CLIMATE RESILIENT DESIGN STANDARDS & GUIDELINES

FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

BOSTON PUBLIC WORKS DEPARTMENT

OCTOBER 17, 2018

SECTION 5.0

SAMPLE HARBORWALK (SEAWALL) BARRIER

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)

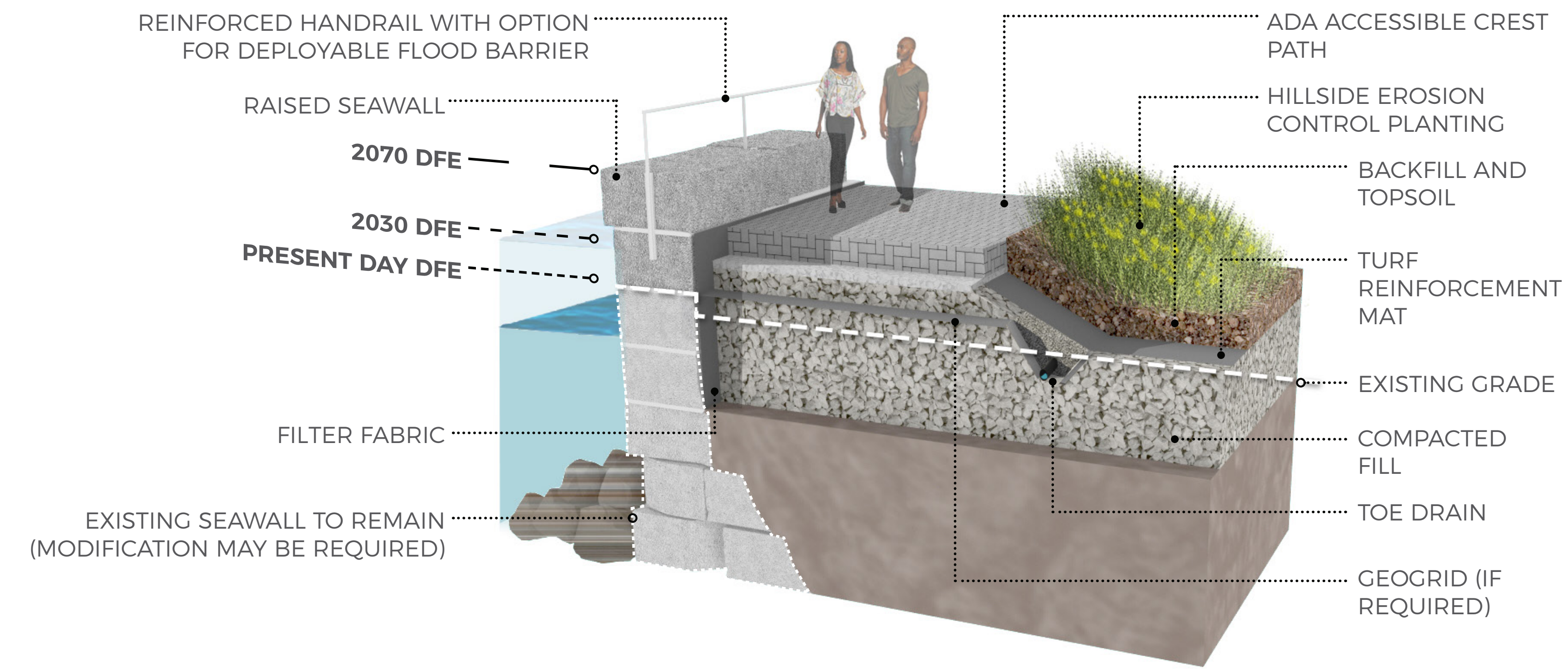
CAD

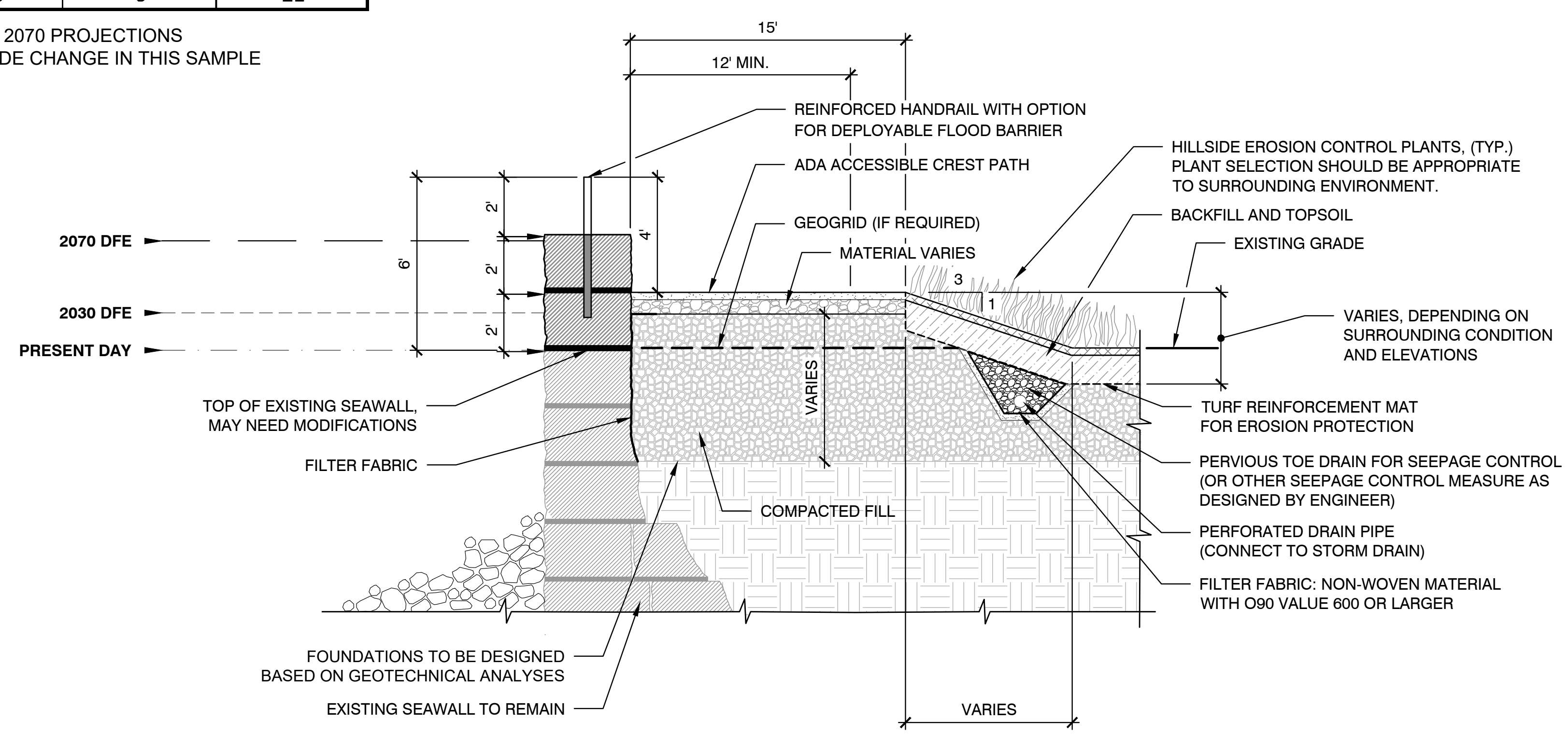
PDF

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

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FIGURE 8

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

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

200 0 200
Scale In Feet

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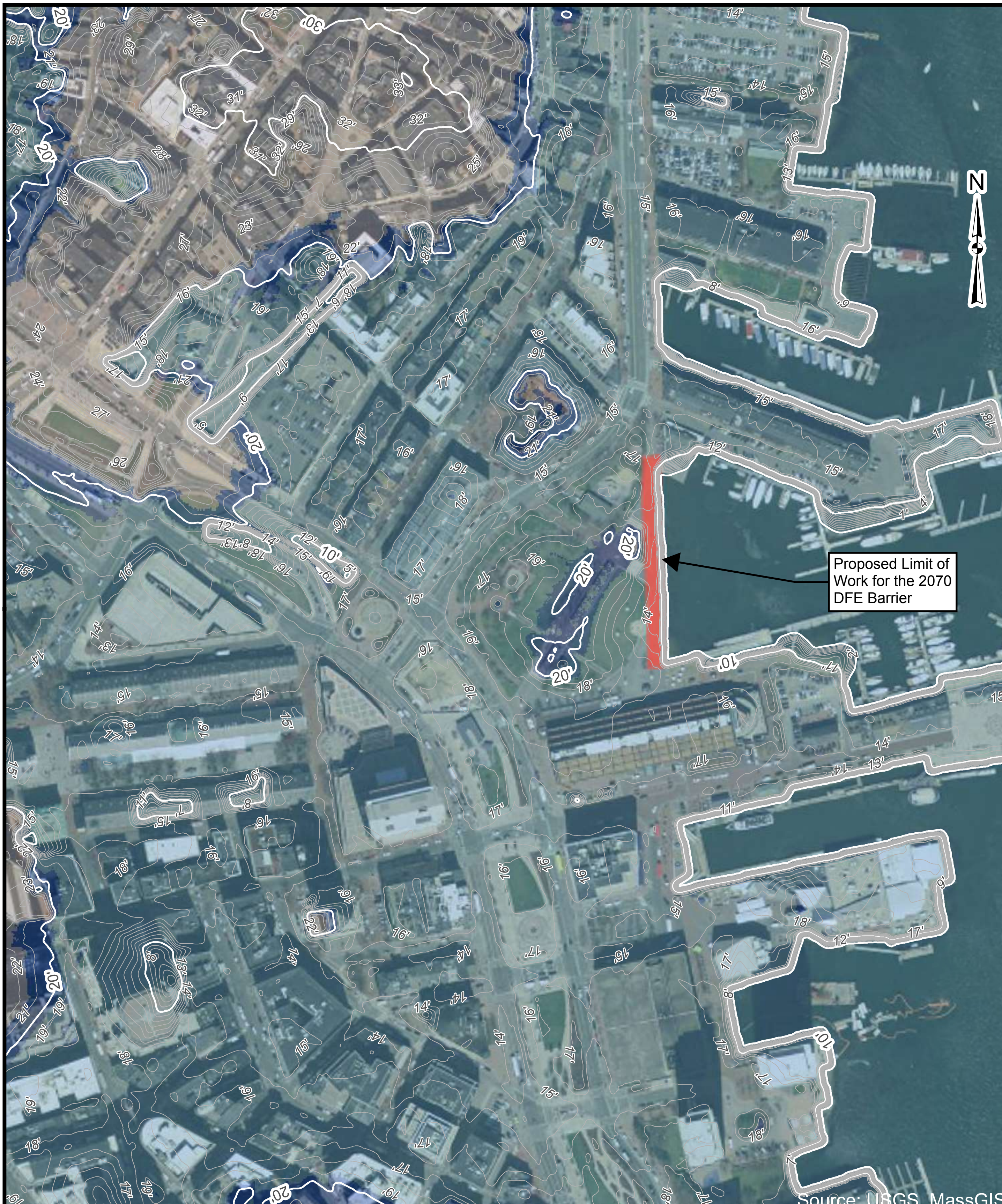

FIGURE 9

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

APPENDIX D. SAMPLE HARBORWALK (SEAWALL) DESIGN CONSIDERATIONS

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This appendix provides additional design considerations for designing a sample harborwalk (seawall) barrier as provided in **Section 5.0 Sample Harborwalk (Seawall) Barrier** of the Climate Resilient Design Standards and Guidelines. 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 flood barrier design process described in the guidelines. The sample Harborwalk barrier should be used by engineers and designers to understand the process of advancing conceptual design to implementation.

D1. CLIMATE DESIGN ADJUSTMENTS AND TIMELINE

The following climate design adjustments were prepared using previous climate studies developed for the City of Boston and surrounding municipalities. Refer to **Section 2.0 Climate Design Adjustments for Useful Life** of the guidelines for additional information. Preliminary climate design criteria and considerations for sea level rise, extreme precipitation, and extreme heat are presented below. The following assumes a design life of greater than 50 years, so the 2070 time horizon is anticipated. Time horizons to consider include the present, 2030, 2050 and 2070 time horizons.

Sea Level Rise (BH-FRM) and Storm Surge	• The sample site is within the Boston Planning & Development Agency (BPDA) “SLR-BFE” zone via the zoning viewer.
	• The sample site is located near numerous present 1% annual flood pathways along the waterfront near the sample site.
	• The BH-FRM model results include the base flood elevation of 19.4 ft. BCB by 2070.
	• The BH-FRM sub-model results are not yet available for design:
	  ◦ associated flood depth with the 1% annual flood event for each time horizon.
	  ◦ flood duration or residence time for the 1% annual flood event for each time horizon.
	  ◦ flood pathways for the 1% annual flood event that pass through the sample site and/or flood the sample site for each time horizon.
	  ◦ projected wave and wind impacts from the 1% annual flood event for each time horizon.
	• The design flood elevation should be 20.4 ft. at a minimum. Additional studies and the sub-model BH-FRM results are required for final design elevation.

Extreme Precipitation	• Select design storm events for analysis (10%, 4%, 2%, and/or 1% annual design storm events).
	  ◦ The Massachusetts Stormwater Manual currently provides the design storm volumes for analysis of stormwater treatment and conveyance systems.
	  ◦ Boston Water and Sewer Commission (BWSC) uses NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES for design of stormwater systems.
	  ◦ The barrier and upgradient stormwater features should also be designed as adaptable to handle increases in future design storm volumes.
	  ◦ Refer to Section 2.0 of the guidelines for Extreme Precipitation Adjustments identified by Climate Ready Boston.

Extreme Precipitation (continued)	- Suggest increase in 24 hr. volume 1% annual chance event to address future climate conditions. A risk alternative analysis should be considered in the design to evaluate a future condition 1% annual chance precipitation event and the sensitivity of the design to accommodate higher volumes. Refer to Section 2.0 of the guidelines for Extreme Precipitation Adjustments identified by Climate Ready Boston. • Assess high intensity rainfall events (cloudbursts) in the design and modify designs to safely convey the discharge without causing downstream/upstream flooding. *"From 1958 to 2010, there was a 70% increase in the amount of precipitation that fell on the days with the heaviest precipitation. This increase is greater in the Northeast than for any other region of the country." (Climate Ready Boston)*. • The study for drainage on the site should include a comprehensive review of the drainage area/watershed and identify opportunities for stormwater management up-gradient. Drainage area impounded by sample barrier: 1.5 acres. Refer to the stormwater considerations for more details.
Extreme Temperatures	• Consider extreme heat impacts (heatwaves, days above 90°F and annual maximum temperature) to: - Health and Safety - Thermal expansion - Material degradation from excessive heat - Pavement softening - Increased failure/reduced efficiency of electrical/mechanical systems (power outages and pumps) • Consider winter storm impacts: - Health and Safety - Snow and ice ground cover - Plowing and snow removal - Snow storage on-site/off-site - Drainage and infiltration impacts - Ice jams
Incremental Consideration	• If the site is unable to accommodate the design values for the 2070 time horizon, an incremental approach may be selected to meet the 2030 and/or 2050 time horizons. • This may include, but is not limited to, raising grades and wall heights over time to achieve design flood elevations, drainage improvements, pump stations, generators, property acquisition/managed retreat, etc. • All approaches must be documented with a timeline and plan to achieve 2070 flood protection in the future, including operation and maintenance roles and responsibilities.

D2. SITE SPECIFIC AND BOUNDARY CONSTRAINTS

The following site specific and boundary constraints for the Harborwalk barrier (seawalls) are to be used as a guideline when evaluating if a seawall will work on the site. The guidelines provided are not comprehensive and are designed to be context driven to encourage flexibility and balance in flood protection efforts. The goal is to protect sites from flooding and achieve climate preparedness, and to do so, neighboring context must also be considered to aide in contributing to a highly functioning public realm. With this, it is important to carefully identify the constraints and limitations that may impact barrier selection.

Extent of Barrier (Current and Future)	• Using projections for current and future flood paths, identify the barrier extent to fully protect the site and not result in flanking.
	  ◦ Refer to Figure 9 in Section 5.5 for topography in the area. The sample barrier will be flanked, but additional barriers may be identified within the flood pathway that can work in conjunction with this section of seawall.
	  ◦ Designers should keep in mind that sea level will continue to rise beyond 2070 and seek to achieve greater than 50-year useful life when possible.
	• The minimum cross-section of the barrier should consider (at least):
	  ◦ Current elevation and grading of the site – the park behind the sample Harborwalk is mounded.
	  ◦ There is space for slopes (horizontal extent is approximately 3 times longer than the vertical extent per slope) and/or retaining walls.
	  ◦ There may be opportunities to use the handrails as floodwalls to get additional freeboard, which would reduce risk of overtopping.
	  ◦ The sample drawing provided in Section 5.5 includes a table with the height differential and minimum widths for harborwalk (seawall) barriers. For the sample site, in this case, raising the existing seawall 4 ft. (with a 2 ft. increase in height from the existing ground surface) would need to be at least 21 ft. wide with a slope width of 6 ft. to properly protect the waterfront. The final geometry of the harborwalk (seawall) barrier should meet the intentions of the guidelines. The sample is designed to provide an example to consider.
	• Downstream encroachment considerations:
	  ◦ If future development is sample immediately downstream of the barrier, it may “encroach” on the barrier and increase risk for failure mechanisms, such as piping, and damages. The protected open space of the public park reduces that risk.
	• Impacts of neighboring properties shall be considered, including:
	  ◦ Lack of protection of neighboring properties will impact the effectiveness of barrier protection at the site and result in flanking.
	  ◦ It is unlikely that the installation of this sample barrier will alter the flood path and result in neighboring properties becoming more susceptible to flood waters diverted from the site.
	  ◦ Design to reduce flanking, overtopping, and alternate/unplanned flood pathways.
	  ◦ Barriers should tie into higher elevations or structures to effectively protect the site without directing water to neighboring sites. This is not feasible at this sample site, so additional barriers will need to be planned in other sites within the floodpath.

Extent of Barrier (Current and Future, continued)	• In this case, the sample barrier does not tie into higher elevations or structures. Where it is not feasible to close off the flood pathway on your site without extending onto other sites/properties, an incremental approach should be considered. Refer to Section 7.0 for guidance on temporary and deployable flood barriers. • 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.
Zoning	• Contact the BPDA to evaluate zoning regulations and requirements. • Identify any current regulations that may prevent the design and implementation of certain barrier types. ◦ There may be restrictions on structure heights, weights, locations, materials used, etc. • Identify the Designated Port Areas (DPA)s in Boston and assess the site location for proximity to DPAs. • The sample site is not within a Designated Port Area (DPA) in Massachusetts. However, water dependent land use should still be considered in design.
Available Open Space	• A possible easement could be the public park adjacent to the barrier site. • Based on preliminary LiDAR, there appears to be open space available for construction and installation efforts, as well as ongoing operations and maintenance. • Optimize opportunities to connect to the waterfront wherever possible. ◦ The grades are being raised approximately 2 ft. behind the sample seawall to limit the affect of the wall on the view from the public park. The grades may be raised higher than 2 ft. so there is no seated wall, but grade changes off the site may require more space as a result. • A sample design drawing is provided in Section 5.5 help to identify sample space requirements for barriers. • Prior to design, refer to the slope tables and design drawings to assess if there is a sufficient amount of space available.
Public Right-of-Way	• The intent of the guidelines is to protect the public right of way (ROW) from flooding. • Pedestrian ROWs should remain uninterrupted or be redirected. • Barrier design should include pedestrian access. • All public ROW shall follow ADA requirements and guidance from the Massachusetts Office on Disability.

Private Properties	• Barriers may extend across multiple properties.
	  ◦ Coordination is necessary between property owners if barriers are to encroach upon neighboring properties. This would include collaboration with property owners of commercial and residential properties along the wharfs near the sample site.
	  ◦ Barrier selection may change based on constraints of additional properties.
	• Easements may pass through the site, or the barrier may encroach onto nearby easements.
	  ◦ Coordination will be necessary between the owners of the site and the easement holders.
	  ◦ Easement access shall be maintained at all times and may need to be relocated upon implementation of barriers.

Operational Capacity	• The barrier may be easily accessed for maintenance and operation purposes. • Responsibility shall be established for the barrier pertaining to operation and maintenance efforts. • Maintenance shall include necessary cleaning and upkeep of the barrier such that the barrier performs as designed in flood events.
Off-Site Impacts (Adjacent and Downstream)	• Drainage areas will be impacted, and additional/modified drainage systems may need to be implemented to accommodate higher inflow rates. Figure 7 in Section 5.5 shows the impacted drainage area for the sample site. • Stormwater runoff must be considered when selecting and designing barrier types. 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. • This sample site may serve as an example to neighboring sites that seek to provide similar flood protection.

Climate Ready Boston Criteria	• Climate Ready Boston created criteria to identify opportunities for resilient design. In general, the BPWD Climate Resilient Design Standard and Guidelines address effectiveness, feasibility, and design life and adaptability. However, the following additional criteria should be considered for the site:
	• Social Impacts
	  ◦ The sample barrier will continue to provide recreational and cultural opportunities and serve as part of the Harborwalk and the adjacent public park.
	  ◦ The aesthetic impact of the sample barrier will include a 2 ft. wall that may function as a bench.
	• Equity
	  ◦ The sample barrier will continue to provide equitable access to waterfront.
	• Value Creation
	  ◦ Consider opportunities for new value creation on sites and/or adjacent sites.
	• Environmental Impact
	  ◦ More green space will help to reduce urban heat island.
	  ◦ Consider human health benefits and impacts.
	  ◦ Creating stormwater detention in the watershed behind the barrier will result in improved reduction in stormwater flooding.
	  ◦ Consider mitigation of other climate hazards.

Incremental Considerations	• As sea level rises, the flood path will change and grow to include more impacted properties. Current barrier locations may need to change as sea level continues to rise and flood events increase in size and intensity.
	• The installation of a barrier designed to current projections will not withstand flooding and sea level rise associated with future (2030, 2050, 2070) projections.
	  ◦ When possible, barrier designs should be completed to accommodate up to the highest projection currently available.
	  ◦ If incremental protection is required due to budgetary or other constraints, barriers should be designed with the knowledge that additional height/loading will be added in the future.
	• Site specific incremental considerations, both vertical and horizontal, are as follows:

Incremental Considerations (continued)	• Boundaries – may change as sea level rises and flood events become more severe. Barriers may not be able to be relocated and will need to be redesigned in the case of a decrease in protection capability. • Bridging Gaps – the implementation of barriers will be necessary to combat flooding and the impacts of climate change. Additional barriers may be needed in the future to bridge the gap between what may currently be protected, and what will need further protection measures. • Barrier Modification – in addition to redesigning barriers to accommodate new boundaries, barriers may need to be modified to properly protect against flood levels. Barriers should be capable of increasing the protection height or supporting a supplemental protection method—such as deployable barriers as handrails. • Master Plans – shall be changed according to the locations and sizes of barriers. • Planning – as time continues, areas along the coast may become more susceptible to flooding and storm events. This may lead to needed protection of these areas and provide physical and operational constraints regarding development and use.
Operation & Maintenance	• Operation and maintenance will be similar to floodwall and levee considerations. • Proximity to the coastline/harbor may result in larger operation and maintenance needs as weather/erosion/corrosion may have a significant effect on the barrier. • Site locations that encroach into public or pedestrian rights-of-way may need more operation and maintenance efforts to meet City of Boston requirements.
Costs	• Operation and maintenance costs will be estimated by current and project future wage rates and the manpower estimated for regular maintenance associated with the selected barrier, including stormwater management. • Permitting costs will be required for implementation of barriers in jurisdictional areas. • Site boundary changes may lead to additional costs in the future to adjust/redesign the barrier to accommodate flood pathways. • Addition of barrier height in the future should be considered.

D3. STORMWATER CONSIDERATIONS FOR FLOOD PROTECTION

Stormwater management controls are linked directly to climate conditions. The management of stormwater accumulated behind any new barrier is critical. As rainfall amounts and intensities change over time, it becomes necessary to consider how stormwater systems can function – both today and in the future – to safely convey, treat, and manage stormwater. Stormwater Management controls for Harborwalk barriers (seawalls) such as the sample Harborwalk along a public park provide the opportunity to create a seawall barrier for coastal sea level rise protection, while serving as a space for stormwater management and maintaining views of the waterfront.

Studies and Investigations Required:

- Watershed Delineation and Stormwater Drainage Model
- GIS Analysis of Stormwater Detention Opportunities in the watershed
- Zoning and Land Use Assessment to modify Building Resilience Requirements
- Utility Conflict Investigations and Stormwater Pumping
- Water Quality Modeling of Stormwater Control Measures.

Green Infrastructure (GI)	• Use GI designs from Boston Water and Sewer Commission Low Impact Development Stormwater Design Manual to provide guidance for green stormwater control measures in the upgradient watershed to reduce stormwater flooding impacts. • Consider GI stormwater control measures at the public park to treat stormwater generated by the park and from upgradient and offsite sources. • Collect, detain and treat stormwater drainage from neighboring streets. • Design GI features to meet at a minimum the Massachusetts Stormwater Management Standards Volume 1 Chapter 1. • Use GI designs from Massachusetts Stormwater Handbook Volume 2, Chapter 2, Stormwater BMPs. • Harborwalk barriers will include space for required structural pretreatment BMPs such as deep sump catch basins, oil/grit separators, proprietary structures, and sediment traps. • Harborwalk barriers present limited opportunities to incorporate stormwater treatment GI designs other than media filters, tree box filters, and proprietary treatment devices. Opportunities for underground stormwater detention could be placed in the public park. • The use of GI designs for stormwater management at the sample Harborwalk site can help lead to improved local stormwater treatment.
Volume Capture and Control	• Post-development stormwater discharge rates must not exceed pre-development rates. This Standard may be waived for land subject to coastal storm flowage. The calculation is based upon any new impervious surfaces created from the design of the harborwalk barrier such as walkways, road surfaces, and potentially the sides of the harborwalk itself if the slopes are designed with an impervious cover. • Assess high intensity rainfall events (cloudbursts) in the design and modify designs to safely convey the discharge without causing downstream/upstream flooding. • Pumping systems should be sized to handle stormwater volumes trapped on the land side as well as potential ocean overtopping during extreme storm surge to prevent flooding.

Off-Site Impacts & Flooding	• Barrier designs should have no significant impacts off-site. • The end points of the harborwalk barrier must be tied into elevations that will not cause bypass and diversion of floodwaters onto adjacent properties. Figure 9 in Section 5.5 shows topographic considerations for the sample harborwalk barrier. The sample barrier does not tie in to any adjacent elevations. Opportunities for additional barriers should be considered for future protection of adjacent properties.
Water Quality	• The stormwater design should incorporate the appropriate stormwater treatment measures in accordance with the Massachusetts Storm Water Manual. Design the project associated stormwater best management practices (BMPs) using GI or LID approaches as the first try – then non-GI approaches or combinations. • Designs must address appropriate MS4 pollutants including sediment, nutrients, metals, oils, greases, etc. The design must address urban stormwater pollution in discharges. ◦ Stormwater designs associated with the wall should incorporate a treatment train approach to remove large trash and debris, remove sediment and turbidity, filter or trap other pollutants (nutrients and oils and grease) and potentially daylight and aerate to remove bacteria. • New stormwater management systems must be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS). • A long-term operation and maintenance plan must be developed and implemented such that stormwater management systems function as designed. • Consider a range of options that are appropriate to treat expected pollutants from the site. Pollutants can be things like sediment, turbidity, metals, and oils and greases. If there is space available at a harborwalk site, GI/LID infrastructure should be considered first for stormwater treatment. Proprietary stormwater treatment designs may be necessary in ultra-urban settings with little space available for green solutions.
Watershed Approach	• Assess watershed conditions to incorporate a comprehensive delay, store and discharge approach for managing stormwater with a drainage basin study. • The drainage area to the sample raised Harborwalk has limited green and open space available to accommodate detention storage for stormwater during precipitation events, except for the adjacent public park. • Identify potential upgradient stormwater management approaches to delay, store, and discharge stormwater trapped by the barrier. Drainage area is 1.5 acres for the sample site. See Figure 7 in Section 5.5 for more detailed drainage area information.
Co-Benefits	• A harborwalk barrier at the sample location will create the opportunity to construct new public green space and passive recreation on the harborwalk and adjacent to the barrier. • Flood reduction behind the sample barrier will improve local economics and property values. • More green space will help to reduce urban heat island effects. • Creating stormwater detention in the watershed behind the harborwalk will result in improved reduction in stormwater flooding.

Incremental Considerations	• Adaptive management approach can be considered for GI stormwater controls in the watershed. • Evaluate current zoning and new development/redevelopment potential in the upgradient watershed and the need for land use controls/change. • Assess retreat options in the watershed with buy-back opportunities for low lying structures. • Build flooding resilience into new construction/redevelopment in the watershed.
Operation & Maintenance	• Refer to the Utility Considerations for Stormwater Utility Management and Maintenance. • GI Stormwater controls associated with Harborwalk barriers will require site specific O&M plans to remove trapped sediment and pollutants and to maintain vegetation in the GI stormwater treatment structures.
Costs	• Hydrologic models and studies will cost $50,000 - $100,000 for this sample site. Watershed GI designs could cost $100,000 - $200,000 depending upon the number of watershed detention options that are identified. Construction of GI stormwater solutions could cost $1M - $3M.

D4. UTILITY CONSIDERATIONS FOR FLOOD PROTECTION

Raising seawall barriers, like the sample Harborwalk barrier, along a public park and a wharf with commercial and residential properties, will not require significant utility modifications at the site since there are limited utilities in the vicinity. There is only one sewer outfall that crosses the sample Harborwalk. Other known utilities at the sample site are adjacent or parallel to the seawall. Flood protection designs should limit penetrations through any flood barrier as much as possible. Utility penetrations through flood barriers provide a pathway for floodwater either through the conduit, in the bedding material surrounding the conduit, or along the outside walls of the conduit (a serious structural-integrity problem often referred to as “piping”). Although utility penetrations through any barrier should be minimized, where a structure or utility passes through a flood barrier, precautions must be taken to prevent passage of flood water through the barrier. Additionally, any utility that crosses a harborwalk barrier shall be assessed carefully for the potential to pass sea water through or under the barrier, thereby adding to flooding behind the barrier. Passage of seawater through or under a harborwalk barrier shall be prevented. Work shall be conducted in accordance with federal, state, and local regulations.

Studies and Investigations Required:

- Data Collection for underground and overhead utilities, including materials, dimensions, year of installation
- Data and records on existing sewer outfalls
- Data on utility service connections
- Jurisdictional requirements for materials (for example, MWRA or BWSC standards for installation of water mains and appurtenances)
- Utility Conflict Investigations.

Survey	• Records for existing utilities, both overhead and underground, shall be requested early in the design process. • A professional surveyor shall conduct a site survey and identify utilities, both overhead and underground. The survey shall include elevation data for utilities when possible (for example, clearance for overhead wires and depth of underground utilities). • Use Boston City Base datum on elevation survey work. • Identify flood zones on any mapping efforts, overlay utility survey with flood maps with climate projections. • Identify mechanical assets and their elevation relative to the design flood elevation.

Water Utilities	• Approximately 300 ft. of existing 20 in. water main at the public park is within the footprint of the sample Harborwalk barrier. This portion of water main (and associated valves and appurtenances) would need to be relocated to the west of the Harborwalk, using restrained bends to connect to the existing water main alignment outside of the Harborwalk barrier footprint.
	  • The pipeline should be constructed with restrained joints to minimize the possibility of water main failure.
	  • All materials and methods of installation shall be in accordance with BWSC standards.

Sewer Utilities	• Figure 8 in Section 5.5 shows locations of sewer utilities in the sample Harborwalk area around the public park.

Sewer Utilities (continued)	• Sewer mains and catch basins exist on the dry side of the sample Harborwalk. There is one combined sewer outfall (CSO) that crosses the sample barrier. Additionally, one sewer manhole and approximately 75 ft. of 28 in. sewer main are within the footprint of the sample Harborwalk seawall.
	• Sewer mains shall remain at their existing elevations. A change in elevation may affect the gravitational direction of flow.
	• The sewer manhole and sewer main under the sample Harborwalk barrier should be relocated to the west of the Harborwalk. An alternative would be to relocate the manhole 245 ft. to the south, at the intersection of two sewer mains, and eliminate the 245 ft. of sewer main. Sewer services in this area shall be identified and taken into consideration when relocating the sewer manhole and sewer main.
	• The combined sewer main crossing the barrier shall be assessed for structural integrity related to the additional material and Harborwalk weight.
	  ◦ If a sewer outfall is assessed to be structurally insufficient, a structural liner shall be installed.
	  ◦ Sewer outfalls shall be left at their existing elevations.
	• For sewers adjacent to the barrier, but not crossing it:
	  ◦ Consider relocating the sewer main and its structures to be further from the barrier to prevent adverse impacts to the integrity of the Harborwalk barrier. An additional option/alternative would be to construct/install a structural liner in the sewer main to minimize the possibility of sewer main failure.

Combined Sewers and Combined Sewer Overflows (CSO's)	• Figure 8 in Section 5.5 shows the locations of combined system utilities in the area around the sample Harborwalk barrier and the public park.
	• Elevated seawall barriers in this area must consider the nearby combined sewers to the north and to the south, and related facilities.
	• Combined sewers include sanitary and stormwater flows, and are gravity pipe systems that can allow water to flow in either direction, depending on hydraulic conditions.
	• The sample project area includes combined sanitary and stormwater flows. This means catch basins discharge into the combined sewer main. However, catch basins are on the dry side of the barrier at the sample site.
	• It shall be assessed whether it is feasible to separate the drain from the sewer system. If possible, catch basins shall be diverted to a dedicated drain line and removed from the sewer.
	• Combined sewers discharge to the MWRA sewer system. When flows exceed the local BWSC system capacity or the MWRA interceptor sewer capacity, discharges occur through overflow pipes to the local receiving water. Considerations:
	  ◦ Coordinate with MWRA to prevent MWRA interceptors from surcharging into the areas behind barriers.
	  ◦ Coordinate with MWRA to assess if MWRA interceptors have the necessary capacity to receive increased combined flows due to future storm intensity and duration.
	  ◦ Consider additional stormwater separation in combined sewer tributary areas to reduce flows to the MWRA interceptor system. Discharge separated stormwater flows to receiving waters as noted above.

Combined Sewers and Combined Sewer Overflows (CSO's, continued)	• Outfalls can act as conduits to flood protected areas. One 84-inch combined sewer outfall exists at the sample site. The outfall crosses the sample Harborwalk barrier and should be equipped with a tide gate per below.
	• Most existing Boston Water and Sewer Commission CSO's have tide gates installed on them. Considerations:
	  ◦ Review records for Harborwalk barrier sites and evaluate if tide gates exist.
	  ◦ If no tide gate exists or the tide gate requires replacement, install a tide gate on the outfall to act as a conduit for flood protected areas.
	  ◦ Installation and management for possible pumping systems to move any accumulated stormwater during high tides and storm surges.

Stormwater Utilities	• Figure 8 in Section 5.5 shows locations of stormwater utilities in the area around the sample Harborwalk barrier and public park.
	• No dedicated storm drains exist in the sample Harborwalk project area. Catch basins discharge to the combined sewer.
	• An analysis of stormwater infrastructure should be performed for each project area to evaluate and address stormwater needs, such as stormwater separation, relocation of stormwater assets, re-grading the ground surface, and pump station design.
	• See notes in the "Combined Sewers and Combined Sewer Overflows (CSO's)" section above, regarding separating the drain from the sewer.
	• Capacity (size) of new gravity-based stormwater pipes should be sized as required with sample grade changes and flood elevations.
	• Pumping stations may be necessary to manage stormwater. The following should be considered:
	  ◦ Pump redundancy, over-design of wet-well capacity (future flow volumes), pump approaches, trash accumulation and removal, on-site generators and power supply.
	  ◦ Installation of water level sensors to monitor rise and fall of water surface elevations to be tied to SCADA. This information is very helpful to measure storm impacts and calibrate storm water models.
	  ◦ Pump Stations shall be designed to withstand flooding. Elevations of power supplies, stand-by generation or any electrical or mechanical equipment should be above the design flood elevation.
	  ◦ Discharge or pump station flows should consider treatment and scour protection.

Electric Utilities	• Locations of the electric utilities in the sample project area are unknown. • Electric utilities (duct banks and conduits), allow pathways for significant flows through any flood barrier. Consideration: ◦ Identify utilities crossing the barrier and evaluate ownership, construction methods and likelihood of an existing flow path. If an existing flow path is identified, ducts shall be sealed to create watertight barriers. • Consider overhead utility clearance. Power poles and overhead wires shall be relocated.

Electric Utilities (continued)	• Owners of electrical utilities shall be notified of the project and should be notified of sample locations for water, sewer, and storm water utilities. Coordinate utility locations with private utility owners. • Electrical substations and ground mounted transformers shall be designed to withstand flooding. These facilities should be installed above or protected from the design flood elevation.

Gas Utilities	• Locations of the gas utilities in the sample project area are unknown.
	• Gas mains are pressure pipes and therefore do not provide conduits for passage of storm water though any barrier. However, low pressure gas mains that operate at ¼ to ½ psi can be susceptible to water infiltration from floods. Considerations:
	    • Maintain the ability to investigate gas leaks
	    • Valve boxes and vaults need to remain accessible, as well as the gas mains themselves.
	• Owners of gas utilities shall be notified of the project and should be notified of sample locations for water, sewer, and storm water utilities. Coordinate utility locations with private utility owners.
	• Gas regulator stations shall be designed to withstand flooding. Elevations of power supplies, stand-by generation or any electrical or mechanical equipment should be above the design flood elevation.

Communications Utilities	• Locations of communications utilities in the sample project area are unknown. • Communications utilities (duct banks and conduits), allow pathways for significant flows through any flood barrier. Consideration: • Identify utilities crossing the barrier and evaluate ownership, construction methods and likelihood of an existing flow path. If an existing flow path is identified, ducts shall be sealed to create watertight barriers. • Consider overhead utility clearance. Power poles and overhead wires shall be relocated. • Owners of communication utilities shall be notified of the project and should be notified of sample locations for water, sewer, and storm water utilities. Coordinate utility locations with private utility owners.
Other Utilities	• Other utilities (such as municipal owned fiber, MBTA, or fire alarms) may exist. Utility owners can be identified by visiting this website: https://hwy.massdot.state.ma.us/webapps/utilities/select.asp • Steam utilities may exist. Steam pipes are pressure pipes and therefore do not provide conduits for passage of storm water though any barrier. However, low pressure steam pipes can be susceptible to water infiltration from floods.
Incremental Considerations	• Planning for incremental increase in flood protection must be conducted during design such that utilities are designed and constructed with the ability to accommodate future changes and additions to provide supplementary protection. • Access to utilities must be maintained with consideration for future changes. • Loading in the future configuration must be included in the design. Though adequate for demands from the present configuration, a utility may not meet requirements for future conditions; therefore, analysis and design of the utility

Incremental Considerations (continued)	must consider future loading conditions, including future increased loads by the additional roadway or barrier height. • In general, it is difficult to modify below grade structures. It is recommended that designers be conservative with selecting pipes and materials to avoid the need for frequent reinvestment.
Operation & Maintenance	• Utility infrastructure shall be maintained with the typical frequency according to each utility owner. Groundwater may impact frequency due to saltwater corrosion. • 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. (GENERAL PERMITS FOR STORMWATER DISCHARGES FROM SMALL MUNICIPAL SEPARATE STORM SEWER SYSTEMS IN MASSACHUSETTS, Final 2016). • 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 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. • Pump stations for detained stormwater should be inspected monthly and following precipitation events when they are activated. • Keep a hardcopy or electronic record of 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.
Costs	• Costs for each utility shall be coordinated between the utility owner and the municipality. • Grant opportunities may exist for utility improvement projects. • Relocation of 300 ft. of 28 in. water main is estimated to cost $120,000. • This cost does not include valve replacement as valve location data was unavailable for estimating. • Relocation of 75 ft. of 28 in. sewer main is estimated to cost $55,000. • Relocation of one sewer manhole is estimated to cost $12,000 (including manhole abandonment). • Stormwater pump stations can vary in costs considerable based on their capacity. Typical cost variations can be between $500k and $20M. • A typical 36”-48” tide gate and structure on a stormwater outfall may cost $200k - $500k. • A typical 72-inch tide gate (or dual tide gate equivalent) and structure on a stormwater outfall may cost $450k -$500k.

D5. STRUCTURAL CONSIDERATIONS FOR FLOOD PROTECTION

Raising a seawall barrier will require a significant amount of structural considerations. The following considerations should be assessed for the design and construction of a seawall for the sample site.

Studies and Investigations Required:

- Condition Assessment of Existing Seawall Barrier
- Design of Sample Wall Extension and Connection to Existing Wall
- Analysis of Existing Seawall Barrier for Modified Conditions

Anticipated Loads	• Increased temperature and heat waves may impact performance of thermally sensitive materials that may be used for a harborwalk barrier. Designers should assess design considerations for warmer climates in addition to considering how extreme cold temperatures may impact operations and maintenance. • Flooding conditions will result in increased hydrostatic and uplift pressures on structures, dependent on tides and groundwater levels. • Flood protection structures are expected to encounter impact forces from wind, waves, ice, and debris. • The self-weight of new and existing structures must be accounted for. • Earth pressures on existing structures may change depending on the type of flood protection selected and must be included in analysis of both new and existing structures to remain. • Structures with walkways or with unrestricted land side access behind them must be evaluated for live load surcharge. The design live load surcharge will vary based on access restrictions and can include pedestrians, snow removal equipment, emergency vehicles, or truck traffic. • Harborwalk barriers may be designed with handrailing to allow for the implementation of deployable flood barriers. Barriers should be evaluated for the live load on the handrailing with and without deployable barriers.
Condition Assessment – Existing Structures	• Gather relevant information on existing seawalls and any surrounding structures from existing contract, record, or as-built drawings, if available. Note materials used, design at time of construction, and intended use/functionality. • If the above information is unavailable, or to supplement the above information, perform exploratory testing such as probes, test pits, and borings as required. • Observe existing structures for signs of damage including cracking, failing mortar, and separation of blocks. Additionally, assess conditions of existing structures by performing a hands-on field observation of accessible areas and perform material sampling/testing as required. • Identify necessary repairs to be made to portions of the existing seawall that will remain intact to improve water tightness and structural capacity (chinking, point, etc.). • Thoroughly clean the remaining portions of the existing seawall immediately before patching or construction to remove salt or other contaminants. • Analyze the portions of the existing seawall that will be reused to evaluate if the existing structure can support the new seawall overtop as well as increased hydrostatic pressure and soil pressure.

Walls	• As stated above:
	  • Existing wall information will need to be gathered.
	  • Existing wall information may need to be supplemented by exploratory testing.

Walls (continued)	• The existing wall will need to be analyzed for above-mentioned loads and for the sample modified wall condition. • Sample wall extension will require connection to the existing wall sufficient to transfer loads applied above the connection. • Sample wall extension should be made of similar material to existing wall if possible to improve aesthetics. • Structures to act as flood protection barriers must be impervious to water. This should be considered when selecting sample materials and designing modifications required for existing structures. Consider adding a waterproofing membrane to decrease permeability. • Consider geotextiles to reduce the risk of losing fill behind the wall due to erosion/wave action.

Materials	• Material selection can have a significant impact on the capacity of structures exposed to extreme environmental conditions. The following considerations and suggestions apply to structures which will act as a flood protection barrier:
	  ◦ Use air-entrained concrete with low permeability to minimize damage caused by freeze-thaw cycles and the absorption of salt.
	  ◦ Consider adding pozzolans, such as fly ash, to the concrete mix. Pozzolans increase strength while reducing alkali-silica reaction, permeability, and cost of replacing concrete.
	  ◦ Use corrosion-resistant and impervious materials, such as steel or aluminum alloys.
	  ◦ Select grout and mortar products specifically designed for marine environments.
	  ◦ Choose a handrail material that is corrosion resistant.
	• Secondary walls and elements not acting as a flood protection barrier may not require specialized materials or detailing.

Connections	• The anchorage connection between the existing and new wall must be:
	  ◦ Designed for above mentioned anticipated loads
	  ◦ Watertight/Impervious to maintain the impermeability of the sample Harborwalk barrier
	  ◦ Corrosion resistant

Durability	• Provide a drainage plan for water collecting behind the wall to prevent hydrostatic pressure, or design for fully saturated retained soil. • Damage resistance to tear, puncture, debris impact, and excessive deformation must be considered in the design of flood protection structures such as harborwalk barriers. The ability to repair future damage should also be examined during the design process. • Any damage to the existing seawall barrier must be repaired and actions for preventing future damage should be considered. • Though the above-mentioned opportunities for damage may not lead to structure failure, it may render the element functionally obsolete if the structure no longer retains water.
Failure Mechanisms	• Analyze sample wall configuration for sliding, overturning, overtopping, and bearing failures due to anticipated loads. • Analyze connections of new wall segments to old wall segments as well as anchorage of handrail for shear, tensile, breakout, pullout, blowout, and splitting.

Constructability	• Consider time and budget constraints associated with permitting. • Site conditions can impose access restrictions or limitations on potential construction methods which may be required for various structural options. Restrictions and limitations must be considered in the design phase. • Construction of various components for the harborwalk barrier could require work within an active waterway or within a natural resource area. These types of construction may require extensive permitting, increasing the time and cost associated with a project that could render the selection of a harborwalk barrier infeasible. This must be considered during the planning phase when choosing between potentially feasible barrier options. • Consider restrictions for time of year for working in water, if work in the water is required. Certain aspects of construction for harborwalk barriers may require warmer/colder temperatures for installation.
Incremental Considerations	• A plan of incremental increase in flood protection must be included as part of the design. Elements of harborwalk barriers must be constructed with the ability to accommodate future changes and additions that provide supplementary protection. ◦ For the sample harborwalk barrier site, incremental options could include: raising the seawall in the future, replacing the open handrail with a solid wall, or installing a deployable flood barrier on top of the sample wall. The design and analysis take should anticipate loads and demands from incremental considerations.

Operations & Maintenance	• The following operations and maintenance procedures apply to the steel railing and steel connection elements present on the structure.
	  ◦ Exposed surfaces should be washed to remove debris buildup, deicing salts, ocean spray, vegetation growth, and pigeon excrement.
	  ◦ 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.
	• The following operations and maintenance procedures apply to the stone base of the structure.
	  ◦ Exposed surfaces should be washed to remove debris buildup, vegetation growth, deicing salts, ocean spray, and pigeon excrement.
	  ◦ Stone elements should be routinely inspected for surface damage, including chinking, cracking, and failure in joint material, and repaired accordingly.

Costs	• It is unlikely that plans are available for the existing seawall along the public park waterfront. Exploratory and materials testing is likely required. • An investigation will need to be performed prior to assessing the condition of existing seawall and therefore cost implications are unknown at this time. If the wall is assessed to be unsuitable to raise wall height and grades behind it, this will impact the project cost significantly and may result in a new seawall and/or expensive foundation support. • The suitability of soils for foundations can render shallow (inexpensive) foundations infeasible requiring the need for deep (expensive) foundations.

Costs (continued)	Suitability of soils will not be known until an exploratory geotechnical investigation has begun. • Access to the land side of the sample site appears readily available, but access restrictions from the water are unknown currently. Investigation into water access restrictions should be made to assess exploratory/materials testing and construction restrictions. • Significant permitting costs are anticipated. • Inspection of the seawall should be performed at regular intervals and additional maintenance performed as recommended in the inspection reports.

D6. GEOTECHNICAL CONSIDERATIONS FOR FLOOD PROTECTION

Primary geotechnical considerations for the harborwalk barrier at this location include foundation support, wall stability, potential for settlement, and effects on adjacent structures. The wall should be designed as a floodwall in accordance with the United States Army Corps of Engineers (USACE) guidance provided in EM-1110-2-2502, Retaining and Flood Walls. A licensed Geotechnical Engineer shall be engaged to perform subsurface explorations, perform geotechnical analyses, provide design recommendations, and observe conditions during construction of flood barriers.

Subsurface Investigations	• Conduct subsurface explorations to evaluate general subsurface conditions including bearing and slope stability conditions, potential for under-seepage pathways and settlement. • Explorations should consist of borings spaced every 100 to 500 ft. along the harborwalk alignment. Borings should be performed in phases when possible, initially conducting widely spaced “pilot” borings during conceptual design, followed by closer spaced borings during design development. • Borings should, at a minimum, extend 10 ft. into natural bearing soils or to 50 ft. depth, whichever is encountered first. Borings should extend deeper if pervious or soft foundation soils are encountered to define the thickness of these materials for applicable geotechnical analyses. • Conduct test pits to evaluate condition and geometry of the existing wall and foundation to evaluate its existing stability, as well as existing foundations, buried structures, and utilities, as necessary.
Impacts to Existing Structures	• Harborwalk barriers can impart significant surcharge on the underlying utilities located within the “zone-of-influence” of the barrier. The ”zone-of-influence” is defined by a line extending out 2 ft. from the edges of the barrier, and then downward and outward at a slope of 1H:1V (Horizontal: Vertical). There do not appear to be existing above-ground structures located within the “zone-of-influence” of the sample harborwalk barrier. • If existing structures are found at the sample site, identify their load carrying capacity. If the existing structures cannot bear the additional soil loads (vertical and lateral) consider increasing structure capacity, bridging solutions or relocation of the structure/utility. • Raise in grades will cause settlement of soils and foundations within the “zone-of-influence” of the barrier. The amount of settlement will depend on subsurface conditions. If anticipated settlement and associated structure movement is unacceptable, consider underpinning, bridging the soil loads or relocation of the structure/utility. • Plan for incremental raise in grade. Design for future anticipated loading conditions.
Global Stability	• Perform global stability analysis in accordance with USACE guidelines. Given the available existing space at the sample site, the Harborwalk can be constructed with 3H:1V (Horizontal: Vertical) slopes on the dry side, which is considered stable against global stability failure and preferable for maintenance activities. • Check lateral sliding, overturning, and global stability for the sample wall (including existing height) during end-of-construction, steady-state seepage (during design flood), rapid drawdown (if applicable), and seismic conditions as described in USACE guidelines for floodwalls.

Global Stability (continued)	• Evaluate the need to include grid reinforcement within new backfill to provide additional stability.
Settlement	• Settlement may result in loss of freeboard or damage to structures within and around the barrier. Based on the existing subsurface conditions, estimate the anticipated settlement of the constructed harborwalk. • Barrier design should account for estimated settlement. Evaluate the need to overbuild the wall to account for potential loss of freeboard due to settlement and grade change. • The wall structure should be designed to tolerate estimated differential settlement along the length of the wall. • 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.
Seepage/ Groundwater	• Seepage shall be managed to prevent sediment transport. • Flood Protection Systems must be designed to prevent excessive hydraulic gradients, internal erosion and loss of material (piping), and/or sand boils caused by excessive hydraulic gradients and under-seepage. • Underseepage control may need to be accomplished by cutoff walls such as steel sheeting or an impervious trench, flood-side or dry-side blankets, dry-side seepage berms, pressure relief wells, and/or pervious toe trenches as described in EM 110-2-1913 and EM 1110-2-2502. • Types of underseepage control used will be site specific and will depend on the nature of the foundation soils and toe conditions. • 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.
Scour Protection	• Protection should be provided on the flood side to withstand the anticipated erosional forces. Riprap is a commonly used revetment type and is generally recommended for areas subjected to wave forces and currents. In areas shielded from higher erosional forces, lower cost methods, such as grass cover, gravel, or paving, may be sufficient. • Consider use of riprap, hardscape, or a turf reinforcement mat to protect the dry side of the barrier from erosion due to overtopping or heavy rain during storm events.
Materials	• Relatively homogenous, well-graded earthen materials, such as MassDOT M1.0.3.0 Gravel Borrow, are considered preferable for use as fill material. Material should be selected, placed, and compacted as required to prevent detrimental seepage and maintain overall stability. • If possible, use in-kind wall materials (granite blocks) to raise the height of the existing wall.
Drainage	• Place filter fabric behind the stone masonry wall units to prevent soils migration from land to water.
Foundations	• Check supporting capacities of the existing wall foundation and soils with the weight of additional backfill and wall materials.

Foundations (continued)	• Design analyses should consider wall movement under flood load conditions, and the seepage pathway that may be created around the foundation and future wall because of wall movement. • The type of foundation should be selected based on existing subsurface materials, with considerations for settlement, bearing, earthwork requirements, and other geotechnical considerations. • Bottoms of footings should bear a minimum of 4 ft below finished grade for frost protection.
Incremental Considerations	• Design and analyses should consider future wall heights and anticipated increased loading.

Operations & Maintenance	• Inspect the wall(s) after flood events, and at least once per year to help evaluate if the system will continue to function as intended. Some general geotechnical operation and maintenance considerations are as follows:
	  ◦ 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 sinkholes and settlement on the dry side, sandboils and turbid seepage through or beyond the toe of the 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.

Cost	• Adjacent structures requiring protection of adverse effects related to the construction of a flood barrier may impart large costs to the project. • Conditions of the existing wall can have large cost implications on sample designs. Availability of existing structure and foundation information will reduce the need for exploring to find the information. • Many different permitting requirements can be triggered. Creating permit applications and attending approval meetings can be expensive and can initiate long project delays, further impacting costs. • Access to the site can impact exploratory and construction cost. • Annual inspection costs are estimated to range between about \$10k to \$15k. Costs of repairs will vary. Minor repairs, such as filling erosion gullies and replacing hardscape can range from about \$10k to \$30k.

D7. ACCESSIBILITY AND TRANSPORTATION CONSIDERATIONS FOR FLOOD PROTECTION

The City of Boston does not want to block access to the waterfront by constructing flood barriers. Accessibility shall be considered when designing the harborwalk barrier and/or raising the seawall. This includes considering pedestrian and vehicle access, as well as connectivity with the rest of the built environment. Public health and safety are paramount. The Right of Way should be kept clear of flood debris, water, ice, and snow. The pedestrian walkways should consider the following items.

Abutters	• Coordination with property owners and stakeholders, including but not limited to MassDEP, MassDOT, MBTA and community organizations.
Sidewalks	• Pedestrian access to the harborwalk, including split sidewalks or pathways, shall be ADA compliant (per Massachusetts Architectural Access Board MAAB).
Intersections	• The sample harborwalk path intersects with access paths. A 2 ft. grade change is proposed for the sample barrier, which may impact intersections within 16 ft. of the barrier. Maximum 7.5% slope shall be maintained for ADA compliance.
Bridges/Underpasses	• No bridges or underpasses are located within 500 ft. of the sample site.
Accessibility and ADA	• Sidewalks or pathways constructed along the harborwalk must be ADA compliant. • The minimum width of the path shall be 12 ft. so that a maintenance vehicle can bypass a wheelchair without impeding movement.
Roadway Base Construction/Materials	• The access path material shall be ADA complaint.
Parking	• Parking is not recommended for the sample Harborwalk.
Grading	• Sample slopes are 3H:1V (horizontal:vertical) for the Harborwalk slope on the land side of the barrier to satisfy global stability and facilitate maintenance activities and recreational opportunities.
Signage, Pavement Markings and Traffic Signals	• Not applicable for the harborwalk barrier. However, informative signage is recommended to educate the public on the project and sea level rise.
Bike lanes	• Shared bike paths shall be implemented on the access path. • The minimum width of the path shall be 12 ft. so that a maintenance vehicle can bypass a wheelchair without impeding movement.
Incremental Considerations	• Harborwalk paths may be elevated over time to connect barriers.
Operation & Maintenance	• Access paths shall be inspected at least every month for deterioration or washouts. The path shall be inspected after heavy rainfall for damage.
Costs	• Costs associated with the access paths include the supplemental materials for washouts and low areas. • Costs that will be expected are a one-ton dump truck, backhoe with an operator plus one laborer on the ground to work with the operator.

D8. GROUNDWATER CONSIDERATIONS FOR FLOOD PROTECTION

Changes in sea level rise can lead to changes in the coastal area's groundwater table, including depth to groundwater and depth of saltwater intrusion. The impact of local sea level rise and groundwater levels in the Boston area is not yet well defined. That study should be performed, and relationship identified to develop a plan for managing groundwater impacts relative to the site and surrounding features.

The implementation of a Harborwalk barrier, based on the sample site location, may affect groundwater in the area around the sample site. Groundwater studies should be completed prior to design, and management efforts should be designed to work around the barrier once constructed. Drainage will be necessary on the inland side of the barrier; as groundwater conditions are site specific, considerations will be different for each location. To properly assess constraints and mitigate or manage the risks associated with groundwater, detailed investigations and analysis will most likely be required. These analyses should be performed to gain a better understanding of physical factors that may limit drainage, soil and groundwater contaminants, and how adjacent assets and land uses depend on groundwater availability. In addition to the studies completed, the following considerations should be evaluated:

Uplift	• Uplift pressure may result in damage to buried pipes, bridges, buildings, and other features not designed for higher groundwater tables and uplift pressure. • Additional structural reinforcement and waterproofing may be required for underground structures. • Consider elevating buried utilities above future groundwater projections (not yet developed).
Freshwater-Saltwater interface	• Higher salinity may impact coastal ecosystems (vegetation and habitats), such as marshes. • Thinner freshwater lens. Studies conducted in Maryland indicate that barrier islands are subject to substantial thinning of the freshwater lens due to changes in sea level rise (J.P. Masterson et. Al, 2013). This may impact vegetation, habitat, and any areas surrounding the barrier that depend on fresh groundwater. • Identify any existing wells near the sample site and perform groundwater sampling to characterize existing groundwater.
Utilities	• Saltwater intrusion into water treatment facilities may result in killing bacteria used for biological treatment of water. • Higher salinity may result in faster corrosion of buried utilities. Higher chloride concentration due to salinity may corrode drinking water pipes and result in public health impacts (A. Brooks et. Al, 2011). Corrosion of buried electrical pipes may impact power distribution and public health and safety. • New utilities should use salt-water resistant materials to reduce risk of damage.
Seepage	• Timber piers supporting historic structures in Boston rely on the groundwater to prevent rotting and support historic structures. Before a sheet pile or cutoff wall is designed to reduce seepage through the flood barrier, a study should consider impacts to nearby foundations and structures. • Seepage from higher groundwater tables may result in more frequent groundwater inundation in below grade structures. Preliminary studies in Hawaii indicate that changes in tide levels due to sea level rise may cause widespread groundwater inundation (Rotzoll and Fletcher, 2013). • Soil conditions will impact groundwater flow and inundation. For example, gravel will have a higher rate of flow through the material than a fine grained material, such as silt or clay. Refer to the geotechnical section for additional considerations.

Drainage	• Higher groundwater levels may result in reduced stormwater infiltration and affect stormwater drainage systems. Refer to the stormwater considerations provided for additional guidance on stormwater drainage. • Groundwater pumps should consider back-up generation and redundancy. Power generation may be compromised due to climate impacts. • In projects with dewatering, consider reducing the rate of extraction for well fields near the coast and increasing the rate of discharge for wells in other areas to manage groundwater in areas near the coast. • Pumping groundwater may result in land subsidence. See section below.
Land Subsidence	• More pumping may be required to reduce below ground flooding, which may exacerbate land subsidence. Groundwater extraction should be managed to avoid land subsidence.
Pollutants	• Groundwater pollution can occur when contaminants are released at the ground surface and filter through the soil into the groundwater table. Higher groundwater tables increase the risk of pollution. Consult with licensed professional environmental engineers to identify risks at the site for spills and/or releases and identify if additional measures should be considered to protect the groundwater table.
Incremental Consideration	• The impacts of local sea level rise with respect to groundwater levels in the Boston area is not yet well defined. In developing a plan for managing groundwater impacts at a site, a local groundwater study should be performed to identify such impacts. This study should include ongoing gauging of site groundwater monitoring wells to evaluate local groundwater impacts from sea level rise. • During routine utility replacement, consider replacing pipe materials with salt-resistant materials to reduce corrosion damage.
Operations & Maintenance	• Evaluate service life due to corrosion of buried pipes. Develop plan for O&M. • Manage sump pumps and coordinate with the City and neighbors so that groundwater sump pumps do not discharge or worsen impacts on other properties. • Consider using groundwater monitoring transducers to record changes in the groundwater table. Collect data at least 4 times a year to analyze.
Costs	• As the relationship between sea level rise and groundwater is not yet well defined in the Boston area, the projected costs may vary greatly. • Costs for utilities are included in the utility considerations.

D9. VEGETATIVE CONSIDERATIONS FOR FLOOD PROTECTION

The Harborwalk is a long-term cooperative project between the City of Boston, the Boston Planning and Development Agency, MassDEP, and the Boston Harbor Now to maintain the nearly 43 miles of walkable waterfront in the city as public access areas. Raising the seawall barrier will not require significant landscape controls at the sample site as no new pervious surfaces will be created. However, other opportunities should be considered at harborwalk locations where space may allow for seasonal and/or temporary planters to be deployed, or at landscape areas adjacent to the harborwalk that might allow for plant materials to assist in the mitigation of climate change effects, including, but not limited to, stormwater mitigation and quality, heat island effect and erosion controls. Further considerations are addressed in the following sections:

Tree & Root Systems	• Trees may be considered to assist in the reduction of urban heat island temperatures, however, the critical rootzone of each tree variety and location should be considered as to not compromise the integrity of the seawall. A 20 ft. minimum distance from the footprint of the barrier is recommended. • Root barriers may be required to prevent encroachment and migration of tree roots below pavements and within the critical zone of the seawall.

Plant Performance Goals:	• Choosing the correct plants is an important consideration, particularly in the urban realm and along densely populated pedestrian corridors such as the Harborwalk. Selecting incorrect plants may lead to increased maintenance, failure of plants to thrive or loss of plant material altogether. Careful planning and site analysis are important first steps. It is critical for plant selection along the Harborwalk to align with the sample growing conditions, adjacent use area activities and evaluate their landscape value.
	• Some site conditions to keep in mind when selecting plants include:
	  • Light availability, intensity and duration (full sun to deep shade)
	  • Water availability, both quantity and quality
	  • Exposure to wind and temperature extremes
	  • Soil type, drainage and compaction
	  • Hardiness Zone
	  • Competition from other plant types
	  • Below ground conditions particularly in urban locations
	  • A major factor to consider is insects and disease resistance
	• Aesthetic considerations for plant selection include:
	  • Growth habit (height, shape, spreading)
	  • Season and color of bloom
	  • Foliage texture, color and shape
	  • Winter interest, fruits and seeds
	  • Benefits to wildlife
	  • Fall color
	  • Longevity
	  • Maintenance requirements

Open Space	• Plant materials in this location will create the opportunity to enhance public green space and both passive and active recreation opportunities adjacent to the harborwalk.

	• The use of plants will help to reduce urban heat island and increase equity in the adjacent open spaces.

Conservation Commission	• Plant selections and materials must meet the requirements of the City of Boston Conservation Commission and the Massachusetts Wetland Protection Act: https://www.boston.gov/departments/environment/conservation-commission and https://www.mass.gov/regulations/310-CMR-1000-wetlands-protection-act-regulations accordingly.
	• City agencies and stakeholders associated with the sample Harborwalk and/or the adjacent public park should be consulted prior to implementation, including but not limited to:
	  • City of Boston Conservation Commission
	  • Boston Planning and Development Agency
	  • Massachusetts Department of Environmental Protection
	  • Boston Parks and Recreation Department
	  • Climate Ready Boston
	  • Boston Harbor Now
	• Harborwalk plant materials may include be included in the strategy for GI designs such as bioretention, raingardens or similar elements at adjacent landscape areas, if the space is available, that may allow for stormwater treatment opportunities.
	• Harborwalk GI plant material selections and designs should consider salt tolerate low maintenance, durable plants, shrubs and small trees.

Invasive & Native Plants	• Known invasive plant materials should never be used. See list of Massachusetts invasive plants: https://www.mass.gov/service-details/invasive-plants. • While the sample site may provide an opportunity to use unique and non-native plant materials should they be desired, low maintenance and urban appropriate plant materials should be considered as certain plant varieties may require increased maintenance or not be successful.
Incremental Considerations	• A flexible plant material implementation approach can be considered for GI stormwater controls in the watershed but may not necessarily be tied to specific timelines as they relate to the incremental height increases of the harborwalk and may be deferred or seasonally installed as part of the sample site Harborwalk and public park operation and maintenance programs. • Evaluate current zoning and new development or redevelopment potential on the upgradient watershed and the need for land use change.
Operation & Maintenance	• Low-maintenance landscaping does not mean no maintenance will be required as plants require some routine care to succeed. In addition to plant selection, the proper planting practices and grouping of plant types according to their needs for water, fertilizer and maintenance will go a long way to promote good plant health. With good site evaluation and proper plant selection, plants will thrive and enhance the open space and Harborwalk as a public asset for many years. • Consideration of a maintenance program may include the start of a Friends of organization that works hand in hand with the City and other stakeholders to keep the harborwalk clean and well maintained. • Barrier areas and plant materials shall be kept free from refuse and debris. Plant materials shall be maintained in a healthy growing condition, near and orderly in appearance in perpetuity from the time of the growth season. If any plant material dies or becomes diseased, they should be replaced.

Costs	• Plant costs will vary based on the sample landscaping. Coordinate with a landscape designer to identify costs relative to the initial construction and identify a plan for regular maintenance associated with the sample landscaping.