed for the NYNJHATS project have been estimated using a cost curve developed from prior USACE projects. This curve reflects relatively simple pump stations where the pumps are located directly at the line of protection and there is no need for a force main or check valves, resulting in very low dynamic head loss. The storm surge barriers considered for the current assessment are presented in Table 6-1. The larger barriers under consideration, such as the Arthur Kill, Verrazzano Narrows, Jamaica Bay, and the Rockaway to Sandy Hook Barriers, are expected to be operated in a manner that limits closures during larger low-frequency storm events. Deployment of large SSBs solely during low-frequency storm events will leave properties in the study area vulnerable to residual high-frequency flooding. Therefore, these barriers are expected to be supplemented with high-frequency local protection features, such as levees or floodwalls, or with non-structural measures. High-frequency local protection features will also provide protection against interior flooding, so additional interior drainage pump stations have not been included for the SSBs.

**Table 6-1: Summary of Interior Pumping at SSBs**

| SSB | Drainage Area (ac) | Storage Area (ac) | DA/SA | Pump/ Inflow Ratio | Inflow (100-yr) | Pump Required (cfs) | Pump Station Cost (2022 PL) |
|---|---|---|---|---|---|---|---|
| **Gowanus** | 1,714 | 17.04 | 100.6 | 57% | 771 | 439 | $12,700,000 |
| **Newtown** | 7,833 | 152.14 | 51.5 | 41% | 3,025 | 1,240 | $21,020,000 |
| **Hackensack** | 122,577 | 5,787.7 | 21.2 | 20% | 8,320 | 1,664 | $17,680,000 |
| **Eastchester Creek** | 8,187 | 204.3 | 40.1 | 35% | 2,052 | 718 | $17,770,000 |
| **Howard Beach** | 1,801 | 53.4 | 33.7 | 31% | 771 | 239 | $7,630,000 |
| **Bay Gate** | 24,813 | 654 | 37.9 | 34% | 5,795 | 1,970 | $11,920,000 |
| **Raritan** | 704,000 | 2,643.65 | 266.3 | 80% | 56,100 | 22,440* | $204,220,000 |

**Assume 50% of flow required (44,880 cfs / 2 = 22,440 cfs)*

The pumping capacities of the four gates listed in Table 6-1 range from a high of 57% of the peak 1% AEP at the Gowanus Canal barrier, to a low of 20% of the peak 1% AEP flow at the Hackensack River barrier. The need for a comparatively low pump capacity at the Hackensack Barrier is reasonable given the presence of extensive storage available in the Hackensack Meadowlands. In contrast, the Gowanus Canal is an industrial canal in an urban area and has relatively little storage available, resulting in the need to pump a larger proportion of the peak inflow.

## 6.3 Shore-Based Measures Interior Drainage

### 6.3.1 General Approach

Areas protected from exterior flood elevations are subject to interior residual flooding from stormwater runoff. Thus, interior drainage facilities may be required to safely store and discharge the runoff to limit interior residual flooding. Typically, interior drainage is managed with a series of gravity outlets/outfalls, natural storage, excavated ponding, and pumping. On rare occasions, runoff can be diverted through or around the line of protection using pressure interceptors. Where space is available, the interior drainage can often be managed with gravity outlets, natural storage, and ponding. The cost of interior drainage facilities can vary with the size of the drainage area relative to the length of the line of protection, the cost of real estate, and the complexity of the existing drainage system.

As space becomes more limited, static interior drainage features can be supplemented with pump stations to reduce the water volume to be stored. The addition of the pumping capacity typically results in higher initial costs and a substantial increase in operating costs over the life of the project. One advantage of including pumping capacity is that the overall drainage facilities are easier to adapt to rising sea levels.

Where space is very limited, there may be no area for ponds or natural storage, and the drainage must be handled almost entirely by gravity pipes and pumps. In some cases, particularly in New York City, the stormwater outfalls are combined with wastewater to form Combined Sewer Overflows (CSOs). While several older projects, such as the New Bedford Hurricane Barrier, allowed open ponding of the CSO, it is anticipated that future projects will require special handling of CSO discharge. At this time, special requirements or the associated costs related to handling of CSO discharges have not been evaluated or incorporated into the interior drainage assessment.

### 6.3.2 Cost Estimate Development

For the purposes of estimating preliminary costs of interior drainage facilities behind fixed lines of risk reduction, three conditions were identified based on the storage/access constraints. These conditions are:

| | |
|---|---|
| Unlimited/Limited Access: | This represents locations with enough volume to store floodwaters, typically without pumping, and areas where some limitations in space or high real estate costs make it more cost effective to pump a portion of the inflow. |
| Very Limited Access: | Fully developed locations where there are no areas available for natural or constructed storage. The drainage, therefore, requires pumping a high proportion of the inflows. |
| Combined Sewer Overflow: | Areas where local drainage is predominantly based on CSO facilities require a unique approach. This may include construction of underground storage or construction of pump stations with backup capacity. Interior drainage requirements for areas with CSOs have not been evaluated at this stage of the study. |

### 6.3.3 General Interior Drainage Costs / Linear Foot Costs

Preliminary interior drainage linear foot costs for a fixed line of protection were estimated based on the historical costs of such facilities for previously constructed or currently proposed USACE projects of a similar nature in the New York/New Jersey area. From an analysis of the interior drainage costs for these projects, the calculation of preliminary interior drainage costs for the "Unlimited/Limited Access" and "Very Limited Access" conditions yielded an Unlimited & Limited Access Average cost per linear foot of $1,489 and a Very Limited Access Average cost per linear foot of $3,511.

### 6.3.4 CSO Considerations

The historical costs assessment described above utilized data from locations that do not have special requirements to address CSOs. In areas with combined drainage systems (sanitary and stormwater), additional design constraints are expected to avoid open ponding of stormwater that is contaminated with wastewater. The majority of the CSO areas to be considered lie within New York City. Initial assessments of CSO drainage requirements for coastal resilience projects developed by NYC have assumed that the CSO will need to be pumped through the SBM to limit backup and ponding. The preliminary cumulative costs for CSO pumping developed by others for some areas, such as the NYC financial district, exceed $1 billion. This level of drainage costs could significantly alter the comparison of alternatives and the selection of the TSP. Thus, a detailed assessment of the CSOs was warranted.

Seventy-eight (78) CSO sub-basins (mapped drainage areas to outfalls) were identified**.** The interior drainage cost estimate for these areas was based on a conceptual level flow estimate to size the requisite pump stations and a conceptual chamber design to provide sluice gate and flap gate chambers for direct gravity discharges as well as a chamber to facilitate effluent bypass to a pump station during storm surges that block the gravity flow. The NYC drainage design standard is to accommodate a 5-year AEP flow with full buildout; that is, the flow that will be used to estimate pump station capacity. This approach is generally consistent with the concept of Minimum Facilities, which are intended to maintain the function of the existing drainage system.

### 6.3.5 CSO Flow Calculations / Pump Costs / Bypass Chambers

Flow estimates for each CSO outfall were developed using drainage areas and capacity/design information available from the NYC Department of Environmental Protection (NYCDEP). No hydrologic routing or hydraulic models were developed, only peak inflows. Pump station costs have been estimated using the NYC wastewater pump station cost curve. An additional 25% flow was added to incorporate redundancy in the pump station sizing. The costs were increased 20% and 60% (80%) to account for bypassing and automated trash racks, respectively. Conceptual chamber quantities for the sluice and flap gates were developed using the designs currently under development for the USACE South Shore Staten Island Coastal Flood Risk Management Project. The outfalls and associated dimensions were identified using the NYCDEP drainage maps. Quantities and costs for each outfall were estimated using a typical chamber dimensions calculator. A number of assumptions were made when calculating the quantities and cost per drainage area. Assumptions related to:

- Combined sluice and flap gate chambers
- Chamber layout

- Pipe data and chamber dimensions

### 6.3.6 CSO Pump Station Costs

The total cost estimate per CSO drainage area includes the sluice and flap gate chamber cost as well as the pump station cost with bypassing and trash rack.

### 6.3.7 SBM Interior Drainage Costs

Total interior drainage costs per SBM are shown in Table 6-2.

**Table 6-2: SBM Total Interior Drainage Costs**

| SBM Location | Length (FEET) | Base Cost (LF cost) | New Outfall Chambers | Pump Stations | Total |
|---|---|---|---|---|---|
| **Astoria SBM** | 21,205 | $69,976,500 | $0 | $0 | $69,976,500 |
| **Coney Island** | 61,700 | $80,210,000 | $13,609,600 | $226,270,800 | $320,090,400 |
| **Gowanus Canal** | 3,000 | $9,900,000 | $21,035,400 | $79,421,400 | $110,356,800 |
| **Long Island Sound West** | 8,000 | $26,400,000 | $6,241,800 | $417,214,800 | $449,856,600 |
| **East Harlem SBM** | 24,916 | $38,370,800 | $60,306,100 | $104,887,800 | $203,564,700 |
| **Hackensack Perimeter SBM** | 57,422 | $74,648,600 | $0 | $0 | $74,648,600 |
| **Haverstraw SBM** | 9,514 | $12,368,200 | $0 | $0 | $12,368,200 |
| **Long Island City Astoria SBM** | 17,153 | $56,604,900 | $0 | $0 | $56,604,900 |
| **New Jersey along Hudson River SBM** | 43,055 | $141,889,500 | $0 | $0 | $141,889,500 |
| **New York City West Side SBM** | 32,283 | $71,791,900 | $43,580,300 | $138,045,600 | $253,417,800 |
| **Ossining SBM** | 3,789 | $4,925,700 | $0 | $0 | $4,925,700 |
| **Tarrytown SBM** | 7,324 | $14,111,200 | $0 | $0 | $14,111,200 |
| **Yonkers** | 13,093 | $17,020,900 | $0 | $0 | $17,020,900 |
| **TOTALS =** | 302,454 | $618,218,200 | $144,773,200 | $965,840,400 | $1,728,831,800 |

**2020 Price Level*

## 6.4 Risk Reduction Features

The SSB operational parameters for the six largest storm surge barriers will likely require maintaining the gates in the open position during high-frequency storm events and/or as a surge approaches, as discussed in section 4.2. RRFs are incorporated to manage flood risk for such events. The interior drainage costs for the RRFs were estimated in the same manner as described above for linear foot costs.

# 7 Individual Structure Risk Management (Non-Structural and Ring-walls)

## 7.1 Introduction

As a part of plan development, the use of non-structural measures or ring-walls/ring-levees was investigated as both an alternative to structural measures and as supplemental measures to address gaps in the alternative structural plans. The TSP includes a range of measures identified to address localized areas where there are buildings potentially exposed to flooding at some gaps in the RRFs.

Alternatives developed and evaluated include a comprehensive plan, incorporating all structures within the 1% annual chance exceedance (ACE) floodplain, and smaller components, intended to supplement the structural plans, which feature storm surge barriers, gates, and SBMs. More details of the methodology used to develop the Individual Structure Risk Management (ISRM) measures and their development and analysis are included in Sub-Appendix B5 (Nonstructural Measures and Ringwalls Sub-Appendix).

## 7.2 ISRM Measure Identification

The plans and measure selection have been generated using a decision algorithm that was developed and applied for other projects. This algorithm analyzes key structure attributes to assign the most appropriate measure to each individual structure, and to estimate the construction cost based on reference unit costs derived for typical structure types.

The baseline algorithm includes four generic types of measure for application to individual structures, within which more specific treatments are incorporated, to account for variations in the configuration of the basic structure types.

- Wet Floodproofing – Wet floodproofing measures allow floodwater to penetrate lower, non-living space areas of the structure via vents and openings in order to reduce the effects of hydrostatic pressure and, in turn, to reduce flood-related damages to the structure's foundation.
- Dry Floodproofing – Dry Floodproofing measures allow floodwaters to reach the structure but diminish the flood threat by preventing the water from getting inside the structure walls. Dry floodproofing measures considered in this analysis make the portion of a building that is below the flood level watertight, through attaching watertight closures to the structure in doorway sand window openings.
- Elevation – Elevation involves raising the lowest finished floor of a building to a height that is above the flood level. This option was considered both as a standalone measure and in conjunction with additional construction. In some cases, the structure is lifted in place and foundation walls are extended up to the new level of the lowest floor. In other cases, the structure is elevated on piers, posts, or piles.
- Structural Ring-walls and Ring-levees – Ring-walls are floodwalls or levees constructed to encircle individual structures or small groups of buildings for which other non-structural treatments are impractical or unfeasible, due to their size or configuration.

Ring-wall systems are typically primarily fixed floodwalls or levees outside the perimeter of the building or property with deployable swing gates, roller gates, or flip-up gates at different entry points.

Acquisitions were not included in the current plan formulation since the data is not currently sufficient to evaluate specific locations in detail. Also, a program of acquisitions must comply with the Uniform Relocation Assistance and Real Property Acquisition Act (URA), which requires the provision of equivalent housing in the same area, which is likely to prove challenging in the real estate market in the study area.

## 7.3 Design Flood Elevation Criteria

Design protection elevation is the primary regulatory criteria. It is the elevation to which the main floor of any structure identified for non-structural treatment must be protected from flood inundation. The design protection elevation is the Base Flood Elevation (BFE) (the 1% annual chance exceedance water surface elevation) at each individual structure plus freeboard, as mandated by local floodplain management regulations. For structures in New Jersey, the mandated freeboard is one additional foot, while in New York State the mandated freeboard is two additional feet. Additionally, to comply with current Federal Emergency Management Agency (FEMA) regulations and USACE policy, the design protection elevation for ring-walls in both states typically require three feet of freeboard above the base flood elevation.

| | | |
|---|---|---|
| Design Flood Elevation: | New Jersey: | 1% ACE + 1 foot |
| Design Flood Elevation: | New York: | 1% ACE + 2 feet |
| Design Flood Elevation: | Ring-walls, NJ and NY: | 1% ACE + 3 feet |

For the purposes of this analysis, the BFEs used for all structures were taken to be the 1% AEP elevation in the year 2030, assuming an intermediate sea level rise scenario. While these elevations may not align exactly with BFEs depicted in current effective flood insurance rate maps for the area, the water surface elevations from the hydrodynamic modeling were used since they better represent risks at the time of implementation than the current flood insurance rate maps.

## 7.4 Identification of Individual Measures

The evaluation of what measure should be applied to each property in the floodplain utilized the property data compiled for the economic analysis of damages avoided. A decision algorithm, as presented in Table 7-1, was applied to assign a non-structural measure to residential structures and smaller commercial properties. It was assumed that ring-walls would be applied at large commercial structures with the length of the ring-wall estimated based on the size of the building.

### Table 7-1: Primary Decision Logic

| Typical Structure Type | Flood Level | Decision Condition 1 | Decision Condition 2 | Treatment |
|---|---|---|---|---|
| **Slab-On-Grade** | >= Main Floor | Design Flood Elevation – Ground < 3 | n/a | Sealant & Closures |
| | | Design Flood Elevation – Ground >= 3 | n/a | Elevate Building |
| | < Main Floor | < Main Floor | n/a | Raise AC |
| | | >= Main Floor | Protection Level – Ground < 3 | Sealant & Closures |
| | | | Protection Level – Ground >= 3 | Elevate Building |
| **Basement-Subgrade** | >= Main Floor | n/a | n/a | Elevate Building |
| | < Main Floor | < Main Floor | | Fill Basement + Utility Room |
| | | >= Main Floor | n/a | Elevate Building |
| **Raised (Crawlspace)** | >= Main Floor | n/a | n/a | Elevate Building |
| | < Main Floor | < Main Floor | n/a | Raise AC + Louvers |
| | | >= Main Floor | n/a | Elevate Building |
| **Basement-Walkout** | >= Main Floor | n/a | n/a | Elevate Building |
| | < Main Floor | < Main Floor | Design Flood Elevation – Ground < 3 | Fill Lower Floor + Space |
| | | | Design Flood Elevation – Ground >= 3 | Fill Lower Floor + Space |
| | | >= Main Floor | n/a | Elevate Building |
| **Bi-Level / Raised Ranch** | >= Main Floor | n/a | n/a | Elevate Building |
| | < Main Floor | < Main Floor | Design Flood Elevation – Ground <= 3 | Sealant & Closures |
| | | | Design Flood Elevation – Ground >3 | Raise Lower Floor + Space |
| | | >= Main Floor | n/a | Elevate Building |
| **Split Level** | >= Main Floor | n/a | n/a | Elevate Building |
| | < Main Floor | < Main Floor | Design Flood Elevation – Ground < 3 | Sealant & Closures |
| | | | Design Flood Elevation – Ground >=3 | Elevate Building |
| | | >= Main Floor | n/a | Elevate Building |

*Note: Design Flood Elevation includes freeboard.*

## 7.5 Development of Unit Costs

Unit costs were developed for the application of all the measures in the array of alternatives to typical structures of varying sizes. The analysis referenced non-structural costs developed for other projects. Sources used to establish quantities, items, and costs for the various non-structural measures were:

- Village of Freeport, Nassau County, NY, Elevation of Residential Homes
- McDowell County, WV, Section 202 Acquisition/Demolition/Site Restoration Project
- RSMeans Cost Data
- Homeowner's Guide to Retrofitting (FEMA 312)
- Correspondence with private commercial entities (Davis Brothers Engineering Corp. Smartvent/Floodproofing.com)

The reference cost for ring-walls was taken from the cost estimate for a stand-alone floodwall of height 6.5 feet above grade, derived as part of the structural plan development.

## 7.6 Alternative Assessments

Alternatives that were developed and evaluated include a comprehensive standalone plan for the 1% ACE floodplain, and standalone plans for a smaller floodplain area that could be implemented independent of any structural measures. These plans were developed and screened for potential benefit and cost viability based on aggregate values for each economic reach. In addition to standalone plans, ISRM measures were developed for buildings as supplemental measures to address gaps in RRF limits associated with the alternative SSBs. The assessment of these supplemental RRF measures was not subject to incremental benefit cost justification since their economic performance is hydraulically connected to the operation of the SSBs. It is expected that the inter-relationship of costs and benefits associated with SSB operation and RRF design levels will be evaluated jointly as part of the optimization stage.

Table 7-2 provides a summary of the number of buildings evaluated for ISRM within different floodplain extents for all economic reaches. The screening level costs include preliminary assumptions regarding secondary cost considerations, including contingencies, costs associated with real estate administration, preconstruction design and engineering, permits, and temporary accommodation for homeowners/residents. These secondary costs are presented in Table 7-3. These costs were added separately to the construction cost estimates on an aggregated reach-by-reach basis to compute a total implementation cost for comparison to project benefits.

### Table 7-2: Individual Structure Risk Management – Screening Level Costs

| Treatment/Cost Component | # of 7 Ft* | Cost of 7 Ft* | # of 8 Ft* | Cost of 8 Ft* | # of 9 Ft* | Cost of 9 Ft* | # of 1% ACE | Cost of 1% ACE |
|---|---|---|---|---|---|---|---|---|
| Elevate | 21,459 | $4,967,166,000 | 34,425 | $7,909,735,000 | 46,813 | $10,748,379,000 | 56,043 | $12,847,591,000 |
| Floodproof | 317 | $15,806,000 | 472 | $28,801,000 | 765 | $48,309,000 | 34,632 | $4,131,519,000 |
| Ring-wall | 4,066 | $20,963,353,000 | 6,689 | $33,742,744,000 | 9,139 | $45,803,660,000 | 13,390 | $63,876,238,000 |
| Estimated Construction Cost | 25,842 | $25,933,795,000 | 41,586 | $41,668,750,000 | 56,717 | $56,587,816,000 | 104,065 | $80,855,348,000 |
| Contingency | | $12,328,672,000 | | $20,227,937,000 | | $27,816,139,000 | | $40,631,749,000 |
| Total Construction Cost | | $38,262,466,000 | | $61,896,687,000 | | $84,403,957,000 | | $121,487,097,000 |
| Real Estate Administration | | $245,509,000 | | $395,078,000 | | $538,823,000 | | $988,618,000 |
| Preconstruction Design & Engineering | | $4,820,460,000 | | $7,793,278,000 | | $10,626,685,000 | | $15,360,302,000 |
| Supervision, Inspection & Admin | | $4,593,000,000 | | $7,429,106,000 | | $10,129,978,000 | | $14,578,452,000 |
| Temporary Accommodation | | $283,812,000 | | $456,072,000 | | $621,186,000 | | $960,648,000 |
| Permits | | $49,336,000 | | $79,358,000 | | $108,102,000 | | $166,804,000 |
| Implementation Cost | 25,842 | $48,573,406,000 | 41,586 | $78,720,344,000 | 56,717 | $107,608,570,000 | 104,065 | $154,988,852,000 |

**Equivalent*

**Table 7-3: Secondary Costs Applied to ISRM**

| Secondary Cost Component | Elevate | Floodproof | Ring-wall |
|---|---|---|---|
| **Contingency (New York City)** | 60% | 60% | 60% |
| **Contingency (New Jersey, New York State)** | 40% | 40% | 40% |
| **Real Estate Administration[1]** | $9,500 | $9,500 | $9,500 |
| **Preconstruction Design & Engineering** | 15% | 15% | 12% |
| **Supervision, Inspection & Administration** | 12% | 12% | 12% |
| **Temporary Accommodation[2]** | $12,000 | $6,000 | $6,000 |
| **Permits[3]** | $2,000 | $1,000 | $1,500 |

*Notes: 1. Includes access negotiations, required easements, and deed restrictions*
*2. Assumes $3,000 per month; four months for elevation and two months for floodproofing or ring-walls*
*3. Assumes no variances required*

The comparison of project benefits to costs was performed for the plan developed based on the floodplain equivalent to a 7 ft NAVD 88 flood event at the Battery. This is consistent with the preliminary SSB operations scenario and allows the ISRM plans to be compatible with the RRF benefits assumptions. For screening purposes, the benefits accruing from standalone ISRM measures (i.e., the reduction in flood damages to structures and their contents) have been evaluated based on the assumption that the measure will eliminate all damages below the frequency of the SSB operations scenario. This assessment somewhat understates the effectiveness of the measures to reduce damages to each structure for events up to the Design Flood Elevation (DFE). This understatement of benefits is at least partially offset because the approach also understates the potential for damage to garages and foundations at levels below the DFE. As such, the resulting benefits are considered reasonable for screening reaches for cost effectiveness.

Review of the comparison of the benefits to costs for standalone ISRM features did not identify reaches that were economically justified with a Benefit to Cost Ratio (BCR) greater than 1.0. The analysis did identify that ISRM features located behind SSBs have a higher BCR. The ISRM features provide additional benefits because of the reduction of damages associated with 1) interior flooding when the barrier gates are closed and 2) increasing water levels behind the barrier because runoff exceeds any pumping capacity provided with the SSB.

A summary of the ISRM Features for the TSP is provided in section 8.2.3.

# 8 The Tentatively Selected Plan

## 8.1 Plan Evaluation and Plan Selection

Based on the engineering studies and preliminary designs presented within this Engineering Appendix and its supporting materials, cost estimates were prepared, and benefits were determined for each NYNJHAT Study alternative. These analyses are detailed in the Cost Engineering and Economics Appendix, respectively. Based on the evaluations described in the Economics Appendix and the main text of the feasibility study report, Alternative 3B has been identified as the Tentatively Selected Plan (TSP). At this stage in the study, the TSP is still considered preliminary and will be further refined throughout the remaining duration of the feasibility study and during the Pre-construction Engineering and Design phase. The description of the plan in the Final FR/EIS will include additional detail developed during the feasibility level design process.

## 8.2 Features of the TSP

The communities in the NYNJHAT Study area experience substantial risk from coastal flooding. Low-lying and flood-prone coastal neighborhoods and developed areas were identified as areas where CSRM measures could be implemented. Measures that provide a flood risk reduction function were developed and designed to generate project alternatives that would reduce the risk of flooding from the 1% AEP event, including SLR under USACE's intermediate scenario in the year 2095.

### 8.2.1 Shore-Based Measures and Storm Surge Barriers

TheSBMs and SSBs collectively form a flood risk reduction system. SBMs include, amongst others, floodwalls, levees, seawalls, and reinforced dunes. With varying ground elevations, prototypical SBM heights (measured from ground elevation) range between 7 feet and 20 feet. SSBs are in-water structures with a gated opening (or openings) to allow for the passage of flow and vessels during normal day-to-day conditions. The gates of an SSB will be closed prior to a storm arriving and impede the storm surge, and thus provide flood risk reduction for the region behind it. Project alignments were defined through an approach that generally selected and placed SBMs along the coastal edge while protecting as many existing assets as was practically feasible. Projects were developed by considering realistic project extents, where determination of such realistic project extents was established based on shoreline type, length, topography, land use, planning considerations, project scope, inundation extents, flooding pathway, and existing topography.

Figure 8-1 provides an overview of Alternative 3B and shows the extent and location of the proposed measures (RRFs are not displayed on the image for clarity). Sub-Appendix B3 includes the TSP Plan Set and provides a detailed depiction of all structural measures included within the TSP. Annex D of Sub-Appendix B1 (Shore-Based Measures Sub-Appendix) includes details of the reduced risk areas associated with this alternative.

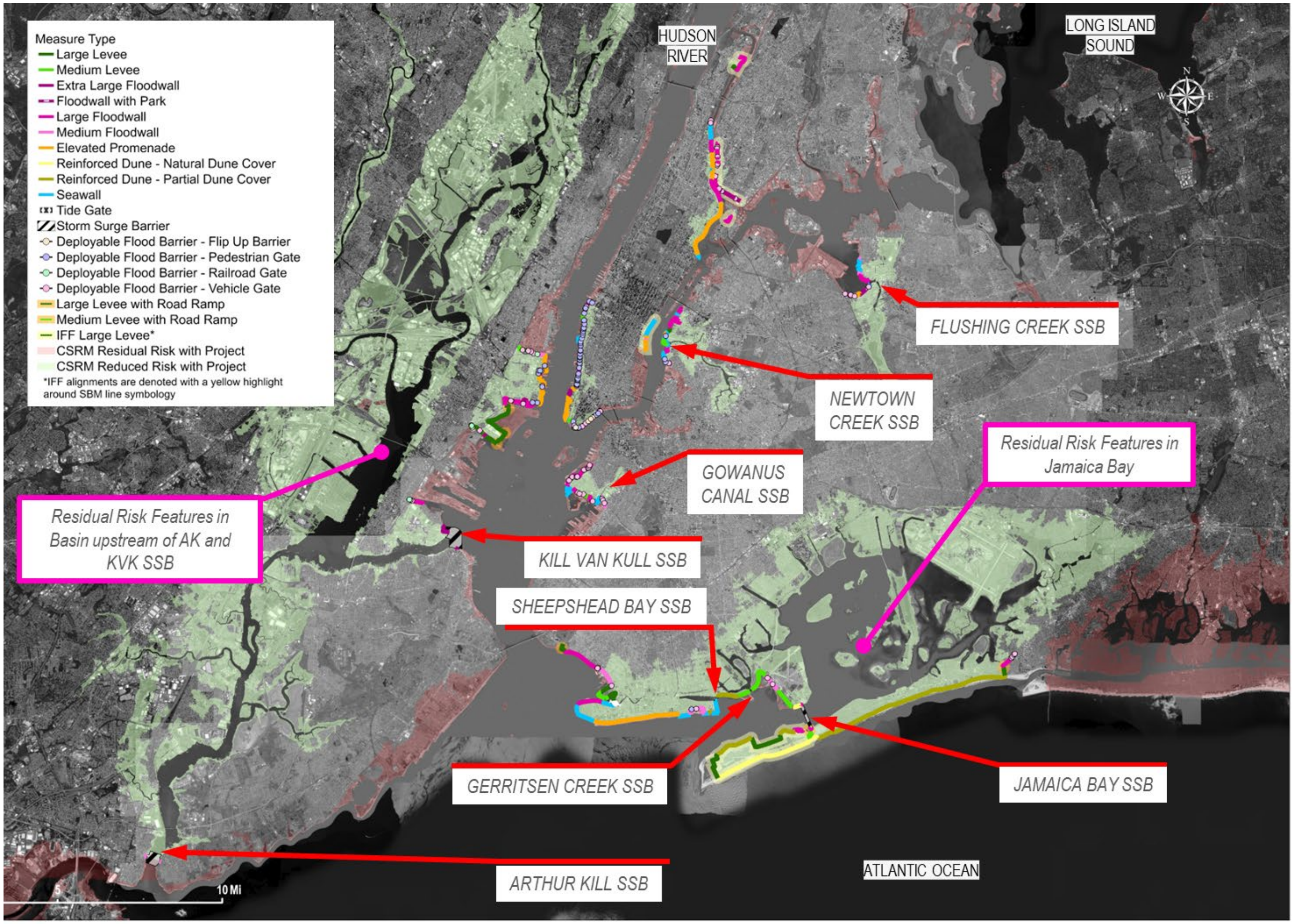



**Figure 8-1: Overview of Structural CSRM Measures of the NYNJHAT Study TSP. Green areas highlight the reduced risk areas for the 1% AEP event (including SLR up to the year 2095) with the proposed project (RRFs are not displayed for clarity.**

The proposed structural measures of the TSP (Alternative 3B) include the following SBMs and SSBs:

- **The Jamaica Bay storm surge barrier.** In conjunction with the adjoining SBM alignments, this SSB provides flood risk reduction for flood prone areas around Jamaica Bay. The Jamaica Bay SSB spans approximately 3,800 ft from shore to shore and has two gated navigable passages, each 200 ft wide, and 15 gated auxiliary flow openings each 150 ft wide. Conventional sector gates are proposed for the navigable passages and vertical lift gates for the auxiliary flow gates. The proposed structure crest elevation is +18 ft NAVD88. Additional details are provided in Table 8-1.
- Shore-based measures along the Atlantic Ocean shorefront on the Rockaway Peninsula which tie into the Jamaica Bay SSB. These SBMs mainly consist of reinforced dunes.
- **Shore-based measures at the western end of the Rockaway Peninsula.** These measures are placed around the Breezy Point area and are included to mitigate for induced flooding.
- **Shore-based measures along the southern shorelines of Brooklyn, NY, that connect to the Jamaica Bay SSB.** Within this alignment, two additional smaller storm surge barriers are included that allow for vessel passage and access to Sheepshead Bay and Gerritsen Creek. Additional details for both SSBs are provided in Table 8-1.
- **The Arthur Kill storm surge barrier and shore-based measures that connect to it and tie into high ground.** The Arthur Kill SSB spans approximately 2,300 ft from shore to shore and has one gated navigable passage 600 ft wide, with a sill elevation at -40 ft NAVD88 and 2 gated auxiliary flow openings each 75 ft wide. A floating sector gate is proposed for the navigable passages and vertical lift gates for the auxiliary flow gates. The proposed structure crest elevation is +19 ft NAVD88. Additional details are provided in Table 8-1.
- **The Kill van Kull storm surge barrier and shore-based measures that connect to it and tie in at high ground.** The KvK SSB spans approximately 3,300 ft from shore to shore and has one gated navigable passage 800 ft wide, with a sill elevation at -55 ft NAVD88 and 5 gated auxiliary flow openings each 150 ft wide. A floating sector gate is proposed for the navigable passages and vertical lift gates for the auxiliary flow gates. The proposed structure crest elevation is +19 ft NAVD88. Additional details are provided in Table 8-1. The Arthur Kill and Kill van Kull SSB jointly provide flood risk reduction to the upstream adjoining water bodies and low-lying areas around it. This includes the Arthur Kill, Kill van Kull, Newark Bay, and the Hackensack and Passaic River.
- **A storm surge barrier at Gowanus Canal and adjoining shore-based measures.** The Gowanus Canal SSB spans approximately 200 ft from shore to shore and has one gated navigable passage 100 ft wide, with a sill elevation at -21 ft NAVD88. The gated opening provides for both the passage of flow and vessels. A miter gate is proposed for the gated opening. The proposed structure crest elevation is +16 ft NAVD88. Additional details are provided in Table 8-1. On the east side of the SSB, SBMs tie into higher ground. On the west side of this SSB, SBMs are proposed to provide flood risk reduction for the Red Hook neighborhood and are placed in proximity to, or at, the coastal edge.

- **A storm surge barrier at Newtown Creek and adjoining shore-based measures.** The Newtown Creek SSB spans approximately 400 ft from shore to shore and has one gated navigable passage 130 ft wide, with a sill elevation at -26 ft NAVD88. The gated opening provides for both the passage of flow and vessels. A conventional sector gate is proposed for the gated opening. The proposed structure crest elevation is +17 ft NAVD88, and additional details are provided in Table 8-1. On the south side of the SSB, SBMs extend along the East River shoreline and tie into higher ground at Greenpoint Avenue. On the north side of this SSB, SBMs are proposed along the waterfront of Long Island City (LIC). The SSB and SBM alignments form a system that provides flood risk reduction to the low-lying areas of LIC, Greenpoint, and the larger Newtown Creek area.
- **A storm surge barrier at Flushing Creek and adjoining shore-based measures.** The Flushing Creek SSB spans approximately 500 ft from shore to shore and has one gated navigable passage 135 ft wide, with a sill elevation at -19 ft NAVD88 and 2 gated auxiliary flow openings each 75 ft. A vertical lift gate is proposed for all gated openings. The proposed structure crest elevation is +18 ft NAVD88, and additional details are provided in Table 8-1. SBMs follow the shoreline on both the north and south sides of the SSB and collectively provide flood risk reduction for the low-lying areas around Flushing Creek.
- **Shore-based measures along the East River and Harlem River.** SBMs are proposed between approximately East 88th Street and West 165th Street in Manhattan, NY, to provide flood risk reduction to the low-lying and flood prone areas along the Harlem River.
- **Shore-based measures along the Harlem River in the Bronx, NY**. SBMs are proposed in this area divided over two reaches, that each tie to high ground and run along the south side of the Mott Haven neighborhood and extend north up to 153rd Street Station near Yankees Stadium. These measures are included to mitigate for induced flooding.
- **Shore-based measures along the Harlem River in the vicinity of the University Height Bridge.** SBMs between Sherman Creek and just north of University Heights Bridge (West 207th Street, Manhattan, NY). These measures are included to mitigate for induced flooding.
- **Shore-based measures on Randall's Island, NY.** SBMs are proposed to form a partial perimeter floodwall on Randall's Island around the Icahn Stadium, tied into high ground on either end, and function to mitigate for induced flooding.
- **Shore-based measures along the East River between East 25th and East 44th.** SBMs are proposed along the shoreline of the East River and mitigate for induced flooding.
- **Shore-based measures along the southern and western shorelines of Manhattan, NY.** An SBM alignment is proposed that follows the Manhattan shoreline and runs from the Brooklyn Bridge along the waterfront to Battery Park, around Battery Park and Battery Park City, along the West Side Highway and Hudson River Park, up to West 34th Street to then terminate at high ground on West 34th Street, Manhattan, NY.
- **Shore-based measures for Jersey City, NJ**. Shore-based measures are proposed following approximately the southern extent of the rail yard between Jersey City and Hoboken, and connect to SBMs along the Jersey City waterfront. SBMs are proposed all

along the Jersey City waterfront and along the southern shoreline of the Paulus Hook neighborhood to then continue and connect to SBMs proposed in Liberty State Park, and then tie-off to high ground in the vicinity of Bayview Avenue and Garfield Avenue (Jersey City, NJ).

### 8.2.2 Risk Reduction Features

The proposed SSBs have gated openings, and during normal hydrometeorological conditions flows and tidal exchange will be unimpeded. Water levels can be managed in the water bodies upstream of the SSBs, also referred to as “basins”, by gate closure. “Basin” in this context refers to a temporary basin because water control actions are expected to be undertaken only during storm conditions. In the basin upstream of the AK and KvK SSB as well as the Jamaica Bay basin, complementary RRFs to manage the risk of more frequent flooding are proposed for developed non-natural areas. Shorelines protected by the AK, KvK, and JB SSB would still face residual risk from flooding events that may be too minor to trigger an SSB closure. The RRF alignments mitigate residual flood risk under the assumption that the SSB closure criterion is El. +7 ft NAVD88. As such, the need for RRFs is directly correlated to the assumed inability to operate these major storm surge barriers frequently. The assumption is that there will be strict constraints on the operation of these SSBs (indicated with SCO in Table 8-1). The residual flood risk for the coastal areas upstream of the other storm surge barriers is assumed to be mitigated by a lower closure elevation, i.e., operation is only moderately constrained (MCO). Thus, more frequent operation is assumed to be possible for these storm surge barriers and no complementary RRFs are needed.

Similar as with the SBMs, RRF project alignments were defined through an approach that generally selected and placed RRFs along the coastal edge while protecting as many existing assets as was practically feasible. Projects were developed by considering realistic project extents, where the determination of such realistic project extents was established based on shoreline type, length, topography, land use, planning considerations, project scope, inundation extents, flooding pathway, and existing topography. RRFs are measures that have a reveal height (the height between top of wall and ground level) ranging from 3 ft to 8.5 ft. In a few specific instances, RRFs are proposed to cross existing waterways that are navigable. For these locations, a navigable gate was selected as an assumed cost-effective alternative to many miles of land-based RRF features along the water’s edge.

The proposed structural measures of the TSP (Alternative 3B) include the following RRFs:

- **Risk Reduction Features in Jamaica Bay, NY.** The RRFs proposed in Jamaica Bay are based on project alignments that were identified in an earlier feasibility study (USACE, 2018). Proposed RRF projects are along the shorelines of the following neighborhoods: Canarsie, Norton Basin, Motts Basin, Bayswater Park, Broad Channel, and Inwood.
- **Navigable RRF Gate at the Head of Bay, Jamaica Bay, NY**. Located in Jamaica Bay, this proposed navigable structure has a crest elevation of +10 ft NAVD88. The Head of Bay gate spans approximately 900 ft from shore to shore and has one gated navigable passage 60 ft wide, with a sill elevation at -10 ft NAVD88 and 2 gated auxiliary flow openings each 150 ft wide. This gated structure provides flood risk reduction to the

low-lying and flood-prone areas of the far eastern end of the Jamaica Bay. Additional details for this structure are provided in Table 8-1.

- **Navigable RRF Gates at Old Howard Beach, NY**. Located in Jamaica Bay, two structures are proposed to provide flood risk reduction to the Rockwood Park, Old Howard Beach, and Hamilton Beach neighborhoods. One gate is located at the head of Hawtree Basin, the other gate is located at the head Shellbank Basin, west and east of Old Howard Beach, respectively. Both navigable structures have a crest elevation of +10 ft NAVD88 and have one gated navigable passage 60 ft wide, with a sill elevation at -10 ft NAVD88. Additional details for both structures are provided in Table 8-1.
- **Risk Reduction Features along the Arthur Kill and Kill van Kull.** A number of RRF projects are proposed along the Arthur Kill and Kill van Kull, as well as lower Newark Bay, to mitigate residual flood risk. Proposed RRF projects are along the Northern shoreline of Staten Island (three individual smaller project areas), along the shoreline of Tottenville, NY, along Morses Creek, and along the shorelines of the Elizabeth River.
- **Risk Reduction Features in upper Newark Bay and along the Passaic and Hackensack River.** A number of RRF projects are proposed along the shorelines of Kearny Point (both on the Hackensack and Passaic River) to provide flood risk reduction for this area. Additional RRFs are proposed along the shorelines of the Passaic River and Hackensack River in locations where developments or neighborhoods at the water's edge are in low-lying areas and subject to flooding for a water level at +7ft NAVD88.
- **Navigable RRF Gate at the Hackensack River, NJ**. Located in the Hackensack River, this proposed navigable structure has a crest elevation of +10 ft NAVD88. The Hackensack RRF gate spans approximately 1,900 ft from shore to shore and has one gated navigable passage 100 ft wide, with a sill elevation at -23 ft NAVD88 and 5 gated auxiliary flow openings each 150 ft wide. This gated structure provides flood risk reduction to the low-lying and flood-prone areas in the Meadowlands that are upstream of this structure. Additional details for this structure are provided in Table 8-1.

**Table 8-1: Summary of Navigable Barriers Included Within the TSP**

| Navigable Structure Location | Structure Type | Federal Channel | Existing Depth [ft, NAVD88] | Authorized Channel Depth [ft, NAVD88] | Navigable Passage Min. Practical Width Opening [ft] | Navigable Passage Min. Depth of Opening [ft NAVD88] | Navigable Passage Min. Depth of Opening [ft MLLW] | Navigable Passage Gate Type | No. of Auxiliary Flow Openings | Auxiliary Flow Gate Type | Total Length[4] [ft] | Crest Elevation [ft, NAVD88] | Strict constrained operation (SCO) or moderately constrained operation (MCO) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Arthur Kill** | SSB | Arthur Kill Channel | 35 | -38 | 600[1,3] | -40 | -37 | Floating Sector Gate | 2 | Vertical Lift Gate | 2,300 | 19 | SCO |
| **Kill Van Kull** | SSB | Kill Van Kull | 50-55 | -53 | 800[1,3] | -55 | -52 | Floating Sector Gate | 5 | Vertical Lift Gate | 3,300 | 19 | SCO |
| **Jamaica Bay** | SSB | Rockaway Inlet | 20-30 | -21 | 200[1] | -25 | -22 | Sector Gate | 15 | Vertical Lift Gate | 3,800 | 18 | SCO |
| **Newtown Creek** | SSB | Newton Creek | 20-25 | -23 | 130 | -20 | -18 | Sector Gate | 0 | N/A | 400 | 17 | MCO |
| **Gowanus Canal** | SSB | Gowanus Creek | 10-15 | -18 | 100 | -22 | -20 | Miter Gate | 0 | N/A | 200 | 16 | MCO |
| **Flushing Creek** | SSB | Flushing Bay and Creek | 10-20 | -15 | 135 | -21 | -17 | Vertical Lift Gate | 2 | Vertical Lift Gate | 500 | 18 | MCO |
| **Sheepshead Bay** | SSB | Sheepshead Bay | 30-35 | -6 | 100 | -20 | -18 | Sector Gate | 2 | Vertical Lift Gate | 800 | 17 | MCO |
| **Gerritsen Creek** | SSB | N/A | 20-25 | N/A | 115 | -19 | -17 | Vertical Lift Gate | 2 | Vertical Lift Gate | 400 | 17 | MCO |
| **Hackensack River RRF** | RRF Navigable Gate | Hackensack River | 20-25 | -18 | 100[1,3] | -23 | -20 | Sector Gate | 6 | Vertical Lift Gate | 1,800 | 10 | MCO |
| **Head of Bay Gate RRF** | RRF Navigable Gate | N/A | 5-10 | N/A | 100 | -20 | -18 | Sector Gate | 2 | Vertical Lift Gate | 900 | 10 | MCO |
| **Old Howard Beach East Gate RRF** | RRF Navigable Gate | N/A | 15-20 | N/A | 60 | -15 | -13 | Sector Gate | 0 | N/A | 550 | 10 | MCO |
| **Old Howard Beach West Gate RRF** | RRF Navigable Gate | N/A | 5-10 | N/A | 60 | -15 | -13 | Sector Gate | 0 | N/A | 450 | 10 | MCO |

*Notes:*

1. *Practical width of navigable passage based on one-way traffic*
2. *Practical width of navigable passage based on two-way traffic*
3. *Practical width of navigable passage limited based on existing authorized channel dimensions*
4. *Total Length of barrier measured from SBM to SBM and rounded up to the nearest 100 ft increment*

### 8.2.3 Individual Structure Risk Management Features

The TSP includes measures identified to address localized areas where there are buildings potentially exposed to flooding at some gaps in the RRFs for Alternative 3B. The number of properties impacted and the aggregate construction costs (without contingency or other secondary costs) are presented in Table 8-2.

**Table 8-2: Summary of Supplemental ISRM Measures for TSP 3B**

| Economic Reach | # of Non-Structural | Non-Structural Construction Cost | # of Ring-wall | Ring-wall Construction Cost |
|---|---:|---:|---:|---:|
| **NYC 6** | 5 | $1,027,000 | 2 | $14,264,000 |
| **NYC 7W** | 6 | $1,285,000 | 6 | $27,588,000 |
| **NJ 8N** | 10 | $2,069,000 | 8 | $39,844,000 |
| **NJ 8S** | 28 | $6,286,000 | 11 | $60,692,000 |
| **NJ 9** | 24 | $5,874,000 | 7 | $32,815,000 |
| **NJ 11** | 22 | $4,750,000 | 11 | $44,560,000 |
| **NJ 12** | 8 | $1,748,000 | 11 | $31,748,000 |
| **Total by Account** | 103 | $23,039,000 | 56 | $251,511,000 |
| **TSP Plan Total** | 159 | | | $274,551,000 |

## 8.3 Adaptability of the TSP

The TSP includes a combination of SSBs and land-based measures along critical shorelines. As noted earlier, shorelines protected by an SSB would still face residual risk from flooding events that may be too minor to trigger an SSB closure. Smaller land-based measures, like floodwalls and berms, may be developed along such shorelines to address this risk. These measures are termed as RRFs. Land-based solutions to mitigate flood risks – both minor and major – along shorelines where flood risk is not reduced by an SSB are termed as SBMs. An illustration of this system is provided in Figure 8-2.

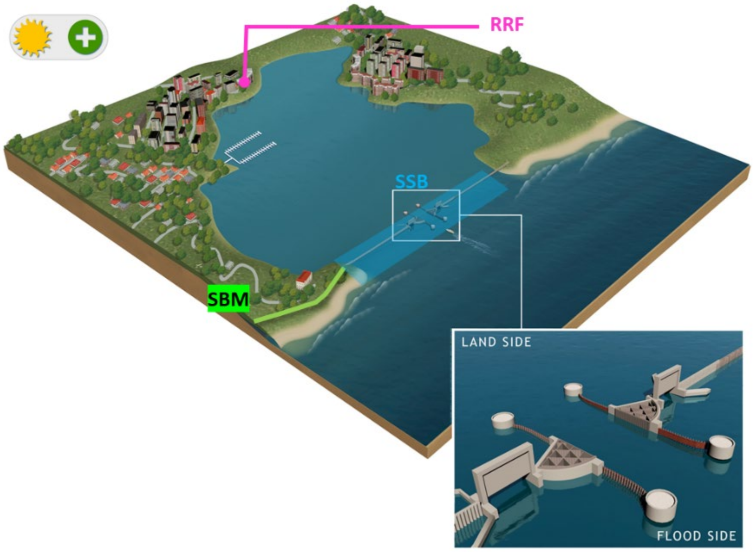



**Figure 8-2: Schematic Illustration of Structural CSRM Measures under NYNJHAT Study**

The closure criterion for the SSBs is defined as the still-water level at which the barrier will be operated to close. Upon closure, the water level within the basin protected by the barrier would be at a level not exceeding the closure criterion. Any RRFs within the basin would therefore be designed to offer protection from flooding at offshore water levels up to the closure criterion. Possible additional rise in basin water levels from corresponding precipitation and inland flows through the duration of the barrier closure are also taken into appropriate consideration in the RRF design.

Sea Level Change (SLC) is projected to cause mean sea levels to rise globally through the next century. Although, SLC is a global phenomenon, the rate of change varies across the geography and is also influenced by local vertical land movement due to geologic factors. Figure 8-3 shows the trend of the historical rise of mean sea level at the Battery, NY, as measured by the NOAA gauge at this location. The magnitude of future global rise in sea levels, which determines the local rate of Sea Level Rise (SLR), depends on a variety of factors that are hard to project with certainty; and as per USACE guidelines (USACE ER 1110-2-8162), three different projection curves are usually considered for planning purposes with the intention of bounding this range of uncertainty. These USACE curves – low, intermediate, and high – for the Battery, NY, are shown in Figure 8-4.

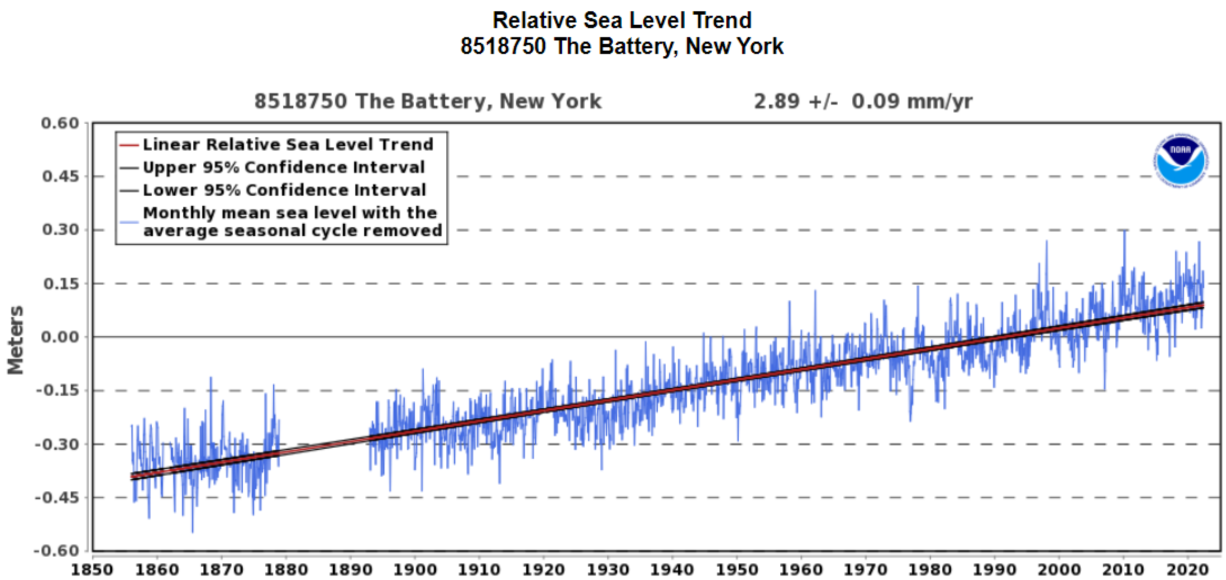



**Figure 8-3: Historical SLR at the Battery, NY (NOAA)**

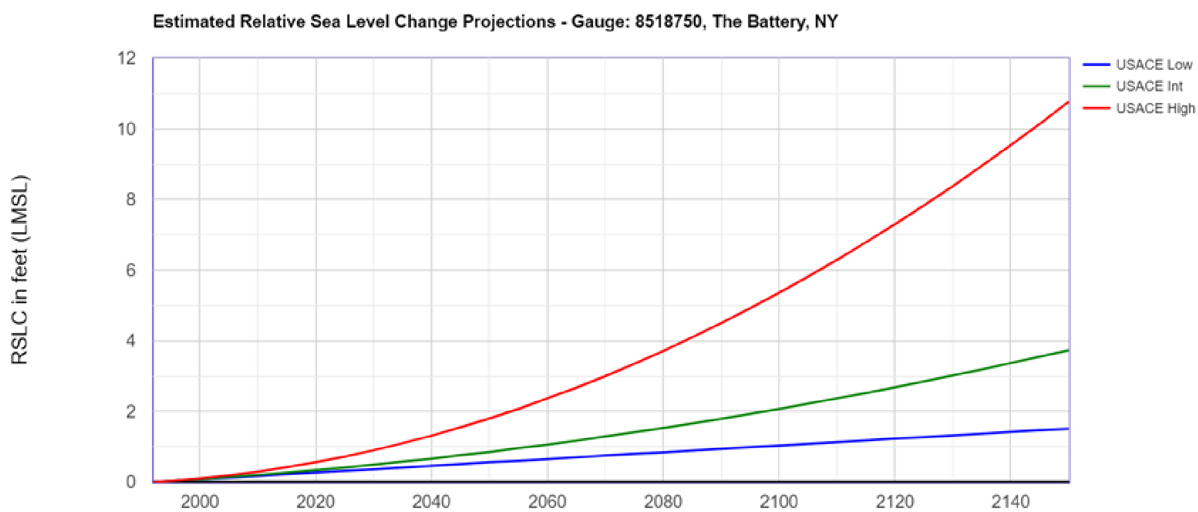



**Figure 8-4: USACE Projected SLR Curves at the Battery, NY**

Increasing sea levels would lead directly to the closure criterion being met more frequently with progressively smaller storm surges, thereby implying more frequent operations of the SSBs. Due to the logistical and cost considerations involved in SSB operation, too-frequent operations of the SSB may not be desirable. Once such a point is deemed5 to be reached, it may be necessary to adjust the closure criterion to be higher to avoid unacceptably frequent closures. This would expose the basin area to flooding from storms with intermediate surge, where surge height is in the range between the original closure criterion (up to which the RRFs were designed) and the updated

[5] The criterion for determination of this threshold based on observed future conditions would have to be established during the optimization of the Tentatively Selected Plan

closure criterion. That would then necessitate additional mitigation measures in the form of updating of the RRF design (heights or extents) or other non-structural measures. Furthermore, if high levels of SLR, beyond the design values, are observed, possible adaptation of SBM designs and extent or even the SSB design itself may be needed to maintain the project's level of risk reduction.

### 8.3.1 Evaluation for Different Closure Criteria

Several closure criteria are hereby evaluated from the standpoint of required adjustments or adaptation due to projected rise in mean sea levels.

Sea level rise shifts the stage frequency curve higher so that the still-water level corresponding to a specified average recurrence interval is now correspondingly higher[6]. As a result, a fixed closure criterion would be met more frequently over time with sea level rise. The change in average closure interval with different levels of sea level rise is shown in Table 8-3. The actual rate of sea level rise would only determine how quickly the average closure frequency would change with time. As per USACE ER 1110-2-8162, which requires the performance of alternatives to be evaluated under all three USACE scenarios, the projected timelines of these SLR milestones (whole number relative increases in mean sea level) under the three USACE projection curves – low, intermediate, and high – were evaluated, as shown in Table 8-3. For example, with a closure criterion of +7 ft NAVD88, the expected average recurrence interval for SSB closure is about 3.5 years (in year 2057 under the USACE Intermediate SLR scenario) with 1 ft of SLR. With 2 ft of SLR, this recurrence interval is expected to be reduced to about 1.5 years. Furthermore, the initial 1 ft of SLR is projected to occur in the years 2096, 2057, and 2033 on the USACE low, intermediate and high projection curves, respectively.

**Table 8-3: Effective Average Recurrence Intervals (in Years) of SSB Closure with Different Levels of SLR for Specified Closure Criteria, and the Occurrence Year of each SLR Level Based on USACE Projection Curves**

| SSB closure criterion | +1 ft SLR | +2 ft SLR | +3 ft SLR | +4 ft SLR | +5 ft SLR | +6 ft SLR |
|---|---|---|---|---|---|---|
| +7 ft | 3.5 | 1.5 | < 1 | < 1 | < 1 | < 1 |
| +8 ft | 7.5 | 3.5 | 1.5 | < 1 | < 1 | < 1 |
| +9 ft | 16 | 7.5 | 3.5 | 1.5 | < 1 | < 1 |
| +10 ft | 32 | 16 | 7.5 | 3.5 | 1.5 | < 1 |
| **Projection curve** | | | | | | |
| USACE Low | 2096 | - | - | - | - | - |
| USACE Int | 2057 | 2098 | 2130 | 2157 | - | - |
| USACE High | 2033 | 2054 | 2070 | 2084 | 2096 | 2107 |

As the AEP of a given still-water level increases with time due to sea level rise, the long-term exceedance probability of the closure criterion indicating the likelihood of a closure event also increases for future time periods. The long-term exceedance probabilities (LTEPs) of the closure criteria over the hundred-year planning period (2045 to 2145) based on each USACE SLR

[6] Nonlinearities in the response of stage frequency with SLR have not been investigated.

projection curve are shown in Table 8-4 for 25-year discrete time intervals. This provides an indication of the likelihood of at least 1 operation of the SSB over the 100-year planning horizon of the project.

**Table 8-4: LTEP (%) of the Closure Criteria over 100-Year Planning Horizon**

| USACE Curve | Planning Horizon | Closure Criterion +7 ft NAVD88 | Closure Criterion +8 ft NAVD88 | Closure Criterion +9 ft NAVD88 | Closure Criterion +10 ft NAVD88 |
|---|---|---|---|---|---|
| **Low** | 2046-2070 | 99.2 | 90.4 | 68.0 | 44.8 |
| | 2071-2095 | 99.7 | 93.9 | 74.0 | 50.1 |
| | 2096-2120 | 99.9 | 96.4 | 79.9 | 55.6 |
| | 2121-2145 | 100 | 98.1 | 85.2 | 61.3 |
| **Intermediate** | 2046-2070 | 99.8 | 95.7 | 78.0 | 53.8 |
| | 2071-2095 | 100 | 99.2 | 90.3 | 67.9 |
| | 2096-2120 | 100 | 100 | 98.0 | 84.7 |
| | 2121-2145 | 100 | 100 | 99.9 | 96.7 |
| **High** | 2046-2070 | 100 | 100 | 97.8 | 84.7 |
| | 2071-2095 | 100 | 100 | 100 | 99.8 |
| | 2096-2120 | 100 | 100 | 100 | 100 |
| | 2121-2145 | 100 | 100 | 100 | 100 |

### 8.3.2 Possible Adaptation Pathways

The data in Table 8-3 showing decreasing average interval between SSB closures over time are schematically represented from an adaptation perspective in graphical form in Figure 8-5 and Figure 8-6. Figure 8-5 shows the projected fall in average closure interval with intermediate SLR and possible future adaptation through closure criterion adjustments and expanded RRFs. One possibility here is to accept the shortened average interval between closures so that the existing measures can be left unchanged; however, it is assumed here that the closure criterion is adjusted up correspondingly for every foot of SLR (an objective threshold based on a practical observation metric to trigger possible future adaptation measures still needs to be established as part of the TSP optimization). Under this scenario, the closure criterion would be increased from +7' NAVD88 to +8' NAVD88 in 2057, and again from +8' NAVD88 to +9' NAVD88 in 2098 to match the 2 ft of SLR assuming the USACE Intermediate projection. At each of these points in time, the closure criterion adjustment would also need to be accompanied with updating the floor risk reduction measures within the basin to bridge the gap in flood protection levels caused by raising the closure criterion. Such an update could, for example, include adaptation of the RRFs or the non-structural measures. The update of the RRFs may involve height adjustments of designed measures or additional measures to protect areas newly at risk from the higher basin design water levels.

Figure 8-6 shows a similar graph for the USACE High SLR projection curve. The difference here with respect to the intermediate curve is that the closure criterion adjustments and the corresponding RRF adaptations would have to happen within a more compressed timeline due to the faster rate of SLR. For instance, if the future adjustments in closure criterion and accompanying RRF adaptations are still triggered upon every foot of sea level rise, such steps would then be needed in 2033 (closure criterion change from +7' to +8'), 2054 (+8' to +9'), and 2070 (+9' to +10'). In general, the observation can be made that adaptation will be needed at some future point in time. The question is, how soon will that need to happen and at what rate are adaptations expected?

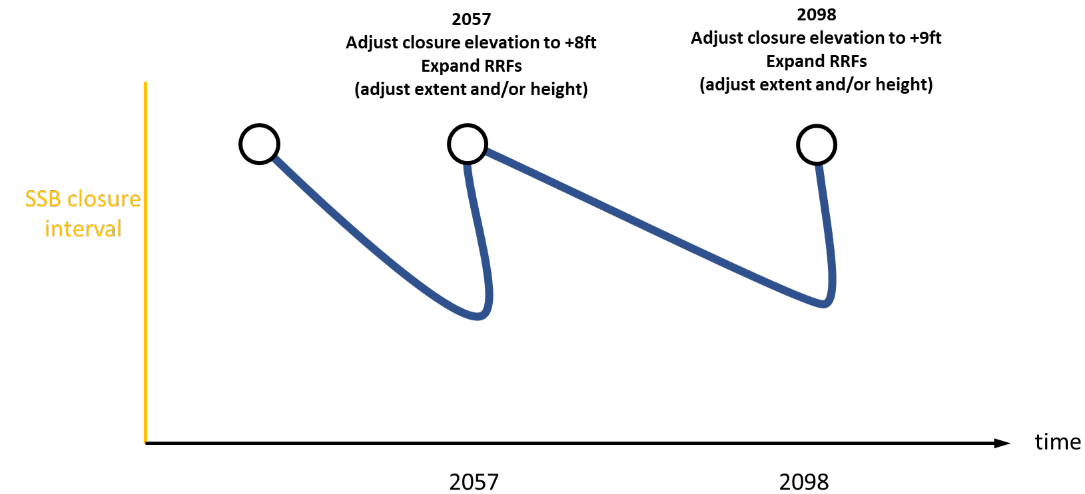



**Figure 8-5: Possible Management of SSB Closures and RRF Adaptations with USACE Intermediate SLR**

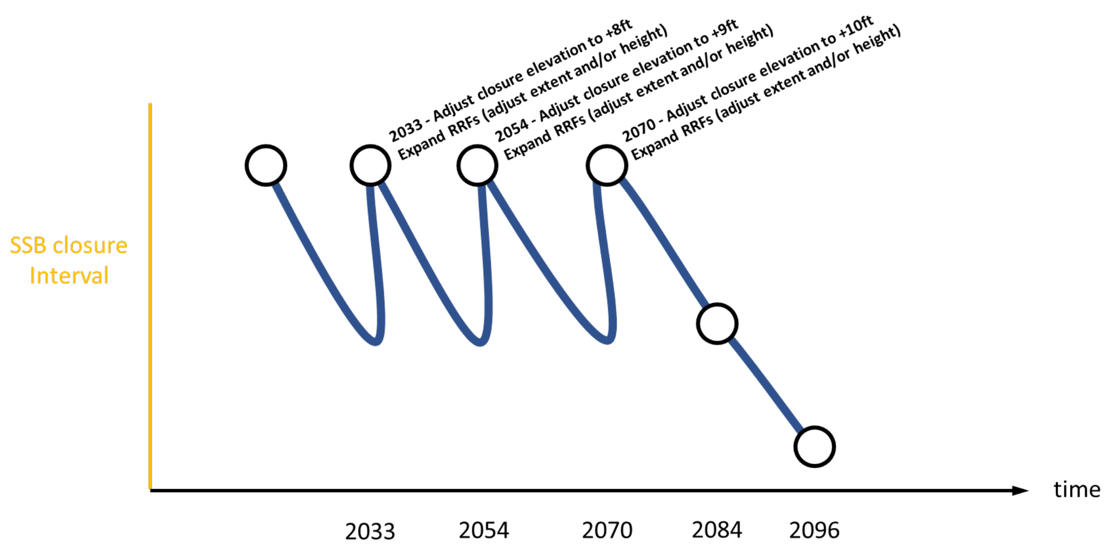



**Figure 8-6: Possible Management of SSB Closures and RRF Adaptations with USACE High SLR**

To better understand and visualize the set of possible actions and their trigger sequence and timeline as would be determined by the rate of observed SLR, a schematic illustration of the "Dynamic Adaptive Policy Pathways", as per Haasnoot et al (2013), is shown in Figure 8-7. This shows the set of possible actions on the y-axis and time on the x-axis. A possible sequence of adopted actions is shown using colored lines, with possible decision points (shown as circles) potentially triggering a new action. Potential decision points are assumed for every foot of SLR,

although their time of occurrence may vary depending on the future observed SLR. Their times of possible occurrence with SLR following the USACE Intermediate curve are shown in blue, and following the USACE High curve, are shown in red[7]. Sticking with the status quo for any action may lead to potential economic inefficiencies (higher costs or loss of benefits) due to changing environmental conditions at some point in the future. These are indicated with gray dotted lines.
The potential adaptation pathway in Figure 8-7 is just one example of many possible adaptation pathways and shows a decision point triggering an adjustment of the Closure Criterion to +8 ft accompanied with RRF upgrades. Upon a further 1 ft increase in sea level, the closure criterion could be adjusted correspondingly again with another round of RRF upgrades. Upon 3 ft of SLR, this action is repeated; but the SBMs would also need to be upgraded, as their current functional design is for 2.5 ft of SLR under the TSP. So, these decision points branch into two parallel adaptation/action pathways (shown in purple and blue). Each of these branches then may require similar subsequent adaptations at future decision points as shown. An example of another potential adaptive policy pathway involving SSB closure criterion adjustments with non-structural measures (instead of RRF upgrades) for intermediate flood risk mitigation is shown in Figure 8-8.

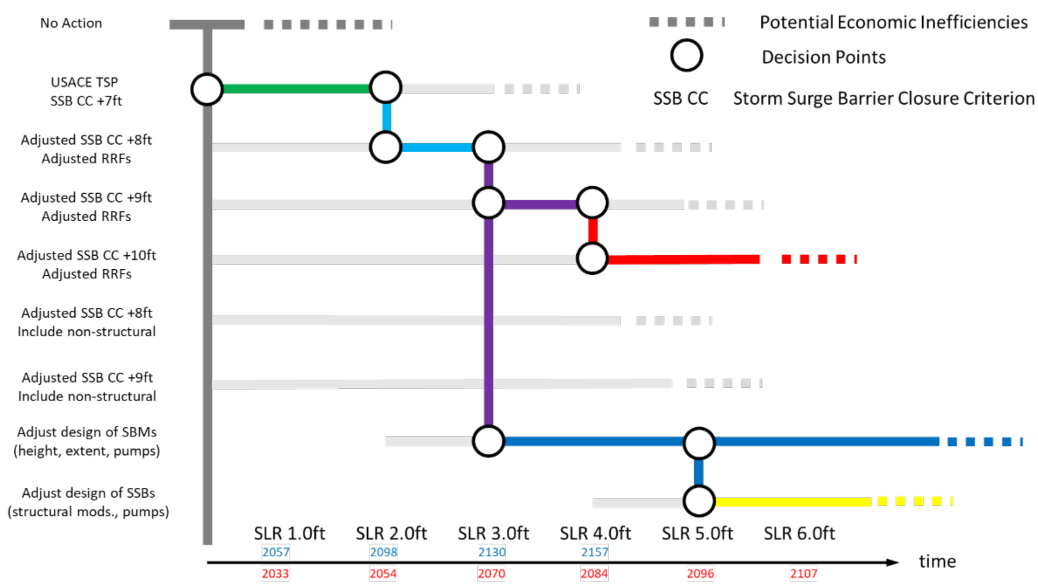



**Figure 8-7: A Dynamic Adaptive Policy Pathway for NYNJHAT Study involving adjusted RRFs**

[7] Only the years of interest to cover the end of the planning horizon (2150) for the projected timelines of SLR milestones are shown on the x-axis

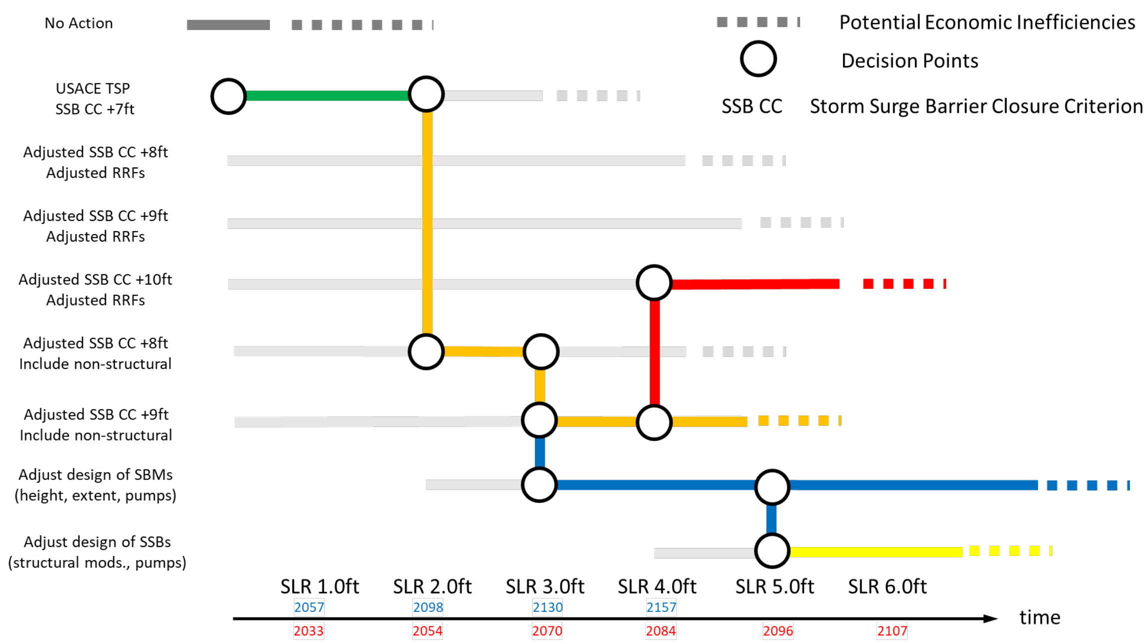



**Figure 8-8: A Dynamic Adaptive Policy Pathway for NYNJHAT Study Involving Non-Structural Measures on the Upstream Side of the Storm Surge Barriers**

The examples shown here illustrate just two of several possible pathways. Moreover, the decision points do not necessarily need to occur at the 1-foot increments of SLR, and an appropriate optimal threshold to trigger these decision points would still need to be determined. The eventual course of action at each decision point will need to be based on the observed SLR, and a lead time is needed to plan for, design, and construct adaptive measures. As a result, agency action will need to precede the decision point. If one finds that over the 21st century the SLR trajectory is closer to the USACE high scenario, decision points may be based on 2ft increments or more, to prevent going through the cycles of decision, design, and construct adaptation in rapid succession.

### 8.3.3 Adaptability Summary

SSBs are designed to offer flood risk reduction from relatively infrequent coastal storm threats. High frequency of SSB operations adds to their lifetime Operations and Maintenance (O&M) costs and may not be desirable. The tolerance for frequent operations may be especially low for the more prominent barriers that intersect busy navigation routes that are hence classified as Strict Constrained Operation (SCO) barriers (see also 4.3). The closure criterion for all SSBs would be set primarily during the initial design phase to achieve an appropriate balance between their marginal cost and benefit. But projected SLR may add to the marginal costs and have negative impacts to the economy or the environment for a fixed closure criterion by increasing the required number of SSB operations through the service life of the barrier. If the frequency of required closure makes this solution inefficient, one solution is to increase the closure criterion to reduce the required frequency of closure to acceptable levels. This could potentially expose areas on the upstream side of the storm surge barriers to higher water levels than what the existing flood mitigation measures (RRFs) were designed for. However, additional nonstructural or perimeter measures can be implemented over time in adjustment to the SLC rate being experienced without adding expensive adaptability costs to their initial construction. Even under the High SLC curve, the initial storm surge barrier designs proposed under the TSP can be adapted to maintain project performance, from a flood risk reduction perspective, over a 100-year planning horizon. Analysis of the changing stage frequencies with SLR has been used to inform concepts of several possible adaptative policy pathways and their consequences for different levels and rates of SLR. Because the design level of the TSP has not been optimized, the quantitative triggers for adaptation and quantitative data to define the potential adaptation measures have not yet been defined. A better definition of the possible triggers for adaptation and adaptation options will be established after optimization of the TSP.

# 9 Recommendations for Future Phases

The Feasibility Phase is the first phase in the USACE Civil Works Project Development Process. The completion of the Feasibility Phase will be marked by approval by the Chief of Engineers and signature of the Chief's Report, which is then submitted to Congress for consideration. If the project is authorized and funded by Congress, the project will enter the PED phase. Due to the large size, scope, and complexity of the NYNJHAT Study, engineering assumptions have been made to facilitate the development of feasibility level designs for the study alternatives. The PDT has identified design tasks to complete during later stages of the feasibility phase as well as design tasks to complete during PED assuming successful approvals, authorization, and appropriation.

## 9.1 Recommendations for Further Study of the SBMs

### 9.1.1 Recommendations for Alignment Refinements

The NYNJHAT study alternatives were based on the SBM alignments developed during plan formulation. Refinements and alterations to the SBM alignments were made over the course of the feasibility study to allow for better implementation of SBMs and incorporation of stakeholders' comments. RRF alignments and IFF alignments were added to each study alternative, where applicable, during the feasibility study since those were not defined in the early plan formulation phase of the study.

In many instances, the alignment or the selection of the SBM relied on a high-level review of available data. It should be reiterated that no site-specific topographic survey, bathymetric survey, condition survey, and/or geotechnical analysis have been completed. Instead, in accordance with USACE's SMART planning principles, the alignment and selection of SBM type was based on qualitative data and a desktop-level analysis, which yield generalizations of existing conditions. It is understood that those further refinements will be completed at later stages of the study when additional time and resources can be focused on the most viable alternative or alternatives.

The implications of these assumptions are that further optimization of the alignment is possible and that for reaches where conflicts are most apparent, an alternative comparison on a reach-by-reach basis is recommended. In such a study, alternate alignments would be compared amongst each other and evaluated and screened using criteria such as, but not limited to, cost, constructability, and impacts. The following studies are recommended to further refine the alignment of the selected alternative in optimization during the post-TSP study phase or during PED:

1. Site topographic survey
2. Existing structure condition survey
3. Site-specific geotechnical data
4. Site-specific metocean study
5. Bathymetric survey for alignments following existing bulkhead lines
6. Site use and traffic studies

7. Wetland survey and mapping
8. Comprehensive interior drainage modeling
9. Continuation of stakeholder and public outreach such that input and comments from stakeholders can further inform alignment alternatives to be evaluated
10. An analysis of easement delineation and real estate studies such that impacts beyond the footprint of the measures can be preliminarily assessed
11. Utility investigations and as-needed service diversions or relocations studies
12. Cost Estimates and impact assessments for alignment alternatives
13. ADA and egress studies
14. Site hazardous studies
15. Optimization study for RRFs with various SSBs closure criteria

Lastly, it is recognized that large parts of the NYNJHAT Study area are highly developed. Over the course of the NYNJHAT Feasibility Study, separate new projects and developments have been or may be planned, and may go into construction in the future. Given the large study area, it has not been possible to fully coordinate all future CSRM related developments with the NYNJHAT Study TSP. For these separate CSRM related studies and projects, which have not been assumed to be in place as part of the NYNJHAT Study future without project condition (see Section 2), continued coordination will be needed to further refine and optimize the reaches and proposed alignments between those studies and projects, and what may be advanced as part of the NYNJHAT Study. A brief list of projects that will need further coordination is provided below. It is recognized that this list is likely incomplete.

- FEMA plans for a perimeter flood barrier for the Cedarhurst-Lawrence High School (related to RRFs in Jamaica Bay)
- Battery Park City Authority's (BPCA) plans for perimeter flood risk reduction plan around Battery park City
- NYC's resiliency plans for The Battery and the Seaport area
- NYC resiliency plans for the Red Hook neighborhood
- NYC resiliency plans for East Harlem River
- Resilient NJ – Raritan River and Bay Communities
- Resilient NJ – Resilient Northeastern New Jersey
- USACE Continuing Authority Program Section 103 Study of Hallets Cove, Queens, NY
- The NY and NJ Harbor Deepening Channel Improvements Study (USACE). Navigable passage dimensions of SSBs may need to be reassessed and refined based on recent (2022) released Chief's report
- Hudson Raritan Estuary (USACE). PED phase is underway and includes projects throughout the estuary and Jamaica Bay that may require coordination with the proposed features of the TSP.

### 9.1.2 Recommendations for Further Design Refinements of SBMs

The preliminary designs for the SBMs are of sufficient detail to support quantity take-offs. The SBMs used here are limited to a total of twenty-seven (27) and are at a level of detail commensurate with a feasibility study. Assumptions as discussed in the report have been made to advance the design; but it should be noted that additional data and studies are needed for the next design phase to refine the SBM designs such that more site-specific measures can be developed for the recommended alternative. Recommendations for next phases of the project include:

1. Evaluate the need for refinement of the SBMs and development of additional site-specific SBMs.
2. Assess and design the transitions between various SBMs and transitions between existing and proposed SBMs.
3. Assess and design transition from SBMs to existing high ground (tie-ins or tie-offs).
4. Refine the requirements for future adaptability and refine the SBM designs to incorporate adaptability into the design.
5. Setting the wave overtopping criterion and optimize it for the study. Ideally, the overtopping criterion is informed by the two main considerations:
    a. The ability of the risk reduction system to handle the volume of overtopping (i.e., pumping or storage on the protected side of the risk reduction alignment may allow for accepting large overtopping volumes), and
    b. The type of construction on the protected side of the alignment, e.g., grey infrastructure has a relative high tolerance for large overtopping discharges prior to the onset of structural failure while levees have a lower tolerance. Given the urban nature of the study and relatively high portion of grey SBMs, a higher overtopping criterion could be considered.
6. Complete a gate-type evaluation. For locations where deployable floodgates and tide gates are required, determine the best gate types, sizes, and configurations.
7. Assess the control, security, and deployment requirements for the deployable flood barriers.
8. Evaluate the need for maintenance and inspections for each SBM.
9. Continuation and furthering stakeholder and public outreach such that input and comments from stakeholders (including city, state agencies, and the public) can be incorporated for better integration of the SBMs into the urban fabric.
10. Coordinate and provide supports for non-structural elements, such as lighting, conduits, landscaping, public amenities, and utilities.

## 9.2 Recommendations for Further Study of the SSBs

### 9.2.1 Introduction

This study is the first where a suite of storm surge barriers is evaluated for the New York and New Jersey Harbor. The conceptual designs for the storm surge barriers as part of the NYNJHAT Study alternatives are based upon a broad yet comprehensive data analysis for the entire study area with equal level of detail for each storm surge barrier. The basis of design, albeit preliminary, are analogously and consistently prepared for all storm surge barrier locations and include, amongst other items; the latest hydrodynamic storm surge modeling results to establish boundary conditions for design, AIS traffic data analyses, and a basis for the minimum required dimensions of the navigable passages. Most importantly, the conceptual designs and geometries of the storm surge barriers are evaluated using hydrodynamic models and are not solely analyzed on an individual basis but analyzed using a systems approach (USACE ERDC, 2019). This document is the first step in an iterative design process using a systems approach, whilst previous completed studies in large part only provided singular concepts and did not assess impacts to the regional hydrodynamics, nor did those studies use such assessments to further the conceptual designs.

Furthermore, the gate types are selected based on a high-level but full review of hydraulic gate types, and the applicability of such gates is based on the review of constructed storm surge barriers. The conceptual design as presented herein is in part informed by the data and characteristics of other storm surge barriers that have been constructed throughout the world. As such, the conceptual design is built upon proven concepts and principles which in turn improve the reliability of the overall concept. Reliability is a key notion during the concept development of these storm surge barrier designs.

However, in some instances, the concepts considered are larger in scope and scale than those that currently exist in practice. Nonetheless, although some elements are proportionally larger, there is good confidence that the concepts presented are both constructible and feasible in their implementation.

Despite the depth and breadth of preliminary evaluation, this assessment of navigable passage widths and storm surge barrier configurations shall not be construed as definitive recommendations or requirements for actual design for implementation. Significant additional study is required to substantiate the width, location, and configuration of the navigable passages and auxiliary flow gates, including a full evaluation of navigational, environmental, ecological, and cost considerations, amongst others.

The next sections provide a framework of additional studies and engineering analyses that should be considered and what those efforts should at a minimum entail[8].

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[8] These sections are geared towards engineering analyses and studies, while it is recognized that environmental, economic, socioeconomic and other studies would be required similarly.

### 9.2.2 Iterative Design – Next Steps

Following the analyses described within this report, there are several overarching topics that warrant further investigation and are considered logical next steps as part of an iterative design process. For completeness, these topics are summarized here. One of the main tasks to be evaluated for each storm surge barriers is a siting study. A complete siting study for the storm surge barriers would evaluate pros and cons of various alignment and conceptual design alternatives for each storm surge barrier. For the Arthur Kill and Kill van Kull SSB, a high-level, abbreviated siting study was completed and is documented in Sub-Appendix B2 (Storm Surge Barrier Sub-Appendix). A detailed siting study should consider the following topics:

- Navigable passage dimensions:
  - The required width of the navigable passage
  - Requirements for one-way versus two-way traffic for the navigable passage (further detailed below under Navigation – Section 9.2.5, below)
- The impact of current velocities on navigation and the required dimensions of openings within the storm surge barrier to minimize impacts to navigation conditions. In particular:
  - For the Jamaica Bay storm surge barriers, preliminary modeling results indicate that under the configuration of NYNJHAT Study Alternatives 3A, 3B, and 4, flow velocities through the navigable passage could exceed 3knts around 10% of the time for all alternatives under normal hydrometeorological conditions (USACE ERDC, 2019).
  - Alternate storm surge barrier alignments with a longer span and relatively lower percentage of flow impediment may alleviate such concerns.
- Existing channel conditions and proposed sill elevation: For a number of storm surge barrier locations, the reported channel conditions are less than the authorized channel dimensions due to shoaling. The sill elevation of the navigable passage has been determined based on authorized channel depth, yet at certain locations this may require substantial channel maintenance (i.e., dredging) prior to construction of the storm surge barrier. A notable example is provided below:
  - Newtown Creek
    - The recommendations from the 2016 report (CH2MHill, 2016b) to set the sill elevation at -20 ft NAVD88 is utilized here to establish the conceptual design with the understanding that the recommendations were the result of a site-specific feasibility study at a higher level of detail than the feasibility analysis of storm surge barriers at a regional scale discussed herein. It should be emphasized, however, that the channel is authorized at -23 ft MLLW (-26 NAVD88), and, as such, a limitation to the authorized channel depth needs to be accepted at a later date
  - At other locations where SSBs and RRF navigable gates are proposed, shoaling is present in navigable channels or bathymetric data is outdated, making the estimate of needed sill depths and potential restrictions on cross-sectional flow area challenging. Bathymetric surveys and further refinements to improve the layout

and geometry are needed at later stages of the study. This issue is specifically noted for the Port Washington SSB, Hempstead Harbor (Glen Cove) SSB, and the pair of RRF navigable gates at Howard Beach.

- Alternative gate types for the navigable passage:
  - It should be noted that this is a high-level evaluation as no site-specific borings are available and designs for the gates are still conceptual in nature. Further recommendations regarding geotechnical evaluations are provided below.
  - For the Arthur Kill and Kill van Kull SSB, a floating sector gate is conceptually proposed. The gate size (600 ft and 900 ft for AK and KvK, respectively) is of the same order of magnitude of constructed floating sector gates (1,190ft and 660ft for Maeslant and St. Petersburg Storm Surge Barrier, respectively). The gate housing of the floating sector gates occupies a relative substantial portion of the cross-section of the existing waterway and reduces the existing flow area. If there are concerns with respect to current velocity and impacts to tidal prism, alternate gate configurations, which occupy a smaller percentage of the existing cross-section, can be investigated.
  - For those locations where air clearances are restricted, or the option exists to make air clearances restricted, lift gates may be suitable alternatives.
  - Apart from the examples provided here, it is recommended to analyze, cost, and compare alternate gate types for all selected storm surge barriers.

- Alternative gate types for the auxiliary flow gates:
  - For the majority of the storm surge barriers, the lift gate was selected for the auxiliary flow structures. At those locations where reverse head conditions are of limited concern, a tainter gate is most likely also a viable option. For example, the USACE study for Jamaica Bay (USACE-WES, 1976) considered tainter gates. Applicability of tainter gates will, in large part, depend on reverse head conditions and the potential for relatively high load concentration on the trunnion bearings. In addition, for locations that are shallower with a fairly even bathymetric profile, rotating segment gates or inflatable gates could be considered as an option as well.
  - The conceptual designs presented maximized the number of auxiliary flow gates to the extent practicable, to minimize impacts on flow exchange. For some SSBs, the number of lift gates is changed compared to prior studies, e.g., for the Jamaica Bay and Hackensack River storm surge barrier. At some locations, a different configuration (less openings or slightly less total flow area) may result in no appreciable difference in tidal flow exchange but could potentially be more economical.
  - Apart from the examples provided here, it is recommended to analyze, cost, and compare alternate auxiliary flow gate types for all selected storm surge barriers.

- Geotechnical site conditions:
  - Foundation concepts were based on a high-level evaluation as no site-specific borings are available and the designs for the gates are still very conceptual. It is

recommended that a geotechnical data gap analyses be completed, site-specific geotechnical data be gathered as needed to supplement available information, and a design geotechnical profile be established for each storm surge barrier location. Site-specific ground investigations may be conducted in phases to balance the need for progressively more detailed data at each project milestone against both funding availability and risk that a given barrier location may not be implemented.
    - Following data collection, gate-type selection should be revisited considering foundation constraints, estimated seepage gradients, constructability, etc.

### 9.2.3 Constructability

The siting and eventual construction of a storm surge barrier is a complex undertaking, and practical constraints may influence the eventual design based on constructability considerations. Constructability will influence design considerations, structure type, project costs, phasing requirements, and schedule. Large civil works projects involving marine-based construction are represented by significant complexity and cost factors. These factors are generally exacerbated as water depth, flow velocities, and proximity to navigation channels are considered. Likewise, structure configurations used to overcome the spatial and loading criteria for which the structure must perform also heavily influence complexity and cost. Hence, basic constructability assessments must be performed to consider viability and provide for proof of concept for foundations and structure types under consideration.

Constructability evaluations are an inherent part of any major civil works undertaking. Among the many considerations when considering constructability, the following should be considered:

- Maintenance of navigation and navigational impacts during construction
- General method of construction (e.g., in-the-dry, in-the-wet)
- Temporary works (e.g., cofferdams)
- Site access (e.g., barge-based work versus land-based access via temporary trestle)
- Site staging and laydown areas
- Material deliveries to the work site (e.g., floating concrete plant)
- Contractor capabilities, and the availability of both specialized contractors and equipment needed to perform the work
- Feasibility, availability, and locations of off-site fabrication areas for modular elements (e.g., graving dock for float-in elements)
- Variability of subsurface conditions and methods used to provide adequate foundations
- Impact from tides, current, weather, and other environmental factors on construction activities
- Extreme event scenarios, preparedness provisions, and similar risk considerations
- Potential availability of construction materials, including quality and quantity
- Waste and recycled materials considerations, including beneficial use

- Environmental considerations affecting construction activities (e.g., relocations, noise, work period restrictions)
- Construction schedule, including a variety of phasing and funding scenarios

### 9.2.4 Hydraulics, Hydrology, and the Aquatic Environment

The complexity of the regional hydraulics and hydrology warrants further study in the following topics:

- Permissible overtopping quantities and permissible leakage through the storm surge barrier to optimize structure elevation:
    - Currently an overtopping criterion of 200 l/s/m is applied, which could still be considered a conservative criterion as some coastal structures can accommodate higher overtopping discharges if properly designed for (USACE, 2002).
    - Besides the proposed conventional option, one alternate option that can be considered is a gated weir structure that allows for both flow-through during normal hydraulic and meteorological conditions, while allowing for flow over the crest during severe storm surge conditions. The purpose of the storm surge barrier is to impede storm surge, which does not equate to complete blockage of the flow.
- Analyses of impacts to the tidal flow exchange and impacts to the tidal amplitude as a result of the proposed geometry. Such analyses should further the work completed by ERDC (USACE ERDC, 2019) and continue the iterative design process to refine the storm surge barrier geometry, and include:
    - Assessment of the impact on water surface elevations, discharges, and average velocities in the openings;
    - Assessment of local hydraulic changes in the inner basin, harbor, or bay, such as local velocities and currents, salinities, tidal levels and circulation which are essential to pollution, fish and wildlife, and other environmental and ecological considerations; and
    - Analyses of potential changes in tidal flow exchange and impacts on salinity, water quality, and ecology. This study is currently ongoing (NYBEM).
- Analyses of potential changes in tidal flow exchange and the impacts on both local and far-field morphology:
    - The net longshore sediment transport at both Sandy Hook and Rockaway Inlet are directed towards the New York Bight. Future analysis will need to evaluate the potential for erosion and sedimentation in the region of the storm surge barriers.
- Sea level rise sensitivity and adaptability analyses when the Tentatively Selected Plan has been optimized:
    - Perform tests with different SLC scenarios and investigate changes in hydrostatic and dynamic loading as well as changes in overtopping discharge, and identify options and project features that can provide for an adaptable design.

    - Adaptive management may be necessary or structural improvements may be needed if the observed sea level rise exceeds the planning criteria; such provisions would be included in the design to accommodate improvements if and when needed.

- Impacts to water levels on the protected side during gate closures (reverse head conditions):
    - Analysis of inflows and potential for a rise in water levels on the protected side of the storm surge barrier after gate closure. This holds for all storm surge barriers discussed herein, but of particular note is the conceptual design for the Hackensack River storm surge barrier (USACE, February 1989) and Newtown Creek (CH2MHill, 2016b), which included a pump stations in line with the gated barrier.
    - Analysis of joint probability of river discharge (flood levels) and storm surge levels. This is of particular interest for the Hackensack River storm surge barrier.

- Impacts to water levels to adjacent areas on the flood side of the storm surge barriers.
- Analysis of impacts to water quality during and after gate closures.

### 9.2.5 Navigation

The New York Bight, between Sandy Hook and the Rockaway Peninsula, is the principal entrance to the New York and New Jersey Harbor and is one of the busiest waterways in the USA. Constructing a storm surge barrier across a major navigation channel (as proposed for the KvK SSB and AK SSB) will require further study in the following areas:

- Waterway traffic:
    - One-way versus two-way vessel passage, including meeting, passing, and overtaking
    - Number, frequency, and intensity of vessel passage
    - Vessel wait areas, queuing, and wait times
    - Storm surge barrier positioning and fairway lengths for maneuvering
    - Trends for future vessel traffic, including vessel size and frequency
    - Passage of recreational vessels

- Currents, cross currents, wind, tides, surge, weather, night, visibility, and other environmental considerations for vessel passage.
- Navigation evaluations, including pilot and navigation industry input, and real-time simulations to assess, amongst others:
    - Flow and cross-current considerations
    - Gate approach and departure
    - Passing vessel assessments

- Requirements for Aids-to-Navigation, guide structures, and protective structures.
- Requirements for vessel traffic service, including advisory/control/restrictions on navigation.

- National security considerations.

### 9.2.6 Operations and Maintenance

Considerations for operations and maintenance affect the overall design philosophy. Operations and maintenance cost are a substantial part of the lifecycle cost of storm surge barriers. Important factors that determine operations and maintenance costs are (modified after van Ledden, et al. 2012): 1) maintenance of the movable parts of the structure; 2) painting (steel) parts of the structure; 3) operations and maintenance personnel costs; 4) cost of an operational data and decision support network; 5) inspection of parts, including submerged parts; 6) control systems, remote operations, emergency operations, and redundant systems; and 7) size, scope, equipment, and location of facilities to support operations and maintenance. The following topics will require further study:

- Operational criteria for gate closure and the expected frequency of gate closures
- Time scales for deployment, reliability, and operation of gate and warning systems
- Reliable operation of the storm surge barrier (gate closures) to obtain a reduction in flood risk
- Reliable operation of the storm surge barrier gates to minimize the impacts of gate closures on navigation and the aquatic environment
- Reduce to the extent practicable the complexity of Operations and Maintenance, Repair, Replacement and Rehabilitation (OMRR&R)

### 9.2.7 Multi-functionality of a Storm Surge Barrier Complex

Several storm surge barriers discussed herein would be constructed in close vicinity to industrial and residential development areas. The tie-in to the shore-based perimeter flood risk reduction system and the integration of the form and function of the storm surge barrier would require further study. There may be opportunities to further blend form and function and assess shared uses and multi-functionality of this civil works complex such that it provides additional benefits to the community. Topics that require further study are:

- Inclusion of transportation infrastructure (roadways, bridges, and tunnels)
- Potential for connections to existing transportation infrastructure
- Inclusion of recreational areas, educational areas, and other considerations for public access
- An assessment of aesthetics

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## Sub Appendices

Engineering Appendix Sub-Appendices follow hereafter.

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|---|---|
| Sub-Appendix B1 | Shore-Based Measures Sub-Appendix |
| Sub-Appendix B2 | Storm Surge Barrier Sub-Appendix |
| Sub-Appendix B3 | TSP Plan Set |
| Sub-Appendix B4 | Interior Drainage Sub-Appendix |
| Sub-Appendix B5 | Nonstructural Measures and Ringwalls Sub-Appendix |
| Sub-Appendix B6 | ERDC CSTORM/ADCIRC Model Report Sub-Appendix |
| Sub-Appendix B7 | ERDC AdH Model Report Sub-Appendix |