CLIMATE RESILIENT DESIGN STANDARDS & GUIDELINES

FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

BOSTON PUBLIC WORKS DEPARTMENT

OCTOBER 17, 2018

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ACKNOWLEDGEMENTS

The City of Boston wishes to acknowledge those who participated on the Technical Advisory Group (TAG) for their review and feedback during the development of the guidelines. The TAG attended three workshop meetings provided feedback on the approach, sample barriers, site locations, and design operations and maintenance considerations.

- City of Boston Mayor's Office
- Boston Public Works Department
- Boston Planning and Development Agency (BPDA)
- Boston Environment Department
- Boston Parks and Recreation
- Boston Transportation Department
- Boston Water & Sewer Commission (BWSC)
- Massachusetts Department of Transportation
- Massachusetts Port Authority (Massport)
- Massachusetts Bay Transportation Authority (MBTA)
- Massachusetts Emergency Management Agency (MEMA)
- Massachusetts Department of Conservation and Recreation (DCR)
- Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA)
- Eversource
- National Grid
- Ramboll
- Nitsch Engineering
- Kleinfelder
- Green International
- Deltares

The City of Boston would like to extend special thanks and gratitude to the City of Miami Beach, Florida, for sharing their experience surrounding raising roadways, managing stormwater, and creating public value with the project team.

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SECTION 1.0 INTRODUCTION

1.1 BACKGROUND

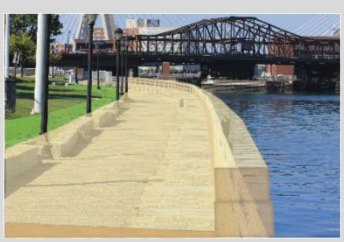
Through multiple initiatives, the City of Boston (the City) is preparing for 40 inches of sea level rise (SLR) by 2070. The Climate Ready Boston initiative is working to identify vulnerabilities and provide conceptual solutions throughout neighborhoods in Boston; the *Coastal Resilience Solutions for East Boston and Charlestown Final Report* was completed in 2017, the South Boston coastal resilience report is underway, and more studies are planned to follow. The City experienced significant coastal flooding during two Nor'easters in 2018. Recent findings of the *Feasibility of Harbor-wide Barrier Systems: Preliminary Analysis for Boston Harbor*, prepared by the Sustainable Solutions Lab at UMass Boston, indicate that shore-based climate adaptation solutions have significant advantages over a harbor-wide strategy for the City. With the growing number of conceptual solutions, emphasis on shore-based flood protection, and urgency for action, the City proactively identified that a framework for designing and evaluating climate resilient projects was needed to protect the public right-of-way (ROW).

The City is drafting a new policy to protect the public ROW from acute and chronic flooding due to SLR and storm surge. The Boston Public Works Department (BPWD) has prepared the *Climate Resilient Design Standards and Guidelines* for engineers and designers as guidance when designing flood barriers to protect the public ROW. The guidelines are intended to provide climate design adjustments and a standardized climate resilient design process for flood barriers. This document is meant to augment existing City and State design standards by considering climate impacts and managing segmental shore-based flood protection projects over time.

The guidelines present design, operations and maintenance (O&M), and cost considerations necessary to advance conceptual flood barrier ideas to implementation. Four sample barrier types and sample sites within the City were selected to provide example design considerations and real-world context for designing flood protection. The sample flood barrier types, identified below, are based on conceptual recommendations in previous Climate Ready Boston studies:

- **Vegetated Berm**: construct a vegetated earthen berm to serve as a flood barrier, with the goals of creating open space and additional value along Boston's waterfront.
- **Harborwalk (Seawall) Barrier**: transform the existing Boston Harborwalk into a flood barrier that maintains pedestrian connectivity to the waterfront.
- **Raised Roadways:** elevate roadways to act as a flood barrier (or as emergency access/evacuation routes).
- **Deployable Flood Barriers:** deploy temporary flood barriers as short-term solutions while long-term solutions are designed, permitted, and constructed.


Above: Vegetated Berm


Harborwalk (Seawall) Barrier


Raised Roadways


Deployable Flood Barriers

The above sample flood barrier options are not a comprehensive list and do not include all possible scenarios, opportunities, or challenges that may be encountered as these projects progress from concept to implementation. The guidelines are designed to be a living document that is updated regularly with new information as Climate Ready Boston climate projections are updated and projects are implemented.

1.2 GUIDELINES ORGANIZATION

The guidelines are organized to intuitively lead users through the process of designing flood protection for projected climate conditions, while evaluating applicable design considerations, operation and maintenance procedures, and related costs. Climate adaptation embodies a wide spectrum of policy, design, and engineering strategies. The City encourages designers to take a holistic approach and consider the Climate Ready Boston Evaluation Criteria presented in the *Coastal Resilience Solutions for East Boston and Charlestown Final Report* (effectiveness, feasibility, design life and adaptability, social impacts, equity, value creation, and environmental impact) in addition to the considerations provided in this document. A summary of each section of the guidelines is provided below.

SECTION 2.0: CLIMATE DESIGN ADJUSTMENTS FOR USEFUL LIFE

Climate change will impact the design parameters that engineers and designers have historically used for flood protection projects. The guidelines have identified "climate design adjustments" to account for SLR and storm surge, extreme precipitation, and extreme heat based on previous climate studies developed for the City and surrounding municipalities. The adjustments are structured by useful life with baseline climate parameters and projections for the 2030, 2050, and 2070 time horizons (where data were available) to remain consistent with Climate Ready Boston studies.

SECTION 3.0: CLIMATE RESILIENT FLOOD BARRIER DESIGN

General engineering design considerations, operations and maintenance standards, opinions of probable cost, and incremental approaches to advance conceptual design of flood barriers are presented in this section. The general considerations are applied to each of the four sample barrier types to provide samples for guidance.

SECTION 4.0 SAMPLE VEGETATED BERM

This sample barrier is an earthen embankment (4 feet high) with vegetated slopes. The sample has a walking path along the top and access paths that connect the dry side to the top of the barrier. This sample barrier requires significant space to construct, and the slopes (minimum of 3H:1V (horizontal:vertical)) were selected for stability and maintenance considerations. Hybrid techniques that include retaining walls and steeper slopes may be considered for sites, but for the purposes of the guidelines, the barrier is an earthen embankment only. The site for this sample barrier is an open space along the waterfront.

SECTION 5.0 SAMPLE HARBORWALK (SEAWALL) BARRIER

The Boston Harborwalk is approximately 43 miles and varies greatly along the shoreline. The site for this sample barrier is an existing stone masonry seawall within the Harborwalk and an open space located behind the wall. The sample includes adding 4 feet to the existing seawall and raising grades approximately 2 feet behind the wall. The sample considers the use of handrails as deployable floodwalls to accommodate additional flood heights beyond the 50-year useful life.

SECTION 6.0 SAMPLE RAISED ROADWAY BARRIER

Two options for raised roadways were used for discussion to understand appropriate context, challenges, and opportunities associated with raising roadways in urban settings.

- **Option 1**. Raising the roadway and sidewalk profiles 4 feet in areas where the buildings are set back at least 14 feet from the back of sidewalk.
- **Option 2**. Raising the roadway and sidewalk profiles 4 feet in newly developed areas with properties designed for access at higher elevations.

SECTION 7.0 DEPLOYABLE FLOOD BARRIER GUIDANCE

Deployable flood barriers, also referred to as temporary flood barriers, are defined as a barrier system that is deployed before and/or during a flood event and retracted after a flood event. Long-term, engineered solutions are preferred over deployable flood barriers. If temporary flood barriers are proposed, it is recommended that they be used while long-term solutions are being designed, permitted, and constructed. They can also be used for gaps and crossings of new flood barriers where permanent protection is not currently feasible. A Comparison Matrix is provided that considers several temporary flood defense barrier types, including modular rigid barriers, flexible barriers, and passive barriers.

SECTION 8.0: REFERENCES

The Climate Resilient Design Standards and Guidelines were developed referencing numerous publications developed by others. A list of references is provided at the end of the report to guide readers to additional information that may help with similar projects.

APPENDICES

Additional information and materials that provide supplemental context and additional detail to the design considerations in the guidelines are attached as appendices.

Appendix A. Overview of Flood Barrier Types

This appendix provides an overview of flood barrier types and examples of where they have been successfully implemented.

Appendix B. General Design Considerations

This appendix supports the design considerations outlined in Section 3.0 of the guidelines. The design considerations presented in Section 3.2 are described in more detail and include examples of best practices.

Appendix C. Sample Vegetated Berm Barrier Design Considerations

This appendix supports the design considerations outlined in Section 4.0 of the guidelines. The design considerations presented in Section 4.2 are described in more detail and focus on opportunities and challenges associated with the vegetated berm barrier at the sample site.

Appendix D. Sample Harborwalk (Seawall) Barrier Design Considerations

This appendix supports the design considerations outlined in Section 5.0 of the guidelines. The design considerations presented in Section 5.2 are described in more detail and focus on opportunities and challenges associated with the Harborwalk (raised seawall) barrier at the sample site.

Appendix E. Sample Raised Roadway Barrier Design Considerations

This appendix supports the design considerations outlined in Section 6.0 of the guidelines. The design considerations presented in Section 6.2 are described in more detail and focus on opportunities and challenges associated with the raised roadway barrier at the sample site.

Appendix F. Deployable Flood Barrier O&M Considerations

This appendix supports the design considerations outlined in Section 7.0 of the guidelines. The operations and maintenance (O&M) considerations presented in Section 7.3 are described in more detail and focus on the protocols and considerations that should be evaluated for operational capacity when identifying a deployable flood barrier.

Appendix G. Climate Resilient Flood Barrier Sample Specifications

This appendix includes sample specifications that may be used to support coastal flood protection projects.

SECTION 2.0 CLIMATE DESIGN ADJUSTMENTS FOR USEFUL LIFE

Climate change, including projected changes in sea level rise, precipitation, and temperature, will impact the existing criteria used to design built infrastructure. Flood protection structures need to be designed for future loading conditions. The following climate design adjustments were taken from projections presented in *Climate Change and Sea Level Rise Projections for Boston: The Boston Research Advisory Group Report* prepared for Climate Ready Boston. These adjustments are meant to be used as a starting point for selecting preliminary climate resilience design parameters during design of site-specific flood protection structures. These adjustments are not intended to replace existing codes and standards and should be used to augment existing design standards.

The adjustments are structured by useful life with baseline climate parameters and projections for the 2030, 2050, and 2070 time horizons (where data were available) to remain consistent with the Climate Ready Boston universal time horizons. Useful life is generally longer than design life and represents the extended service life of most infrastructure and should be assessed using professional knowledge, prior useful lifetime frames, and projected future conditions. The useful life estimates will inform the selection of climate adjustments to increase infrastructure resilience. The 2070 time horizon represents a 50-year useful life and should be the goal for flood barrier design. The 50-year useful life may not be feasible for all projects, so climate design adjustments for 2030 and 2050 time horizons are presented to help designers select an incremental approach.

The 2030 time horizon represents the climate projections through 2040; the 2050 time horizon represents the climate projections from 2041 to 2060; and the 2070 time horizon represents the climate projections from 2061 to 2080. Climate projections do not end at 2070, so the City encourages all designs to consider how flood protection can be adapted beyond a 50-year useful life.

Barriers protecting the public right-of-way, critical infrastructure, and/or projects costing more than $10 million (design and construction) should undergo a formal climate risk-based assessment for design. This assessment should include a minimum of a detailed, project specific vulnerability and risk assessment and cost-benefit analysis. Critical infrastructure, as referenced in these guidelines, includes assets identified in Boston's Hazard Mitigation Plan. The following types of facilities should also be considered critical for the purpose of estimating freeboard and the need for additional assessments:

- Hospitals and health care facilities
- Emergency Response (Police, Fire, Rescue, Ambulance) facilities and related items (garages, shelters, operations centers, communications, back-up generators, substations, etc.)
- Correctional facilities
- Wastewater treatment plants
- Water storage tanks
- Operations centers
- Public works yards
- Municipal buildings
- Schools and facilities that may be used as emergency shelters
- Power transmission facilities, substations, and power generation stations
- Critical transportation networks (emergency evacuation routes, public transportation, aviation facilities, tunnels, bridges, train and transit maintenance yards and shops, traffic signals)
- Facilities where residents have limited mobility or ability (such as nursing homes and care facilities)
- Buildings or structures that contain hazardous waste; waste transfer stations
- Pumping stations (stormwater and sanitary)
- Fueling storage and fuel stations
- Ventilation buildings and fan plants
- Telecommunications
- Major food distribution centers

Preliminary climate design adjustments for sea level rise, extreme precipitation, and extreme heat are presented in the following subsections. The data presented are minimum criteria and should be updated as new data are available. Engineers and planners should provide a rationale for selecting useful life criteria during design.

2.1 SEA LEVEL RISE AND STORM SURGE

Current Federal Emergency Management Agency (FEMA) 1% Flood Insurance Rate Map (FIRM) Maps identify the existing flood zone and base flood elevation (BFE) for the City. The maps do not consider impacts from sea level rise (SLR) and future 100-year floodplains. The Boston Harbor Flood Risk Model (BH-FRM) is a dynamic flood model that identifies probability of inundation and depth of flooding under current and future (2030, 2050, and 2070) SLR and storm surge considerations.

The Boston Planning and Development Agency (BPDA) has developed a SLR-BFE layer on their zoning viewer, which shows the BFE for each parcel in the projected flood hazard area with 40 inches of SLR (2070 time horizon) based on the BH-FRM. The SLR-BFE varies based on parcel location and shall be considered a minimum value to use for planning purposes.

The 1% annual flood event elevations, presented in Table 1 below, are intended to be used as a sample minimum BFE. Additional data from the BH-FRM should be used for design including, but not limited to, annual exceedance probabilities, flood depths associated with those probabilities, flood pathways, flood duration, wave impacts, and probability exceedance curves over all time periods. The results of a site-specific vulnerability and risk assessment may identify a more extreme storm event for design, such as a 0.2% or 0.1% annual storm event.

The typical useful life of flood protection structures is 50 years or longer with regular maintenance and upkeep. New construction projects should aim for a minimum Design Flood Elevation (DFE) that meets the 2070 time horizon. The DFE includes minimum freeboard standards; 2 feet for critical facilities and barriers protecting the public right-of-way, and 1 foot for non-critical facilities.

> *"Freeboard" tends to compensate for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood and floodway conditions, such as wave action, bridge openings, and the hydrological effect of urbanization of the watershed.*
>
> - Federal Emergency Management Agency
> https://www.fema.gov/freeboard

Incremental approach: If 2070 DFE is not feasible to achieve at this point due to available funding and/or site constraints, intermediary DFE presented below should be used to prepare a plan to reach the 2070 DFE elevation incrementally. Temporary, deployable flood barriers may use intermediary DFE (2030 and 2050 time horizons) but are not considered appropriate for long-term flood defense from SLR and storm surge.

Table 1. Sea Level Rise Design Adjustments – Reference the BH-FRM for site-specific BFE

End of useful life	Sea Level Rise Adjustment	1% annual flood event elevation (BFE) *BCB	Minimum DFE for non-critical assets *BCB	Minimum DFE for critical assets *BCB
Baseline	N/A	15.7	16.7	17.7
2030	+9 inches	17	18	19
2050	+21 inches	18	19	20
2070	+40 inches	19.5	20.5	21.5

Notes:
2030: Through 2040
2050: 2041 to 2060
2070: 2061 to 2080
1% annual flood event is also known as the 100-year flood event.
Boston City Base (BCB) Datum can be converted to NAVD88 by: NAVD88 = BCB – 6.46 ft.

2.2 EXTREME PRECIPITATION

Drainage planning and stormwater management for flood protection structures should assume future precipitation increases behind the barrier, as well as on the flood side. The Boston Water and Sewer Commission (BWSC) uses NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES for design of stormwater collection and management systems. The climate projections presented in Table 2 below are recommended for stormwater design.

Table 2. Extreme Precipitation Design Adjustments

Peak Hourly Intensity Rainfall (inch/hour)			
End of useful life	**10% annual design storm (in/hr)** (BWSC 2015 (A1FI))	**2% annual design storm (in/hr)**	**1% annual design storm (in/hr)**
Baseline (NOAA 14)	1.66	2.33	2.62
2035	1.78	*Data not available*	*Data not available*
2060	1.91	*Data not available*	*Data not available*
2100	2.11	*Data not available*	*Data not available*
Total Storm Depth (inches/24 hour)			
End of useful life	**10% annual design storm (in)** (BWSC 2015 (A1FI))	**2% annual design storm (in)**	**1% annual design storm (in)** (City of Cambridge 2015)
Baseline (NOAA 14)	5.25	7.18	8.08
2035	5.60	*Data not available*	10.2
2060	6.03	*Data not available*	*Data not available*
2100	6.65	*Data not available*	11.7

Notes:
10% annual design storm is also known as the 10-year flood event.
2% annual design storm is also known as the 50-year flood event.
1% annual design storm is also known as the 100-year flood event.

Designers should use available projections and trends from the Climate Ready Boston studies, reference available extreme precipitation studies, perform a sensitivity analysis to evaluate existing and proposed system capacity, and use professional judgement to design for future design storms where data has not yet been developed and for stormwater and drainage planning considerations.

A risk-based alternative analysis and cost-benefit analysis should be considered during design to evaluate future precipitation events for barriers protecting the public right-of-way. Observations from agencies such as NOAA are suggesting that within the useful life of a flood barrier, the 1% annual storm event precipitation depth and intensities could increase from 20% – 50% above current values. Prjoects should reference BWSC standards and consider the capacity of the existing systems.

For example, since it is more difficult to incrementally increase below-grade drainage systems, precautionary projections, such as the A1F1 from the BWSC Comprehensive-Integrated Sustainable Wastewater and Storm Drainage System Facilities Plan Final Report (BWSC, 2015), may be used to select conduit/pipe size, but above ground drainage swale design may use less conservative design storm values.

2.3 EXTREME HEAT

Extreme heat is a concern for flood protection structures due to several reasons, including but not limited to:

- Health and safety impacts
- Thermal expansion
- Material degradation from excessive heat
- Pavement softening
- Increased failure/reduced efficiency of electrical/mechanical systems (power outages and pumps)

The following estimated number of days above 90°F and average annual temperatures should be considered at a minimum in material selection, operations and maintenance planning, and stormwater management (emergency generation and power outages as well). Engineers and designers should document what climate adjustments were selected and the rationale for selection.

Table 3: Extreme Heat Design Adjustments

Extreme Heat Events		
End of useful life	# days above 90°F (Rossi et all, 2015)	Average Summer Temperature (°F) (Houser et al, 2015)
Baseline	11	69
2030	20-40	69-73
2070	25-90	Up to 84 by 2100

Notes:
Baseline: 1971 through 2000
2030: Through 2040
2070: 2061 to 2080

Cold temperatures in addition to extreme heat should be accounted for during design to consider the impacts associated with New England winter weather, including but not limited to:

- Health and safety impacts
- Snow and ice ground cover
- Plowing and snow removal
- Snow storage on-site or off-site
- Drainage and infiltration impacts
- Ice jams

SECTION 3.0 CLIMATE RESILIENT FLOOD BARRIER DESIGN

3.1 DESCRIPTION AND ASSUMPTIONS

Climate resilience embodies a wide spectrum of policy, engineering, and design strategies. The City encourages designers to consider additional strategies to achieve resilience beyond protection, including retreat (relocation and/or elevation) and accommodation (green infrastructure, blue infrastructure, and/or embracing flood waters), in addition to the Climate Ready Boston key principles of effectiveness, feasibility, design life/adaptability, social impacts, equity, value creation, and environmental impact.

This section provides the design, operations, maintenance, and cost considerations for designing resilient flood protection in the City. Flood barriers to protect the public right-of-way should be designed for a minimum 50-year useful life; therefore, the 2070 climate projections are used to inform design. The climate adjustment to 2070 conditions may not be currently feasible due to existing physical, structural, and/or operational conditions, so this section includes recommendations on how flood barriers can be adapted over time. This document does not supersede existing local or State regulations and codes.

Conceptual ideas for barriers to protect the public right-of-way were completed as part of the vulnerability assessments and conceptual solutions for recent neighborhood studies by Climate Ready Boston. Climate Ready Boston has a map of existing and proposed resilience projects in the City of Boston on the Coastal Resilience Projects Tracker. The considerations provided in this document are intended to help engineers and designers advance conceptual ideas for flood barriers protecting the public right-of-way.

The flood barrier design process, as described in this document, should inform the design to achieve at least 25% completion. The City requires that a narrative and documentation accompany the design to show that the guidelines have been considered throughout the process and engineers and designers are meeting the standard of care for flood protection before the project is presented to the City. The focused goal of this process is to establish that climate impacts and adjustments have been considered and sites have been adequately designed to provide effective, feasible, and flexible flood protection of the right-of-way.

PRIOR TO IMPLEMENTING THE GUIDELINES, THE CITY OF BOSTON RECOMMENDS THE FOLLOWING:

Assess flood exposure and impact to the public right-of-way

The intent of the guidelines is to design flood barriers that protect and maintain access to the public right-of-way before, during, and after flood events. Designers should evaluate if flood waters can pass through a site and flood the right-of-way. Flood pathways may not be a direct route from the waterfront to the right-of-way, so engineers and planners should coordinate with the City of Boston if a barrier is proposed to protect the public right-of-way from flooding.

Consider legal issues and tolerance for failure

Currently there are several emerging regulatory and statutory requirements being considered in the Commonwealth of Massachusetts to address climate adaptation and mitigation. Regardless of the proposed regulations and statutes being considered by legislators, there is still current legal responsibility to protect public health and safety from harm.

The Boston Green Ribbon Commission and Conservation Law Foundation prepared a Climate Adaptation and Liability: A Legal Primer and Workshop Summary Report in January 2018. The report summarized workshops held in 2017 that sought to identify potential liability issues and other impediments to implementing climate adaptation. This document does not present legal liability applicable to design guidelines developed herein, however, the City encourages designers to review the report to better understand the context in which legal liability plays into climate adaptation projects.

<u>**Identify conceptual barrier for protection of right-of-way**</u>

In the development of these guidelines, the City of Boston examined a range of flood protection/barrier types and where they have been successfully implemented. Refer to **Appendix A – Overview of Flood Barrier Types**.

The sample barriers presented in these guidelines do not represent the full spectrum of options for climate adaptation. While these guidelines focus predominantly on flood protection for the public right-of-way, there are other climate resilient measures that should be considered in all projects. Retreat strategies may include relocating or elevating infrastructure and buildings. Accommodation strategies may include embracing flood waters (i.e. living with water) and considering natural and nature-based solutions. Designers should consider measures that create value in the City of Boston, as well as layering strategies for effectiveness and redundancy in design.

The Climate Ready Boston Evaluation Criteria established in the *Coastal Resilience Solutions for East Boston and Charlestown Final Report* presents a framework to evaluate proposed climate resilience strategies. The categories include **effectiveness, feasibility**, **design life and adaptability**, **social impact**, **equity**, **value creation**, and **environmental impact**. Please refer to the Climate Ready Boston report for additional information regarding these categories and design features. The barrier should knit into a neighboring context, contribute to a highly-functioning system of public realm that works for all, and enable accessibility, livability, and connectivity.

<u>**Consider public perception and acceptability of flood barrier**</u>

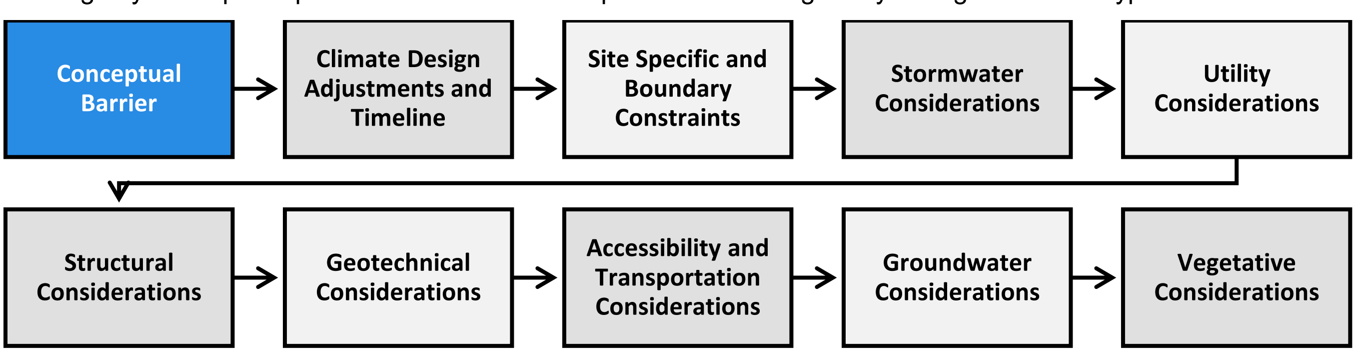
Public engagement and outreach are key for successfully implementing flood protection projects in the City. At the very beginning, a communications plan for public engagement and outreach should be developed so that the public can provide input and ask questions about the barrier and how it may affect them. The plan should include education and multiple forums for feedback. This step is integral for public acceptance of the barrier.

3.2 GENERAL FLOOD BARRIER DESIGN CONSIDERATIONS

Engineering and design considerations will affect the barrier design and incremental phasing of the barrier. The design considerations presented in this section reflect the Climate Ready Boston Evaluation Criteria, but focus predominantly on **effectiveness**, **feasibility**, and **adaptability** for protecting the right-of-way from flooding. This is not to suggest that the other criteria are not essential to the design process, however, focusing on the engineering and physical considerations will allow engineers and designers to technically advance the conceptual barrier idea.

This section provides a wide range of design considerations but is not a comprehensive list of all potential considerations. Engineers should use these considerations to augment the existing standard of care provided for projects and identify opportunities to create value wherever feasible. The design considerations and recommended additional studies may be used to tailor resilience options to individual projects based on site-specific information. The design considerations are summarized in the following subsections and discussed in greater detail in **Appendix B – General Design Considerations**.

The sample barriers described in Sections 4.0 through 6.0 provide sample design considerations related to the following key concepts to provide context and examples for how design may change based on type and location.



DESIGN CONSIDERATIONS

Refer to **Appendix B – General Design Considerations** for detailed general design considerations and guidance

Climate Design Adjustments and Timeline	► Refer to Section 2.0 for climate design adjustment for useful life. Evaluate a risk-based approach for identifying design parameters based on exposure, sensitivity, adaptive capacity, and consequence of flooding. ► Sea Level Rise & Storm Surge Climate Adjustments. ▲ Evaluate if the site is within the Boston Planning and Development Agency "SLR-BFE" zone via the zoning viewer. ▲ Identify if the site is within a major flood pathway that will impact the right-of-way. ▲ Identify if the site should be designed for the 1%, 0.2%, or 0.1% annual flood event. ▲ Boston Harbor Flood Risk Model (BH-FRM) Design Details: Probability of flooding, flood depth, duration of flood, flood pathways, wave impacts, wind velocity. ► Extreme Precipitation. ▲ Select design storm events for analysis (10%, 4%, 2%, or 1% annual storm). ▲ Estimate the drainage area contained by new barrier. ► Extreme Temperature. ▲ Evaluate heatwave, annual maximum temperature, and winter storm impacts. ► Incremental Climate Adjustments. ▲ If 50-year useful life climate design adjustment is not feasible, identify approach to reach climate design adjustment over time.
Boundary Constraints and Site Considerations	► Identify the extent of the barrier (current and future, if proposed incremental approach). ► Identify related zoning regulations and requirements. ► Evaluate available open space. ▲ What is needed for construction, operations, and maintenance? ▲ What are the downstream encroachment considerations? ► Identify opportunities to maintain the public right-of-way and access to waterfront. Livability, walkability, connectivity, and social and neighborhood context are essential. ► Coordinate with private properties and abutters. ▲ Existing or new easements must be established. ► Consider existing operational capacity to maintain barrier. ▲ What is the ease of access to site for maintenance vehicles and equipment? ► Conduct a Phase I Environmental Site Assessment to assess if the potential exists for Recognized Environmental Conditions including soil and/or groundwater impacts. ► Identify off-site impacts resulting from barrier – both sites adjacent to barrier and inland. ▲ Will neighboring sites have stormwater redirected or stored on them? ► Consider Climate Ready Boston Evaluation Criteria (social impact, equity, value creation). ► Estimate incremental impacts to boundary and site constraints.
Stormwater Considerations	► Identify Green Infrastructure (GI) opportunities and challenges. ▲ Consider Low Impact Design (LID), Extreme temperatures (drought, frozen ground). Refer to vegetative considerations. ► Assess volume capture and control. ▲ What are opportunities to resist, delay, store, and/or discharge stormwater?

Stormwater Considerations (continued)	► Identify possible off-site flooding impacts. ► Consider water quality. ▲ Polluted stormwater runoff is commonly transported through municipal separate storm sewer systems (MS4 pollutants). ► Evaluate watershed approach for stormwater management. ▲ Assess inland opportunities to delay, divert, store in off-site areas. ► Consider incremental and adaptive management approach, and possible current or future land use changes. ► Establish inspection, debris and sediment removal, and maintenance processes essential to system performance.
Utility Considerations	► Coordinate with local utility providers to identify gas, electric, communications, and other utilities that may be located within the project area. Consider engaging a professional subsurface utility engineering firm to identify utilities. ► Eliminate perpendicular barrier crossing of utilities. If elimination is not feasible, consider placing the conduit within a watertight sleeve to protect the barrier and the utility from movement. ► Estimate additional loads on existing utilities resulting from raised grades and higher groundwater levels. ► Identify existing connections to surrounding infrastructure and buildings. ► Water utilities considerations. ▲ What are impacts to fire hydrants and emergency access? ► Sewer utilities considerations. ▲ Look for opportunities to implement backflow valves and seal manholes. ► Combined Sewer Overflow (CSO) and Outfalls considerations. ▲ Off-site flooding may back up CSOs behind barrier. Study the extent of the stormwater system to the critical nodes and identify preliminary vulnerability of these locations. ▲ Implement tide gates and establish operations and maintenance protocols. ► Stormwater utilities considerations. ▲ Future pump stations may need to be constructed in the vicinity to manage stormwater behind barrier. ▲ Design for pump redundancy, over-design of wet-well capacity (future flow volumes), pump approaches, trash accumulation and removal, on-site generators and power supply (emergency systems also). ► Consider relocation of infrastructure to maintain access to utilities.
Structural Considerations	► Estimate anticipated loads. ▲ American Society of Civil Engineers (ASCE) guidance provided in ASCE 7-16, earth pressures with raised grades, live loads, etc. with climate adjustments. ► Assess condition of nearby existing structures. ▲ Perform field inspection and data review. ► Wall considerations. ▲ Floodwalls should be designed in accordance with United States Army Corps of Engineers (USACOE) guidance provided in EM-1110-2-2502, Retaining and Flood Walls. ► Material considerations.

Structural Considerations (continued)	▲ Consider impact of increased extreme temperatures and sensitive materials. ► Connection considerations. ▲ Analyze shear, tensile, breakout, pullout, blowout, splitting, etc. ► Durability considerations. ▲ Prioritize “Safe-to-Fail” design. ▲ Identify repair considerations. ► Identify possible failure mechanisms and the likelihood of progressive failure. ► Constructability considerations. ► Incremental considerations may include lengthening barrier vertically and/or laterally. Design for final loading conditions. ► Establish annual inspections and maintenance protocols.
Geotechnical Considerations	► Conduct subsurface explorations to evaluate overall subsurface conditions, seepage conditions, bearing capacity, and potential for settlement. ► Identify impact to existing structures. ▲ Raised grades may result in a surcharge on the underlying utilities or adjacent structures located within the “zone-of-influence” of the barrier. ► Perform stability analysis. ▲ Earthen flood barriers should be designed in accordance with USACOE guidance provided in EM 1110-2-1913, Design and Construction of Levees. ▲ Slopes of 3H:1V (Horizontal:Vertical) are recommended for stability and ease of maintenance. ► Perform settlement analysis. ► Assess seepage. ▲ Prevent sediment transport. ▲ Cutoff walls or trenches; if used, consider area groundwater hydrology and its effects on area foundations. ► Erosion and scour protection considerations. ▲ Place riprap in areas with high erosional forces. ▲ Materials and vegetation must be able to withstand wave action and saltwater. ► Foundation considerations. ▲ Overdesign foundation to support future loads. (i.e. if grades or walls are planned to be raised over time). ▲ Incorporate foundations for future floodwalls as needed into the embankment. ► Establish annual monitoring and maintenance program for embankment structures.
Transportation & Accessibility Considerations	► Maintain ADA accessibility and connection to inland area (existing buildings, sidewalks, roadways) and waterfront. ► It is unacceptable to raise a roadway four to six feet and leave existing sidewalks and entries at grade if there is less than 14 feet between the back of the existing sidewalk and a building; clearance greater than 14 feet may be required for public health and safety. ► Accessible routes shall not exceed 5% slope. Changes in slope for connections to side streets, driveways, and parking lots shall not exceed 15%, so vehicles do not bottom out. ► The minimum width of access paths shall be 12 feet so that a maintenance vehicle can bypass a wheelchair without impeding movement. ► Bridges and underpasses within 500 feet of a barrier should be analyzed for clearance.

Transportation & Accessibility Considerations (continued)	► Raising roadways will impact the public and stakeholders beyond the immediate streetscape. Coordinate with property owners and stakeholders, including but not limited to the City, MassDOT, Massachusetts Bay Transportation Authority (MBTA), community organizations, and private property owners. ► Construction materials should consider increases in heat as well as freezing temperatures. ► Evaluate parking needs. ► Create maintenance accessibility (vehicle or tracked equipment). ► Develop snow, ice, and stormwater management tasks that are critical for proper maintenance. ► Incremental considerations include access to surrounding infrastructure and redevelopment of roadways and property over time. ► Streetscapes should consider emergency vehicle access (police, fire, EMS), and meet City Standards for Boston Complete Streets and the BPWD Roadway Design Standards.
Groundwater Considerations	► Higher tides may increase groundwater levels and may result in reduced stormwater infiltration and affect stormwater drainage systems. ► Barriers must be designed to prevent excessive hydraulic gradients, internal erosion and loss of material (piping), and sand boils caused by underseepage. ► Uplift pressure may impact underground structures. ► Freshwater-Saltwater interface may impact: ▲ Coastal ecosystems ▲ Water treatment ▲ Corrosion of buried structures ► Higher groundwater may increase the risk of contaminant transport. ► Groundwater intrusion risks in below grade structures, including steam infrastructure.
Vegetative Considerations	► Current USACOE setbacks and easements do not allow for trees to be within 15 feet of dams or levees. ► Identify native or naturalized salt tolerant vegetation and non-invasive plant materials appropriate to the surrounding microclimate and ecosystem and complement passive recreational activities. ► Evaluate aesthetic considerations to create value. ► Promote open space opportunities. ► Select plants with erosion control qualities for embankments and steep slopes. Woody vegetation and brush can also prevent observation of deficiencies forming that increase the risk of failure. Trees are not permitted on flood barriers because of their root systems. If trees are uprooted during a storm event, the barrier may result in a breach. Tree root systems also pose a risk as a flood pathway; roots rot over time and can provide pathways for animals to burrow. If trees are desired, a root barrier system may be designed for the inland side of the barrier (waterfront side is a higher risk of breaching the structure). A structural wall may be designed in the embankment to reduce the impact of a breach. The wall should consider groundwater, geotechnical, and structural considerations. ► Consider plants that are "low maintenance" such as grasses and groundcovers that may also provide habitat that are tolerant of urban pollutants (emissions, oils, etc.). ► Consider plant heights as they relate to view-sheds and corridors towards the water and also the inland side.

3.3 OPERATIONS AND MAINTENANCE AND COST CONSIDERATIONS

Proper operations and maintenance (O&M) activities are critical to the performance of flood protection structures and reducing risk. O&M is necessary so that the flood barrier serves its intended purpose throughout its intended useful life. The objectives of O&M should be defined during design and construction processes. An O&M approach should include considerations provided in each of the design considerations. There may be additional functional objectives (such as recreational opportunities or roadway processes) that need to be considered in addition to the flood risk management components. Cost considerations should evaluate both O&M and capital costs.

IDENTIFY O&M REQUIREMENTS FOR THE FLOOD BARRIER

Identify the proposed O&M features for the flood barrier. The objectives of O&M should be defined during design processes, which may include, but are not limited to, the following:

- Specific requirements for construction
- Comprehensive annual visual inspections and before and following storm events
- Defined failure mechanisms
- Regular maintenance program for the barrier, surrounding area, and stormwater features
- Communications plan
- Scheduled training, trial emergency response test, communications test
- Real time monitoring and supervision
- Specific requirements related to incremental implementation of flood barriers
- Asset management
- Records and data management
- Emergency/response procedures with annual Emergency Action Plan updates
- Damage repair capabilities
- Feasibility of O&M (short-term and long-term)
- Technical proficiency and training of staff
- Benefit/cost ratio and affordability
- Environmental impact (people, animal, plants, water, etc.)
- Social interaction
- Preventing long-term damage
- Public outreach
- Improvement of processes and updating plans
- Back up and contingency plan (failure response plan details)

IDENTIFY PARTIES RESPONSIBLE FOR FLOOD PROTECTION MAINTENANCE AND OPERATIONS

There are many organizations and individuals involved in flood barrier O&M that need to collaborate to coordinate these activities. The O&M components of flood protection projects should include input from those who are responsible for management of the barrier, those affected by O&M, and interested parties; this may include, but is not limited to, input from:

- Regulatory Authorities
- City of Boston Public Works Department
- City of Boston Environment Department
- City of Boston Transportation Department
- Boston Water and Sewer Commission
- Boston Planning & Development Agency
- MassDOT and MBTA
- Property owners
- Developers
- Planners
- Insurance companies
- General public

The level of engagement for these organizations with respect to flood risk management varies. The following graphic may be helpful in understanding the level of engagement from organizations (based on FLOODsite, 2009, after Arnstein 1969).

All O&M plans should ***seek a minimum level of <u>consultation</u> from organizations***, with goals of ownership and empowerment. Once the organizations are involved, roles related to implementation, operations, and maintenance of the flood barrier need to be clarified. All parties should provide information relevant to their financial and operational capacity so that the optimum solution can be identified.

PREPARE AN OPINION OF PROBABLE COST BASED ON THE DESIGN CONSIDERATIONS

If several conceptual barrier types are being considered, this step may include a formal alternatives analysis. A formal alternatives analysis shall include a triple bottom line cost-benefit analysis (TBL-CBA). This method evaluates cost benefit and life cycle cost analyses across the triple bottom line, which includes financial, social, and environmental design impacts. The results of these analyses should be provided to project stakeholders.

Design considerations that may impact cost are included in design considerations provided in **Appendix B**, **Appendix C**, **Appendix D**, and **Appendix E**. Additional studies and considerations will impact costs at each site. Additional studies are recommended to advance design and prepare cost estimates.

The opinion of probable cost prepared for each sample barrier is based upon the City's experience and database of costs with similar types of projects in the City and surrounding urban area. The costs are based on the sample design drawings prepared for each sample flood barrier and assumed a contingency of 30% due to the limited information used to apply to each sample and sample site. Refer to the sample barriers in Sections 4.0 through 6.0 for examples.

The following items are not included in the opinion of probable costs developed for these guidelines but should be accounted for by developers, engineers, and planners interested in flood protection projects:

ITEMS NOT INCLUDED IN SAMPLE COST ESTIMATES Description of additional costs that should be accounted for in final design	
Owner's Costs	► Internal costs borne by the Owner during the planning and execution of this work. ► Owner's engineer or project management services including construction inspection/oversight.
Design & Permitting	► Site specific detail engineering and design services. ► Local, state, and federal permitting.
Construction, Logistical, Insurance	► Road closures/traffic re-routing/police special details. ► Relocation of utilities except as indicated. ► Utility company delays when disconnecting/relocating/reconnecting lines. ► Limited site access/urban congestion and constraints. ► Easements. ► Work in and around wetlands. ► Marine construction. ► Ferry/shipping impact. ► Construction near Logan Airport. ► Silt curtains/turbidity barriers.
Environmental, Accidents	► Impaired access due to accidents (auto traffic/boats). ► Flooding. ► Downed power lines and trees. ► Snow and ice delays.
Adverse Site Conditions	► Discovery of historical artifacts/sites. ► Pilings from wharves/buildings. ► Contaminated soil/urban fill. ► Large debris (vehicles, ships, containers). ► Unsuitable soils (requiring over excavation, ground improvement, and/or foundation support).

PREPARE AN OPINION OF PROBABLE ANNUAL COSTS AND LIFE CYCLE COST FOR FLOOD BARRIER O&M

Costs must consider annual O&M costs in addition to capital expenditures. O&M considerations that may impact cost are included in the considerations provided in **Appendix B**, **Appendix C**, **Appendix D**, **Appendix E**, and **Appendix F**. Refer to the sample barriers in Sections 4.0 through 7.0 for examples.

Stormwater Management O&M and Cost Considerations

O&M related to stormwater management is essential to designs that propose barriers, as barriers will now impound inland flood waters (either caused by precipitation events or overtopping). The infrastructure needed for stormwater management may include, but is not limited to, pump stations, generators, underground utilities, stormwater treatment systems, and green infrastructure.

Barrier projects in the City of Boston should anticipate similar stormwater management considerations as the City of Miami Beach case study and should consider how winter weather (snow, ice, salt, etc.) may impact designs. Stormwater annual cost considerations should include:

- energy costs for pump stations and system redundancy
- reassigned or new staff (or contractors) to maintain the new pump stations, generators, treatment systems, and utilities associated with stormwater management
- new O&M equipment needed for stormwater management
- operations management support
- staff training

Elevated pump station associated with raised roadways Sunset Harbour, Miami Beach, FL

CASE STUDY: RAISED ROADWAYS

The City of Miami Beach, Florida is raising roadways by two feet to reduce flood risk. The projects have included new streetscape opportunities, including lower sidewalk café spaces. In addition to raising roadways, the projects have included the installation of over 30 pump stations, which have cost the City of Miami Beach over $500M.

The pump stations and infrastructure associated with Miami Beach's stormwater management requires ongoing maintenance and control operations to prevent flooding behind the raised streets, in addition to typical street sweeping and catch basin cleaning. The new maintenance routine includes weekly inspections and system cleaning (debris capture and removal). The maintenance is performed by two full-time, two-person crews each equipped with a vacuum jet truck to service the new pump stations.

As the City of Miami Beach intends to continue to raise roadways, an additional 30 pump stations are planned for construction, and, with it, additional demands for stormwater O&M.

Raised roadway in Sunset Harbour, Miami Beach, FL

3.4 BARRIER SELECTION

Once the design, O&M, and cost considerations have been evaluated, the designer should identify if the conceptual barrier to protect the public right-of-way is feasible as originally intended, or if modifications to the design are necessary. Additional steps are required to continue to advance design of the flood barrier.

DEVELOP A PERMITTING STRATEGY

Permitting should be considered during design processes. Public and private entities should coordinate with federal, state, and local agencies to understand current regulations and requirements for designing along the waterfront and identify permitting requirements for the site and surrounding area. Identify potential permits, schedules, and costs for the barrier based on review of existing information pertinent to the project and current regulatory agencies and regulations, including but not limited to:

- Boston Planning and Development Agency Article 80
- Coastal Zone Management (CZM) review
- Federal Emergency Management Agency (FEMA) review
- Massachusetts Emergency Management Agency (MEMA) review
- Department of Conservation and Recreation (DCR) review
- Massachusetts Department of Environmental Protection (MA DEP) - Chapter 91 Waterways License
- Massachusetts Wetlands Protection Act – Notice of Intent
- Massachusetts Endangered Species Act
- Massachusetts Environmental Policy Act (MEPA) – EIR or ENF
- MA DEP - 401 Water Quality Certification
- United States Army Corp of Engineers (USACOE) - Section 404 Permit
- Federal Consistency Review
- National Pollutant Discharge Elimination System (NPDES)
- Beneficial Use of Solid Waste Permit

Following review of the regulations, develop a permitting strategy to help guide the decision process. This may include producing a Permit Matrix, which should include a narrative of each permit necessary, reasoning for permit inclusion, a schedule, and anticipated fee for permitting the barrier.

There is an opportunity to evaluate flood insurance relief for real estate protected by the proposed barrier if it is designed and built to FEMA Levee Standards. This would provide relief on the protected side from flood insurance requirements.

IDENTIFY ADDITIONAL FEASIBILITY STUDIES AND ASSOCIATED COSTS NEEDED TO ADVANCE DESIGN

Additional studies may be necessary based on the considerations identified in Section 3.3 (design considerations) and Section 3.4 (O&M and cost considerations). These studies may include engineering explorations or analyses as well as planning studies. Based on the results of the studies and analyses, use professional judgement and the previously identified considerations to select an approach that works for the site, the public, and the City of Boston.

ASSESS OPPORTUNITIES TO INCREASE RELIABILITY OF SOLUTION

The barrier should consider redundancy in the system and contingencies for failure to reduce risk and increase system reliability. This is especially critical for flood protection that involves deployable flood barrier protection. See Section 7.0 for additional guidance. Reliability is tied directly to a risk-based O&M approach and may include a risk register.

The designer should consider elements that reduce the potential for loss and damages. For example, the area behind the flood wall may be compartmentalized to limit flooding in the event of barrier overtopping, flanking, or failure.

EVALUATE INCREMENTAL ADAPTATION FEASIBILITY AND ESTABLISH TIMELINE FOR IMPLEMENTATION

The selected barrier and approach should identify routes to incremental adaptation, including a segmental approach to a unified vision for waterfront protection. Many of the barrier approaches will need neighboring partners to implement solutions for an integrated approach. This may include, but is not limited to, increasing the height or length of the structure, modifying existing structures to serve new functions, property acquisition, easements, or temporary or deployable systems to connect gaps.

If the current design cannot accommodate flood protection for a 50-year useful life (2070 climate design adjustments), identify a plan to achieve that protection in the future and related considerations and costs. For example, funding and size constraints may limit the berm height to 2-foot grade change. Where the barrier footprint cannot be expanded and/or slopes steepened, the designer may consider designing and constructing the foundation for a future flood wall. Future additions of a shorter flood wall (2 feet) will require fewer funds, less earthwork, and be implemented more quickly since the foundation has already been designed and constructed.

Section 4.0 – Sample Vegetated Berm Barrier includes a sample drawing and concept for incremental grade changes and identifying a cross-section width to allow for grade changes without steepening slopes.

The guidelines are focused on a 50-year useful life, which utilizes the 2070 climate design adjustments. Climate projections do not stop at 2070, and there is additional uncertainty in the range of projections for the end of the century. As climate projections are updated over time, the design should consider flexibility to improve or adjust in the future. Considerations for flood protection beyond a 50-year useful life should be included in the incremental approach and timeline for adaptation.

Graphic rendering of cross-section of incremental vegetated berm option presented in Section 4.0 Sample Vegetated Berm Barrier.

3.5 SAMPLE BARRIER EXAMPLES

The following four barrier types were identified to illustrate the *Climate Resilient Design Standards and Guidelines for Protection of the Public Rights-of-Way* based on conceptual ideas from Climate Ready Boston studies:

- Section 4.0: Sample Vegetated Berm Barrier
- Section 5.0: Sample Harborwalk (Seawall) Barrier
- Section 6.0: Raised Roadway Barrier
- Section 7.0: Deployable Flood Barrier

The flood barrier options presented in the guidelines are not a comprehensive list and do not include all possible scenarios, opportunities, or challenges that may be encountered as these projects progress from concept into design. The following sections are intended to be used as samples to guide designers through the many considerations for design. For simplicity, all barriers are assumed to be 4 feet in height for flood protection with a 50-year useful life and consider options to increase flood protection by an additional 2 feet (i.e. a total of 6 feet of flood protection).

SECTION 4.0 SAMPLE VEGETATED BERM BARRIER

4.1 DESCRIPTION AND ASSUMPTIONS

This section provides guidance for designing a sample vegetated berm, which is also known as an earthen levee. Collectively, the design considerations, operations and maintenance (O&M) considerations, incremental approach, and opinion of probable costs are intended to be used as a sample to reflect the intent of the climate resilient flood barrier design process described in the guidelines. The sample should be used by engineers and planners to illustrate the process of advancing conceptual design to implementation.

A sample site location was selected to test the climate resilient flood barrier design process and identify sample considerations (design and O&M) and prepare an opinion of probable cost. The sample location is intended to provide practical context, related opportunities, and challenges. ***The locations do not reflect any intentions of the City of Boston to proceed forward with design or implementation of the sample barrier at this time***. Additional studies are required to design and implement a comprehensive solution. The sample location selected for the sample vegetated berm is an approximately 1-mile long section of open space along the waterfront that is part of the existing Harborwalk in Boston. The following assumptions were made for the purposes of developing sample vegetated berm considerations and an opinion of probable cost:

- The sample site will serve as the context for sample considerations. Engineering considerations are provided for illustration of sample opportunities and challenges, but site-specific engineering analyses should be performed for the development of actual design considerations. A list of additional studies to be completed to advance design is included in this section and may vary based on real conditions encountered in engineering and planning analyses.
- The figures and drawings developed for the sample berm are intended to support the considerations outlined in the guidelines and are not considered finalized for design. Additional site-specific data are critical to advancing figures and drawings.
- As this site is a sample for purposes of developing the guidelines, no survey was prepared for the site and surrounding areas. All relative information is based on ESRI (Environmental Systems Research Institute), LiDAR (Light Detection and Ranging) and Climate Ready Boston information.
- The sample berm is intended to be implemented incrementally, if needed. To design the berm for a shorter useful life (2030 climate adjustment minimum), a grade change of +2 feet from existing ground surface is assumed for the design flood elevation (DFE), which includes freeboard. To design the berm for a 50-year useful life (2070 climate adjustment), a grade change of +4 feet from existing ground surface is assumed for the DFE. The alignment of the berm may lengthen over time as well.
- The barrier is designed to be able to accommodate a +2 feet grade change in addition to the 50-year useful life design (i.e. a combined final grade change of + 6 feet).
- The vegetated berm is not designed with a setback from the waterfront. It is assumed that waves will impact the harbor/flood side slope. There may be sites within the City that a vegetated berm is feasible with a setback from the waterfront and outside of high erosional force zones.
- The crest and inland/dry side of the vegetated berm can be used as public space.
- The crest will continue to serve as the Boston Harborwalk. It is assumed that at least one Americans with Disabilities Act (ADA) accessible path from the dry side is needed to connect the toe of the berm to the crest.
- Slope inclinations of 3H:1V (Horizontal:Vertical) with an ADA access path were assumed for the purposes of developing a sample cross-section and guidelines. It may be feasible to steepen slopes and include retaining walls where space is limited, but the sample cross-section does not include this option.
- All sample considerations assume that there are no property boundary or easement conflicts and that the existing site can support the construction, operations, and maintenance of the berm.

- The sample considerations provided in this section may not apply to all sites where a vegetated berm is proposed. Additional considerations not covered in this section may apply. Site-specific information will drive considerations and the process.
- The process and sample considerations do not supersede local, state, or federal regulations.

Coordination among the City of Boston, Boston Parks and Recreation, Department of Conservation and Recreation (DCR), other agencies, and the community is necessary for the following process and considerations. A communications plan should be established to include public participation in the process. Refer to Section 3.1 for recommended considerations prior to implementing the guidelines.

4.2 SAMPLE VEGETATED BERM BARRIER DESIGN CONSIDERATIONS

The design considerations for the Vegetated Berm reflect a range of engineering and physical considerations for the concept to identify challenges and opportunities for implementation. This is not a comprehensive list of all potential considerations, and additional criteria, including **value creation**, **social impact**, **equity**, and **environmental co-benefits,** should also be considered alongside the considerations outlined in these guidelines. Engineers and planners should use these considerations to augment the existing standard of care provided in projects and to identify opportunities to create value wherever feasible. Additional studies are recommended to advance design. A summary of the overall design considerations is provided below. More detailed discussions of the considerations are included in **Appendix C – Sample Vegetated Berm Design Considerations**. Refer to the sample design drawing and figures in Section 4.5 for the following considerations.

DESIGN CONSIDERATIONS Refer to **Appendix C – Sample Vegetated Berm Design Considerations** for more detailed design considerations	
Climate Design Adjustments and Timeline	► The sample site is within the Boston Planning & Development Agency (BPDA) “SLR-BFE” zone via the zoning viewer. The Boston Harbor Flood Risk Model (BH-FRM) results include the base flood elevation (BFE) of 19.3 feet Boston City Base (BCB) for the 2070 time horizon. Minimum design flood elevation (DFE) of 20.3 feet BCB (assuming 1 foot of freeboard). ► The present 1% annual flood pathway originates at the northern tip of the site. Additional 1% annual storm entry points based on the 2030, 2050, and 2070 time horizons occur south of the site. An incremental approach may be feasible to extend the flood barrier to block the pathway over time. See Figure 1 in Section 4.5. ► There are other flood pathways in the area for which the barrier will not provide protection; additional flood pathways originating from north and west of the project site may result in flooding behind the barrier. Coordination with the flood protection plans at the flood pathways originating off-site is essential to a comprehensive, unified approach. See Figure 5 in Section 4.5 for topographic considerations. ► BH-FRM downscaled design data for flood depth, flood duration, pathways, and projected wave and wind are not yet developed for design. ► Use data available in Section 2.0. Evaluate threshold for higher volumes, such as 20%-30% higher volumes than the current 10% annual 24 hr. design storm volume in inches (5.2 inches current to 6.6 inches future), and 20%-50% higher volumes than the current 1% annual 24 hr. design storm (8.1 inches current to 11.7 inches future). ► Sample drainage area impounded by future barrier: 0.6 sq. miles.
Boundary Constraints and Site Considerations	► The sample site is part of a DCR reservation and is located to the east of a college campus exposition center, residential neighborhoods, and a parking lot. It is located south of a beach and public park. The site is located along the Boston Harborwalk and within the public right-of-way. Easements may be necessary along the dry-side (inland side) of the barrier based

Boundary Constraints and Site Considerations (continued)	on actual property line survey data (not performed for this sample). See Figure 1 in Section 4.5. ► A Phase I Environmental Site Assessment should be conducted to assess if the potential exists for Recognized Environmental Conditions including soil and/or groundwater impacts. ► Based on preliminary LiDAR information, there is enough room to construct the sample vegetated berm minimum cross-section (57-foot wide with an access path) in this location. Several properties will be impacted by the construction of the berm and may encroach on the inland toe of slope. See Figure 2 in Section 4.5. ► The final barrier for a 50-year useful life will be approximately 1 mile long and should extend a minimum of 20 feet into the abutments (higher grades at 20.3 feet BCB) to reduce risk of flanking and failure at abutments. The final proposed alignment is shown in attached Figures 1 through 5 in Section 4.5. ► An incremental approach may be feasible to address near-term flood risk, which would result in an approximately 2000-foot long vegetated berm to protect for the 2030 DFE. The barrier could be increased in height and in length over time to achieve flood protection for the 2070 time horizon. See Figure 1 in Section 4.5. ► The site development should consider social impacts, equity, value creation, and environmental impact. For example, the berm may include recreational and cultural opportunities in addition to protecting affordable housing and creating or revitalizing equitable access to the waterfront.
Stormwater Considerations	► The vegetated berm may be designed to accommodate stormwater management with green infrastructure designs such as bioretention/raingardens, constructed stormwater treatment wetlands, media filters, sand and organic filters, and wet basins. ► There may be potential inland stormwater management approaches to delay, store, and discharge stormwater trapped by the barrier (drainage area is 0.6 sq. miles). See Figure 3 in Section 4.5. This stormwater may be managed from the nearby collegiate campus stormwater systems. Coordinate with the campus to understand existing capacity. ► Plan for long-term management of stormwater volume reduction on the inland side of the berm through land use controls, retreat, private property stormwater management, and general reduction in impervious surfaces. ► There is a potential for causing additional flooding damage to adjacent properties by the barrier trapping stormwater on the dry side. Consider sizing stormwater features and conveyance to extreme rainfall and cloudbursts; conduct a risk analysis/cost benefit analysis. ► On-site retention of the first inch of runoff from new impervious surfaces is required by the Boston Water and Sewer Commission (BWSC). ► Post design peak stormwater discharge must equal pre-design peak discharge. ► Final design should address MS4 Pollutants. Use green infrastructure concepts to treat stormwater where possible or create a treatment train approach to manage and improve water quality for total suspended solids (TSS), nutrients, metals, and oils and grease. ► Provide design space for pumping chambers to manage inland stormwater for current stormwater volumes and future conditions. Space is currently available along the dry side of the existing Harborwalk for siting stormwater pumping chambers. Pumping systems should be sized to handle stormwater volumes trapped on the dry side as well as potential ocean overtopping during extreme storm surge to prevent flooding. There may be additional considerations associated with the pump stations, including aesthetics and noise. Ownership and management of pump stations should be identified in this process.
Utility Considerations	► There is a BWSC storm outfall (72 inches) with no tide gate through the sample barrier alignment near the southern tip of the proposed berm alignment. The existing outfall through

Utility Considerations (continued)	the alignment should be evaluated and designed for utility retrofits, including a tide gate. See Figure 4 in Section 4.5. ► The Harbor Point project area includes combined sanitary and storm water flows (CSOs). This means catch basins discharge into the combined sewer main. All catch basins are on the dry side of the barrier. The designer should identify whether the new barrier will impact CSO stormwater volumes in coordination with increased rainfall projections. See Figure 4 in Section 4.5. ► Coordinate with local utility providers to identify gas, electric, communications, and other utilities that may be located within the project area. ► Future pump stations may be constructed in the open space near the berm to manage stormwater behind the barrier. See Stormwater considerations above.
Structural Considerations	► Structural considerations will most likely not apply to the vegetated berm design since the sample design is a vegetated earthen embankment. However, in the event that unfavorable site conditions, such as poor-quality soil and/or limited space, are encountered, a retaining wall may be required. ► The design and construction of a retaining wall should reference general structural considerations in Section 3.0 – General Design Considerations and Appendix B.
Geotechnical Considerations	► Conduct subsurface explorations to evaluate overall subsurface conditions, potential contamination, seepage conditions, bearing capacity, and potential for settlement. ► There does not appear to be existing structures located within the geotechnical "zone-of-influence" of the proposed berm that could be affected by the new soil loads. ► Identify the load carrying capacity of existing utilities that cross beneath or near the proposed sample berm. ► Underlying soil must be capable of supporting the weight of the berm and live load requirements (small service vehicles for emergency and maintenance access). Perform global stability analyses in accordance with United States Army Corps of Engineers (USACOE) design guidance. Given the space at this site, the berm can be constructed at a 3H:1V (horizontal:vertical) slope on either side, which is considered stable against global stability failure and is beneficial for maintenance activities. ► Depending on the subsurface conditions, evaluate the need for overbuilding the berm to account for potential settlement. ► The use of riprap for scour protection is appropriate based on the expected currents and wave action. Riprap is readily available. ► Grass may be planted to provide protection on the berm crest and landside slope to minimize erosion due to overtopping or heavy rain during storm events. ► Incorporate foundations for future floodwalls as needed into the embankment.
Transportation and Accessibility Considerations	► ADA accessibility and connection to inland area and waterfront is required. Accessible routes shall not exceed 5% (1V:20H (vertical:horizontal)) slope. ► The minimum width of the path shall be 12 feet so that a maintenance vehicle can bypass a wheelchair without impeding movement. ► Differential settlement along the berm alignment may impact accessible slopes. Ongoing maintenance should be expected to level pathways to meet accessibility criteria. Paving materials for paths shall be ADA compliant. ► Create maintenance accessibility (vehicle or tracked equipment). ► Evaluate walkability, livability, and waterfront connectivity with pedestrian and bike paths.

Groundwater Considerations	► Higher tides may increase groundwater levels and may result in reduced stormwater infiltration and affect stormwater drainage systems. ► Berms must be designed to prevent seepage from emerging on the landside slope. This may be achieved by constructing the berm using low permeability material, constructing the berm to be sufficiently wide to prevent seepage during flood events, or by inclusion of a pervious toe, toe trench, and/or vertical or horizontal drainage layers in accordance with USACOE design guidance. ► Berms must be designed to prevent excessive hydraulic gradients, internal erosion and loss of material (piping), and sand boils caused by underseepage. ► The type of underseepage control used will be site specific based on subsurface conditions. Underseepage control can be accomplished by cutoff walls such as steel sheeting or an impervious trench, riverside blankets, landside seepage berms, and/or pervious toe trenches. ► Cutoff walls or trenches, if used, shall consider area groundwater hydrology and its effects on area foundations, particularly in areas where buildings are supported on timber piles.
Vegetative Considerations	► Current USACOE setbacks and easements do not allow for trees to be within 15 feet of dams or levees. Trees are not permitted on levees because of their root systems. If trees are uprooted during a storm event, the barrier may result in a breach. Tree root systems also pose a risk as a flood pathway; roots rot over time and can result in pathways through the soil. Tree root systems also provide pathways for animal burrows to create additional pathways in the soil and barrier. If trees are desired, a root barrier system may be designed for trees on the inland side of the barrier (not ocean side) or structural wall may be designed in the embankment to reduce the impact of a breach. The wall should consider the impact of the groundwater interface and structural and geotechnical considerations. ► Identify native or naturalized salt tolerant vegetation and non-invasive plant materials appropriate to the surrounding microclimate and ecosystem and complement passive recreational activities. ► Plants should be tolerant of urban pollutants (such as emissions and oils). ► Select plants with erosion control qualities for embankments and steep slopes. Woody vegetation and brush can also prevent observation of deficiencies forming that increase the risk of failure. ► Consider plants that are “low maintenance” such as grasses and groundcovers that may also provide habitat. ► Consider plant heights as they relate to viewsheds and corridors towards the water and also the inland side.

4.3 OPERATIONS AND MAINTENANCE AND COST CONSIDERATIONS

Operations and maintenance (O&M) are critical to the performance of the vegetated berm and reducing risk. O&M is necessary so that the berm serves its intended purpose throughout its intended useful life. O&M will be similar to levee, dam, and dike considerations, and additional O&M considerations related to specific design considerations are provided in **Appendix C – Sample Vegetated Berm Design Considerations**. The following O&M components are associated with a vegetated berm:

<u>Annual inspections and inspections before and following storm events (note: inspections during storm events may be recommended based on existing conditions as well)</u>

- Check for signs of erosion due to precipitation and overtopping. Signs of erosion include gullies, caving, or scarps. Repair eroded areas. Consider providing increased erosion protection in areas where ongoing erosion is observed.

- Check for and remove encroachments into the flood barrier. These may include trees and other woody vegetation, debris, animal nests, animal burrows, or unapproved manmade elements such as fencing, irrigation systems, gardens, etc.
- Check embankments for signs of global instability, including slumping, longitudinal cracking along the crest, and bulging at the toe. Areas exhibiting signs of slope instability should be stabilized as directed by a licensed engineer.
- Check for sinkholes, low areas, or ruts on or near embankment crests due to settlement or pedestrian or vehicular traffic. Fill low areas with compacted embankment material as needed to prevent ponding of water and maintain design crest elevation.
- Check for sandboils and turbid seepage through the barrier and at or beyond the toe, which may be indicative of internal erosion of the embankment or foundation material.
- Check for leakage or seepage around non-earthen structures, such as pipes, gates, and walls passing through and adjacent to the flood barrier.
- Where pressure relief wells are used, qualified well drillers should perform well testing to check for clogging of the filter or well screen, and clear wells as needed.
- Check for clogging of drainage pipes.
- Check for tilting, sliding, or settlement of wall structures. If movement is considerable, repair as directed by a licensed engineer.

Riprap flood-side slope maintenance

- Replace displaced or missing riprap as necessary to protect the upstream slope. Fill voids with compacted gravel borrow.
- Maintain brush to ground surface on the slope to facilitate visual inspections.

Access path maintenance

- The access path should be maintained for pedestrian and bike access, including ADA accessibility. Maintenance vehicles will access the berm to perform maintenance and minor repairs.
- If the access path is stone dust, it shall be inspected at least monthly for deterioration or washouts. The path shall be inspected after heavy rainfall for damage.
- Grade and compact the stone dust path as necessary to maintain ADA compliant access. Supplemental stone dust should be kept close to the site for efficient repairs.

Vegetation maintenance

- Prepare an O&M program associated with plant material management, including water requirements, pruning, and mowing schedules. This may be seasonal.
- Grassed areas should be mowed regularly. The 3H:1V (horizontal:vertical) slope of the berm facilitates maintenance activities.
- Low-maintenance landscaping does not mean no maintenance will be required as all plants require some routine care to succeed.
- Remove trash and debris from barrier areas and plant materials.
- Plant materials shall be maintained in a healthy growing condition, neat and orderly in appearance in perpetuity from the time of the growth season. If any plant material required by this dies or becomes diseased, they should be replaced.

Stormwater maintenance

- Standard stormwater infrastructure (inlets, catch basins, deep sumps) should be maintained with typical frequency. Inspections and debris and sediment removal should occur when sediment accumulation in the sump reaches 50% of the available volume.
- Establish and implement inspection and maintenance frequencies and procedures for stormwater assets. Inspect stormwater assets annually at a minimum or according to manufacturer recommendations for

proprietary devices. Include asset management appropriate for the asset and connect with GIS for optimization and management of maintenance and operation records, O&M manuals, and work order management.

- Trash and debris captured in urban stormwater assets will require removal as much as weekly to prevent clogging or bypass during precipitation events.
- The level of effort pertaining to stormwater O&M will vary based on the type and number of pumps, stormwater volume and captured debris (sediment, salt, trash), size of wet wells, water quality treatment process, etc. Pump stations for detained stormwater should be inspected at least monthly and following precipitation events when they are activated.
- There may be additional O&M requirements associated with generators providing back-up and emergency power supply to pump stations.

O&M Plan

- All features should be documented in an O&M plan detailing regular monitoring and maintenance practices, performance assessments, plans for investment, fair weather repairs, and rapid response for storm events.
- Records should be kept of O&M activities.
- There should be scheduled training events and regular updates (every 5 years) of the O&M plan. Annual O&M costs should be updated on a regular basis with O&M plan updates to reflect actual costs incurred and forecasted repairs, as well as evaluate cost-saving opportunities.

There may be additional functional objectives (such as recreational opportunities associated with the berm) that need to be considered in addition to the flood risk management components. The BWSC is responsible for O&M of the stormwater in the project area. If stormwater pump stations are necessary to manage inland stormwater, ownership and maintenance of the new barrier system should be identified in the development of the O&M plan. The following annual O&M costs for the vegetated barrier are anticipated:

Item	Annual Probable Cost
Annual inspections and storm inspections	$6,000 - $8,000
Riprap flood-side slope maintenance	$2,000 - $6,000
Access path maintenance	$4,000 - $8,000
Vegetation maintenance	$8,000 - $12,000
Stormwater maintenance	See Note 5 below
O&M Plan	$2,000 - $4,000
Opinion of Probable Cost (Annual)	**$22,000 - $38,000**

The cost assumes the following in addition to the assumptions provided above:

1. Annual inspections will be performed by a registered professional engineer.
2. Minor repairs, such as filling erosion gullies and replacing riprap, can range from about $10,000 to $30,000 based on extent of damages. Annual repairs are not expected, so costs are estimated based on a 5-year occurrence interval.
3. Access path maintenance includes stone dust material, a one-ton dump truck, backhoe with an operator, plus one laborer on the ground to work with the operator. Annual repairs are expected with increase precipitation projections.
4. Vegetation maintenance assumes annual O&M costs for brush cutting and clearing, mowing during the growing season, and green infrastructure maintenance.
5. Annual stormwater maintenance costs were not estimated based on the level of design provided for the sample barrier development. The level of effort pertaining to stormwater maintenance will vary based on the type and number of pumps, size of wet wells, water quality treatment process, etc. Stormwater infrastructure should be inspected monthly, and typical catch basin cleaning costs are $200/structure/cleaning.

6. The O&M plan assumes regular updating on maintenance records, cost estimates, forecasted repairs, annual update of the plan, and training staff every 5 years.

Cost considerations should reflect the features identified in the design considerations for capital costs and life-cycle costs of the infrastructure based on design considerations and existing information. An opinion of probable construction cost was developed for the sample vegetated berm.

B.1 Vegetated Berm Barrier - 2030 DFE Conditions

The sample vegetated berm would extend approximately 2,000 feet and assumed grade change is approximately 2 feet.

Item	Probable Cost ($/100-LF)
Riprap Scour Protection	$17,000
Berm Including Crest and Access Paths	$45,000
Erosion Control Plantings	$27,000
Subtotal	**$89,000**
Contingency (30%)	$27,000
Opinion of Probable Cost ($/100-LF)	**$116,000**
Opinion of Probable Vegetated Berm Cost (2000 LF)	**$2.3 M**

The cost for a flood barrier for 2030 DFE flood protection assumes the following in addition to the assumptions provided above:

1. Riprap Scour Protection includes costs associated with the riprap installation, including bedding layer and filter fabric. The use of a coffer dam to install the scour protection has not been included.
2. Berm Including Crest and Access Paths includes costs associated with the installation of the berm and crest and access paths, including excavation of the inspection trench, embankment fill, and toe drain.
3. Erosion Control Plantings includes the installation of the topsoil, erosion control plantings and turf reinforcement mat for the crest and access path shoulders and berm earthen slopes.
4. The following is not included: Owner's Costs, Design/Permitting, Construction/Logistical/Insurance, Environmental/Accidents, Adverse Site Conditions. This opinion reflects sample design considerations prepared for the guidelines and does not reflect engineering analyses prepared for design.

B.1 Vegetated Berm Barrier – 2070 DFE Conditions (Incremental Increase)

The sample vegetated berm would extend approximately 5,300 feet and assumed grade change is approximately 2 feet in addition to the 2030 DFE berm construction.

Item	Probable Cost ($/100-LF)
Riprap Scour Protection	$9,000
Berm including Crest and Access Paths	$22,000
Erosion Control Plantings	$16,000
Subtotal	**$47,000**
Contingency (30%)	$14,000
Opinion of Probable Cost ($/100-LF)	**$61,000**
Opinion of Probable Vegetated Berm Cost (5300 LF)	**$3.2 M**

The cost for a flood barrier for 2070 DFE flood protection from 2030 DFE conditions (incrementally increased) assumes the following in addition to the assumptions provided above:

1. Riprap Scour Protection includes costs associated with the extension of the riprap, including bedding layer and filter fabric.
2. Berm Including Crest and Access Paths includes costs associated with increasing the height of the berm along with the installation of the crest and access paths, including embankment fill and toe drain extension.
3. Erosion Control Plantings includes the installation of the topsoil, erosion control plantings and turf reinforcement mat for the crest and access path shoulders and berm earthen slopes.
4. A typical 72-inch tide gate (or dual tide gate equivalent) and structure on a stormwater outfall may cost $450k to $500k. This was not included in the opinion of probable cost, but should be considered with utility retrofits on the existing stormwater outfall on the sample site.
5. The following is not included: Owner's Costs, Design/Permitting, Construction/Logistical/Insurance, Environmental/Accidents, Adverse Site Conditions. This opinion reflects sample design considerations prepared for the guidelines and does not reflect engineering analyses prepared for design.

4.4 BARRIER SELECTION

Based on the sample design, O&M, and cost considerations developed for the guidelines, a vegetated berm may be feasible at the sample site. The existing site layout and open space in the area makes this a feasible option to consider further. The following additional studies are recommended to advance design:

- Analysis of potential permits and current regulatory agencies and regulations.
- Survey, including existing features, utilities, natural resources (wetlands, habitat), topography, and property lines within at least 100 feet of the proposed alignment. See Figure 5 in Section 4.5 for a sample LiDAR topographic survey.
- Utility conflict analyses. Coordinate with local utility providers to identify gas, electric, communications, and other utilities that may be located within the project area.
- Hydrologic analysis with rainfall with a 50-year useful life climate adjustment in the 0.6-sq. mile drainage area impounded by the sample barrier (fully constructed). Subsequent conveyance, infiltration, storage, and discharge assessments.
- Stormwater management design and pump station feasibility assessments.
- Subsurface exploration and subsequent stability, settlement, and seepage analyses.

The approach for the vegetated berm identifies a route to incremental adaptation from 2030 DFE to 2070 DFE. The approach includes raising the height of the barrier incrementally and lengthening the barrier along future flood pathways. The initial barrier would likely extend approximately 2,000 feet to protect the community from the current and 2030 1% annual storm entry points (i.e. the 2030 DFE condition). Over time, the barrier would increase to the 2070 DFE and extend another approximately 3,000 feet south along the waterfront. See Figure 1 in Section 4.5.

The guidelines are focused on a 50-year useful life, which utilizes the 2070 climate adjustments. Climate projections do not stop at 2070, and there is additional uncertainty in the range of projections for the end of the century. As climate projections are updated over time, the design should include flexibility to be adjusted in the future. Considerations for flood protection beyond a 50-year useful life should be included, such as raising grades, in the incremental approach and timeline for adaptation based on the design, O&M, and cost considerations.

At this sample site, the design of the vegetated berm should be coordinated with efforts to provide flood protection at adjacent locations to provide the most effective solution for the surrounding neighborhood. The final approach should include a unified vision for waterfront protection and public improvement. The design must include coordination with stakeholders to identify a solution that integrates with the physical environment and community needs and desires. It is important to also consider existing and proposed resilience projects that are ongoing in the City of Boston. Climate Ready Boston has a map of these projects available on the Coastal Resilience Projects Tracker.

4.5 SAMPLE DESIGN DRAWING AND FIGURES

CLIMATE RESILIENT DESIGN STANDARDS AND GUIDELINES FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

B.1 VEGETATED BERM BARRIER

Refer to Climate Resilient Design Standards and Guidelines for notes and guidance.

DOWNLOADABLE FILES:

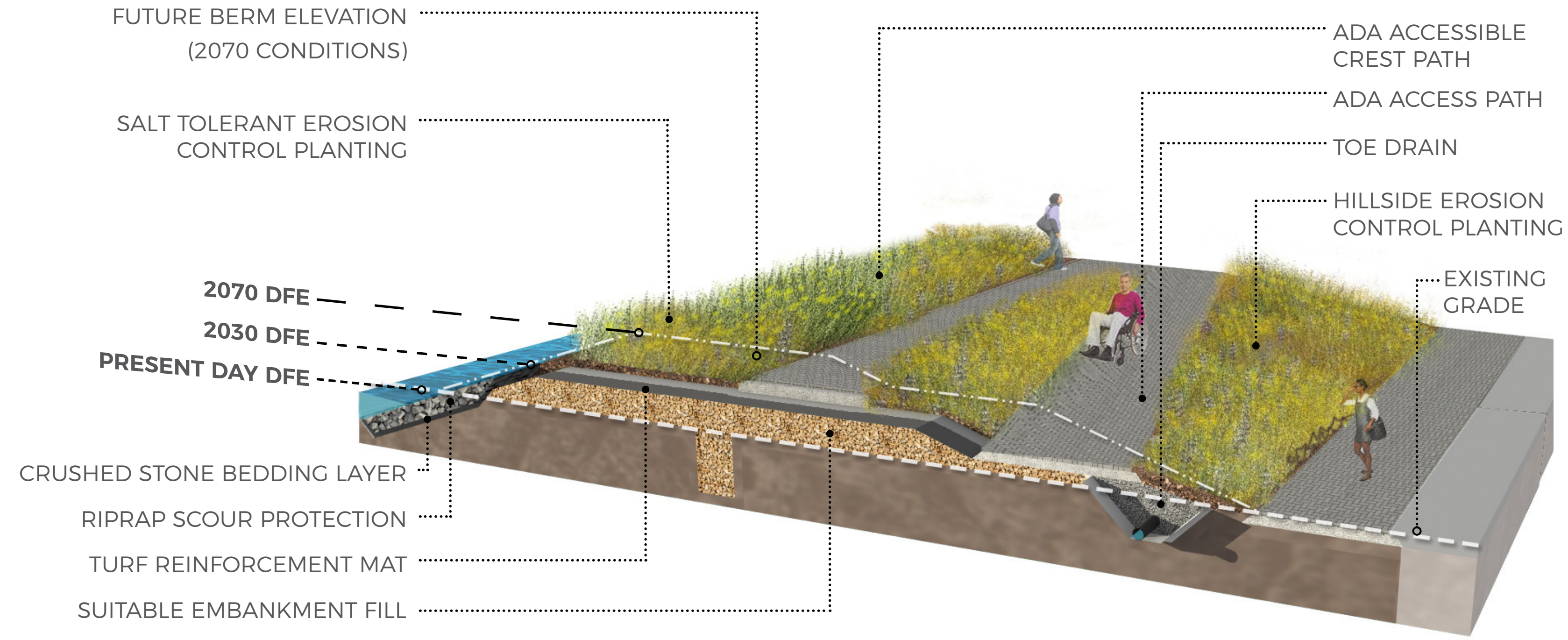
Standard PWD Details for reference and download can be found here

SAMPLE

B.1. SAMPLE VEGETATED BERM BARRIER

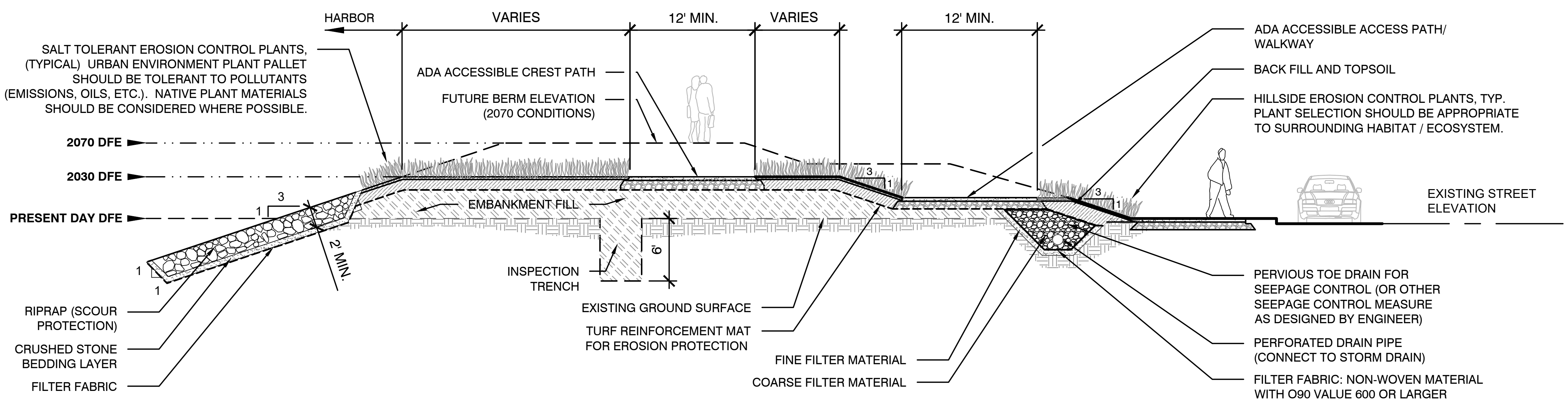
CAD

PDF

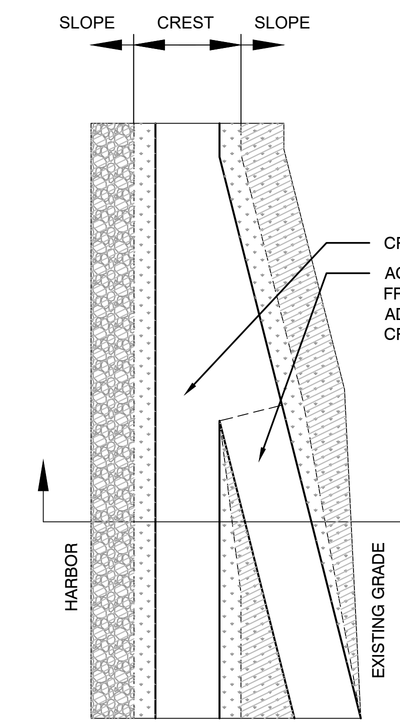


SAMPLE VEGETATED BERM CROSS SECTION WIDTHS (Crest, slope, and possible access path)					
Increased Height from Existing Ground Surface (+__ft)	Minimum Crest Width	Slope Width	Access Path Width	Total Width (no Access Path)	Total Width (with Access Path)
1	18	6	12	24	36
2	18	12	12	30	42
3	18	18	12	36	48
4	18	24	12	42	54
5	18	30	12	48	60
6	18	36	12	54	66

NOTE: 4 FT. IS USED FOR SAMPLE BARRIER FOR 2070 PROJECTIONS



INCREMENTAL APPROACH
(SHOWN AS 2030 AS-BUILT)



PLAN VIEW

NOTES:

- FEASIBILITY LIMITED BY SPACE BETWEEN HARBOR AND EXISTING BUILDINGS
- EMBANKMENTS SHALL BE CONSIDERED A LEVEE AND MEET ALL UNITED STATES ARMY CORPS OF ENGINEERS (USACoE) GUIDANCE ON LEVEE DESIGN
- LOCATION IN RELATION TO CURRENT HARBOR EDGE MAY VARY
- FREEBOARD SHOULD BE 12"-24" BASED ON SETTLEMENT ESTIMATE AND CRITICALITY
- DIMENSIONS ARE BASED OFF ASSUMED SLOPES OF 3H:1V (HORIZONTAL:VERTICAL)
- FOR ADDITIONAL CONSIDERATIONS SEE GUIDELINES DOCUMENT
- DFE - DESIGN FLOOD ELEVATION (FREEBOARD INCLUDED)
- 2070 DFE: THE DESIGN FLOOD ELEVATION FOR THE 1% ANNUAL FLOOD EVENT WITH 40 INCHES OF SEA LEVEL RISE. DESIGN FLOOD ELEVATION (DFE) INCLUDES FREEBOARD ON TOP OF THE BASE FLOOD ELEVATION

SAMPLE - NOT TO SCALE

1 CITY HALL SQUARE
ROOM 714
BOSTON, MA 02201-2024

PUBLIC WORKS DEPARTMENT
(T): 617 635 4900
(E): publicworks@boston.gov

FIGURE 1

INCREMENTAL APPROACH FOR SAMPLE VEGETATED BERM

LIMITS OF PROPOSED WORK FOR 2030 DFE AND 2070 DFE

Proposed Barrier for the 2030 Design Flood Elevation (DFE)

Proposed Barrier for the 2070 Design Flood Elevation (DFE)

Possible Easement

1,000 0 1,000

Scale In Feet

FIGURE 2

PROPERTIES IMPACTED BY SAMPLE VEGETATED BERM BARRIER

Proposed Barrier for the 2070 Design Flood Elevation (DFE)

Parcels Affected by Proposed Buildout Area

800 0 800

Scale In Feet

Path: \\wse03.local\WSE\Projects\MA\Boston MA\BPWD - Climate Resilience Guidelines\Deliverables\7. Final Guidelines Document\GIS Figures\Build out Considerations - Harbor Walk.mxd **User:** LambertD **Saved:** 10/3/2018 9:29:55 AM **Opened:** 10/3/2018 9:30:27 AM

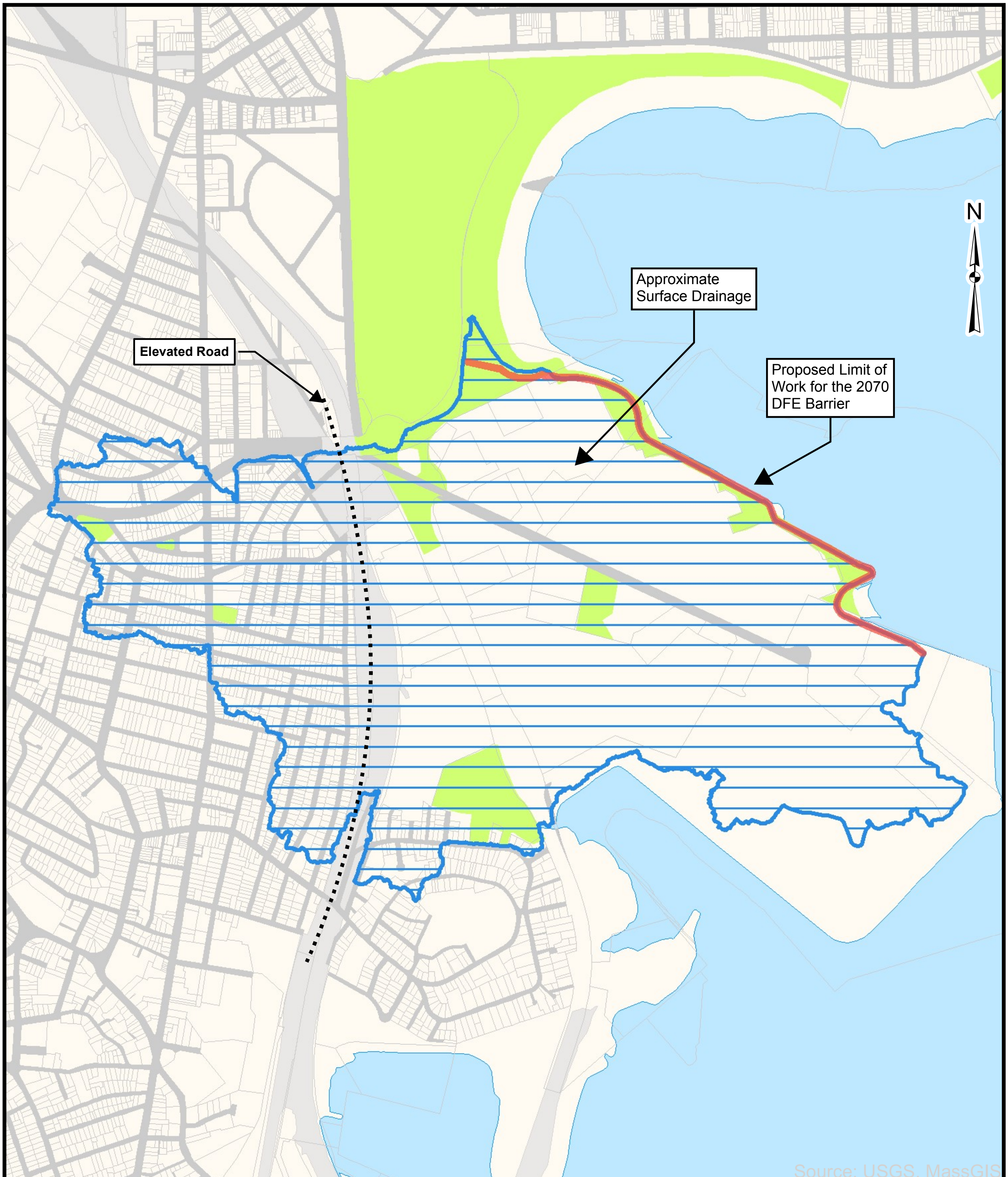


FIGURE 3

PROPOSED LIMIT OF WORK AND DRAINAGE AREA FROM SAMPLE VEGETATED BERM BARRIER

Proposed Limit of Work for the 2070 Design Flood Elevation (DFE)

Drainage Area (422.3 acres)

Protected Open Space (34.18 acres In Drainage Area)

1,000 0 1,000

Scale In Feet

Path: \\wse03.local\WSE\Projects\MA\Boston MA\BPWD - Climate Resilience Guidelines\Deliverables\7. Final Guidelines Document\GIS Figures\Stormwater Considerations - Harbor Walk.mxd **User:** LambertD **Saved:** 10/3/2018 9:40:00 AM **Opened:** 10/3/2018 9:41:29 AM

Proposed Limit of Work fro the 2070 Design Flood Elevation (DFE)

PS Pump Station

Outfall

Catch Basin

Sanitary Manhole

Storm Manhole

Combined Manhole

Combined Sewer

Sanitary Sewer

Storm Sewer

Water Main

Protected Open Space

FIGURE 4

EXISTING UTILITIES IDENTIFIED IN SAMPLE VEGETATED BERM BARRIER PROJECT AREA

1,000 0 1,000

Scale In Feet

Path: \\wse03.local\WSE\Projects\MA\Boston MA\BPWD - Climate Resilience Guidelines\Deliverables\7. Final Guidelines Document\GIS Figures\Wastewater Considerations - Harbor Walk.mxd **User:** ShinnickD **Saved:** 10/3/2018 12:52:32 PM **Opened:** 10/3/2018 12:53:00 PM

FIGURE 5

Index Elevation Contour

Intermediate Elevation Contour

Proposed Barrier for the 2070 Design Flood Elevation (DFE)

Land Below 21.5'

PROPSED LIMIT OF WORK FOR SAMPLE VEGETATED BERM BARRIER WITH TOPOGRAPHIC CONSIDERATIONS

650 0 650

Scale In Feet

Path: \\wse03.local\WSE\Projects\MA\Boston MA\BPWD - Climate Resilience Guidelines\Deliverables\7. Final Guidelines Document\GIS Figures\Land Below 21.5 HarborWalk.mxd **User:** LambertD **Saved:** 10/3/2018 10:06:33 AM **Opened:** 10/3/2018 10:06:52 AM

SECTION 5.0 SAMPLE HARBORWALK (SEAWALL) BARRIER

5.1 DESCRIPTION AND ASSUMPTIONS

This section provides guidance for designing a sample barrier along the Boston Harborwalk. Collectively, the design considerations, operations and maintenance (O&M) considerations, incremental approach, and opinion of probable costs are intended to be used as a sample to reflect the intent of the climate resilient flood barrier design process described in the guidelines. The sample should be used by engineers and planners to understand the process of advancing conceptual design to implementation.

The Boston Harborwalk is approximately 43 miles and varies greatly along the shoreline. Retrofits to the Harborwalk will vary greatly based on location and existing waterfront protection. This sample barrier includes adding a 4-foot seawall to an existing stone masonry seawall, raising grades approximately 2 feet behind the wall, and considering a deployable flood barrier as a handrail on top of the wall to accommodate an additional 2-foot increase in flood protection beyond the 50-year useful life.

A sample site location was selected to test the climate resilient flood barrier design process and identify sample considerations (design and O&M) and opinion of probable cost. The sample location is intended to provide practical context, related opportunities, and challenges. ***The locations do not reflect any intentions of the City of Boston to proceed forward with design or implementation of the sample barrier at this time***. Additional studies are required to design and implement a comprehensive solution. The sample location selected was an approximately 600-foot long stretch of Harborwalk supported by a stone masonry wall. The sample location is bordered by wharfs with residential and commercial properties on both ends. There is an existing public park located behind the sample Harborwalk location. The following assumptions were made for the purposes of developing sample seawall considerations and an opinion of probable cost:

- The sample site will serve as the context for sample considerations. Engineering considerations are provided for illustration of sample opportunities and challenges, but site-specific engineering analyses should be performed for the development of actual design considerations. A list of additional studies to be completed to advance design is included in this section and may vary based on real conditions encountered in engineering and planning analyses.
- The figures and drawings developed for the sample barrier are intended to support the considerations outlined in the guidelines and are not considered finalized for design. Additional site-specific data are critical to advancing figures and drawings.
- As this site is a sample for purposes of developing the guidelines, no survey was prepared for the site and surrounding areas. All relative information is based on ESRI (Environmental Systems Research Institute), LiDAR (Light Detection and Ranging) and Climate Ready Boston information.
- The height of the seawall is intended to be raised 4 feet from the existing top of wall for a 50-year useful life (2070 climate adjustment). To reduce the amount of waterfront access and view created by a 4-foot wall, the grades behind the barrier are intended to be raised 2 feet from the existing ground surface to result in a 2-foot curb wall that can function as a bench along the waterfront.
- The sample barrier is intended to accommodate an additional 2 feet of flood protection, if needed, by designing the wall and hand rail system to become additional flood protection as a deployable flood barrier.
- The barrier is designed as a seawall to meet the climate adjustment related design loads.
- The raised grades inland of the seawall can be used as public space.
- The crest will continue to serve as the Boston Harborwalk. It is assumed that at least one Americans with Disabilities Act (ADA) accessible path from the dry side will connect the toe of the grade change to the crest.
- Slope inclinations of 3H:1V (Horizontal:Vertical) or flatter were assumed to connect the 2-foot grade change to existing grades behind the wall.
- All sample considerations assume that there are no property boundary or easement conflicts and that the existing site can support the construction, operations, and maintenance of the barrier. A list of additional

studies to be completed to advance design is included in this section and may vary based on real conditions encountered in engineering and planning analyses.

- The sample considerations provided in this section may not apply to all sites. Additional considerations not covered in this section may apply. Site-specific information will drive considerations and the process.
- The process and sample considerations do not supersede local, state, or federal regulations.

5.2 SAMPLE HARBORWALK BARRIER DESIGN CONSIDERATIONS

The design considerations for the raised seawall barrier along the Harborwalk reflect a range of engineering and physical considerations for the concept to identify challenges and opportunities for implementation. This is not a comprehensive list of all potential considerations, and additional criteria, including **value creation**, **social impact**, **equity**, and **environmental co-benefits,** should also be considered alongside the considerations outlined in these guidelines. Engineers and planners should use these considerations to augment the existing standard of care provided in projects and identify opportunities to create value wherever feasible. Additional studies may be recommended to advance design. A summary of the overall design considerations is provided below. Detailed discussions of the considerations are included in **Appendix D – Sample Harborwalk (Seawall) Barrier Design Considerations**. Refer to the sample design drawing and several figures in Section 5.5 for the following considerations.

DESIGN CONSIDERATIONS Refer to **Appendix D – Sample Harborwalk (Seawall) Design Considerations** for more detailed design considerations	
Climate Design Adjustments and Timeline	► The site is within the Boston Planning & Development Agency (BPDA) "SLR-BFE" zone via the zoning viewer. The BH-FRM results include the base flood elevation (BFE) of 19.4 feet Boston City Base (BCB) for the 2070 time horizon. Minimum design flood elevation (DFE) of 20.4 feet BCB (assuming 1 foot of freeboard). ► There are numerous present 1% annual flood pathways along the waterfront at the sample site. The site does not extend to the ends of the projected flood pathways. An incremental approach may be feasible to incrementally construct flood barriers along the waterfront. ► Use data available in Section 2.0 and evaluate 20%-30% higher volumes than the current 10% annual 24 hr. design storm volume in inches (5.2 inches current to 6.6 inches future), and 20%-50% higher volumes than the current 1% annual 24 hr. design storm. ► Drainage Basin: 1.5 acres. See Figure 7 in Section 5.5
Boundary Constraints and Site Considerations	► The sample site is part of the existing Boston Harborwalk. There are business and residential properties that are accessed by the Harborwalk. See Figure 6 in Section 5.5. ► A Phase I Environmental Site Assessment should be conducted to assess if the potential exists for Recognized Environmental Conditions including soil and/or groundwater impacts. ► The proposed barrier does not extend far enough to block the numerous flood pathways in the sample area, and it will be flanked without accompanying flood barrier systems. See Figure 9 in Section 5.5. A larger incremental approach is recommended to develop a unified plan for the waterfront. The proposed grade change of 2 feet versus 4 feet is less dramatic and can tie into existing grades with less disruption to the remaining built environment until additional barriers are constructed. ► Adjacent park land could serve as a possible easement. ► Based on preliminary LiDAR information, there is enough room to construct the sample barrier. ► The site development should consider social impacts, equity, value creation, and environmental impact.

Stormwater Considerations	► There is one outfall located within the sample project site. Tide gates may be required for outfalls. See Figure 8 in Section 5.5. ► Areas behind the barrier (public park) may be designed to accommodate stormwater management with green infrastructure designs, such as bioretention/raingardens, constructed stormwater treatment wetlands, media filters, sand and organic filters, and wet basins. ► There may be potential inland stormwater management approaches to delay, store, and discharge stormwater trapped by the barrier. Plan for long-term management of stormwater volume reduction on the upgradient side of the berm through land use controls, retreat, private property stormwater management, and general reduction in impervious surfaces. ► There may be a potential for causing additional flooding damage to adjacent properties by the barrier trapping stormwater on the dry (inland) side. Consider sizing stormwater features and conveyance to extreme rainfall and cloudbursts; conduct a risk analysis/cost-benefit analysis. ► On-site retention of the first inch of runoff from new impervious surfaces is required. ► Post design peak stormwater discharge must equal pre-design peak discharge. ► Address MS4 Pollutants. Use green infrastructure concepts to treat stormwater where possible or create a treatment train approach to manage and improve water quality for total suspended solids (TSS), nutrients, metals, and oils and grease. ► Provide design space for pumping chambers to manage upgradient stormwater for current stormwater volumes and future conditions. Space is currently available along the dry side of the existing Harborwalk for siting stormwater pumping chambers. Pumping systems should be sized to handle stormwater volumes trapped on the dry side as well as potential ocean overtopping during extreme storm surge to prevent flooding. There may be additional considerations associated with pump stations, including aesthetics and noise. Ownership and management of pump stations should be identified in this process.
Utility Considerations	► Existing outfalls or utilities are mapped within the project area. Coordinate with local utility providers to confirm and identify gas, electric, communications, and other utilities that may be located within the project area. See Figure 8 in Section 5.5. ► The existing 84-inch outfall through the seawall should be evaluated and designed for retrofits (if needed). ► Identify records on the 84-inch outfall tide gate and consider replacement, if needed. ► No dedicated storm drains exist in the sample project area. Catch basins discharge to the combined sewer. ► Manhole covers should be protected from damage and water intrusion using reinforced concrete around the top section and frame where appropriate. Manhole covers should be bolted with stainless steel bolts and waterproof gaskets to prevent dislodging. ► Future pump stations may be constructed in the vicinity to manage stormwater behind the barrier. See stormwater considerations above.
Structural Considerations	► Construction of the barrier would likely result in substantial demolition of the existing Harborwalk. ► An existing conditions assessment of the existing seawall is necessary for barrier construction. Construction would include a raised seawall, deployable flood barrier hand railing, and earth work (see Geotechnical Considerations). ► Structural analysis for proposed conditions: ▲ Changed Geometry ▲ Increased Earth and Water Loads

Structural Considerations (continued)	▲ Emergency Vehicle Surcharge Loads (assumes vehicles, such as firetrucks and ambulances, may need to access the top of the barrier and increase the load on the wall) ► Structural design of new components and connection between new and existing seawall. ► The existing Harborwalk at this location is assumed to be able to be raised with in-kind wall material (stone masonry seawall). Additional explorations and analyses are needed to evaluate feasibility of wall retrofits.
Geotechnical Considerations	► Conduct subsurface explorations behind the existing wall to evaluate overall subsurface conditions, seepage conditions, bearing capacity, and potential for settlement. ► Conduct test pits to evaluate condition and geometry of the existing wall and foundation to evaluate its existing stability. ► Identify the load carrying capacity of existing subsurface structures, such as utilities, within the project "zone of influence." If evaluated that the existing structures cannot bear the additional soil loads (vertical and lateral), consider increasing structure capacity, bridging solutions or relocation of the structure/utility. ► Check lateral sliding, global stability, and overturning for the proposed wall during end-of-construction, steady-state seepage (during design flood), rapid drawdown (if applicable), and seismic conditions as described in United States Army Corps of Engineers (USACOE) design guidelines for floodwalls. It may be necessary to include grid reinforcement within backfill to provide additional stability. ► Check supporting capacities of the existing wall foundation and soils. ► Depending on subsurface conditions, long-term settlement may impact existing structures. Check the effect of settlement on existing structures within the "zone of influence" below the new load. Consider supporting existing structures sensitive to movement by underpinning, piles, or other methods as possible. ► Long-term settlement may result in loss of freeboard. It may be necessary to provide additional wall height to account for the expected future settlement. The structure should be designed to tolerate differential settlement along the length of the wall. ► Place filter fabric behind the stone masonry wall to prevent soils migration from land to water. ► Scour protection should be provided on the flood side of the wall. Riprap is generally recommended for areas subjected to wave forces and currents. ► A toe drainage collection system is recommended to manage groundwater and seepage. ► The landside should be protected from erosion due to overtopping using hardscape, turf reinforcement mats, etc. In areas shielded from higher erosional forces, lower cost methods, such as grass cover, gravel, or paving, may be sufficient.
Transportation and Accessibility Considerations	► Consider a split sidewalk to adjust to a 2-foot grade change (not applicable for greater than a 2-foot difference). ► ADA accessibility and connection to inland area and waterfront shall be maintained. ► Accessible routes shall not exceed 5% (1V:20H (vertical:horizontal)) slopes. ► Maintain accessibility for emergency and maintenance vehicle traffic. ► Evaluate walkability, livability, and waterfront connectivity with pedestrian and bike paths.
Groundwater Considerations	► Higher tides may increase groundwater levels and may result in reduced stormwater infiltration and affect stormwater drainage systems. ► Cutoff walls or trenches, if used, shall consider area groundwater hydrology and its effects on area foundations, particularly in areas where buildings are supported on timber piles.

Vegetative Considerations	► The sample site is a paved surface with little to no vegetation considerations required. There may be opportunities to increase vegetation along the sample seawall and the park. ► Plants should be tolerant of urban pollutants (emissions, oils, etc.). ► Consider plants that are low maintenance that may also provide habitat and reduce urban heat. ► Consider plant heights as they relate to view sheds and corridors towards the water and also the inland side. ► Identify native or naturalized salt tolerant vegetation and non-invasive plant materials appropriate to the surrounding microclimate and ecosystem and complement passive recreational activities. ► Trees are not recommended behind flood barriers and walls. If trees are desired, a structural wall may be designed in the embankment to reduce the impact of a breach. The wall should consider the impact of the groundwater interface and structural and geotechnical considerations.

5.3 OPERATIONS AND MAINTENANCE AND COST CONSIDERATIONS

Operations and maintenance (O&M) are critical to the performance of the Harborwalk seawall barrier and reducing risk. O&M is necessary so that the barrier serves its intended purpose throughout its intended useful life. O&M will be similar to floodwall and levee considerations, and additional O&M considerations related to specific design considerations are provided in **Appendix D – Sample Harborwalk (Seawall) Barrier Design Considerations**. The following O&M components are associated with a Harborwalk seawall:

Annual inspections and inspections before and following storm events (note: inspections during storm events may be recommended based on existing conditions as well)

- Check for signs of erosion due to precipitation and overtopping. Signs of erosion include gullies, caving, or scarps. Repair eroded areas. Consider providing increased erosion protection in areas where ongoing erosion is observed.
- Check for low areas or ruts on or near the pathway due to settlement or pedestrian or vehicular traffic. Fill low areas as needed to prevent ponding of water and maintain design crest elevation.
- Check for signs of global instability, including slumping, longitudinal cracking along the road, and bulging at the toe of the embankment. Areas exhibiting signs of slope instability should be stabilized as directed by a licensed engineer.
- Check for sandboils and turbid seepage at or beyond the toe of the slope or wall, which may be indicative of internal erosion of the foundation material. If observed, a licensed engineer should be contacted to evaluate further and provide repair recommendations.
- Check for tilting, sliding, or settlement of wall structures. If movement is observed, repair or continue to monitor as directed by a licensed engineer.

Seawall maintenance

- Exposed surfaces should be washed to remove debris buildup, deicing salts, mineral deposits from a previous flood event, vegetation growth, and pigeon guano.
- The waterproofing membrane and/or coating on exposed walls should be regularly inspected and reapplied if deficiencies are present.
- Stone elements should be routinely inspected for surface damage, including chinking, cracking, and failure in joint material, and repaired accordingly.

Hand rail maintenance

- Exposed surfaces should be washed to remove debris buildup, deicing salts, mineral deposits from a previous flood event, vegetation growth, and pigeon guano.
- The paint and/or coating system protecting exposed metal should be regularly inspected and replaced if deteriorating.
- Metal elements should be regularly inspected for corrosion, and any members exhibiting corrosion should be repaired/replaced.
- Metal elements should be inspected for signs of failure, including cracking, denting, deflection, and missing connection elements, and repaired accordingly.

Outfall maintenance

- Monitor the tide gate at the 84-inch outfall through the barrier. Keep the tide gate free of debris and sediment. Operate and maintain the gate on a regular basis and replace if necessary.

Vegetation maintenance

- Prepare an O&M program associated with plant material management, including water requirements, pruning, and mowing schedules. This may be seasonal.
- Grassed areas should be mowed regularly. The 3H:1V (horizontal:vertical) slope of the berm facilitates maintenance activities.
- Low-maintenance landscaping does not mean no maintenance will be required as all plants require some routine care to succeed.
- Barrier areas and plant materials shall be kept free from refuse and debris.
- Plant materials shall be maintained in a healthy growing condition, neat and orderly in appearance in perpetuity from the time of the growth season. If any plant material required by this dies or becomes diseased, it should be replaced.

Stormwater maintenance

- Standard stormwater infrastructure (inlets, catch basins, deep sumps) should be maintained with typical frequency. Inspections and debris and sediment removal should occur when sediment accumulation in the sump reaches 50% of the available volume.
- Establish and implement inspection and maintenance frequencies and procedures for stormwater assets. Inspect stormwater assets annually at a minimum or according to manufacturer recommendations for proprietary devices. Include asset management appropriate for the asset and connect with GIS for optimization and management of maintenance and operation records, O&M manuals, and work order management.
- Trash and debris captured in urban stormwater assets will require removal as much as weekly to prevent clogging or bypass during precipitation events.
- The level of effort pertaining to stormwater O&M will vary based on the type and number of pumps, stormwater volume and captured debris (sediment, salt, trash), size of wet wells, water quality treatment process, etc. Pump stations for detained stormwater should be inspected at least monthly and following precipitation events when they are activated.
- There may be additional O&M requirements associated with generators providing back-up and emergency power supply to pump stations.

O&M Plan

- All features should be documented in an O&M plan detailing regular monitoring and maintenance practices, performance assessments, plans for investment, fair weather repairs, and rapid response for storm events.
- Records should be kept of O&M activities.

- Schedule training events and regular updates (every 5 years) of the O&M plan. Annual O&M costs should be updated on a regular basis with O&M plan updates to reflect actual costs incurred and forecasted repairs, as well as evaluate cost-saving opportunities.

There may be additional functional objectives (such as recreational opportunities associated with the Harborwalk barrier) that need to be considered in addition to the flood risk management components. In general, the O&M required for a seawall barrier is less than an earthen embankment. It is still essential to perform regular inspections and maintenance activities to identify and address deficiencies as encountered to reduce risk of failure. If stormwater pump stations are necessary to manage inland stormwater, ownership and maintenance of the new barrier system should be identified in the O&M plan. The following annual O&M costs for the Harborwalk (Seawall) barrier are anticipated:

Item	Annual Probable Cost
Annual inspections and storm inspections	\$6,000 - \$8,000
Seawall maintenance	\$2,000 - \$6,000
Handrail maintenance	\$1,000 - \$3,000
Outfall maintenance	\$1,000 - \$2,000
Vegetation maintenance	\$6,000 - \$9,000
Stormwater maintenance	See Note 6
O&M Plan	\$2,000 - \$4,000
Opinion of Probable Cost (Annual)	**\$18,000 - \$32,000**

The O&M cost assumes the following in addition to the assumptions provided above:

1. Annual inspections will be performed by a registered professional engineer.
2. Seawall maintenance includes cleaning exposed surfaces. Minor seawall repairs, such as waterproofing repairs, chinking stones, and repairing cracks, can range from about \$2,000 to \$5,000 based on extent of damages. Annual repairs are not expected, so costs are estimated based on a 5-year occurrence interval.
3. Handrail maintenance includes washing exposed surfaces and repainting materials, as needed.
4. Outfall maintenance depends on the type of outfall existing at the site. The maintenance cost assumes visual assessment only, with no operations or physical maintenance since the type is unknown.
5. Vegetation maintenance assumes annual O&M costs for brush cutting and clearing, mowing during the growing season, and green infrastructure maintenance.
6. Annual stormwater maintenance costs were not estimated based on the level of design provided for the sample barrier development. The level of effort pertaining to stormwater maintenance will vary based on the type and number of pumps, size of wet wells, water quality treatment process, etc. Stormwater infrastructure should be inspected monthly, and typical catch basin cleaning costs are \$200/structure/cleaning.
7. The O&M plan assumes regular updating on maintenance records, cost estimates, forecasted repairs, an annual update of the plan, and training of staff every 5 years.

Cost considerations should reflect the features identified in the design considerations for capital costs and life-cycle costs of the infrastructure based on design considerations and existing information. An opinion of probable construction cost was developed for the sample Harborwalk barrier. Refer to the sample design drawing in Section 5.5 for related items.

B.2 Harborwalk Flood Barrier (Raised Seawall)

The sample barrier would extend approximately 600 feet. The assumed grade change is approximately 2 feet and the assumed wall is raised approximately 4 feet in this sample barrier.

Item	Probable Cost ($/100-LF)
Seawall Extension	$23,000
Handrail	$20,000
Crest Path	$16,000
Erosion Control Plantings	$5,000
Subtotal	**$64,000**
Contingency (30%)	$20,000
Opinion of Probable Cost ($/100-LF)	**$84,000**
Opinion of Probable Barrier (600 LF)	**$0.5 M**

The cost for the Harborwalk barrier assumes the following in addition to the assumptions provided above:

1. Seawall Extension includes costs associated with the installation concrete/stone masonry retaining wall blocks on top of the existing seawall, which includes a layer of geogrid. **The costs for major modifications to the top of the existing seawall have not been included. Costs assume that the existing seawall can be extended without modifications to its foundation.** A thorough geotechnical investigation is required to evaluate the need for deep foundations or ground improvement, which may significantly impact project costs.
2. Handrail includes costs associated with the installation of an aluminum handrail to the top of the new extended seawall. The handrail has been assumed to be designed to ASCE 7 load requirements and designed to install deployable flood barriers. Deployable flood barriers are not included in this estimate. See Section 7.0 for deployable flood defense options.
3. Crest Path includes costs associated with the installation of the 2-foot elevated crest path behind the new extended seawall, including the backfill material for both the path and earthen slope, and the path subbase and pavers.
4. Erosion Control Plantings include the installation of the topsoil, erosion control plantings, and turf reinforcement mat for the crest path earthen slope.
5. The following is not included: Owner's Costs, Design/Permitting, Stormwater Infrastructure, Construction/Logistical/Insurance, Environmental/Accidents, Adverse Site Conditions. This opinion reflects sample design considerations prepared for the guidelines and does not reflect engineering analyses prepared for design.

5.4 BARRIER SELECTION

Based on the sample design, O&M, and cost considerations developed for the guidelines, a retrofitted Harborwalk seawall barrier may be feasible at the sample site. The existing site layout and open space in the area make this a feasible option to consider further, but the project alone will not address flood pathways in the area. In addition to the Climate Ready Boston neighborhood study, the following additional studies would be recommended to advance design of the sample:

- Analysis of potential permits and current regulatory agencies and regulations.
- Survey, including existing features, utilities, natural resources (wetlands, habitat), topography, and property lines within 100 feet of the proposed alignment. See Figure 9 in Section 5.5 for sample LiDAR topography.
- Utility conflict analyses. Coordinate with local utility providers to identify gas, electric, communications, and other utilities that may be located within the project area.
- Existing outfall assessment in conjunction with utility owner.

- Hydrologic analysis with rainfall with a 50-year useful life climate adjustment in the drainage area impounded by the proposed barrier. Subsequent conveyance, infiltration, storage, and discharge assessments.
- Stormwater management design and pump station feasibility assessment.
- Subsurface exploration and subsequent stability, settlement, and seepage analyses.
- Existing seawall condition assessment.

The approach for the Harborwalk seawall barrier identifies a route to adaptation beyond the 2070 DFE with the inclusion of a deployable flood barrier along the handrail. The barrier design considers the additional future loads that will need to be designed for without spending the funds now to implement the solution with this approach. Refer to Section 7.0 for deployable flood barrier considerations related to structural, physical, and operational capacity of a site and product.

A larger-scaled approach is needed to lengthen the barrier across nearby flood pathways to protect the areas behind the sample site. The final approach should include a unified vision for waterfront protection and public improvement. The design must include coordination with stakeholders to identify a solution that integrates with the physical environment and community needs and desires. It is important to also consider existing and proposed resilience projects that are ongoing in the City of Boston. Climate Ready Boston has a map of these projects available on the Coastal Resilience Projects Tracker.

5.5 SAMPLE DESIGN DRAWING AND FIGURES

CLIMATE RESILIENT DESIGN STANDARDS AND GUIDELINES FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

B.2 HARBORWALK AS FLOOD BARRIER (RAISED SEAWALL)

Refer to Climate Resilient Design Standards and Guidelines for notes and guidance.

DOWNLOADABLE FILES:

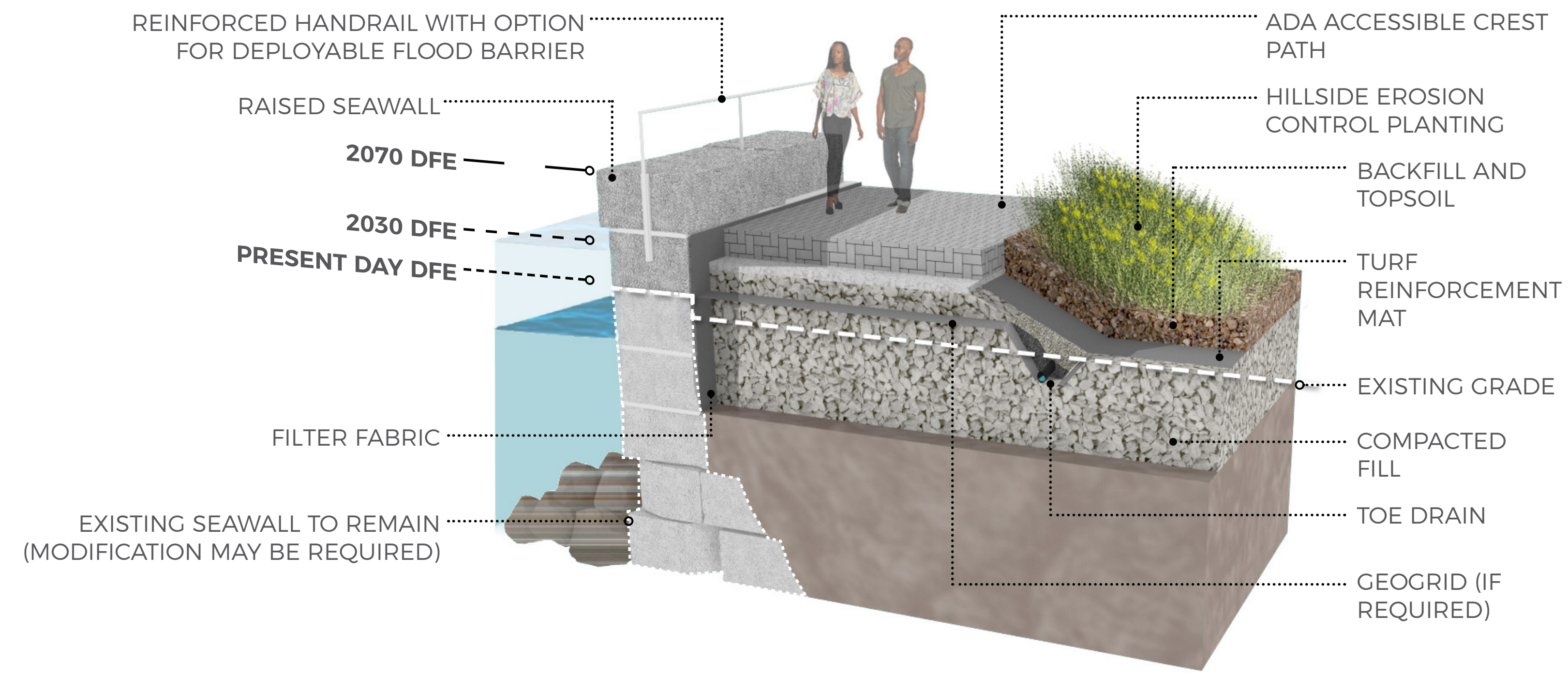
Standard PWD Details for reference and download can be found here

B.2 SAMPLE HARBORWALK AS FLOOD BARRIER (RAISED SEAWALL)

CAD

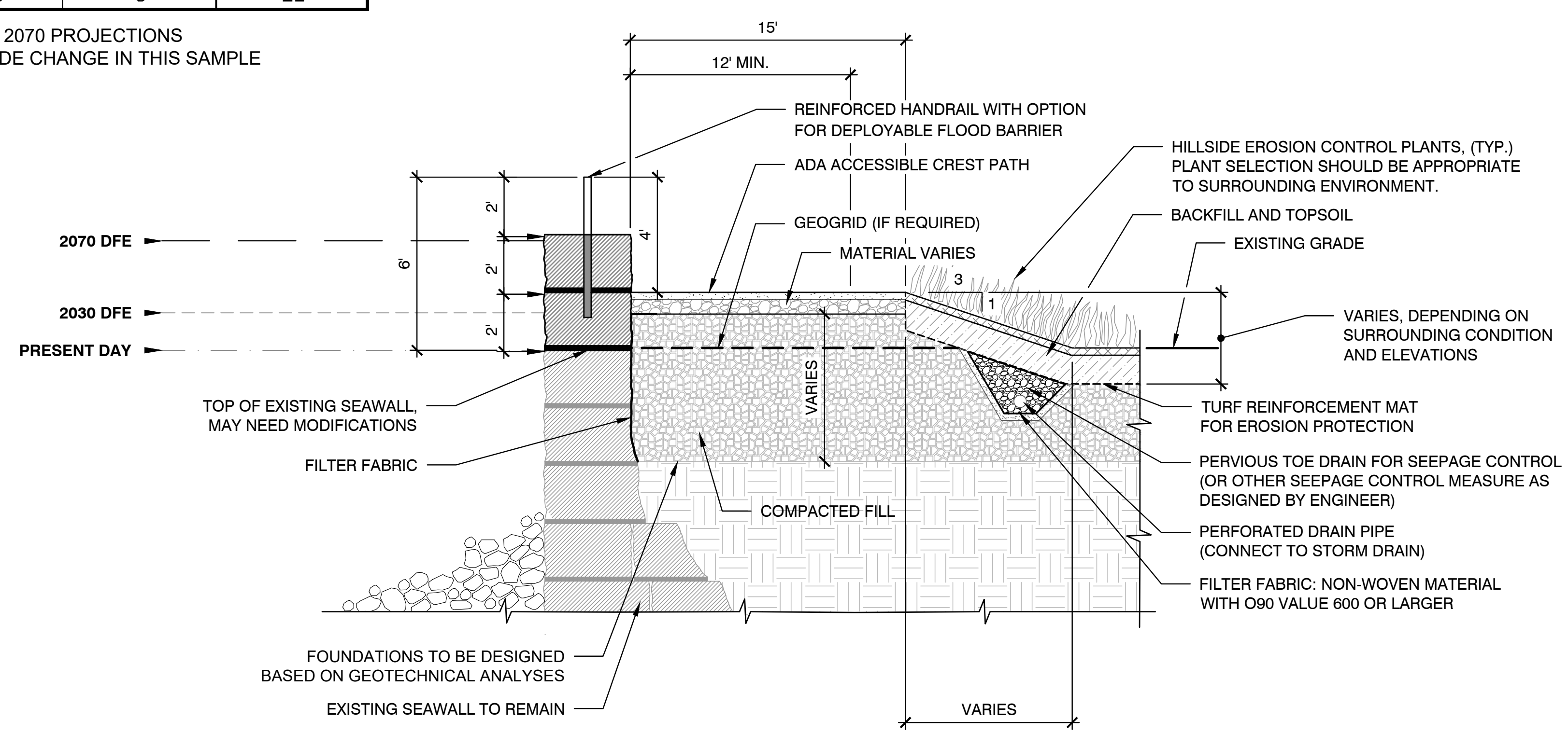
PDF

SAMPLE



SAMPLE HARBORWALK CROSS SECTION WIDTHS (Wall one side, slope one side)			
Increased Height from Existing Ground Surface (+___ ft)	**Minimum Crest Width**	**Slope Width**	**Total Width**
1	15	3	18
2	15	6	21

NOTE: 4 FT. IS USED FOR SAMPLE BARRIER FOR 2070 PROJECTIONS
SEAWALL IS RAISED 4 FT. WITH 2 FT. GRADE CHANGE IN THIS SAMPLE



NOTES:

- HANDRAIL DESIGN FOR ASCE 7 LOADS
- STRUCTURAL DESIGN OF ANCHORAGE IS REQUIRED
- PERFORM WALL STABILITY CALCULATIONS FOR PROPOSED CONDITION (BEARING/SLIDING/OVERTURNING/GLOBAL)
- DIMENSIONS ARE BASED OFF ASSUMED SLOPED OF 3H:1V (HORIZONTAL:VERTICAL)
- FOR ADDITIONAL CONSIDERATIONS SEE GUIDELINES DOCUMENT
- DFE - DESIGN FLOOD ELEVATION (FREEBOARD INCLUDED)
- 2070 DFE: THE DESIGN FLOOD ELEVATION FOR THE 1% ANNUAL FLOOD EVENT WITH 40 INCHES OF SEA LEVEL RISE. DESIGN FLOOD ELEVATION (DFE) INCLUDES FREEBOARD ON TOP OF THE BASE FLOOD ELEVATION

SAMPLE - NOT TO SCALE

FIGURE 6

PROPERTIES IMPACTED BY SAMPLE HARBORWALK (SEAWALL) BARRIER

Proposed Barrier for the 2070 Design Flood Elevation (DFE)

Build Out Area

Parcels Affected by Proposed Buildout Area

200 0 200

Scale In Feet

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FIGURE 7

PROPOSED LIMIT OF WORK AND DRAINAGE AREA FROM SAMPLE HARBORWALK (SEAWALL) BARRIER

Drainage Area (1.5 acres)

Proposed Limit of Work for the 2070 Design Flood Elevation (DFE)

Protected Open Space (1.43 acres In Drainage Area)

200 0 200

Scale In Feet

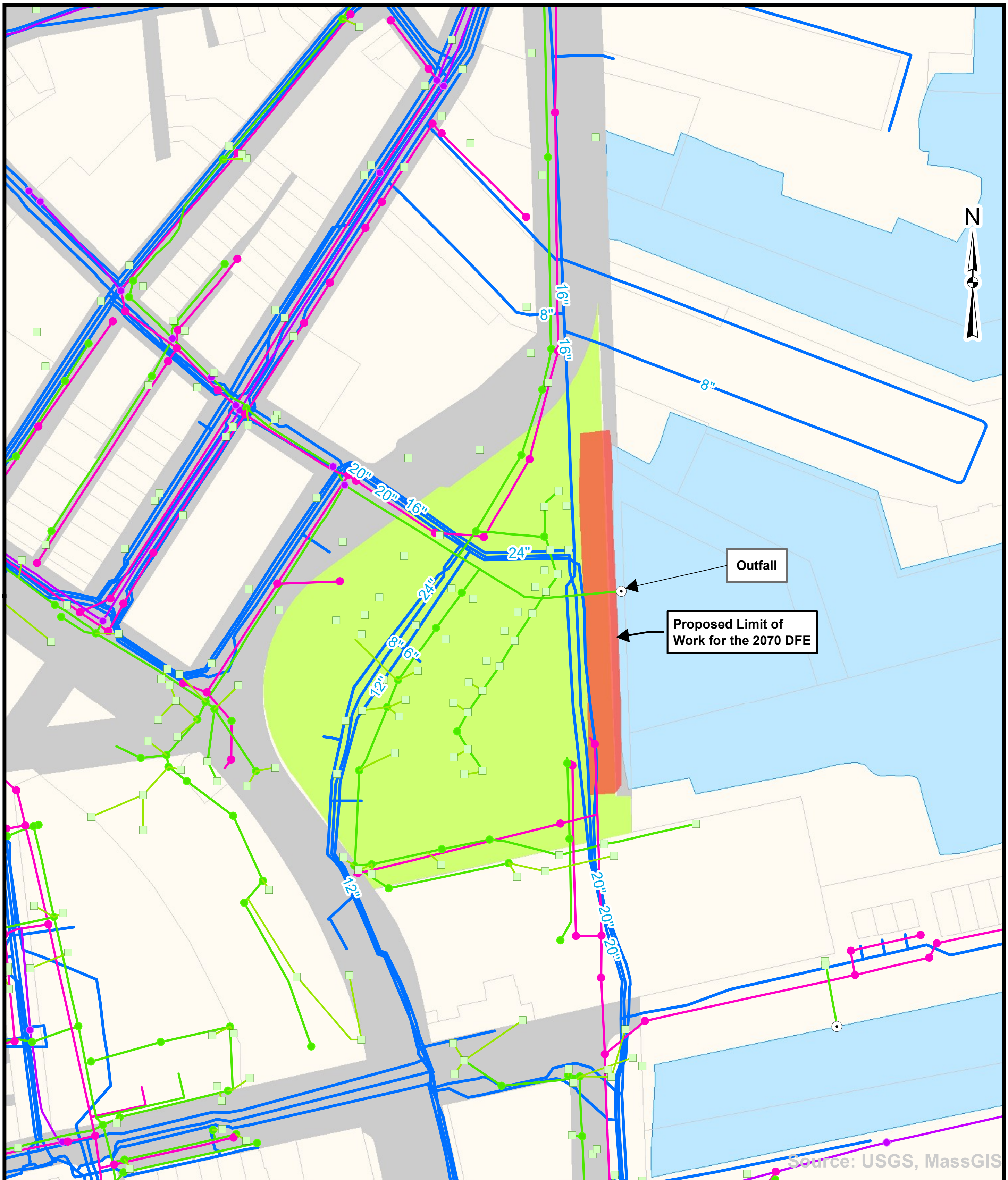

FIGURE 8

EXISITING UTILITIES IDENTIFIED IN SAMPLE HARBORWALK (SEAWALL) BARRIER PROJECT AREA

Proposed Limit of Work for the 2070 Desing Flood Elevation (DFE)

Outfall

Catch Basin

Sanitary Manhole

Storm Manhole

Combined Manhole

Combined Sewer

Sanitary Sewer

Storm Sewer

Water Main

Protected Open Space

200 0 200

Scale In Feet

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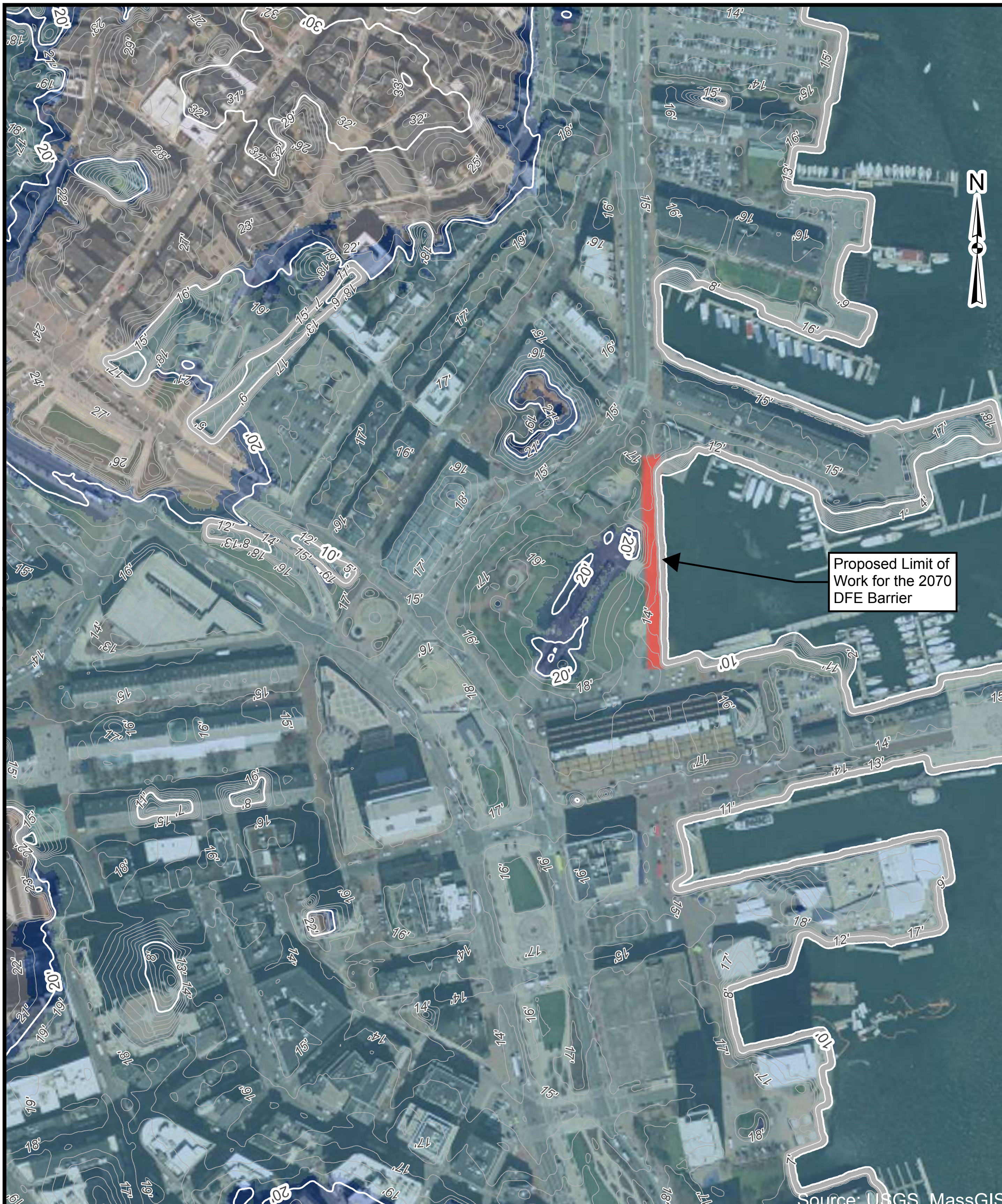

FIGURE 9

PROPOSED LIMIT OF WORK FOR SAMPLE HARBORWALK (SEAWALL) BARRIER WITH TOPOGRAPHIC CONSIDERATIONS

Proposed Barrier for the 2070 Design Flood Elevation (DFE)

Land Below 19.5'

Land Below 21.5'

650 0 650

Scale In Feet

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SECTION 6.0 SAMPLE RAISED ROADWAY BARRIER

6.1 DESCRIPTION AND ASSUMPTIONS

This section provides guidance for designing raised roadways to function as flood barriers. The following may also apply for elevating emergency evacuation routes. Two options for raised roadways with grade changes of 4 feet were considered for sample barrier development:

- **Option 1**. A raised roadway barrier with retaining walls and/or slopes may be feasible in sections of streets where the buildings are set back at least 14 feet from the back of sidewalk.
- **Option 2**. Raising the roadway and sidewalk profiles in newly developed areas with properties designed for access at higher elevations. This may be achieved by working closely with planned development of adjacent properties.

Raising just the roadway and leaving remaining sidewalks and properties in place that are less than the minimum 14-foot setback creates public health and safety hazards as well as impacts to neighborhood vitality and businesses, street operations and maintenance, stormwater and drainage, ADA accessibility, and more. It is not recommended that a raised roadway barrier be utilized in sections of roadways that have existing buildings located at the back of sidewalk. Retrofitting existing buildings is likely unfeasible due to existing below ground structures (basements, garages), settlement impacts with grade changes, structural changes to existing buildings, and loss of use for first floor properties.

Collectively, the design considerations, operations and maintenance (O&M) considerations, incremental approach, and opinion of probable costs are intended to be used as a sample to reflect the intent of the climate resilient flood barrier design process outlined in the guidelines. The sample should be used by engineers and planners to understand the process of advancing conceptual design to implementation.

A sample site location was selected to test the climate resilient flood barrier design process and identify sample considerations (design and O&M) and opinion of probable cost. The sample location is intended to provide practical context, related opportunities, and challenges. ***The locations do not reflect any intentions of the City of Boston to proceed forward with design or implementation of the sample barrier at this time***. Additional studies are required to design and implement a comprehensive solution. The sample location selected was a 2,000 foot-long urban street with residential and commercial properties with first floor or garage access adjacent to the right-of-way. The following assumptions were made for the purposes of developing sample raised roadway barrier considerations and an opinion of probable cost:

- The sample site will serve as the context for sample considerations. Engineering considerations are provided for illustration of sample opportunities and challenges, but site-specific engineering analyses should be performed for the development of actual design considerations. A list of additional studies to be completed to advance design is included in this section and may vary based on real conditions encountered in engineering and planning analyses.
- The figures and drawings developed for the sample barrier are intended to support the considerations outlined in the guidelines and are not considered finalized for design. Additional site-specific data are critical to advancing figures and drawings.
- The sample site provides a significant length of raised roadway such that a flood barrier can be constructed without significant undulations, i.e. without forming a roller coaster effect with the roadway profile.
- The 14 ft. setback assumes that an emergency vehicle can access the lower properties while still maintaining ADA accessibility, appropriate drainage and lighting is provided, snow storage and removal efforts are feasible, utility access is feasible, and Boston’s Complete Streets standards are maintainable. The setback is a minimum value and additional studies are required in design to assess if more clearance is necessary for public health and safety and regular operations and maintenance.

- As this site is a sample for purposes of developing the guidelines, no survey was prepared for the site and surrounding areas. All relative information is based on ESRI (Environmental Systems Research Institute), LiDAR (Light Detection and Ranging) and Climate Ready Boston information.
- The height of the roadway is intended to be raised 4 feet from the existing grade for a 50-year useful life (2070 climate adjustment).
- Incremental vertical grade changes are difficult with substantial infrastructure projects such as roadways, so an initial height greater than 4 feet should be explored to evaluate benefits for flood protection past 2070. An additional 2 feet of flood protection, if needed, may be accomplished with deployable flood barriers. Incremental flood protection may also be achieved by property acquisition and long-term planning.
- Vehicle traffic and parking, bicycle traffic, pedestrian traffic, and access to adjacent infrastructure and roadways must be maintained in design or stated otherwise.
- Gravity-based utilities, such as sewer and stormwater systems, are to be left in place with elevated manholes and pump stations, as needed.
- Slope inclinations of 3H:1V (Horizontal:Vertical) or flatter were assumed to connect the grade change to existing grades. Where space is limited, a retaining wall may be implemented. For the detail drawing provided for “Option 1” a retaining wall on the flood side of the barrier and a vegetated slope on the inland side are assumed. An opinion of probable cost was developed for Option 1 and an additional scenario with two retaining walls.
- There is a Boston Water and Sewer Commission (BWSC) Combined Sewer Overflow (CSO) through the sample street.
- Property on the flood side of the barrier would not be protected from flooding during storm events.
- The design considerations acknowledge there are property boundary or easement conflicts along the barrier. In dense urban environments, larger redevelopment of the area may be required. Parcels of land around the raised roadway may need to be relinquished and evacuated.
- A list of additional studies to be completed to advance design are included in this section and may vary based on real conditions encountered in engineering and planning analyses.
- Communication and coordination with abutters and stakeholders prior to conceptual design is essential to implementation.
- The sample considerations provided in this section may not apply to all sites. Additional considerations not covered in this section may apply. Site-specific information will drive considerations and the process.
- The process and sample considerations do not supersede local, state, or federal regulations.

6.2 SAMPLE RAISED ROADWAY BARRIER DESIGN CONSIDERATIONS

The design considerations for the raised roadway barrier reflect a range of engineering and physical considerations for the concept to identify challenges and opportunities for implementation. This is not a comprehensive list of all potential considerations, and additional considerations to **value creation**, **social impact**, **equity**, and **environmental co-benefits** should also be considered alongside the considerations outlined in these guidelines. Engineers and planners should use these considerations to augment the existing standard of care provided in projects and identify opportunities to create value wherever feasible. Designs must maintain livable, walkable streets in accordance with Boston’s Complete Streets standards and the Boston Public Works Department (BPWD) roadway standards. Refer to Section 6.3 for operations and maintenance (O&M) considerations.

A summary of the overall design considerations is provided below. More detailed discussions of the considerations are included in the **Appendix E – Sample Raised Roadway Barrier Design Considerations**. Refer to sample design drawings and figures in Section 6.5 for the following considerations:

DESIGN CONSIDERATIONS

Refer to **Appendix E – Sample Raised Roadway Barrier Design Considerations** for additional design considerations

Climate Design Adjustments and Timeline	► The site is within the Boston Planning & Development Agency (BPDA) "SLR-BFE" zone via the zoning viewer. The BH-FRM results include the base flood elevation (BFE) of 19.4 ft. and 19.3 ft. Boston City Base (BCB) varying throughout the site for the 2070 time horizon. Minimum design flood elevation (DFE) of 20.4 ft. BCB (assuming 1 ft. of freeboard). ► There are other flood pathways in the sample area for which the barrier will not provide protection; flooding from off-site flood pathways south and east of the site location is still possible. ► BH-FRM downscaled data for flood depth, flood duration, pathways, and projected wave and wind not yet developed for design. ► Use data available in Section 2.0. Evaluate threshold for higher volumes, such as 20%-30% higher volumes than the current 10% annual 24 hr. design storm volume in inches (5.2 inches current to 6.6 inches future), and 20%-50% higher volumes than the current 1% annual 24 hr. design storm (8.1 inches current to 11.7 inches future). ► Drainage Basin: 19.2 acres. See Figure 11 in Section 6.5.
Boundary Constraints and Site Considerations	► The sample site is an urban street with residential and commercial properties along the right-of-way. ► The layout of the sample street is such that access from residences and businesses are located at the back of existing sidewalk. Many businesses have garage entrances also located at the back of sidewalk. See Figure 10 in Section 6.5 for impacted parcels. ► A Phase I Environmental Site Assessment should be conducted to assess if the potential exists for Recognized Environmental Conditions including soil and/or groundwater impacts. ► Based on preliminary LiDAR information, the 14 ft. minimum setback for the sample barrier is not present in this location, with the exception of a sample park area. See Figure 10 in Section 6.5. ► The waterfront side of the sample roadway is a Designated Port Area (DPA). Zoning would be a significant consideration in selection of a raised roadway flood barrier. The barrier would not protect these properties. See Figure 10 in Section 6.5. ► Site development would need to consider a comprehensive redevelopment of the neighborhood. Redevelopment should consider social impacts, equity, value creation, and environmental impact.
Stormwater Considerations	► Consider Green Infrastructure stormwater control measures along the sample street, connecting streets to the east, and the park, as well as streets within the drainage area to treat stormwater generated from inland and offsite sources. The drainage area has several existing green and open space opportunities available to accommodate detention storage for stormwater during precipitation events, including the park and a greenway. ► Identify potential inland stormwater management approaches to delay, store, and discharge stormwater trapped by the barrier. Plan for long-term management of stormwater volume reduction on the upgradient side of the barrier through land use controls, retreat, private property stormwater management and general reduction in impervious surfaces. ► The sample barrier may cause additional flooding damage to adjacent properties by trapping stormwater on the dry (aka inland) side. Consider sizing stormwater features and conveyance to extreme rainfall and cloudbursts; conduct a risk analysis/cost benefit analysis. ► On-site retention of the first inch of runoff from new impervious surfaces is required.

Stormwater Considerations (continued)	► Post design peak stormwater discharge must equal pre-design peak discharge. ► Address MS4 Pollutants. Use green infrastructure concepts to treat stormwater where possible or create a treatment train approach to manage and improve water quality for TSS, nutrients, metals and oils and grease. ► Provide design space for pumping chambers to manage inland stormwater for current stormwater volumes and future conditions. Space is currently available at the sample park for siting stormwater pumping chambers. This area is near a regional low point as well. Pumping systems should be sized to handle stormwater volumes trapped on the dry side as well as potential ocean overtopping during extreme storm surge to prevent flooding. On-site generators may be recommended for operations during larger power outages. Design should consider noise and visual disruption to the neighborhood as well. The role of operations and maintenance associated with the pump stations should be clearly identified in the design phase.
Utility Considerations	► There is a Boston Water and Sewer Commission (BWSC) Combined Sewer Overflow (CSO) through the sample barrier alignment. The existing outfall through the roadway should be evaluated and designed for utility retrofits. See Figure 12 in Section 6.5. ► Existing utilities are mapped within the sample project area. The area includes combined sanitary and storm water flows. Not all catch basins are on the dry side of the barrier. See Figure 12 in Section 6.5. Designers should evaluate whether new barrier will impact CSO stormwater volumes in coordination with increased rainfall projections. ► Coordinate with local utility providers to confirm and identify gas, electric, communications, and other utilities that may be located within the project area. ► Water utilities should be raised during roadway reconstruction. Gravity based systems (like the sewer and drainage) should be left in place unless larger improvements to the utility system are designed to accommodate new elevations and slopes, or pumping systems. ► Manholes should be raised to access utilities from raised ground surface. ► Manhole covers should be protected from damage and water intrusion using reinforced concrete around the top section and frame where appropriate. Manhole covers should be bolted with stainless steel bolts and waterproof gaskets to prevent dislodging. ► Future pump station may be constructed in the vicinity to manage stormwater behind roadway. See stormwater considerations above.
Structural Considerations	► Construction of the barrier would result in substantial demolition of the existing sample roadway and surrounding area. ► An existing conditions assessment of existing structures is necessary for barrier construction. Construction would include a raised roadway, sidewalks, retaining walls, possible relocation of utilities, and earth work (see geotechnical for considerations). ► Structural analysis for proposed conditions: ▲ Changed Geometry ▲ Increased Earth and Water Loads ▲ Emergency Vehicle Surcharge & Live Load ▲ Existing Buildings for Modified Conditions ▲ Existing Structures Adjacent to Roadway on Flood Side ► Design of new components and connection between new/existing roadway.
Geotechnical Considerations	► Conduct subsurface explorations to evaluate overall subsurface conditions, potential contamination, seepage conditions, bearing capacity, and potential for settlement.

Geotechnical Considerations (continued)	► Perform borings, spaced every 100 to 500 ft. along the sample raised roadway alignment, to define the thickness of pervious or soft foundation soils for applicable geotechnical analyses. Borings should be spaced closer together for final design. ► Conduct test pits to evaluate condition and geometry of existing foundations, buried structures and utilities, as necessary. ► Identify the load carrying capacity of existing subsurface structures, such as basements and utilities, within the sample project “zone of influence.” If assessed that the existing structures cannot bear the additional soil loads (vertical and lateral), consider increasing structure capacity, bridging solutions or relocation of the structure/utility. ► Check lateral sliding, global stability, and overturning for the proposed wall during end-of-construction, steady-state seepage (during design flood), rapid drawdown (if applicable), and seismic conditions as described in United States Army Corps of Engineers (USACOE) guidelines for floodwalls and levees. It may be necessary to include grid reinforcement within backfill to provide stability. ► Check supporting capacities of the existing roadway foundation and soils. ► Depending on subsurface conditions, long-term settlement may impact existing structures. Check the effect of settlement on existing structures within the “zone of influence” below the new load. Consider supporting existing structures sensitive to movement by underpinning, piles, or other methods as possible. ► Roadways must be designed to prevent seepage from emerging on the landside. Consider constructing the roadway to be sufficiently wide enough to prevent seepage during flood events, and/or by inclusion of a pervious vertical or horizontal drainage layer. ► Scour protection should be provided in areas where the raised roadway will be subject to erosional forces. Riprap is generally recommended for areas subjected to wave forces and currents. ► Materials for the roadway shall be selected, placed, and compacted as required to prevent detrimental seepage and maintain overall stability of the roadway. Fine-grained soils (such as silts and clays) are not recommended within 4 feet of the roadway for performance.
Transportation and Accessibility Considerations	► It is unacceptable to raise the roadway without raising sidewalks. Raising just the roadway and leaving remaining sidewalks and properties creates public health and safety hazards as well as impacts to neighborhood vitality and businesses, street operations and maintenance, stormwater and drainage, and more. Where there is room (at least 14 ft. between the back of sidewalk and existing buildings), split sidewalks may be viable but should be evaluated for public health and safety considerations (Option 1). ► It will be necessary to reconnect side streets to the higher roadway section. Care must be taken to design the connection to side streets and major driveways in such a way that the approach grades are not excessive. ► Changes in slope shall not exceed 15% and proper sight distance must be maintained from the side street to the new raised roadway for safe passage of pedestrians, bicycles, and other vehicles. ► It may be possible to coordinate a larger-scale redesign of the neighborhood that would enable raising the full profile of the sidewalk and raising/rebuilding existing properties and building utility connections (Option 2). ► ADA Accessibility and connection to inland area, waterfront, and existing buildings. ► Evaluate walkability, livability, and waterfront connectivity with pedestrian and bike paths. ► Maintain accessibility for emergency and maintenance vehicle traffic. ► All existing signs, posts, pavement markings, traffic signals , traffic signal conduits, and street lighting shall be removed and reset/replaced. Designers should account for interconnected

	systems that may be impacted. Refer to the BPWD Roadway Design Standards and Boston's Complete Streets standards.
Groundwater Considerations	► Higher tides may increase groundwater levels and may result in reduced stormwater infiltration and affect stormwater drainage systems. ► Cutoff walls or trenches, if used, shall consider area groundwater hydrology and its effects on area foundations, particularly in areas where buildings are supported on timber piles. ► Raised Roadways may require additional structural reinforcement and waterproofing for underground structures to prevent uplift. ► Soil conditions will impact groundwater flow and inundation. Materials for use with Raised Roadways shall be carefully selected for proper flow rates. ► Pumping may be required to reduce below ground flooding. Groundwater extraction should be managed to avoid land subsidence. ► Groundwater pumps shall consider back-up generation and redundancy. Power generation may be compromised due to climate impacts.
Vegetative Considerations	► Plants along the roadway should be tolerant of urban pollutants (emissions, oils, etc.). ► Consider plants that are low maintenance that may also provide habitat and reduce urban heat. ► Consider plant heights as they relate to view sheds and corridors towards the water and also the inland side. ► Identify native or naturalized salt tolerant vegetation and non-invasive plant materials appropriate to the surrounding microclimate and ecosystem and complement passive recreational activities. ► Current USACOE setbacks and easements do not allow for trees to be within 15 ft. of levees. Trees are not permitted on levees because of their root systems. If trees are uprooted during a storm event, the barrier may result in a breach. Tree root systems also pose a risk as a flood pathway; roots rot over time and can result in pathways through the soil. Tree root systems also provide pathways for animal burrows to create additional pathways in the soil and barrier. If street trees are desired on the raised roadway, a root barrier system may be designed for trees on the inland side of the barrier (not ocean-side) or structural wall may be designed in the embankment to reduce the impact of a breach. Decorative plantings are recommended on the ocean-side of the barrier. The wall should consider the impact of the groundwater interface and structural and geotechnical considerations.

6.3 OPERATIONS AND MAINTENANCE AND COST CONSIDERATIONS

Operations and maintenance (O&M) are critical to the performance of the Raised Roadway barrier and reducing risk. For an asset in the public ROW, O&M is extremely important as the City will need to balance what is being proposed with existing maintenance capabilities across different agencies and/or potential public/private partnerships. For a design to be acceptable, buy-in from key City agencies that will be involved in the overall maintenance of the asset and maintenance roles will need to be clearly defined.

O&M is necessary so that the roadway serves its intended purpose throughout its intended useful life. In addition to the roadway O&M requirements, O&M will be similar to levee, dam, and dike considerations as well as floodwall considerations. Additional O&M considerations related to design considerations are provided **Appendix E – Sample Raised Roadway Barrier Design Considerations**. The following O&M components are associated with raised roadway barrier <u>in addition to regular roadway maintenance</u>:

Annual inspections and inspections before and following storm events (note: inspections during storm events may be recommended based on existing conditions as well)

- Check for signs of erosion due to precipitation and overtopping. Signs of erosion include gullies, caving, or scarps. Repair eroded areas. Consider providing increased erosion protection in areas where ongoing erosion is observed.
- Check for and remove encroachments into the flood barrier. These may include trees and other woody vegetation, debris, animal nests, animal burrows or unapproved manmade elements such as fencing, irrigation systems, gardens, etc.
- Check embankments for signs of global instability, including slumping, longitudinal cracking along the crest, and bulging at the toe. Areas exhibiting signs of slope instability should be stabilized as directed by a licensed engineer.
- Check for sinkholes, low areas or ruts on or near embankment crests due to settlement or pedestrian or vehicular traffic. Fill low areas with compacted embankment material as needed to prevent ponding of water and maintain design crest elevation.
- Check for sandboils and turbid seepage through the barrier, and at or beyond the toe which may be indicative of internal erosion of the embankment or foundation material.
- Check for leakage or seepage around non-earthen structures, such as pipes, gates, and walls passing through and adjacent to the flood barrier.
- Where pressure relief wells are used, qualified well drillers should perform well testing to check for clogging of the filter or well screen, and clear wells as needed.
- Check for clogging of drainage pipes.
- Check for tilting, sliding, or settlement of wall structures. If movement is considerable, repair as directed by a licensed engineer.

Structure maintenance (wall and railings)

- Exposed surfaces should be washed to remove debris buildup, deicing salts, mineral deposits from a previous flood event, vegetation growth, and pigeon guano.
- The waterproofing membrane and/or coating on exposed concrete should be regularly inspected and reapplied if deficiencies are present.
- Concrete structures must be regularly inspected for cracking and spalling. Cracks should be sealed and spalls repaired. Any exposed reinforcing steel should be checked for corrosion and repairs made accordingly.
- The paint and/or coating system protecting exposed steel should be regularly inspected and replaced if deteriorating.
- Steel elements should be regularly inspected for corrosion and any members exhibiting corrosion should be repaired/replaced.
- Steel elements should be inspected for signs of failure including cracking, denting, deflection, and missing connection elements and repaired accordingly.

Vegetation maintenance

- Prepare an operation and maintenance program associated with plant material management including water requirements, pruning and mowing schedules. This may be seasonal.
- Grassed areas should be mowed regularly. The 3H:1V (horizontal:vertical) slope of the berm facilitates maintenance activities.
- Low-maintenance landscaping does not mean no maintenance will be required as all plants require some routine care to succeed.
- Barrier areas and plant materials shall be kept free from refuse and debris.
- Plant materials shall be maintained in a healthy growing condition, neat and orderly in appearance in perpetuity from the time of the growth season. If any plant material required by this dies or becomes diseased, they should be replaced.

Stormwater maintenance

- Standard stormwater infrastructure (inlets, catch basins, deep sumps) should be maintained with typical frequency. Inspections, debris and sediment removal should occur when sediment accumulation in the sump reaches 50% of the available volume.
- Establish and implement inspection and maintenance frequencies and procedures for stormwater assets. Inspect stormwater assets annually at a minimum or according to manufacturer recommendations for proprietary devices. Include Asset Management appropriate for the asset and connect with GIS system for optimization and management of O&M records, O&M manuals and work order management.
- Trash and debris captured in urban stormwater assets will require removal as much as weekly to prevent clogging or bypass during precipitation events.
- Pump stations for detained stormwater should be inspected monthly and following precipitation events when they are activated.
- Once the sample street is raised, there will be an additional cost of maintaining a stormwater pump system (i.e. pumps, generators). The level of effort pertaining to stormwater maintenance will vary based on the type and number of pumps, size of wet wells, water quality treatment process, etc. There may be the need for additional staff to maintain the systems. Maintenance crews and equipment may need to be added to existing personnel. Refer to **Appendix E – Sample Raised Roadway Barrier Design Considerations** for additional guidance related to stormwater maintenance considerations.
- If any underground structures are installed for a pump system, they should be inspected at least once per month and cleaned as needed.
- When raising a roadway, there may be the potential to install large capacity drainage structures so that they can handle a larger storm event. This may reduce O&M costs for those structures
- Keep a written (hardcopy or electronic) record of all required activities including but not limited to maintenance activities, inspections and training or utilize a work order management system for tracking trends and managing efficiently.

O&M Plan

- All features should be documented in an O&M plan detailing regular monitoring and maintenance practices, performance assessments, plans for investment, fair weather repairs, and rapid response for storm events.
- Records should be kept of maintenance and operations activities.
- There should be scheduled training events and regular updates (every 5 years) of the O&M plan. Annual O&M costs should be updated on a regular basis with O&M plan updates to reflect actual costs incurred and forecasted repairs, as well as evaluate cost-saving opportunities.

Regular roadway and utility related maintenance need to be considered in addition to the flood risk management components identified in these guidelines. It is essential to perform regular inspections and maintenance activities to identify and address deficiencies as encountered to reduce risk of failure. The annual O&M costs for the Raised Roadway barrier are anticipated, in addition to regular roadway O&M activities:

Item	Annual Probable Cost
Annual inspections and storm inspections	$6,000 - $8,000
Structure maintenance	$2,000 - $6,000
Vegetation maintenance	$4,000 - $7,000
Stormwater maintenance	See Note 4 below
O&M Plan	$2,000 - $4,000
Opinion of Probable Cost (Annual)	**$12,000 - $25,000**

The O&M cost assumes the following in addition to the assumptions provided above:

1. Annual inspections will be performed by a registered professional engineer.
2. Structure maintenance includes cleaning exposed surfaces. Minor wall repairs, such as waterproofing repairs, repairing cracks can range from about $2,000 to $5,000 based on extent of damages. Annual repairs are not expected, so costs are estimated based on a 5-year occurrence interval.
3. Vegetation maintenance assumes annual O&M costs for brush cutting and clearing, mowing during the growing season, and green infrastructure maintenance.
4. Annual stormwater maintenance costs were not estimated based on the level of design provided for the sample barrier development. The level of effort pertaining to stormwater maintenance will vary based on the type and number of pumps, size of wet wells, water quality treatment process, etc. **It should be assumed that the stormwater costs related to raising roadways will be significant based on similar projects in the City of Miami Beach, Florida.** See below for more details.
5. The O&M plan assumes regular updating on maintenance records, cost-estimates, forecasted repairs, an annual update of the plan, and training of staff every 5 years.

Raised roadway projects in the City of Boston should anticipate similar stormwater management considerations as the City of Miami Beach, Florida raised roadway projects, as well as considering how winter weather may impact these designs (snow, ice, salt, etc.). Stormwater cost considerations should include:

- energy costs for pump stations and system redundancy;
- reassigned or new staff (or contractors) to maintain the new pump stations, generators, treatment systems, and utilities associated with stormwater management;
- new equipment needed for stormwater management;
- operations management support; and
- staff training.

These costs are not included in the estimated annual cost table because they vary greatly based on stormwater volumes and system design. Ownership of the stormwater management, including O&M costs, should be identified early in the design considerations. This will involve coordination with BPWD, Boston Transportation Department (BTD), BWSC, Boston Parks Department, and others. The City should also coordinate with local stakeholders to communicate the impact of raising roadways in the neighborhood on their properties.

Cost considerations should reflect the features identified in the design considerations for capital costs and life-cycle costs of the infrastructure based on design considerations and existing information. An opinion of probable construction cost was developed for sample raised roadway options. Refer to the sample design drawings for related cost elements. For the purposes of simplifying the cost-estimating, it was assumed that the 2,000 ft. alignment on the sample street would have uniform construction.

B.3 Sample Raised Roadway – Option 1. No Built Property Within At Least 14 Feet of Existing Right-of-way (Retaining Wall on Oceanside and Earthen Slope on Landside)

Item	Probable Cost ($/100-LF)
Riprap Scour Protection	$13,000
Retaining Wall	$83,000
Roadway and Sidewalks	$101,000
Storm Water System	$44,000
Water and Sewer Utilities	$232,000
Street Lighting	$32,000

Earthen Slope and Erosion Control Plantings	$12,000
Decorative plantings	$8,000
Subtotal	**$525,000**
Contingency (30%)	$158,000
Opinion of Probable Cost ($/100-LF)	**$683,000**
Opinion of Probable Cost (2000 LF)	**$13.6 M**

The cost for the Raised Roadway- Option 1 assumes the following in addition to the assumptions provided above:

1. Riprap Scour Protection includes costs associated with the riprap installation including bedding layer and filter fabric. The use of a coffer dam to install the scour protection has not been included.
2. Retaining Wall includes costs associated with the installation of the oceanside retaining wall including excavation, rebar, concrete, crushed stone backfill, filter fabric and water proofing. No ground improvement or deep foundation support was assumed.
3. Roadway and Sidewalks includes costs associated with the installation of the raised roadway and sidewalks including gravel backfill, subbase, granite curb, asphalt road surface, roadway striping, concrete sidewalks and guardrails.
4. Storm Water System includes costs associated with the installation of the storm water collection system including the relocation of drainage manhole and installation of new catch basins and drainage pipe. **Costs for pumps and generators are not included. Typical pump station cost variations can be between $500k and $20M**.
5. Water and Sewer Utilities includes costs associated with the relocation of a typical 20 to 24-inch water main and associated services, and the inspection and cleaning of an existing sewer main and the installation of a new sewer manhole. The costs for the relocation of private utilities (gas, electric, steam, telephone, cable, etc.) have not been included and are assumed to be borne by each utility.
6. Street Lighting includes costs associated with the installation of ornamental street light posts and luminaire including conduit, cable and load center.
7. Earthen Slope and Erosion Control Plantings includes costs associated with the installation of the landside earthen slope including embankment fill, filter fabric, topsoil and erosion control plantings.
8. Decorative plantings includes costs associated with the installation of planters along the oceanside and small trees with root containment systems along the inland side of the new roadway. Trees are not permitted on the flood side of the barrier.
9. The following is not included: Owner's Costs, Design/Permitting, Construction/Logistical/Insurance, Environmental/Accidents, Adverse Site Conditions, replacement of Traffic Signal Systems, and any costs associated with neighborhood redevelopment or property acquisition. This opinion reflects sample design considerations prepared for the guidelines and does not reflect engineering analyses prepared for design.

B.3 Sample Raised Roadway – Option 1.A No Built Property Within At Least 14 Feet of Existing Right-of-way (Retaining Walls on both the Oceanside and Landside)

Item	Probable Cost ($/100-LF)
Riprap Scour Protection	$13,000
Retaining Walls	$176,000
Roadway and Sidewalks	$101,000
Storm Water System	$44,000
Water and Sewer Utilities	$232,000
Street Lighting	$32,000

Decorative Plantings	$8,000
Subtotal	**$606,000**
Contingency (30%)	$182,000
Opinion of Probable Cost ($/100-LF)	**$788,000**
Opinion of Probable Cost (2000 LF)	**$15.8 M**

The cost for the Raised Roadway – Option 1.A assumes the following in addition to the assumptions provided above:

1. Riprap Scour Protection includes costs associated with the riprap installation including bedding layer and filter fabric. The use of a coffer dam to install the scour protection has not been included.
2. Retaining Walls includes costs associated with the installation of the oceanside and landside retaining walls including excavation, rebar, concrete, crushed stone backfill, filter fabric and water proofing. No ground improvement or deep foundation support was assumed.
3. Roadway and Sidewalks includes costs associated with the installation of the raised roadway and sidewalks including gravel backfill, subbase, granite curb, asphalt road surface, roadway striping, concrete sidewalks and guardrails.
4. Storm Water System includes costs associated with the installation of the storm water collection system including the relocation of drainage manhole and installation of new catch basins and drainage pipe. **Costs for pumps and generators are not included. Typical pump station cost variations can be between $500k and $20M.**
5. Water and Sewer Utilities includes costs associated with the relocation of a typical 20 to 24-inch water main and associated services, and the inspection and cleaning of an existing sewer main and the installation of a new sewer manhole. The costs for the relocation of private utilities (gas, electric, steam, telephone, cable, etc.) have not been included and are assumed to be borne by each utility.
6. Street Lighting includes costs associated with the installation of ornamental street light posts and luminaire including conduit, cable and load center.
7. Decorative plantings includes costs associated with the installation of planters along the oceanside and small trees with root containment systems along the inland side of the new roadway. Trees are not permitted on the flood side of the barrier.
8. The following is not included: Owner's Costs, Design/Permitting, Construction/Logistical/Insurance, Environmental/Accidents, Adverse Site Conditions, replacement of Traffic Signal Systems, and any costs associated with neighborhood redevelopment or property acquisition. This opinion reflects sample design considerations prepared for the guidelines and does not reflect engineering analyses prepared for design.

B.4 Sample Raised Roadway – Option 2 Raised Roadway and Sidewalks with New Development

Item	Probable Cost ($/100 ft.)
Retaining Walls	$170,000
Roadway and Sidewalks	$96,000
Storm Water System	$44,000
Water and Sewer Utilities	$232,000
Street Lighting	$32,000
Decorative Plantings	$8,000
Subtotal	**$582,000**
Contingency (30%)	$175,000
Opinion of Probable Cost ($/100-LF)	**$757,000**
Opinion of Probable Cost (2000 LF)	**$15.1 M**

The cost for the Raised Roadway – Option 2 assumes the following in addition to the assumptions provided above:

1. Retaining Walls includes costs associated with the installation of retaining walls on both sides of the new roadway and sidewalk right-of-way including excavation, rebar, concrete, crushed stone backfill, filter fabric and water proofing.
2. Roadway and Sidewalks includes costs associated with the installation of the raised roadway and sidewalks including gravel backfill, subbase, granite curb, asphalt road surface, roadway striping and concrete sidewalks.
3. Storm Water System includes costs associated with the installation of the storm water collection system including the relocation of drainage manhole and installation of new catch basins and drainage pipe. **Costs for pumps and generators are not included. Typical pump station cost variations can be between $500k and $20M.**
4. Water and Sewer Utilities includes costs associated with the relocation of a typical 20 to 24-inch water main and associated services, and the inspection and cleaning of an existing sewer main and the installation of a new sewer manhole. The costs for the relocation of private utilities (gas, electric, steam, telephone, cable, etc.) have not been included and are assumed to be borne by each utility.
5. Street Lighting includes costs associated with the installation of ornamental street light posts and luminaire including conduit, cable and load center.
6. Decorative plantings includes costs associated with the installation of planters along the oceanside and small trees with root containment systems along the inland side of the new roadway. Trees are not permitted on the flood side of the barrier.
7. The following is not included: Owner’s Costs, Design/Permitting, Construction/Logistical/Insurance, Environmental/Accidents, Adverse Site Conditions, replacement of Traffic Signal Systems, and any costs associated with neighborhood redevelopment or property acquisition. This opinion reflects sample design considerations prepared for the guidelines and does not reflect engineering analyses prepared for design.

6.4 BARRIER SELECTION

Based on the sample design, O&M, and cost considerations developed for the guidelines, raised roadways are likely not currently feasible at sites similar to the sample street. Raising of the sample roadway cannot be accomplished without significantly disrupting local residents and business owners. The layout of sample street is such that access from residences and businesses are located at the back of existing sidewalk. If the sample street were raised, aside from the expense of reworking many of the existing utilities, access to apartment buildings, retail establishments and driveways would be unable to be utilized. The long-term plan may be to remove the one-story properties to rebuild with properties designed for flooding, but this would be a large investment in the local infrastructure and real estate acquisitions. The raising of roadway would create a levee to protect the east side of the road while properties on the west (waterfront side) would not be protected. There may be opportunities related to neighborhood redevelopment that would make scenarios similar to Option 2 feasible.

Raising roadways grades incrementally is not recommended due to the substantial disruption and costs related to construction. Segments of roadway may be raised over time, but engineers and designers should be mindful of roadway profile undulations in connecting raised grades to lower grades to prevent vehicles bottoming out and enable ADA accessibility. The approach includes raising the height of the roadway and tying the new roadway in to existing elevations above future flood pathways. The guidelines are focused on a 50-year useful life, which utilizes the 2070 climate adjustments. Climate projections do not stop at 2070, and there is additional uncertainty in the range of projections for the end of the century. It may be difficult to adjust the roadway height once constructed, so designers should evaluate deployable flood barriers, short flood walls, and/or raising roadway heights over 4 ft. in identifying plans for flood protection beyond the useful life. Option 1 shows a retaining wall height 2 ft. above the 2070 DFE for additional protection.

The final approach should include a unified vision for waterfront protection and public improvement. The design must include coordination to identify a solution that integrates with the physical environment, communities, and stakeholders. It is important to also consider existing and proposed resilience projects that are going on in the City of Boston. Climate Ready Boston has a map of these projects available on the Coastal Resilience Projects Tracker.

At this time the raised roadway sample would not be appropriate as a project for flood protection without substantial discussion with the community and proposal for neighborhood development. The designer should evaluate other flood barrier types available. The City foresees few opportunities for raising existing roadways to act as flood barriers due to site constraints.

6.5 SAMPLE DESIGN DRAWINGS AND FIGURES

CLIMATE RESILIENT DESIGN STANDARDS AND GUIDELINES FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

B.3 RAISED ROADWAY - OPTION 1 NO BUILT PROPERTY WITHIN AT LEAST 14 FEET OF EXISTING RIGHT OF WAY

Refer to Climate Resilient Design Standards and Guidelines for notes and guidance.

DOWNLOADABLE FILES:

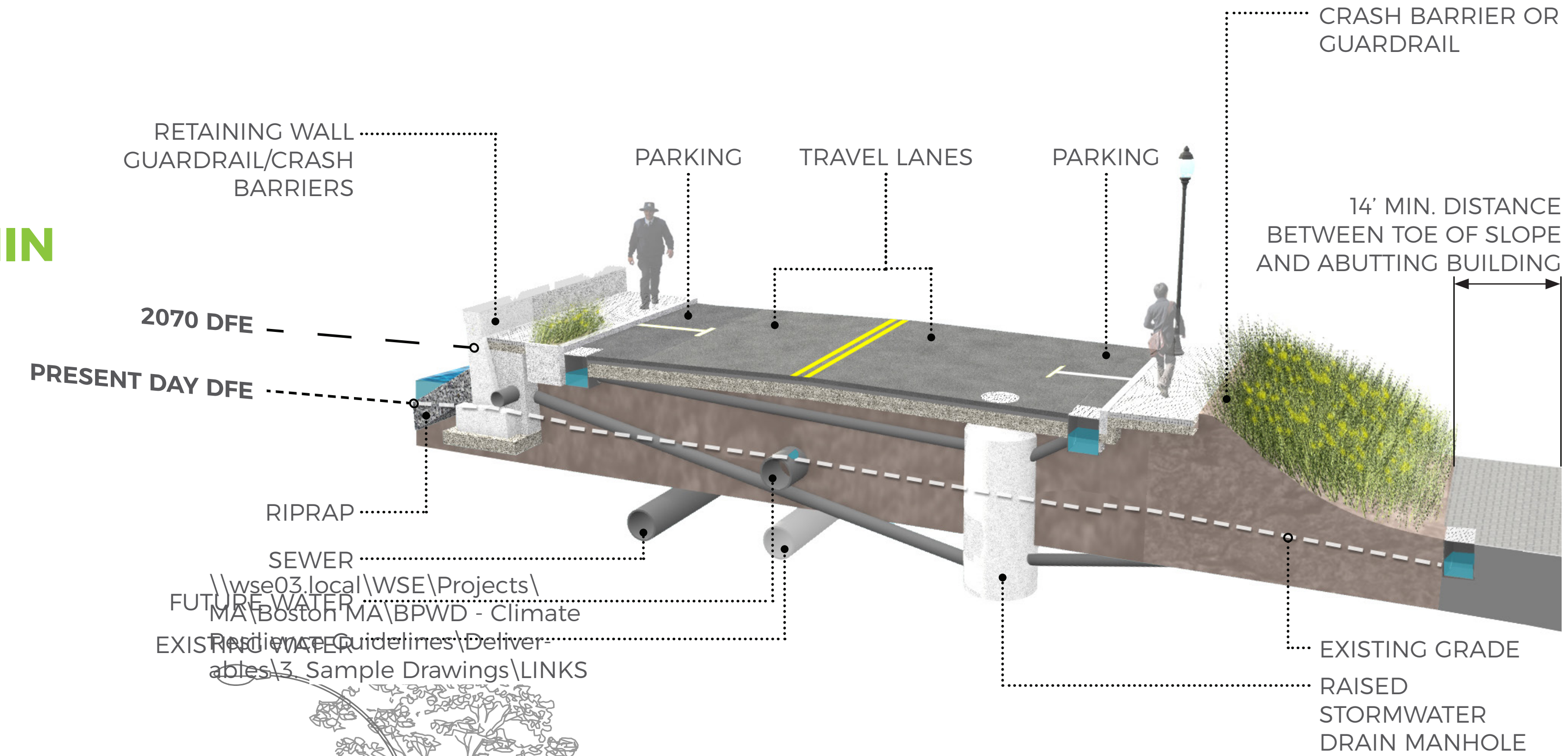
Standard PWD Details for reference and download can be found here

SAMPLE

B.3 SAMPLE RAISED ROADWAY- OPTION 1

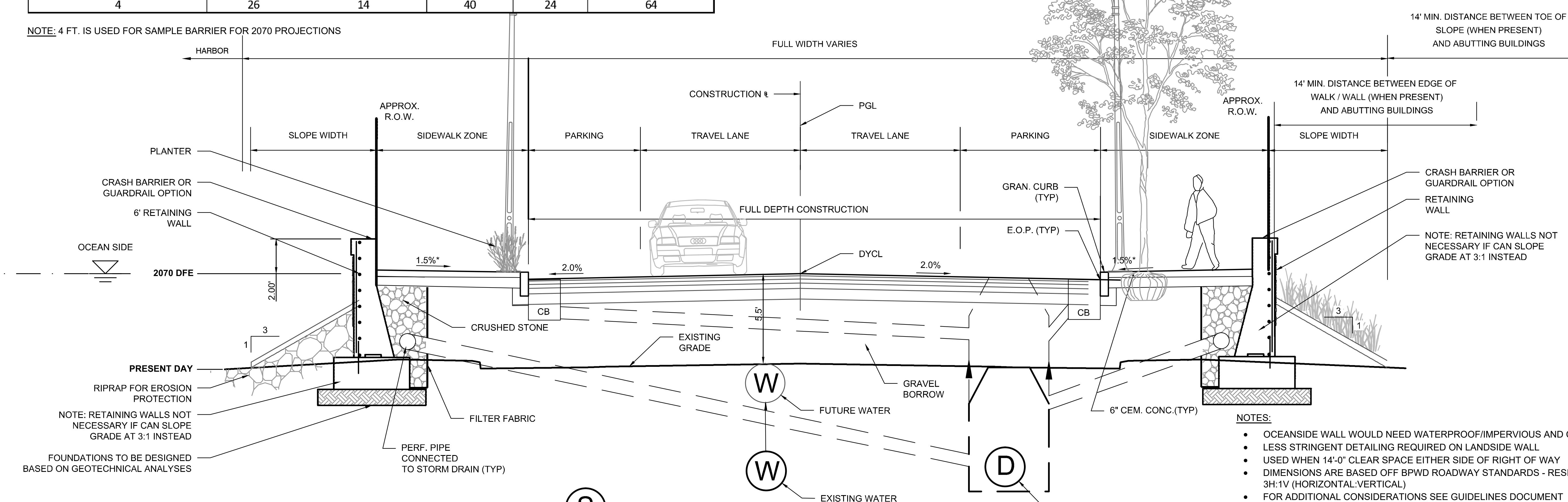
CAD

PDF



SAMPLE RAISED ROADWAY CROSS SECTION WIDTHS - WITH SLOPES					
Increased Height from Existing Ground Surface (+___ft)	Roadway Width	Sidewalk Width (total)	Minimum Crest Width	Slope Width	Total Width (with two side slopes)
1	26	14	40	6	46
2	26	14	40	12	52
3	26	14	40	18	58
4	26	14	40	24	64

NOTE: 4 FT. IS USED FOR SAMPLE BARRIER FOR 2070 PROJECTIONS



SAMPLE - NOT TO SCALE

SAMPLE SECTION

NOTES:

- OCEANSIDE WALL WOULD NEED WATERPROOF/IMPERVIOUS AND CORROSION RESISTANT DETAILING
- LESS STRINGENT DETAILING REQUIRED ON LANDSIDE WALL
- USED WHEN 14'-0" CLEAR SPACE EITHER SIDE OF RIGHT OF WAY
- DIMENSIONS ARE BASED OFF BPWD ROADWAY STANDARDS - RESIDENTIAL & ASSUMED SLOPE WIDTH OF 3H:1V (HORIZONTAL:VERTICAL)
- FOR ADDITIONAL CONSIDERATIONS SEE GUIDELINES DOCUMENT
- DFE - DESIGN FLOOD ELEVATION (FREEBOARD INCLUDED)
- IF SLOPES ARE FEASIBLE, WALLS ARE NOT NECESSARY
- 2070 DFE: THE DESIGN FLOOD ELEVATION FOR THE 1% ANNUAL FLOOD EVENT WITH 40 INCHES OF SEA LEVEL RISE. DESIGN FLOOD ELEVATION (DFE) INCLUDES FREEBOARD ON TOP OF THE BASE FLOOD ELEVATION

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CLIMATE RESILIENT DESIGN STANDARDS AND GUIDELINES FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

B.4 RAISED ROADWAY - OPTION 2 RAISED ROADWAY & SIDEWALKS WITH NEW DEVELOPMENT

Refer to Climate Resilient Design Standards and Guidelines for notes and guidance.

DOWNLOADABLE FILES:

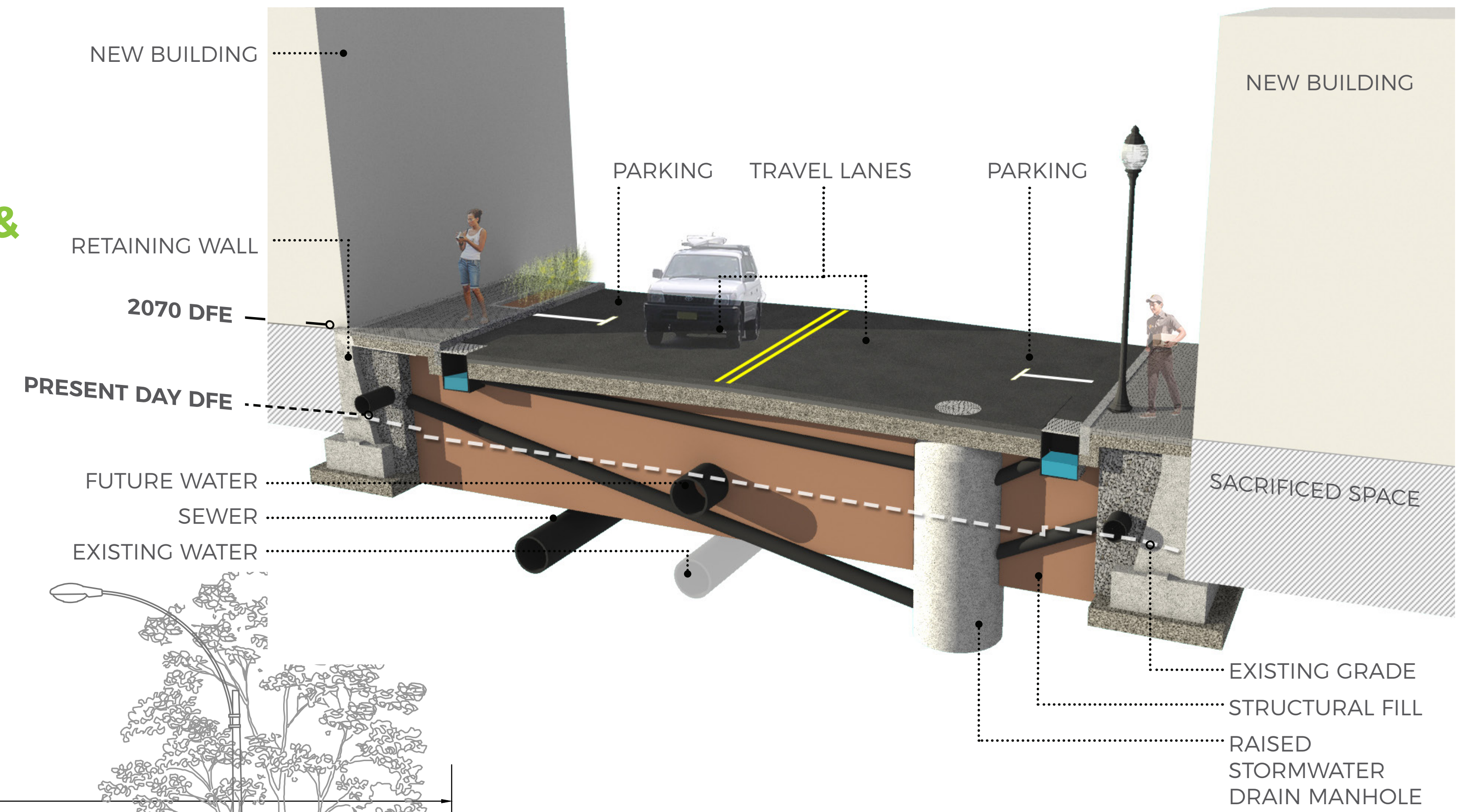
Standard PWD Details for reference and download can be found here

SAMPLE

B.4 SAMPLE RAISED ROADWAY- OPTION 2

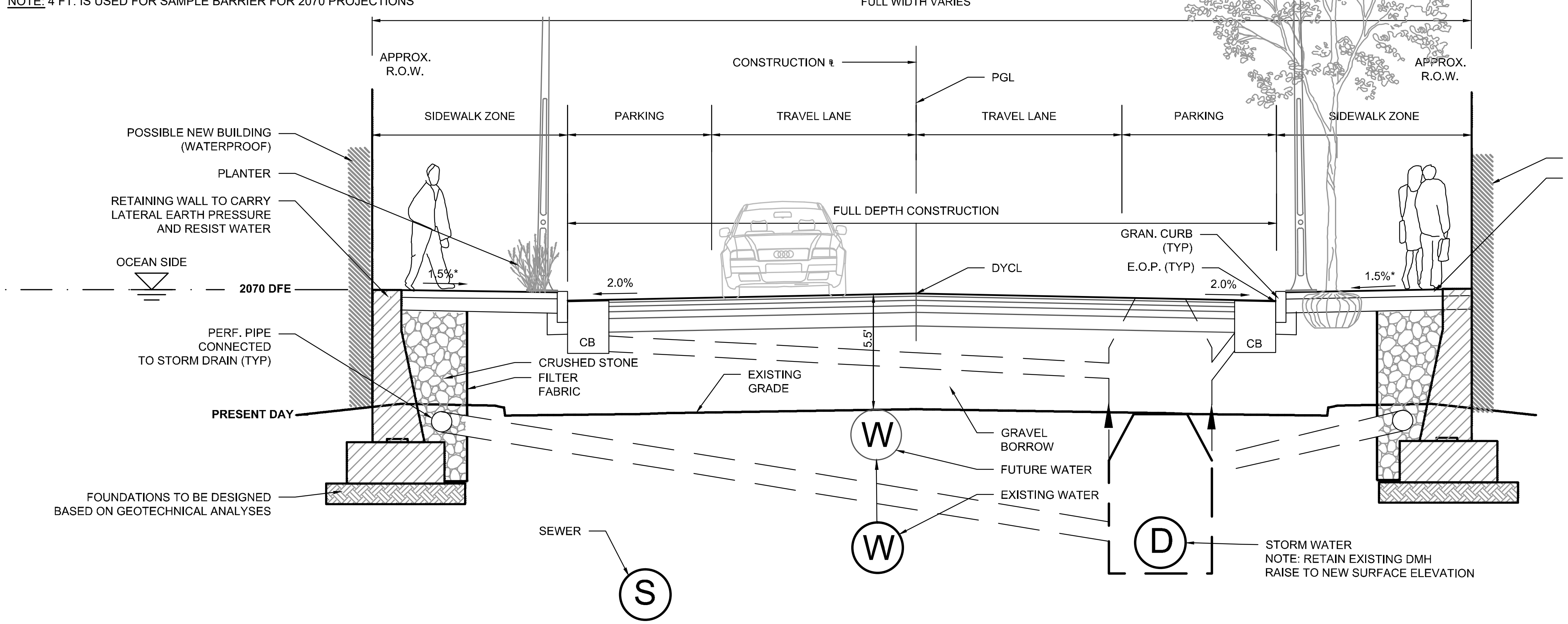
CAD

PDF



SAMPLE RAISED ROADWAY CROSS SECTION WIDTHS - NO SLOPES				
Increased Height from Existing Ground Surface (+___ ft)	Roadway Width	Sidewalk Width (total)	Minimum Crest Width	Total Width
1	26	14	40	40
2	26	14	40	40
3	26	14	40	40
4	26	14	40	40

NOTE: 4 FT. IS USED FOR SAMPLE BARRIER FOR 2070 PROJECTIONS



SAMPLE SECTION

SAMPLE - NOT TO SCALE

RECOMMENDED FOR NEW DEVELOPMENT ONLY

EXISTING STRUCTURES MAY NOT BE DESIGNED FOR INCREASED LOADS ASSOCIATED WITH GRADE CHANGE OR BE ACCESSIBLE TO VEHICLES AND/OR PEDESTRIANS

NOTES:

- OCEANSIDE WALL WOULD NEED WATERPROOF/IMPERVIOUS AND CORROSION RESISTANT DETAILING
- USED ONLY WITH NEW DEVELOPMENT - BUILDINGS AT BACK OF SIDEWALK DESIGNED FOR RAISED ROADWAY
- DIMENSIONS ARE BASED OFF BPWD ROADWAY STANDARDS - RESIDENTIAL
- FOR ADDITIONAL CONSIDERATIONS SEE GUIDELINES DOCUMENT
- DFE - DESIGN FLOOD ELEVATION (FREEBOARD INCLUDED)
- RECOMMENDED FOR NEW DEVELOPMENT ONLY - EXISTING STRUCTURE MAY NOT BE DESIGNED FOR INCREASED LOADS ASSOCIATED WITH GRADE CHANGE OR BE ACCESSIBLE TO VEHICULAR AND/OR PEDESTRIANS
- 2070 DFE: THE DESIGN FLOOD ELEVATION FOR THE 1% ANNUAL FLOOD EVENT WITH 40 INCHES OF SEA LEVEL RISE. DESIGN FLOOD ELEVATION (DFE) INCLUDES FREEBOARD ON TOP OF THE BASE FLOOD ELEVATION

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(E): publicworks@boston.gov

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FIGURE 10

PROPERTIES IMPACTED BY SAMPLE RAISED ROADWAY BARRIER

Proposed Barrier for the 2070 Design Flood Elevation (DFE)

Buildings Impacted by Proposed Raised Roadway

Parcels Affected by Proposed Buildout Area

250 0 250

Scale In Feet

FIGURE 11

PROPOSED LIMIT OF WORK AND DRAINAGE AREA FROM SAMPLE RAISED ROADWAY BARRIER

Catch Basin
Drainage Area (19.2 acres)
Proposed Limit of Work for the 2070 Design Flood Elevation (DFE)
Protected Open Space (0.8 acres In Drainage Area)

250 0 250
Scale In Feet

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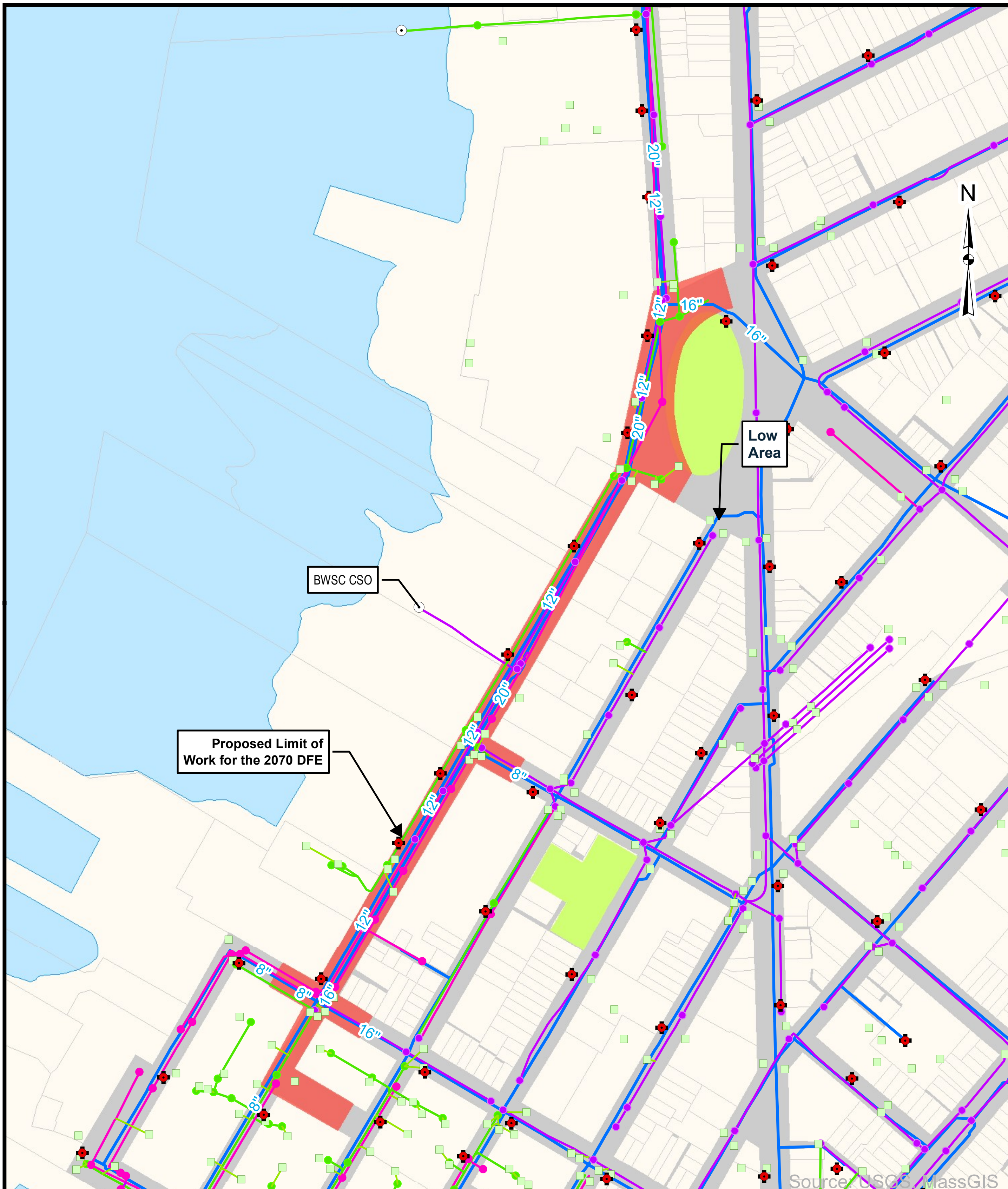

- Outfall
- Fire Hydrant
- Catch Basin
- Sanitary Manhole
- Storm Manhole
- Combined Manhole
- Combined Sewer
- Sanitary Sewer
- Storm Sewer
- Water Main
- Proposed Limit of Work for the 2070 Design Flood Elevation (DFE)
- Protected Open Space

FIGURE 12

EXISTING UTILITIES IDENTIFIED IN SAMPLE RAISED ROADWAY BARRIER PROJECT AREA

250 0 250

Scale In Feet

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FIGURE 13

PROPOSED LIMIT OF WORK FOR SAMPLE RAISED ROADWAY WITH TOPOGRAPHIC CONSIDERATIONS

Index Elevation Contour
Intermediate Elevation Contour
Proposed Barrier for the 2070 DFE
Land Below 21.5'

400 0 400
Scale In Feet

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SECTION 7.0 DEPLOYABLE FLOOD BARRIER GUIDANCE

7.1 DESCRIPTION AND ASSUMPTIONS

Deployable flood barriers are being employed across the City of Boston during flood events to protect private properties. This section provides guidance for selecting appropriate deployable flood barrier solutions, which are also referred to as temporary flood barrier solutions. Deployable flood barriers are defined as a barrier system that is deployed before and/or during a flood event and retracted after a flood event. The guidance provided is modeled after the *Temporary and Demountable Flood Protection Guide*, developed by the Environment Agency of the United Kingdom (Ogunyoye, 2011). Deployable barrier systems types vary and include, but are not limited to, barriers that are:

- pre-installed or partially pre-installed at the location of deployment;
- mobile, i.e. units brought to the location of deployment, constructed, and then removed, such as sand bags;
- passive systems that deploy and retract automatically based on flood levels without human intervention or electricity;
- rigid hard structures (i.e. walls);
- soft flexible structure (i.e. membranes);
- stackable or with features to adjust height of flood protection during an event;
- tubes filled with air or water;
- containers filled with water or aggregate (soil or rock);
- standalone flood defense systems; and/or
- connected to permanent flood protection barriers (such as reinforced walls and doors).

There are numerous deployable flood barrier types and products available, with demand growing for more interim solutions as extreme weather events are experienced more frequently. In lieu of a sample site location for context, this section presents a Comparison Matrix with several existing temporary flood defense barrier types including mobile modular rigid barriers, partially pre-installed flexible barriers, and pre-installed passive barriers. The specific products considered in these documents do not indicated endorsement or reflect a preference for one barrier type over another and do not represent the full spectrum of deployable flood barriers that are available. The intent of including specific products in the guidelines is to illustrate the framework for engineers and designers to evaluate the physical, structural, and operational capacity of products for a site. The process and sample considerations do not supersede local, state, or federal regulations.

If the site is within a flood pathway for the City of Boston, then engineers, designers, and developers should first consider if a permanent protection system is feasible. All sites considering deployable flood barriers should develop a plan for long-term flood protection in coordination with this process. A deployable flood barrier may be identified for temporary use while permanent solutions are design, permitted, and constructed. **The intent of the barrier should be to be deployed <u>only during storm events</u> (not during fair weather high or King tides) and not remain deployed once flood waters have receded.** Coordination with the City of Boston and surrounding stakeholders is necessary to implement deployable flood barriers within the public right-of-way. Temporary barriers may not impact ADA accessibility of the right-of-way when stored and/or deployed, and minimum travel lanes for pedestrians, bikes, and vehicles should be maintained. Emergency access, including access to fire hydrants, must be maintained.

Operational capacity is essential for effective deployment. The barrier may not provide flood protection if it is not deployed as designed and intended due to insufficient operations and maintenance (O&M) of the barrier. Detailed protocols for management, deployment, retraction, and emergency response are an integral part to this process. Owners should consider scenarios where the lead time (time between notice of a storm and successful deployment of barrier) is shorter than expected and/or trained manpower and equipment are not available; these scenarios are common due to the nature and variability of storms, as well as competing demands for limited resources in preparation of a storm. Deployable barriers may not be selected without considerations and documented plans for long-term permanent flood protection.

7.2 DEPLOYABLE BARRIER DESIGN CONSIDERATIONS

The design considerations for deployable flood barriers reflect a range of engineering, physical, structural, and operational characteristics for both the site and product. This framework mirrors the process established in Section 3.0 of the guidelines with some additional considerations included to evaluate product characteristics. To understand the differences between evaluating the site capacity and product capacity, this section is broken up into two sets of design considerations:

- Design Considerations for the Site
- Design Considerations for the Product

A comprehensive evaluation of design considerations for the site and products available is essential to finding the appropriate solution that fits the physical, structural, and operational needs.

Design Considerations for the Site

This is not a comprehensive list of all potential considerations and additional studies may be recommended to advance design. Refer to Section 3.0 Design Considerations for a list of additional considerations that apply to permanent structures and may apply to temporary structures. The designer, engineer, and/or planner should consider the following design considerations *prior* to barrier considerations.

DESIGN CONSIDERATIONS FOR THE SITE	
Climate Design Adjustments	► Refer to Section 2.0 and 3.0 for additional information. ► Identify the base flood elevation (BFE) for the 1% annual flood event. ► Map flood pathways on the site and surrounding areas. ► Evaluate the duration of flood (i.e. how long will the flood be on-site). ► Wind and Wave Impacts (wind is critical prior to flood events). ► Extreme Precipitation projections (water will be trapped inland of the barrier.).
Site Specific Constraints and Design Considerations	► Survey the existing location. ▲ Identify properties, boundaries, utilities, potential for debris. ► Identify the extent of barrier (width and height, including freeboard). ▲ Barrier should be designed to prevent flanking and reduce risk of overtopping. ▲ Evaluate the total length of the barrier. ► Zoning. ▲ Contact the Boston Planning and Development Authority (BPDA) to evaluate zoning regulations and requirements. ▲ Identify any current regulations that may prevent use of deployable barriers. ► Assess available open space for deployment and/or storage of barrier. ► Public Right-of-way (ROW). ▲ Barriers shall not encroach onto the ROW without coordination with the City of Boston. Deployed barriers must maintain a 4 ft. minimum accessible path of travel on the sidewalk, as well as minimum travel width and bike access lanes where applicable. ► Private Properties. ▲ Barriers may extend across several properties. Coordinate with neighbors and the City of Boston for layout and easement considerations.

Site Specific Constraints and Design Considerations (continued)

- Offsite Impacts (Adjacent and Downstream).
  - Deployable barriers may be designed in coordination with neighboring properties to provide a larger protection area.
  - The barrier should not preclude flood protection for adjacent parcels.
  - Evaluate the impact of the barrier on diverting flood water to unprotected areas.
  - Stormwater runoff must be considered when selecting deployable barriers. The implementation of barriers may change existing stormwater flow regime, which could lead to overloading of stormwater systems. Additionally, stormwater runoff may flood off-site areas and could create flooding situations in areas that otherwise might not be within the flood pathway.
- Ground and Terrain conditions.
  - Evaluate the ground condition where the proposed barrier is intended. Are there ground conditions that would impact the deployment of a barrier, such as curbs, undulations, hard surfaces, soft surfaces, snow and/or ice accumulation, slopes, etc.
- Subsurface conditions.
  - The subsurface conditions may not be able to support the deployable barrier. Refer to Section 3.0 for geotechnical considerations.
- Accessibility.
  - If barriers impact egress from a building, the building must be evacuated prior to deployment or additional evacuation measures must be considered.
  - Barriers must not preclude emergency access, including fire hydrant access.
- Volume Capture and Control.
  - Assess high intensity rainfall events (cloudbursts) in the design and modify designs to safely convey the discharge without causing downstream/upstream flooding.
  - The deployable barrier will need adequately sized conveyance and potential temporary mechanical pumping systems to manage the stormwater on the upgradient side of the barrier.
  - Pumping systems should be considered to handle stormwater volumes trapped on the dry side as well as potential overtopping during extreme storm surge to prevent flooding behind the barrier.
  - Stormwater management must include considerations of discharging pumped water so that it is in accordance with BWSC Standards.
- Structural Considerations.
  - Evaluate if the intended alignment of the barrier may connect to existing flood walls. Evaluate existing conditions. Refer to Section 3.0 for structural considerations.
- Incremental Considerations.
  - Consider products with the ability to increase in height or length during deployment.
  - Site specific incremental considerations, both vertical and horizontal, are as follows:
    - Boundaries – will the barrier tie into existing higher grades or walls?
    - Bridging gaps between permanent barrier solutions during storm events until a proper permanent solution can be achieved.
    - Master Plans – shall be changed according to the locations and sizes of barriers.
    - Planning – this project should be coordinated in conjunction with flood protection at relevant nearby sites.

Existing site/owner Operational Capacity **(Refer to Section 7.3 for O&M considerations)**	► Assess Operational Capacity. ▲ Manpower available before, during, and after storm events. ▲ Equipment available before, during, and after storm events. ▲ Technical capabilities of staff (laborer, operator, mechanic, etc.). ▲ Competing additional needs for manpower and equipment before, during and after storm events. ▲ Storage space available at site of off-site. ▲ Training & Inspection needs. ► Identify Available Lead Time. ▲ How long will it take from notice of storm event to get barrier to site? ▲ Reliability of flood notice and forecasting. ▲ What are the alerts/warning systems available? How much notice is typically given? ▲ Assess opportunities to increase lead time. ► False Alarm Cost. ▲ What are the costs/consequences of deploying when the storm event doesn't happen?

Design Considerations for the Product

Every deployable flood barrier has a set of physical, structural, and operational characteristics. Once the site specific and operational capacity is understood, several products may be identified for evaluation. The Comparison Matrix (Matrix) included in Section 7.3 is an example of the design considerations for several products. The products included in these guidelines are not intended to suggest an endorsement of any product or a preference of one barrier type over another. The information presented in the Matrix was provided by the product manufacturers. Refer to the Matrix for sample information and examples of considerations.

DESIGN CONSIDERATIONS FOR THE PRODUCT	
Physical Considerations	► Barrier type. ▲ Modular, rigid, flexible, pre-installed, partially pre-installed, etc. ► Product Dimensions. ▲ Height range. ▲ Width Range. ▲ Adjustable. ► Material Type. ▲ Resistant to environmental/chemical exposure. ▲ Mobile (wheels/cart compatible). ► Pre-Installation Site Modifications. ▲ Required modifications to site for barrier to be used. ► Average Design Life. ► Cost.
Structural Considerations	► Failure mechanisms. ▲ Sliding, excessive seepage, bearing capacity failure, overturning and collapse, settlement, uplift, shear, overtopping, pull out, structural failure boundary condition (overloading).

Structural Considerations (continued)	► Connection type. ▲ Bolt/Velcro/cable. ▲ Corrosion resistant. ▲ Surface requirements for connection. ▲ Connection strength. ► Damage resistance. ▲ Tear/puncture. ▲ Debris/impact. ▲ Tampering. ▲ Wave. ▲ Wind. ► Progressive failure mechanism likelihood.
Operational Considerations	► Installation needs. ▲ Site preparation required prior to deployment. ▲ Time range for deployment. ▲ Manpower required. ▲ Resources required. ▲ Ease of installation. ▲ Installation cost. ► Repair during storm event. ► Retraction needs. ▲ Preparation or cleaning/decontamination required prior to retraction. ▲ Time range for retraction. ▲ Manpower required. ▲ Resources required. ▲ Ease of retraction. ▲ Retraction cost. ► Storage. ▲ Storage container. ▲ Size of storage needed. ▲ Foldable/flexible parts. ▲ Stackable? How high? ► Re-use of product.
Industry Certification	► Industry standard certification/testing. ► Warranty.

7.3 OPERATION AND MAINTENANCE AND COST CONSIDERATIONS

Operations and maintenance (O&M) are critical to the performance of deployable flood barriers throughout its intended useful life. Additional descriptions of protocol recommendations and programs are included in the **Appendix F. Deployable Barrier O&M Considerations.** Using the understanding the operational capacity of the site and product, the following O&M considerations should be addressed:

O&M CONSIDERATIONS

Refer to **Appendix F. Deployable Barrier O&M Considerations** for more detailed considerations.

Develop Management Protocol	► Inspection and Maintenance Program. ► Communications Plan. ► Training. ► Annual Testing and Drills. ► Improvement.
Develop Deployment Protocol	► Notification of Storm Event. ► Lead Time Notification and Mobilization of Resources. ► Road Closures and Access. ► Site Preparation. ► Deployment. ► Stormwater Management. ► Real-Time Monitoring and Supervision. ► Damage Repair.
Develop Retraction Protocol	► Notification of Retraction. ► Mobilization of Resources. ► Site Cleanup (Cleaning and/or decontamination). ► Safety Check. ► Barrier Removal. ► Re-Storage of Non-Damaged Equipment. ► Maintenance, Repair, or Replacement. ► Review and Debrief. ► Removal of Contained Flood Waters.
Develop Failure Response Plan	► Emergency Notification Flowchart. ► Emergency Detection. ► Emergency Evaluation and Classification. ► Examples of Emergency Situations. ► Loss Prevention.

Cost considerations should reflect the features identified in the design considerations for capital costs and life-cycle costs of the infrastructure based on design considerations and existing information. Customization of deployable barriers allows for a range of probable costs. Costs can vary due to height and width requirements, storage capabilities and requirements, deployment and retraction times, and space availability. The Comparison Matrix in Section 7.3 includes a range of costs for a variety of products.

COST CONSIDERATIONS

Review Product Information	► Review the Comparison Matrix provided in Section 7.3 to review information provided by product manufacturers regarding product cost. The costs provided are to be assumed as general estimates and may not reflect the cost of a fully customized/designed barrier system.

Manufacturer Outreach	► Reach out to suppliers of products listed in the Comparison Matrix in Section 7.3 to request more detailed, site specific product cost information. ► The Comparison Matrix does not include all products that may be considered for a site. Populate the Comparison Matrix with additional products for comparison.
Budgeting	► The costs provided in the Comparison Matrix in Section 7.3 are estimates and may change based on the level of flood protection and site requirements. ► Budgets should be reviewed so that there are funds in place for the purchase, deployment, maintenance, and retraction of barrier products that meet criteria and considerations for the site
False Alarm Costs	► The cost associated with deploying and retracting a barrier should be considered in selecting a barrier, especially if the storm event does not happen. This is often referred to as a “false alarm” cost. ► If the required lead time is long, the chance of a false alarm cost increases because forecasts may change as the storm approaches. ► In addition to the financial cost of operations, the cost may be qualitative and include considerations for public perception, business continuity in the area, public transportation, and loss of social programs.
Annual and O&M costs	► Operation and maintenance costs will be assessed by current and project future wage rates and the manpower estimated for regular O&M associated with the selected barrier, including stormwater management. Refer to **Appendix F. Deployable Barrier O&M Considerations** for activities related to O&M. ► Annual costs should consider how deployment needs may change as storm events become more frequent and barrier deployment must occur more often. ► Costs should consider how deployable flood barriers may change once a permanent barrier solution is designed and implemented.
Capital Costs	► In addition to the costs associated with the barrier product, there may be additional site modification costs required for installation. ► There may be additional costs associated with permitting.

7.4 BARRIER SELECTION

The Comparison Matrix provided in the Section 7.3 includes a variety of available products with information from manufacturers for each option. The products identified in the guidelines are not an inclusive list. The Matrix should be updated with information from manufactures to include additional flood barrier types. Using the information in the previous sections, the designer should evaluate what additional studies are needed to advance design and selection of the barrier. It may be necessary to re-evaluate the barriers considered for the site based on the findings of the previous sections, and the designer should always consider long-term potential for flood protection as an alternative.

System reliability is critical to deployable flood barrier effectiveness. The designer should consider what opportunities exist to increase the reliability of the system, which may include designing redundancies, simplifying design connections, designing secondary flood water containment systems, implementing alert systems, on-going monitoring and inspection, and more. One of the main characteristics in the reliability of deploying flood barriers is the operational capacity for deployment. The designer should consider scenarios where trained manpower and equipment are not available even with protocols in place; often storm events increase demand of limited resources so plans should be in place for this scenario. Annual deployment drills are also often done in fair weather conditions and may not reflect actual storm events, such as snowy and icy Nor’easters. There should be a plan developed for scenarios where the flood barrier fails to deploy and an emphasis on safe-to-fail design, redundancy, and flood containment and emergency response.

The approach for the deployable flood barriers provides an opportunity to develop a plan for incremental adaptation over time. The final selection should consider how the deployable barrier will lead to a permanent barrier solution. The approach should include a unified vision for waterfront protection and public improvement. Designs must include coordination to identify temporary and permanent solutions that integrate with the physical environment, communities, and stakeholders. It is important to also consider existing and proposed resilience projects in the City of Boston. Climate Ready Boston has a map of these projects available on the Coastal Resilience Projects Tracker.

7.5 COMPARISON MATRIX AND SAMPLE DEPLOYABLE FLOOD BARRIER INFORMATION

Type	Product	PHYSICAL CHARACTERISTICS									
		Barrier Type	Product Dimensions		Adjustable/Height Can Increase During Service?	Mobility	Material Information		Pre-Installation Site Modification	Average Design Life	Cost
		Description	Height Range	Width Range	Yes/No	Wheels/Cart	Material Type	Resistant to Environmental and Chemical Exposure	(Slight/Moderate/Extensive) *Not including retrofitting existing structures	Number of Years/Uses	Up Front Cost
ENTER TYPE	***ENTER PRODUCT FOR COMPARISON***	*Barrier type and description*	*As provided by product manufacturer*	*As provided by product manufactuere*	*Applicable if additional barrier modifications are available for increased protection height*	*Applicable if product is designed with wheels, or cart-compatible*	*As provided by product manufacturer*	*As provided by product manufacturer*	*As provided by product manufacturer*	*As provided by product manufacturer*	*Custom pricing may be available, as well as unit-based costs*
Modular Barriers											
Rigid/Panel	Aquafence	Modular Barrier: Rigid panels that are placed together to form one cohesive barrier.	4 ft. to 9 ft.	Limitless (current longest stretch is 5100 lf.)	Potentially (Product available)	Yes	Marine grade laminate, stainless steel, aluminum, reinforced PVC canvas	Yes	Slight - Anchor installation for best performace (Varies by site)	50+ years	\$315/lf. - 4 ft. Height \$415/lf. - 5 ft. Height \$575/lf. - 6 ft. Height \$650/lf. - 7 ft. Height \$750/lf. - 8 ft. Height (Additional \$10/lf. for anchors)
Rigid/Panel	FB33 Adjustable Lift-Out Barrier	Modular Barrier: Rigid adjustable panels that can be used as single units or in multiples	6 in. increments from 1.5 ft. to 4 ft.	Dependent on barrier height	No	Yes	Carbon steel (stainless steel option available), neoprene, carbon steel mechanical tubing, closed-cell foam, mastic epoxy painted finishes	Yes	Slight - Optional removable mullions for multi-panel installation (Varies by site)	25+ years	Custom pricing based on required width and height
Rigid/Stop Log	CGSL Stop Logs	Modular Barrier: Stop log style barrier with customizable width and height	2:1 factor of safety based on material yield strength. Can increase height in 6 in. and 8 in. increments		Yes	Yes	6063-T5 aluminum panels, aluminum, low carbon steeel, neoprene seals (Viton and other materials available)	Yes	Moderate - sill/conversion frame installation will require site work (Varies by site)	25+ years	Custom pricing based on required height, width, and jamb type
Rigid/Stop Log	FastLogs Stop Logs	Modular Barrier: Stop log style barrier with customizable width and height	2:1 factor of safety based on material yield strength. Can increase height in 6 in. increments		Yes	Yes	Mill-finish alumnium, steel (primed with one coat rust inhibitive, lead free, red primer), high-density closed cell neoprene sponge	Yes	Moderate - frame/jamb installation will require site work (Varies by site)	25+ years	Custom pricing based on required height, width, and jamb type
Rigid/Hinged	PS Flood Barriers Hinged Flood Barrier (Single)	Modular Barrier: Hinged door barrier with customizable width and height	2:1 factor of safety based on material yield strength		No	Yes	Steel, stainless steel, 6063 aluminum, 6061 aluminum, EPDM rubber	Yes	Moderate - frame/jamb/sill installation will require site work (Varies by site)	25+ years	Custom pricing based on required width and height
Rigid/Sliding	PS Flood Barriers Sliding Flood Barrier	Modular Barrier: Sliding door barrier with customizable width and height	2:1 factor of safety based on material yield strength		No	Yes	Steel, stainless steel, 6063 aluminum, EPDM rubber	Yes	Moderate - frame/jamb/sill installation will require site work (Varies by site)	25+ years	Custom pricing based on required width and height
Membrane Barriers											
Flexible	ILC Dover Vertically Deployed Flex-Wall	Membrane Barrier: Flexible wall with rapid vertical deployment for building and equipment protection	Ideal height for constructability and deployment time is a DFE of 4 ft. above grade or less. Higher heights are possible with the addition of braces to the posts	With itermittent deployable posts, no real limit to span (10 ft. to 12 ft. between posts or connection points)	No	N/A	Kevlar webbings, PVC coated polyester, metal (stainless steel, etc.), H2O covers	Yes	Extensive - excavation efforts (1.5 ft. trench) are necessary for barrier installation (Varies by site)	20 years	Custom pricing based on required width and height; estimated cost range of \$350-550/sf.
Flexible	ILC Dover Side Deployed Flex Wall	Membrane Barrier: Flexible wall with rapid horizontal deployment for building and equipment protection	DFE heights of 1 ft. to 10 ft. above grade (typically, but can go higher)	6 ft. to 60 ft. with deployable or permanent posts	No	N/A	Kevlar webbings, PVC coated polyester, metal (stainless steel, etc.), H2O covers	Yes	Moderate - structural supports may be needed for barrier installation (Varies by site)	19 years	Custom pricing based on required width and height; estimated cost range of \$350-550/sf.
Passive Barriers											
Automatic	Self Closing Flood Barrier (SCFB)	Membrane Barrier: Self-rising floodgate. Rises automatically as floodwaters approach	Up to 12 ft. Design should be verified by structural calculations.	Limitless but requires vertical supports	No	N/A	PUR foam core, fiberglass, gaskets, galvanized steel	Yes	Extensive - excavation efforts are necessary for barrier installation (Varies by site)	25+ years	Custom pricing based on required width, height, loadings needed, and FEMA zones
Automatic	FloodBreak Gate	Membrane Barrier: Self-rising floodgate. Rises automatically as floodwaters approach	No practical limit. Design validated by structural engineer to 39 ft. height (multiple 12 ft. tall gates installed)	Limitless with no stanchions or vertical stops. (100 ft. length gates are installed without stanchions across highways)	No	N/A	Marine grade aluminum, stainless steel fittings, and EPDM rubber gaskets	Yes	Extensive - excavation efforts are necessary for barrier installation (Varies by site)	Decades of service life with minimal maintenance. Recommend to change gaskets every 10 years	Custom pricing based on required width and height

Notes:

1. The types and products provided are not endorsed by the City of Boston and do not indicate a preference for one barrier type over another. The list is not comprehensive and does not reflect all possible products on the market. As products are identified for possible use, they should be entered into this table to compare and contrast with other products. The products should comply with City of Boston policies, zoning, and regulations.
2. Product manufacturers should be contacted to provide content in this table and be able to provide back-up documentation for submittals.
3. The following framework is based on the methodology developed for "Temporary and Demountable Flood Protection Guide," (Ogunyoye, Fola, Richard Stevens, and Scott Underwood, 2011).

Type	Product	STRUCTURAL CHARACTERISTICS																		
		Potential Failure Mechanisms										Connection Type		Surface Requirements	Barrier Resistance to Damage/Load Low (likely damage)/Medium/High (unlikely damage)					Likelihood of Progressive System Failure
		Sliding	Excessive Seepage	Bearing Capacity Failure	Overturning & Collapse	Settlement	Uplift	Shear	Overtopping	Pull Out	Structural Failure Boundary Condition	Bolt/Velcro/ Cable etc.	Corrosion Resistant?	Flat/Dry/Hard etc.	Tear or Puncture	Debris/Impact	Tampering	Wave	Wind	Low/Medium/High
ENTER TYPE	***ENTER PRODUCT FOR COMPARISON***	*As per product manufacturer provided specifications and engineered studies of structural limitations*										*As provided by product manufacturer*	*Based on product material*	*Ideal and adaptable conditions as per manufacturer recommendations for proper barrier performance*	*As per product structural and material characteristics*	*As per product structural and material characteristics*	*As per product structural and material characteristics*	*As per product structural and material characteristics*	*As per product structural and material characteristics*	*As provided by product manufacturer engineered testing results*
Modular Barriers																				
Rigid/Panel	Aquafence	No	No	No	No	No	Yes	Yes	Yes	No	Yes	Bolt	Yes	Ideal conditions: conrete or asphalt, smooth surface Can adapt to: pitch changes, curbs and obstacles, grass, wet surfaces	High (no impact on system stability)	Medium - High	High (most parts that could be removed are under water)	Medium - High	High	Medium (only after damage)
Rigid/Panel	FB33 Adjustable Lift-Out Barrier	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Steel frame mounted to wall, chloroprene rubber seal gasket	Yes	Ideal conditions: smooth surface Can adapt to: sloped surfaces, curbs and obstacles	High	Medium - High	Medium	Medium - High	High	Medium (only after damage)
Rigid/Stop Log	CGSL Stop Logs	No	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	Jamb brackets	Yes	Ideal conditions: smooth surface Can adapt to: sloped surfaces, curbs and obstacles	High	High	Medium	Medium - High	High	Medium (only after damage)
Rigid/Stop Log	FastLogs Stop Logs	No	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	Jamb brackets mounted to face of opening	Yes	Ideal conditions: smooth surface Can adapt to: sloped surfaces, curbs and obstacles	High	High	Medium	Medium - High	High	Medium (only after damage)
Rigid/Hinged	PS Flood Barriers Hinged Flood Barrier (Single)	Yes	Yes	No	No	No	Yes	No	Yes	No	Yes	Frame mounted to existing structure, rubber seal	Yes	Ideal conditions: smooth surface, poured concrete or filled CMU. Cannot adapt to curves, slopes, or obstacles.	High	Medium - High	Medium	Medium - High	High	Low
Rigid/Sliding	PS Flood Barriers Sliding Flood Barrier	No	Yes	No	No	No	No	No	Yes	No	Yes	Frame mounted to existing structure, rubber seal	Yes	Ideal conditions: smooth surface, poured concrete or filled CMU. Cannot adapt to curves, slopes, or obstacles.	High	Medium - High	Medium	Medium - High	High	Low
Membrane Barriers																				
Flexible	ILC Dover Vertically Deployed Flex-Wall	No	No	No	No	No	No	No	No	No	Yes	Metal post receivers and seal bars	Yes	Various	High	High	High	High	High	Low
Flexible	ILC Dover Side Deployed Flex Wall	No	No	No	No	No	No	No	No	No	Yes	Receiver posts	Yes	Various	High	High	High	High	High	Low
Passive Barriers																				
Automatic	Self Closing Flood Barrier (SCFB)	No	No	No	No	No	Yes	Yes	Yes	No	Yes	N/A	N/A	Designed for all applications and site conditions. Work will need to be done to ensure barrier will work when installed	High	High	High	High	High	Low
Automatic	FloodBreak Gate	No	No	No	No	No	Yes	Yes	Yes	No	Yes	N/A	Yes	Can be installed on sloped surfaces (up or down slope), have been installed in a variety of environments (marine, desert, and cold northern climates)	High	High	High	High	High	Low

Notes:

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2. Product manufacturers should be contacted to provide content in this table and be able to provide back-up documentation for submittals.
3. The following framework is based on the methodology developed for "Temporary and Demountable Flood Protection Guide," (Ogunyoye, Fola, Richard Stevens, and Scott Underwood, 2011).

Type	Product	OPERATIONAL CHARACTERISTICS										
		Installation Needs						Repair During Service	Retraction Needs			
		Lead Time (Short/Long)	Time Range	Manpower Required	Resources Required	Pre-Storm Site Preparation	Installation Cost	Yes/No	Time Range	Manpower	Resources Required	Retraction Cost
ENTER TYPE	***ENTER PRODUCT FOR COMPARISON***	*Short: Under 30 minutes Long: 30+ minutes*	*As provided by product manufacturer based on previous site installations*	*As provided by product manufacturer for optimal installation times*	*As provided by product manufacturer; what may aide in easing the installation process*	*Any necessary site work to prepare for ideal barrier installation conditions*	*Installation cost based on area wage rates and required crew sizes*	*Whether or not the barrier is accessible for repairs while in service*	*As provided by product manufacturer based on previous site retraction times*	*As provided by product manufacturer for optimal retraction times*	*As provided by product manufacturer; what may aide in easing the retraction process and what may be necessary to remove debris and water*	*Retraction cost based on area wage rates and required crew sizes*
Modular Barriers												
Rigid/Panel	Aquafence	Long	1 hour: 150 lf. of 4 ft. and 5 ft. panels 1 hour: 120 lf. of higher height panels	6-8 people	Stored off site: flatbed truck, box truck, forklift Stored on site: cart/dolly/A frame, palette jack Tools: battery powered drill	Pre-install drop in sleeve anchors for panel connection (best stability)	Dependent on crew size, wage rate, and transportation needs	Yes	1 hour (same process as installation, plus washing with fresh water hose)	6-8 people	Stored off site: flatbed truck, box truck, forklift Stored on site: cart/dolly/A frame, palette jack Tools: Electric drill to speed up retraction time, broom/rake to remove debris, towels to wipe panels dry, water hose	Dependent on crew size, wage rates, transportation costs, amount of debris to be cleared
Rigid/Panel	FB33 Adjustable Lift-Out Barrier	Short	Under 10 minutes	1-3 people	None; compression clips are hand tightened	Debris clearing may be necessary to ensure ground is free of debris	Dependent on crew size and wage rates	No	Under 1 hour	1-3 people	Possibly a broom or pump to clear debris and remove excess water	Dependent on crew size, wage rates, amount of debris to be removed
Rigid/Stop Log	CGSL Stop Logs	Long	Under 1 hour	8-10 people	Ratchet wrench	Debris clearing may be necessary to ensure ground is free of debris	Dependent on crew size and wage rates	No	Under 1 hour (dependent on width and height of barrier)	1-3 people	Possibly a broom or pump to clear debris and remove excess water	Dependent on crew size, wage rates, amount of debris to be removed
Rigid/Stop Log	FastLogs Stop Logs	Long	Under 1 hour	8-10 people	None; hand tightened installation	Debris clearing may be necessary to ensure ground is free of debris	Dependent on crew size and wage rates	No	Under 1 hour (dependent on width and height of barrier)	1-3 people	Possibly a broom or pump to clear debris and remove excess water	Dependent on crew size, wage rates, amount of debris to be removed
Rigid/Hinged	PS Flood Barriers Hinged Flood Barrier (Single)	Short	Under 5 minutes	1-3 people	None; hand tightened installation	Clean all sealing surfaces and clear area around barrier of any debris	Dependent on crew size and wage rates	No	Under 1 hour	1-3 people	Possibly a broom or pump to clear debris and remove excess water	Dependent on crew size, wage rates, amount of debris to be removed
Rigid/Sliding	PS Flood Barriers Sliding Flood Barrier	Short	Under 5 minutes	1-3 people	None; hand tightened installation	Clean all sealing surfaces and clear area around barrier of any debris	Dependent on crew size and wage rates	No	Under 1 hour	1-3 people	Possibly a broom or pump to clear debris and remove excess water	Dependent on crew size, wage rates, amount of debris to be removed
Membrane Barriers												
Flexible	ILC Dover Vertically Deployed Flex-Wall	Short	Assuming no brace on interim posts, approximately 5 minutes per 20 ft.	1-3 people	Ratchet wrench and screw driver. Torque wrench can ensure the best seal	Clearing of area where barrier will be set up, placing of support posts	Dependent on crew size and wage rates	No	Same as installation. Possible additional time to remove debris and residual water.	1-3 people	Ratchet wrench and screw driver. Torque wrench can ensure the best seal. Broom/rake to remove debris.	Dependent on crew size, wage rates, amount of debris to be removed
Flexible	ILC Dover Side Deployed Flex Wall	Short	Varies. Fully clamped system for a 20 ft. wide system at 6 ft. DFE: 30 minutes Weighted skirt system for a 20 ft. wide system at 6 ft. DFE: 5 minutes	1-3 people	Ratchet wrench and screw driver. Torque wrench can ensure the best seal	Clearing of area where barrier will be set up, placing of support posts	Dependent on crew size and wage rates	No	Same as installation. Possible additional time to remove debris and residual water.	1-3 people	Ratchet wrench and screw driver. Torque wrench can ensure the best seal. Broom/rake to remove debris.	Dependent on crew size, wage rates, amount of debris to be removed
Passive Barriers												
Automatic	Self Closing Flood Barrier (SCFB)	N/A - barrier automatically deploys	30 seconds to a few minutes, depending on flood characteristics	N/A	N/A	Ground and concrete work needed for initial installation (provided by other), debris clearing may be necessary prior to event	Dependent on possibility of manual deployment (crew size and wage rate)	No	Under 10 minutes	1-2 people	Possibly a broom or pump to clear debris and remove excess water	Dependent on crew size and wage rate
Automatic	FloodBreak Gate	N/A - barrier automatically deploys	Depends on water velocity	N/A	None	None. Self clearing. Annual inspection and cleaning is recommended.	None in passive move. Manual lift by forklift (2 employees, wage rate varies) or optional push button hydraulic lift	No	Floats down as water recedes	None in passive mode. 1-2 people for manual retraction	Self retracting in passive mode. Broom or power wash after flood event.	Dependent on crew size and wage rate

Notes:

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2. Product manufacturers should be contacted to provide content in this table and be able to provide back-up documentation for submittals.
3. The following framework is based on the methodology developed for "Temporary and Demountable Flood Protection Guide," (Ogunyoye, Fola, Richard Stevens, and Scott Underwood, 2011).

Type	Product		OPERATIONAL CHARACTERISTICS					CERTIFICATION		
		Reuse of Product (Can be used multiple times)	Storage					Industry standard certification/testing	Warranty	Selection preferred
		Yes/No	Mobile Unit	Stored In	Foldable/Flexible Parts	Stackable	Stackable Height	FM Global, National Flood Barrier Testing & Certification Program	Number of Years	Y/N
ENTER TYPE	***ENTER PRODUCT FOR COMPARISON***	*Based on material resistance to environmental and chemical elements*	*Can the product be moved to other storage locations*	*As per product manufacturer provided storage units*	*Determined by material of barrier; rigid (foldable) or fabric based (flexible)*	*Determined by product design*	*As per product manufacturer provided storage unit or structural limits of barrier components*	*Industry standard certification/testing is available for many barrier types*	*As provided by product manufacturer*	*Compare Products for Site*
Modular Barriers										
Rigid/Panel	Aquafence	Yes	Yes	Storage crate	Foldable	Yes	3 ft. and 5 ft. panels: 63 lf./crate, crates stack 4-high. 250 ft. per 4x7 ft. space 6, 7, 8 ft. panels: 36 lf./crate, crates stack 4-high. 144 ft. per 4x7 ft. space	FM Approved, National Program Tested and Certified	Standard 2 year manufactureres warranty; extension available with service contract	
Rigid/Panel	FB33 Adjustable Lift-Out Barrier	Yes	Yes	Hanging bracket	No	Yes	Bracket dimensions are 38 in. x 17 in.	FM Approved	1 year limited warranty against defects and workmanship from date of shipment	
Rigid/Stop Log	CGSL Stop Logs	Yes	Yes	Rack	No	Yes	10 ft. maximum stackable height	NOT FM approved, exceeds FEMA and NFIP Floodproofing Certification Standards	5 year warranty	
Rigid/Stop Log	FastLogs Stop Logs	Yes	Yes	Rack	No	Yes	10 ft. maximum stackable height	FM Approved	1 year limited warranty against defects and workmanship from date of shipment	
Rigid/Hinged	PS Flood Barriers Hinged Flood Barrier (Single)	Yes	No, stored in place at deployment location	Stored on site/preinstalled	No	N/A	N/A	NOT FM approved but barriers are designed to meet the same criteria. Can be third party tested for an additional cost	0 year limited warranty against defects and workmanship from date of shipment. Additional manufacturers warranty available for purchase totaling up to 5 years	
Rigid/Sliding	PS Flood Barriers Sliding Flood Barrier	Yes	No, stored in place at deployment location	Stored on site/preinstalled	No	N/A	N/A	NOT FM approved but barriers are designed to meet the same criteria. Can be third party tested for an additional cost	1 year limited warranty against defects and workmanship from date of shipment. Additional manufacturers warranty available for purchase totaling up to 5 years	
Membrane Barriers										
Flexible	ILC Dover Vertically Deployed Flex-Wall	Yes	No, stored in place at deployment location	Trench box determined by custom barrier size	Flexible	N/A	N/A	NOT FM Approved, Various ASTM Standards, FM2510, Federal Standard 191 (Textile Test Methods), Federal Motor Vehicle Safety Standard 302, and NASA Standards	Flexibility available. Standard 1 year from date of shipment. Additional warranty for purchase	
Flexible	ILC Dover Side Deployed Flex Wall	Yes	No, stored in place at deployment location	Storage container determined by custom barrier size	Flexible	N/A	N/A	NOT FM Approved, Various ASTM Standards, FM2510, Federal Standard 191 (Textile Test Methods), Federal Motor Vehicle Safety Standard 302, and NASA Standards	Flexibility available. Standard 1 year from date of shipment. Additional warranty for purchase	
Passive Barriers										
Automatic	Self Closing Flood Barrier (SCFB)	Yes	No, stored in place at deployment location	Stored underground/ preinstalled	N/A	N/A	N/A	Not FM rated, meets FEMA flood protection requirements	5 year warranty on material and installation	
Automatic	FloodBreak Gate	Yes	No, stored in place at deployment location	Stored underground/ preinstalled	N/A	N/A	N/A	No testing methodology for permanently installed passive automatic barriers. Passed every customer test and proven in dozens of flood events. Company is hopeful to be able to participate in FM Approval in the next few years	Standard 1 year limited warranty. Extension available with service contract	

Notes:

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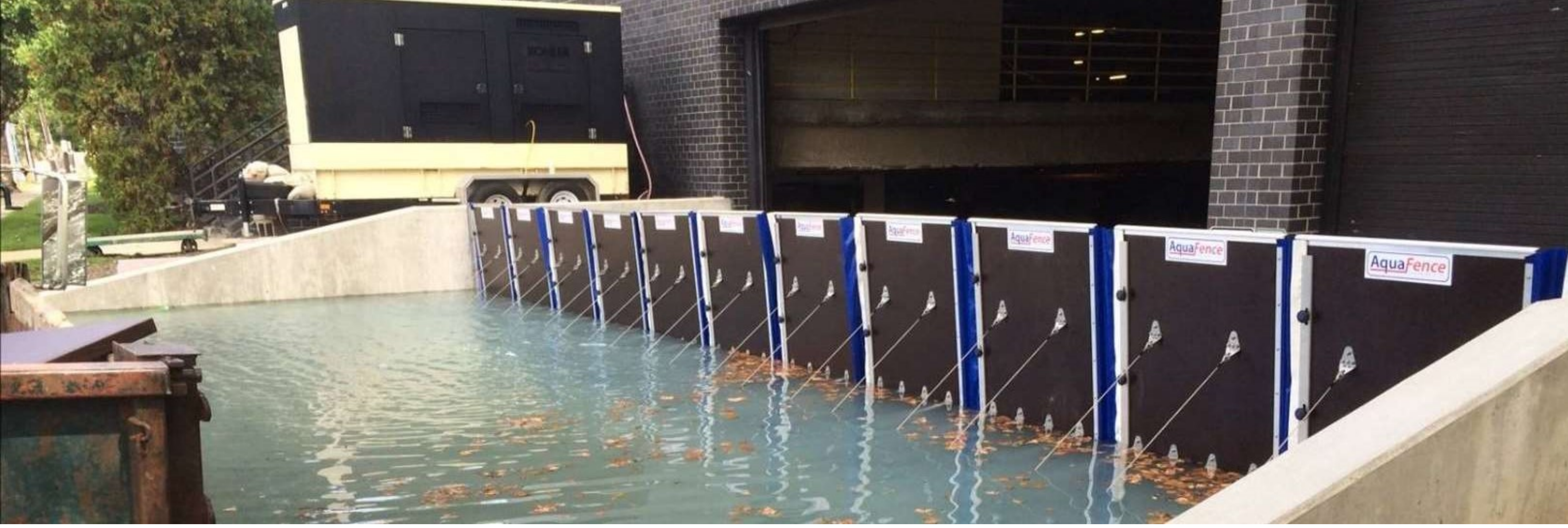


AquaFence®

AquaFence products are used across North America for new construction, existing buildings, water diversion, construction site protection, perimeter protection, interior asset protection, and entrance protection.

AquaFence has the highest-level certifications for Flood Barriers from FM Approvals, US Army Corp of Engineers, and ASFPM. AquaFence is code compliant throughout major metropolitan areas and recognized as a minimally invasive solution with little prep work and no fill material needed.

Municipalities, transportation hubs, commercial properties and industrial complexes worldwide choose AquaFence for its simplicity, rapid deployment, reliable construction, reusability, and ease of break down and storage. This makes AquaFence the leading and most cost effective choice in Flood Barrier protection.

Highlights

- Deploy 100 linear ft./hour with 4-person team
- Unlimited Barrier Length
- No Fill Material Needed
- Minimal Advance Site Work
- No Heavy Equipment Needed
- Reusable dozens of times
- Easy Breakdown
- Site Specific Customizations
- Stackable Storage Crates

US Army Corps of Engineers®

FM APPROVED

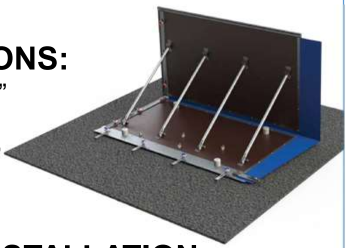
CODE COMPLIANT

- International Building Code IBC 2015
- ASCE 7-10 – Minimum Design Loads for Buildings and Other Structures
- ASCE 24-14 – Flood Resistant Design for Construction

AquaFence®

STANDARD BARRIER SPECIFICATIONS

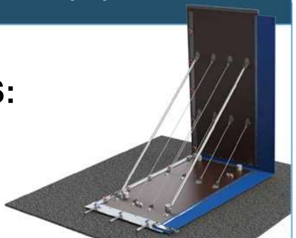
V1200 (4')



DIMENSIONS:
Height: 47.2"
Width: 82.7"
Depth: 47.2"

PANEL INSTALLATION:
Deployment Time 100 linear feet per hour (3-4 person crew)

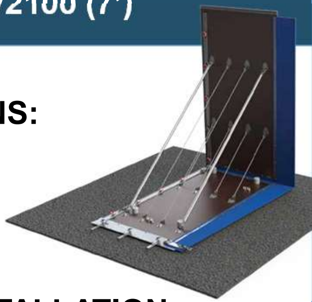
V1800 (6')



DIMENSIONS:
Height: 70.9"
Width: 47.2"
Depth: 70.9"

PANEL INSTALLATION:
Deployment Time 90 linear feet per hour (3-4 person crew)

V2100 (7')



DIMENSIONS:
Height: 82.7"
Width: 47.2"
Depth: 82.7"

PANEL INSTALLATION:
Deployment Time 80 linear feet per hour (3-4 person crew)

MATERIALS

- Marine Laminated Plywood
- Stainless Steel
- Aluminum
- PVC Canvas
- Closed Cell Gasket

RECOMMENDED TOOLS

- Rechargeable Hand Drill
- Pallet Jack or U-Frame Cart

CORNER CONFIGURATIONS

SIDE CLOSERS

STORAGE

Stored in reusable, click lock, stackable wooden crates (L 7.38' x W 4.15' x H 4.23') which can be stacked 4 high. After a deployment, the panels should be cleaned and dried for storage and future use.

SINGLE CRATE STORAGE CAPACITY	
63 linear feet/crate	V1200
36 linear feet/crate	V1800 & Higher

CONTACT

Adam Goldberg
203-939-5176
Adam.Goldberg@AquaFence.com

AquaFence U.S.A.
700 US Hwy 46
Clifton, NJ 07013

www.aquafence.com

PRESRAY

Watertight Products & Flood Protection

Adjustable Flood Barrier with Mechanical Seals

This unique, adjustable flood barrier provides effective flood protection up to 48" in height for almost any door or other opening. The FB33 has been tested and certified by FM Approvals® and exceeds FEMA and NFIP Floodproofing Certification Standards.

Simply set the FB33 panel between pre-installed brackets, turn the handle to expand the sides of the panel, hand tighten the compression clips to create a seal against the floor surface, and walk away. It's that easy.

The FB33 features a patented design that keeps the water out, yet is lightweight and is easily deployed by one person.

A single three-foot-wide FB33 can take the place of 60 sandbags and weighs about the same as one. And, unlike sandbags, it's fast and easy to deploy.

APPLICATIONS — THE FB33 AT WORK…

The FB33 Modular Flood Barrier is perfect for doorways, loading docks, garage doors or any other openings in municipal, industrial or commercial facilities. The FB33 has also been popular for retail stores and strip malls, as, well as apartments and condominiums. If your building is seaside, or in a location prone to flooding, the FB33 may be the perfect solution.

- Patented design is tough, reliable and lightweight
- Modular design allows for easy storage and deployment
- Suitable for new or existing construction
- Custom built for any sized opening
- Multiple panels can be connected with optional mullions
- Exceeds FEMA & NFIP Floodproofing Certification Standards

The FB33 has gone through rigorous impact and leak testing by FM Approvals® and has proven effective and reliable in the field.

www.presray.com ■ 845.373.6700

FB33 PRODUCT SPECIFICATIONS

FB33

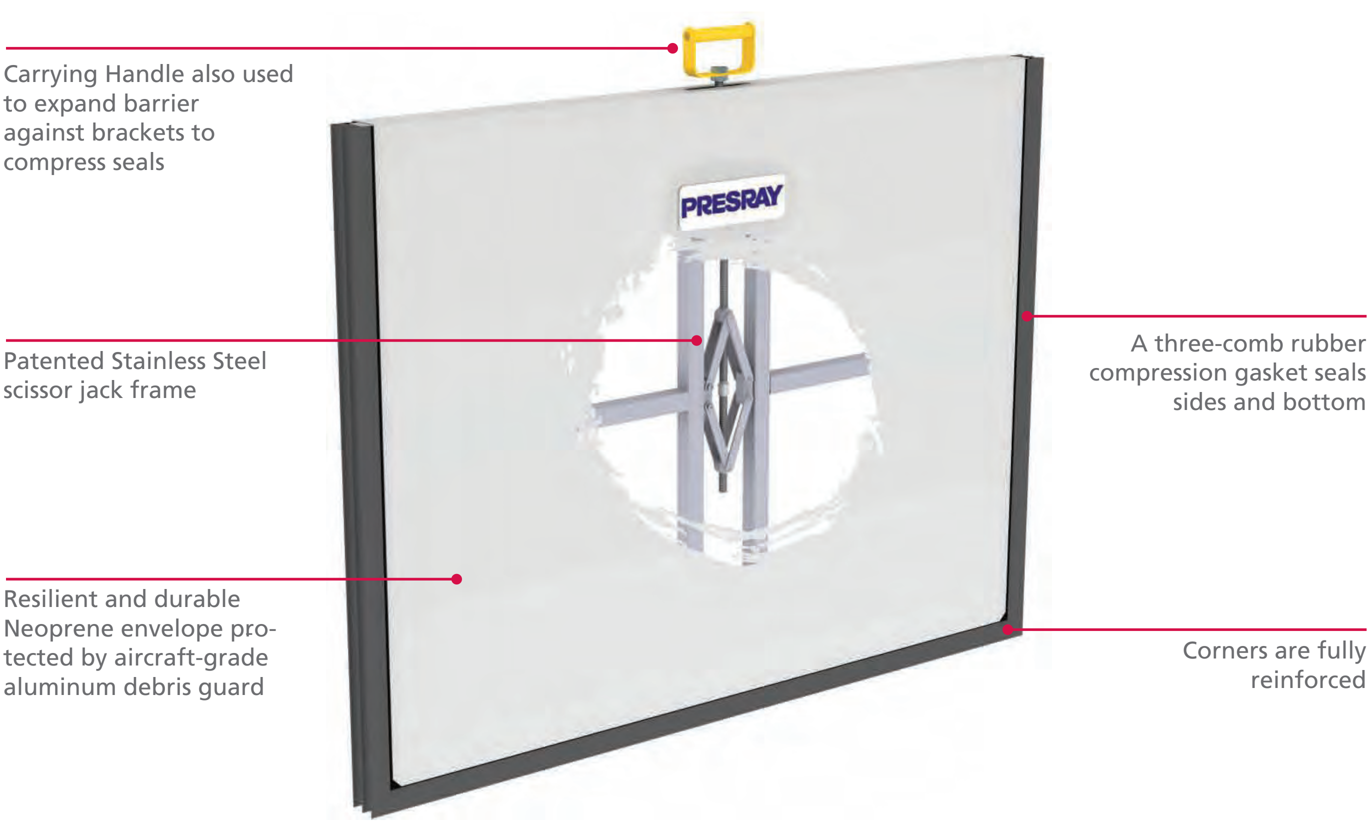
Size	Custom built to the width of the opening
Panel Frame	Carbon Steel mechanical tubing
Panel Envelope	Durable Neoprene
Mounting Brackets	ASTM A569 Carbon Steel (Stainless Steel optional)
Debris Guard	ASTM A569 Carbon Steel (Stainless Steel optional)
Seals	Three-comb, closed-cell foam gaskets
Hardware	Mounting anchors: Stainless Steel when applicable Optional removable mullions for multi-panel installation
Finish	Panel: high solids mastic epoxy painted Wall frame: high solids mastic epoxy painted

AVAILABLE OPTIONS

- Removable mullions to connect multiple panels for openings too wide for single panel
- Stainless Steel wall bracket

BUILT TO MEET YOUR REQUIREMENTS

The FB33 Modular Flood Barrier is custom built to the width of your opening. Depending on the specific nature of your installation, different brackets are used to mount the panel either between the door jambs, or face mounted on the outside of the opening. These steel brackets provide a smooth and strong connection to the wall of the building structure.



FOR MORE INFORMATION

845.373.6700 ■ www.presray.com ■ contact@presray.com

PRESRAY

Watertight Products & Flood Protection

Stackable Flood Barrier with Mechanical Seals

This heavy-duty, stop-log-style flood barrier provides reliable flood protection for wide openings that are subject to relatively high floodwaters. The patented, modular design of CGSL stop logs enables convenient storage and transportation options to site; and easy deployment by one or two people when needed. Compression gaskets, made of high-density, closed-cell neoprene, provide an effective water seal with minimum maintenance. An aluminum sill plate protects recessed threshold to prevent tripping hazard when barrier is not in use.

- Patented design can handle seated and unseated loads
- Compression gaskets provides effective protection with minimum maintenance
- Jamb is on the outside leaving opening clear
- 6″ or 8″ aluminum stop logs are rust free and highly durable
- Exceeds FEMA & NFIP Floodproofing Certification Standards

HEAVY-DUTY FLOOD PROTECTION

CGSL flood barriers exceed FEMA and NFIP Floodproofing Certification Standards. When floodwaters threaten, simply stack logs on top of each other and tighten dogs and bolts to secure the logs. Barriers are available in 6″ and 8″ high logs and are engineered for higher flood waters as compared to our line of FastLogs.™ Various barrier heights can be achieved by simply adding additional logs. These barriers are easily stored and transported when needed.

APPLICATIONS — THE CGSL AT WORK…

CGSL Stop Logs provide effective flood protection in commercial & industrial applications and for critical infrastructure and civic facilities such as transit systems, utilities, stadiums and parking garages. These barriers are engineered to handle seated and unseated loads in large openings, where very low leakage is required in large openings. Suitable for new or existing construction.

www.presray.com ■ 845.373.6700

PRESRAY

PRODUCT SPECIFICATIONS	CGSL
Size	Custom built to match opening size
Panel	6063-T5 aluminum channels
Frame	Low carbon steel with aluminum jamb covers
Seals	Presray type 25 durometer, fully-molded neoprene (Viton® and other materials are available for special environments)
Sill Cover	Aluminum plate
Finish	Panel: Bright aluminum plate Conversion Frame: Primed with rust inhibitive, lead free, red primer

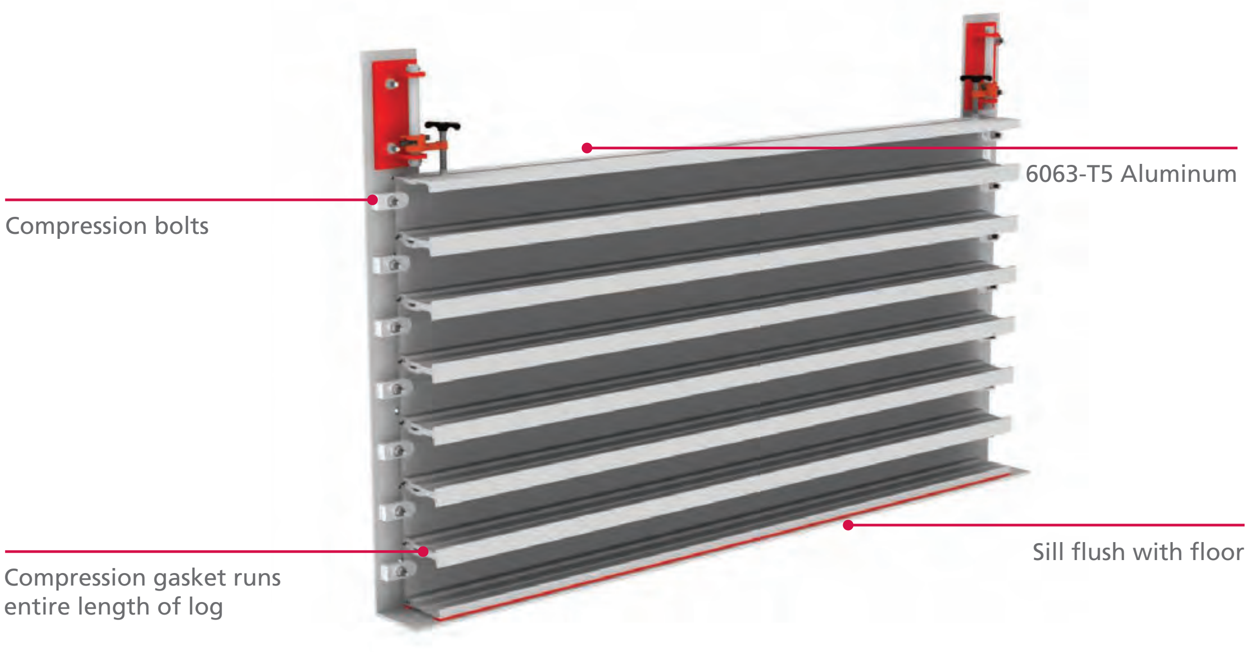
AVAILABLE OPTIONS

- Removable jamb when face mount jamb can't be used
- Compression Gaskets available in Viton® and other materials
- Hinged cover plates for jamb sides and floor sill available in a variety of materials

CUSTOM BUILT TO MEET YOUR REQUIREMENTS

Every CGSL Flood Barrier is custom built from shop drawings to ensure that it meets the special needs of your building or facility.

Barrier is designed with a minimum of a 2:1 factor of safety based on material yield strength, and will provide an effective seal against the flood level for which it is designed.



FOR MORE INFORMATION

845.373.6700 ■ www.presray.com ■ contact@presray.com

FASTLOGS®

FM APPROVED

Stackable Flood Barrier

Using an ingenious, patented design, FastLogs provide lightweight, cost-efficient and reliable flood protection for openings in most buildings. FastLogs are durable and easy to deploy by a single person without any tools.

FastLogs have been tested and certified by FM Approvals® and exceed FEMA and NFIP Floodproofing Certification Standards.

Compression seals are made of high-density, closed cell neoprene sponge between the barrier, wall jambs and floor surface. Finished Shrouds protect the Jamb Brackets when not in use, and can be painted to match the building's color scheme to minimize any aesthetic impact.

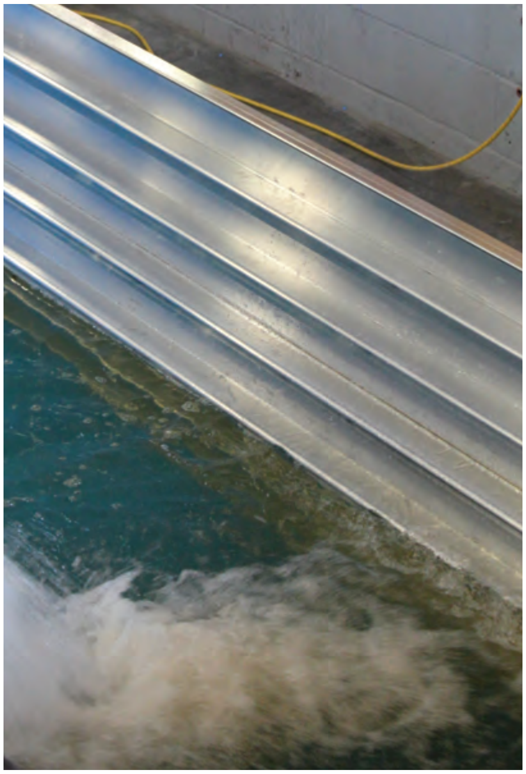
Various barrier heights can be achieved in 6" increments by simply adding additional logs. FastLogs are available in three models: Light Duty (LD), Standard Duty (SD) and Heavy Duty (HD).

APPLICATIONS — FASTLOGS AT WORK...

FastLogs are perfect for large openings, garage doors, loading docks and other openings that require rapid, easy-to-install protection where very low leakage is acceptable.

The ingenious interlocking design of FastLogs causes water pressure against the barrier to tighten the logs by transferring horizontal water pressure into downward pressure on the compression seals located across the bottom of each log.

- Easy and affordable flood protection
- Minimum impact on aesthetics of building
- Heavy-duty, rust-free components
- Logs are easy to store
- Patented design exceeds FEMA & NFIP floodproofing certification standards



PRESRAY

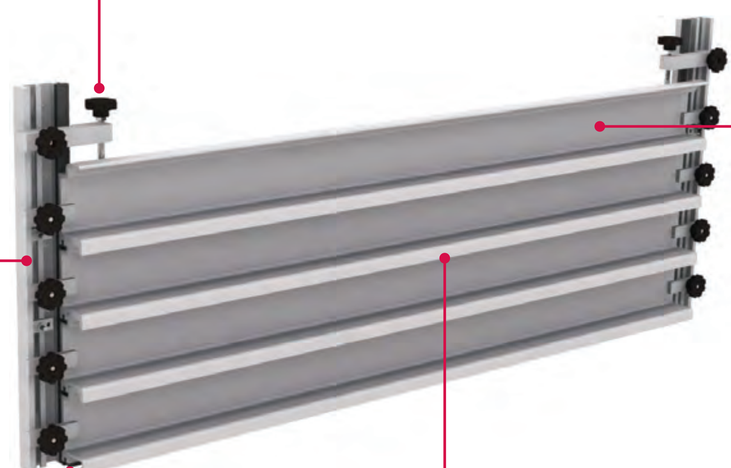
FASTLOGS-SD PRODUCT SPECIFICATIONS	FASTLOGS
Logs	Presray AL6061-T6 aluminum channels
Frames	Presray AL6061-T6 aluminum jamb Extrusion Steel jambs optional for certain conditions
Seal	Presray compression gasket composed of high-density closed cell neoprene sponge with skin, retained in the stop logs and jambs
Hardware	Presray Compression Brackets; Presray Hold Down Brackets; KN8C Turn Knobs
Finish	Stop logs mill-finish aluminum; jambs mill-finish aluminum Steel jambs (if used) primed with one coat rust inhibitive, lead-free, red primer

CUSTOMIZED TO MEET YOUR REQUIREMENTS

Custom cut and assembled to the exact dimensions for your opening, FastLogs are designed with a minimum of 2:1 factor of safety based on material yield strength.

FastLogs are mounted in front of the opening using Jamb Brackets mounted on the face of the building. The Jamb brackets have mounting holes for concrete anchors and bolts (options include epoxy anchors for block walls, and studs for concrete embedment).

Short ordering times are possible because Presray keeps the aluminum logs, jamb brackets and hardware always in stock.



FOR MORE INFORMATION
845.373.6700 ■ www.presray.com ■ contact@presray.com

Model: HSS–550 (Single), HPS–555 (Paired)

Hinged Flood Barriers

PS Flood Barriers

PS Flood Barriers™
Solutions That Hold Water

Hinged Flood Barriers are designed specifically for the height of water protection you require. The barriers are permanently installed and stored in the open position. During flooding, the Hinged Flood Barrier is swung closed and is latched, providing flood protection. The Hinged Flood Barrier is available in a single swing or paired swing configuration.

The Hinged Flood Barrier comes in two variations. The HSS-550 is a single swing flood barrier and the HPS-555 is a "paired swing" flood barrier. Depending upon the layout of your facility, the offering of a single or paired hinged barrier allows for flexibility when designing the flood protection system.

Standard Features:

- Available in mild steel, stainless steel, or aluminum.
- Compression seal—requires no compressed air for activation.
- Latch system designed for simple, quick deployment.

Safe.
Simple.
Durable.

Made in USA.

Application Use:

- Walk doors.
- Sectional doors.
- Retaining walls.
- Driveways.
- Store fronts.
- Interior hallways/room.

Benefits:

- Quick placement when needed.
- Can be done with or without a raised sill.
- Minimum personnel needed to close flood barriers.

Custom sizing and design available.

877.446.1519

psfloodbarriers.com

PS DOORS

PS DOORS
Attn: PS Flood Barriers
1150 South 48th Street
Grand Forks, ND 58201
Phone: 701.746.4519
Toll Free: 877.446.1519
Email: 4psinfo@psdoors.com

ISO9001:2008
CERTIFIED
QUALITY MANAGEMENT SYSTEM

Rev. 120516

Model: HS-560

Sliding Flood Barrier

PS DOORS Flood Protection Solutions

PS Flood Barriers™
Solutions That Hold Water

The Sliding Flood Barrier is designed specifically for the height of flood protection you require. The barrier simply slides horizontally into place covering your opening. The Sliding Flood Barrier is stored at the opening for quick and easy deployment.

Standard Features:

- Mild steel, stainless steel or aluminum.
- Compression seal—requires no compressed air for activation.
- Latch system designed for simple, quick deployment.
- Recessed sill with cover, or flush sill.

Application Use:

- Walk doors.
- Sectional doors.
- Retaining walls.
- Driveways.
- Store fronts.
- Interior hallways/rooms.
- Loading docks.
- Openings with limited swing area.

Safe.
Simple.
Durable.
Made in USA.

Benefits:

- No sill required = no tripping hazard.
- Flood barrier is in place for quick and easy closing on short notice of flooding conditions.
- Minimum personnel needed to place flood barriers when needed.
- Stored right at opening for quick deployment.

Custom sizing and design available.

Professionally Distributed by:

877.446.1519

psfloodbarriers.com

PS DOORS

PS DOORS
Attn: PS Flood Barriers
1150 South 48th Street
Grand Forks, ND 58201
Phone: 701.746.4519
Toll Free: 877.446.1519
Email: 4psinfo@psdoors.com

ISO9001:2008 CERTIFIED
QUALITY MANAGEMENT SYSTEM

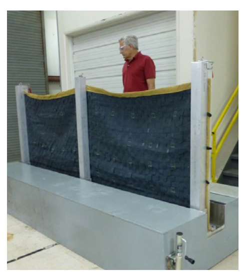
Rev. 120516

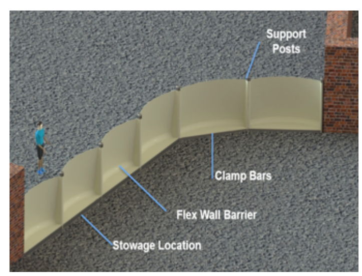
ILC DOVER

FLOOD MITIGATION SOLUTIONS

Vertically Deployed Flex-Wall®

The Vertically Deployed Flex-Wall® is a high-strength fabric wall that can be deployed rapidly for flood protection around/between buildings, across doors of any size or in front of glass walls. It can be scaled to withstand any water height, and can be shaped to fit around any structure, including corners of any angle. It is stored in a covered trench at the point of use so that all materials and components are available when needed. The patented Flex-Wall is simple to operate and can be easily deployed or stowed by a single person within minutes, even in high winds. The Flex-Wall can surround entire spaces (buildings), or span openings and seal against existing walls (doors, driveways, etc.).

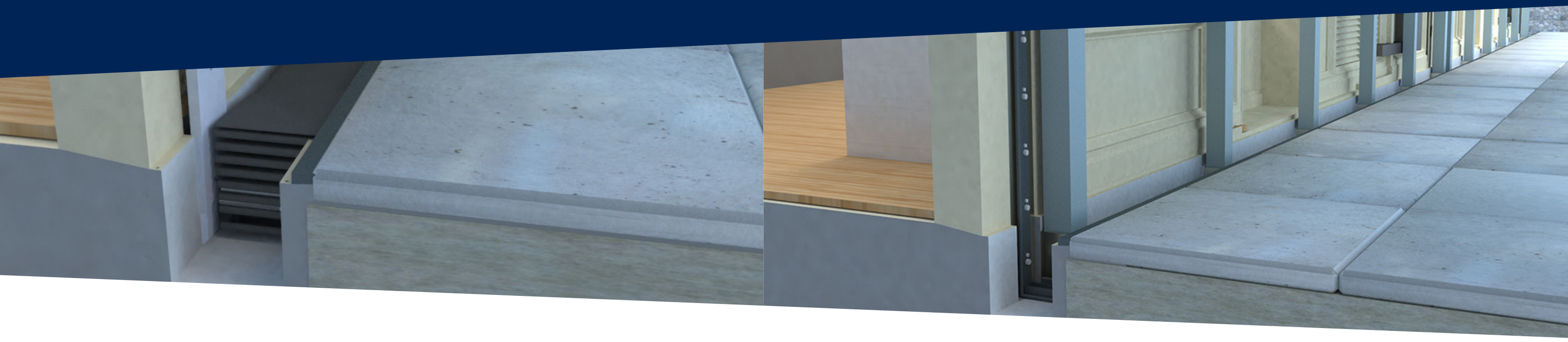




FEATURES AND BENEFITS

- **Point-of-use storage** — Deploys at last moment for minimal operational disruption, resumes operations faster, no lost components
- **Rapid deployment —** Site secured in minutes by one to two people with powered operation; chain fall backup if power outage occurs
- **Compact stowage** — Stores in small spaces
- **Scalable design** — Sized to fit any vertical opening
- **Robust materials and construction** — Withstands debris impacts with optional debris netting
- **Prevents flooding** — Seepage is <0.5 gal/min/ft of perimeter

Vertically Deployed Flex-Wall®



OPERATION

The Vertically Deployed Flex-Wall is deployed by removing the trench container cover, installing the support posts into their receivers, and then lifting and attaching the fabric wall onto the posts. Tall walls are easily deployed by a two-person team.

SYSTEM COMPONENTS

Fabric Wall — Two-layer flexible and damage-tolerant structure

- Structural layer made of Kevlar® and polyester webbings
- Water-retention layer made of PVC-coated polyester

Container — Trench and cover

Receivers — Metal post holders anchored to the trench

Support Posts — Metal beams that react load to the ground

Seal Bar — Structure that attaches and seals the wall deadman to the trench

CONFIGURATION OPTIONS

Short Walls

- Straight support posts
- Fabric wall
- Tamper-proof covers on trench box
- Manually deployed

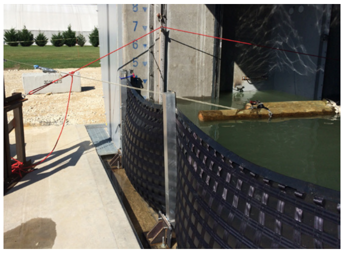
Standard configurations can be modified to meet any water height or perimeter outline.

Tall Walls

- Braced support posts
- Fabric wall
- Tamper-proof covers on trench box
- Manually deployed

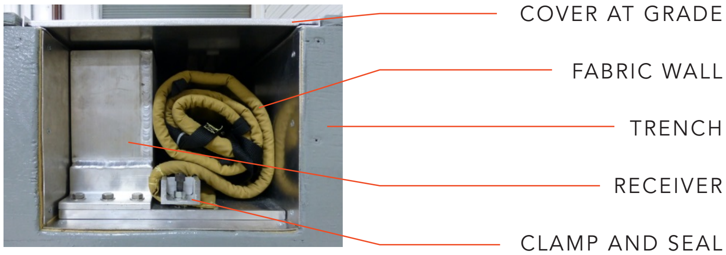
Braced support posts react load to the ground for taller walls.

OUR SOLUTIONS ARE CUSTOM-DESIGNED TO MEET YOUR REQUIREMENTS



5 FPS, 1,000 LB LOG IMPACT TEST

STRUCTURAL WALL CAN BE PACKED INTO A SMALL AREA



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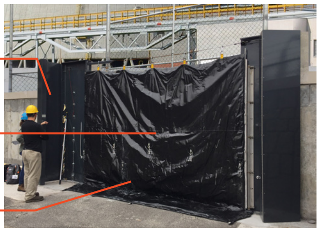
PATENT US 9,453,314

FLOOD MITIGATION SOLUTIONS

Side Deployed Flex-Wall®

The Side Deployed Flex-Wall® is a high-strength fabric wall that can be deployed rapidly for flood protection around/between buildings, across doors of any size or across window walls. The patented system can be scaled to withstand any water height and can be arranged to fit around any structure through the use of intermediate support posts. It is stored in a container at the point of use so that all materials and components are available when needed, and sealed to the ground by either integral weights or clamp bars. The Flex-Wall is simple to operate and can be easily deployed or stowed by a single person within minutes, even in high winds. The Flex-Wall can surround entire spaces (buildings) or free-standing equipment, or span openings and seal against existing walls (doors, driveways, etc.).

STOWED

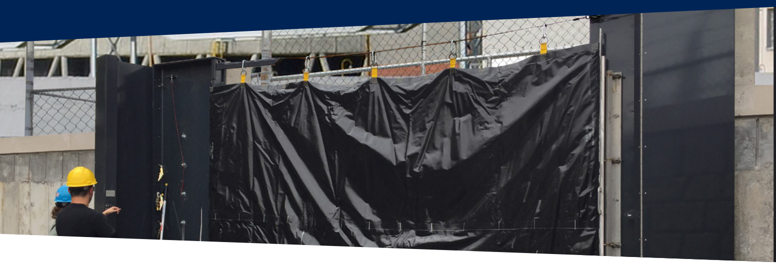


DEPLOYED

FEATURES AND BENEFITS

- **Point-of-use storage** — Deploys at last moment for minimal operational disruption, resumes operations faster, no lost components
- **Rapid deployment** — Site secured in 5 to 10 minutes (weighted skirt) or 15 to 20 minutes (clamped skirt) by one to two people
- **Compact stowage** — Stores in small spaces
- **Scalable design** — Sized to fit any vertical opening
- **Robust materials and construction** — Withstands debris impacts with optional debris netting
- **Prevents flooding** — Seepage is <0.5 gal/min/ft of perimeter

Side Deployed Flex-Wall®



OPERATION

The Side Deployed Flex-Wall is deployed by opening the storage container and pulling the flexible wall across an opening and bolting it to a receiver. Once attached, the integral sealing skirt is lowered and held in place by bolts to ground anchors, or by weights that are integrated into the skirt at the factory. For long spans, intermediate posts can be installed. For tall walls where higher flood levels are a concern or for extremely long spans, a cable would be included that is secured at the storage container and then attached at the receiver during deployment. The Flex-Wall is then pulled across the opening like a shower curtain. Shaped deployment to create a safe landing zone for emergency egress is also possible.

SYSTEM COMPONENTS

Fabric Wall — Two-layer flexible and damage-tolerant structure

- Structural layer made of Kevlar® and polyester webbings
- Water-retention layer made of PVC-coated polyester

Container — Above-ground metal box with tamper-proof door panel

Intermediate Posts — Metal beams that react load to the ground as required, based on span

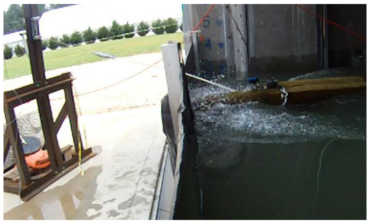
Receiver — Structure that attaches to the wall opposite the container, which accepts the Flex-Wall

CONFIGURATION OPTIONS

- Standard wall heights (2 ft., 4 ft., 8 ft. and 12 ft.)
- Custom heights provided based on flood elevations
- Straight or braced support posts
- Fabric wall with or without debris impact
- Clamped or weighted skirt depending on seepage allowance
- Tamper-proof covers on storage container and anchors
- Components made of any metal or finish
- Deployment support via cables based on wall height and deployment wind conditions

STANDARD AND CUSTOM-CONFIGURED SOLUTIONS TO MEET YOUR REQUIREMENTS

CUSTOMIZATION EXAMPLE OF EMERGENCY EGRESS



LOG IMPACT TESTING PERFORMED AT ILC DOVER TEST FACILITY

12' TALL X 16' WIDE SIDE DEPLOYED FLEX-WALL TESTED AT 10 FT. OF WATER

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FLOODCONTROL INTERNATIONAL

SELF CLOSING FLOOD BARRIERS

The Self Closing Flood Barrier has been in use globally since 1998. Its design uses the approaching floodwaters to automatically raise the barrier. The automatic operation, along with its minimal footprint with no need for steps or ramps makes this type of defence ideal for unmanned sites, for where aesthetic considerations mean that a permanent barrier is not acceptable, or where there would be insufficient warning and manpower to use manually installed barriers.

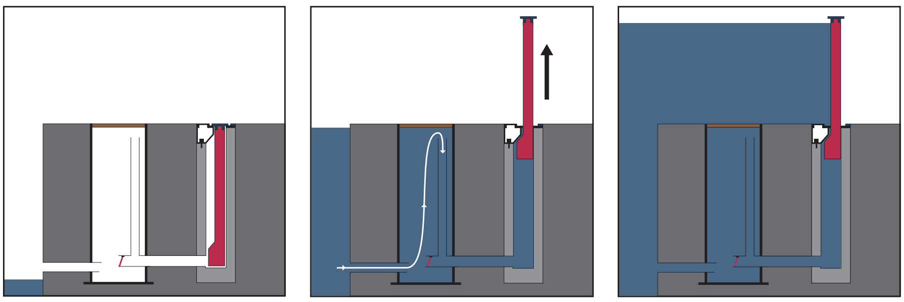
Single barriers are available up to 10m in length and 2.5m in height. Multiple units can be linked together to create long runs where required, with permanent or removable intermediate posts.

OPERATION OVERVIEW

The barrier usually resides below ground in a vertical position within a steel or concrete trough. The barrier consists of a rigid foam core and a GRP outerlayer. When floodwater rises to a pre-determined level, the water spills into service pit and then through a pipe into the trough and causes the barrier to float and raise fully. When the trough is filled, an angled support block locks the barrier into place, sealing it and making it watertight. The barrier is now fully effective and watertight to its full height.

As the floodwater recedes, the barrier lowers to its resting position again. The trough can be 'pumped out' also to lower the barrier before the adjacent groundwater levels recede fully.

Permanent Flood Protection - Barriers rise as the floodwaters rise.



USES

The Self Closing Flood Barrier can be used to protect areas such as:

- Underground garages
- Riverside defences
- Coastal defences
- Railway defences
- Unmanned sites, such as utility stations
- Building openings such as roller shutter doors.

BENEFITS

- Uses the floodwater itself to operate the barrier - no manual intervention required.
- No storage required - the barriers recesses fully into the ground when not in use.
- Fast action - with a fast flood the barrier will close within a minute.
- Easy to test - the pit can be filled with water which automatically lifts the barrier ready for inspection.
- Unlimited lengths - from 1m to 1km or more.

FLOODCONTROL
INTERNATIONAL

SPECIFICATION

Initially we require site plans, cross sections and the flood heights required, as well as a brief to describe the proposed operation of the barrier. It may be prudent for one of our engineers to attend site to discuss the proposed barrier to ensure that the correct barrier is specified. The location of buried services is vital and should be identified before the project has begun. The barrier needs to be connected to a drainage system; gravity drainage is simplest, or the barriers can be specified with pumped removal of floodwater.

REQUIREMENTS

- A site survey is required to obtain dimensions and flood heights. Also, the location of buried services needs to be determined.
- The barriers need to be connected to a drainage system; either by gravity or by pumped removal of floodwater.

CONFIGURATIONS

The Self Closing Flood Barrier configuration is in straight lengths from 1m with the overall flood barrier wall designed into suitable section lengths of up to 10m each as standard. Sections can be linked together using angled guide-posts for changes in direction.

Trough

There are two types of trough available in which the floating wall operates:

(1) Steel:
- utilised for single barriers up to 7m in length.
- Mild steel Grade S235 to BS EN 10025-2: 2004.
- Cathodic Protection designed depending on water type
- Four layer paint protection system applied

(2) Concrete: can be precast or cast in-situ to any length.

Service Pit

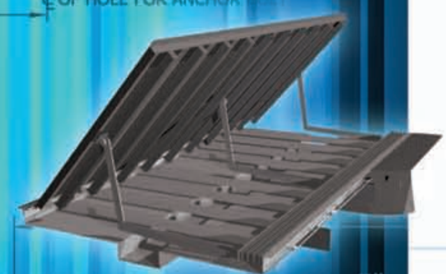
The invert of the service pit must be lower than the trough. The connection to the storm water drainage is for removing the floodwater only and uses a stop-valve to prevent water entering the trough before the trigger level is reached. If the storm water drainage is shallower than the service pit, a pump is required to empty the trough and pit post-flooding. An electrical connection will be required if this is the case.

100% PASSIVE

FULLY AUTOMATIC

24/7 FLOOD PROTECTION

PREVENTION THROUGH INNOVATION



1.713.980.6610
floodbreak.com

PRODUCT DATASHEET

Vehicle Gate

The FloodBreak Vehicle Gate is a fully-engineered system that will automatically block entrances from street-level flooding. Using FloodBreak's passive flood mitigation technology, these vehicular gates provide worry-free flood protection 24/7 while allowing full access to your facility.

Driveways * Loading Docks * Garage Ramps * Equipment Bays

Revolutionary Flood Control

Like the rest of FloodBreak's passive flood mitigation product line, the Vehicle Gate is fully automatic and does not depend on people or power to deploy. It is the only practical, truly passive flood control solution - the preferred method according to FEMA.

The Smart Choice

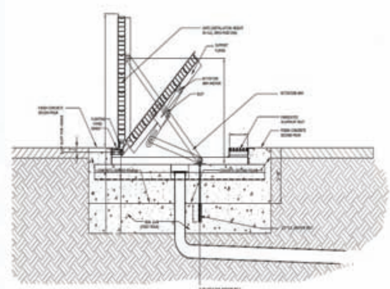
The FloodBreak Vehicle Gate has been protecting customers since 2002. Major hospitals, governments and commercial facilities all rely on FloodBreak's 24/7 flood protection. In the past two years alone, there have been 12 identified flood saving deployments.

How It Works

The FloodBreak system uses hydrostatic pressure created by the rising flood waters to automatically activate the gate. When the flood recedes, the gate automatically returns to its hidden position underneath the ground allowing full access to the facility.

Features:

- **Passive flood mitigation preferred by FEMA**
- **Manufactured to exact size requirements**
- **Weather resistant materials & durable rubber gaskets**
- **Minimal maintenance**
- **No training required**
- **Easy to install**



NO PEOPLE, NO POWER

24/7 CONFIDENCE

FloodBreak
REVOLUTIONARY FLOOD CONTROL

SECTION 8.0 LIST OF REFERENCES

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