CLIMATE RESILIENT DESIGN STANDARDS & GUIDELINES

FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

BOSTON PUBLIC WORKS DEPARTMENT

OCTOBER 17, 2018

SECTION 4.0

SAMPLE VEGETATED BERM BARRIER

SECTION 4.0 SAMPLE VEGETATED BERM BARRIER

4.1 DESCRIPTION AND ASSUMPTIONS

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

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

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

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

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

4.2 SAMPLE VEGETATED BERM BARRIER DESIGN CONSIDERATIONS

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

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

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

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

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

4.3 OPERATIONS AND MAINTENANCE AND COST CONSIDERATIONS

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

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

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

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

Riprap flood-side slope maintenance

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

Access path maintenance

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

Vegetation maintenance

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

Stormwater maintenance

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

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

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

O&M Plan

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

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

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

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

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

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

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

B.1 Vegetated Berm Barrier - 2030 DFE Conditions

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

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

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

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

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

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

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

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

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

4.4 BARRIER SELECTION

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

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

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

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

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

4.5 SAMPLE DESIGN DRAWING AND FIGURES

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

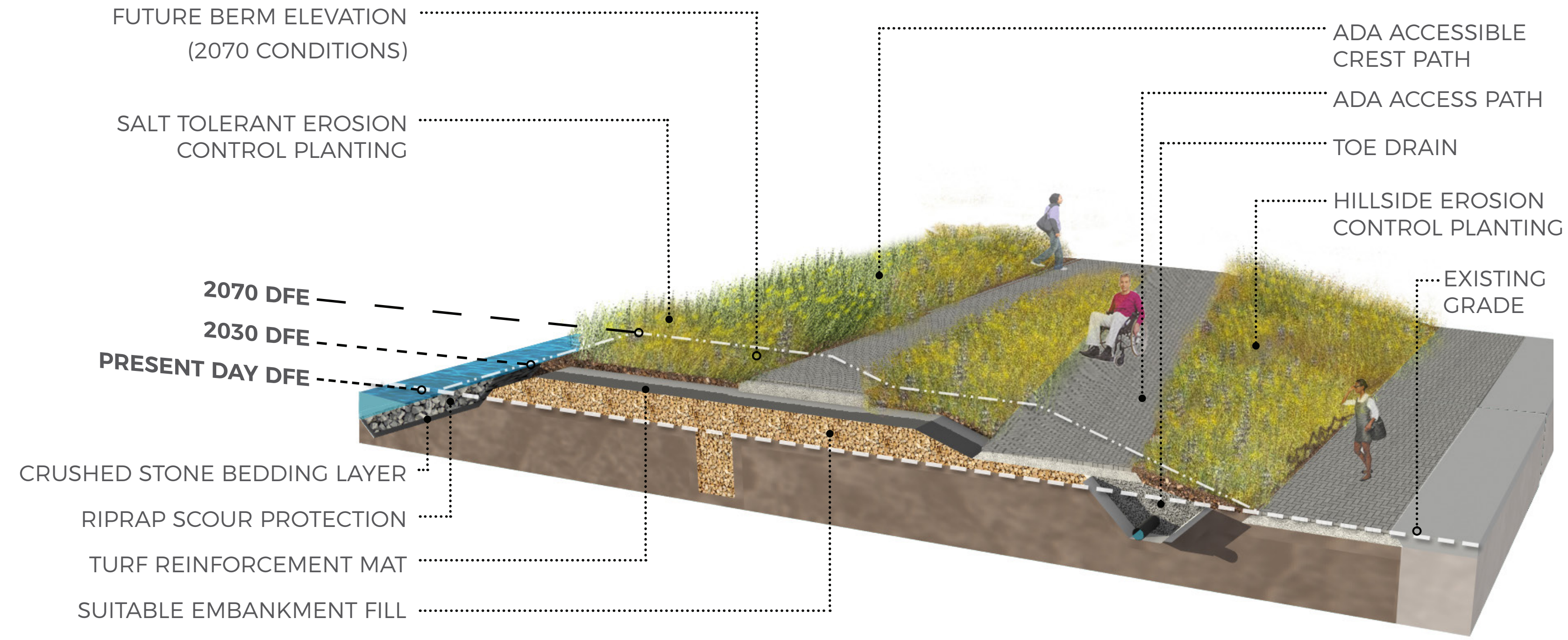
B.1 VEGETATED BERM BARRIER

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

DOWNLOADABLE FILES:
Standard PWD Details for reference and download can be found here

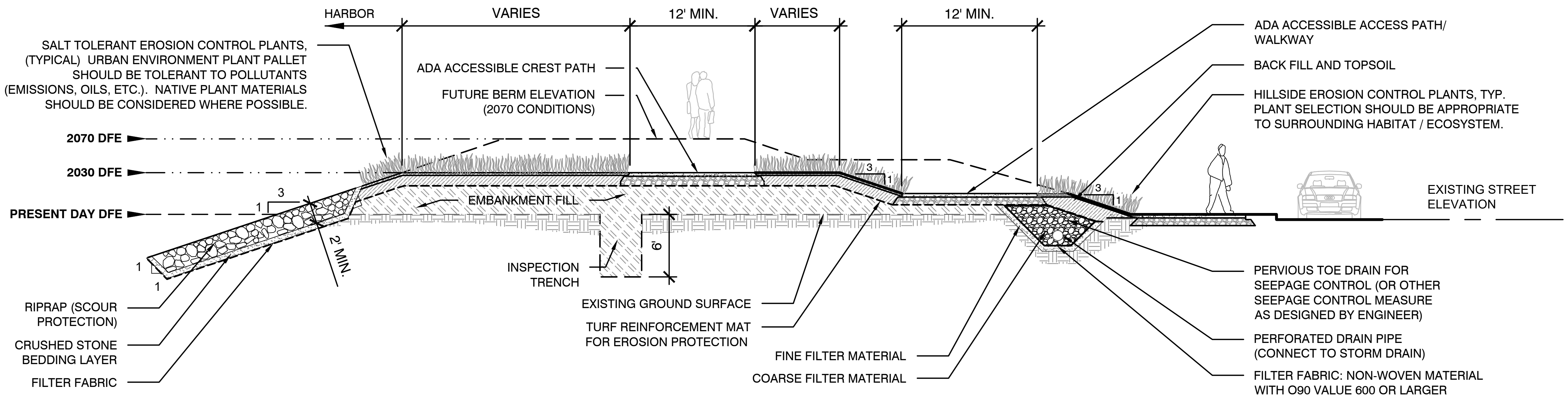
SAMPLE

B.1. SAMPLE VEGETATED BERM BARRIER
CAD
PDF

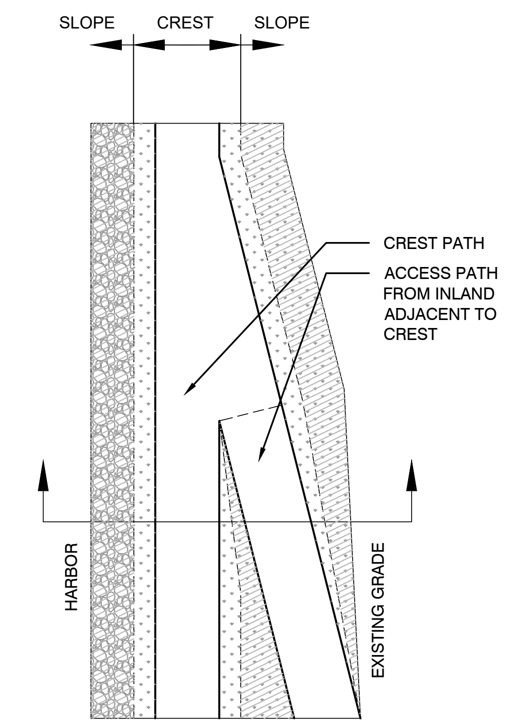


SAMPLE VEGETATED BERM CROSS SECTION WIDTHS (Crest, slope, and possible access path)					
Increased Height from Existing Ground Surface (+__ft)	Minimum Crest Width	Slope Width	Access Path Width	Total Width (no Access Path)	Total Width (with Access Path)
1	18	6	12	24	36
2	18	12	12	30	42
3	18	18	12	36	48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

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



INCREMENTAL APPROACH
(SHOWN AS 2030 AS-BUILT)



PLAN VIEW

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

SAMPLE - NOT TO SCALE

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

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

FIGURE 1

INCREMENTAL APPROACH FOR SAMPLE VEGETATED BERM

LIMITS OF PROPOSED WORK FOR 2030 DFE AND 2070 DFE

Proposed Barrier for the 2030 Design Flood Elevation (DFE)

Proposed Barrier for the 2070 Design Flood Elevation (DFE)

Possible Easement

1,000 0 1,000

Scale In Feet

Path: \\wse03.local\WSE\Projects\MA\Boston MA\BPWD - Climate Resilience Guidelines\Deliverables\7. Final Guidelines Document\GIS Figures\2 Incremental Veg Berm.mxd **User:** LambertD **Saved:** 10/3/2018 9:08:35 AM **Opened:** 10/3/2018 9:09:29 AM

FIGURE 2

PROPERTIES IMPACTED BY SAMPLE VEGETATED BERM BARRIER

Proposed Barrier for the 2070 Design Flood Elevation (DFE)

Parcels Affected by Proposed Buildout Area

800 0 800

Scale In Feet

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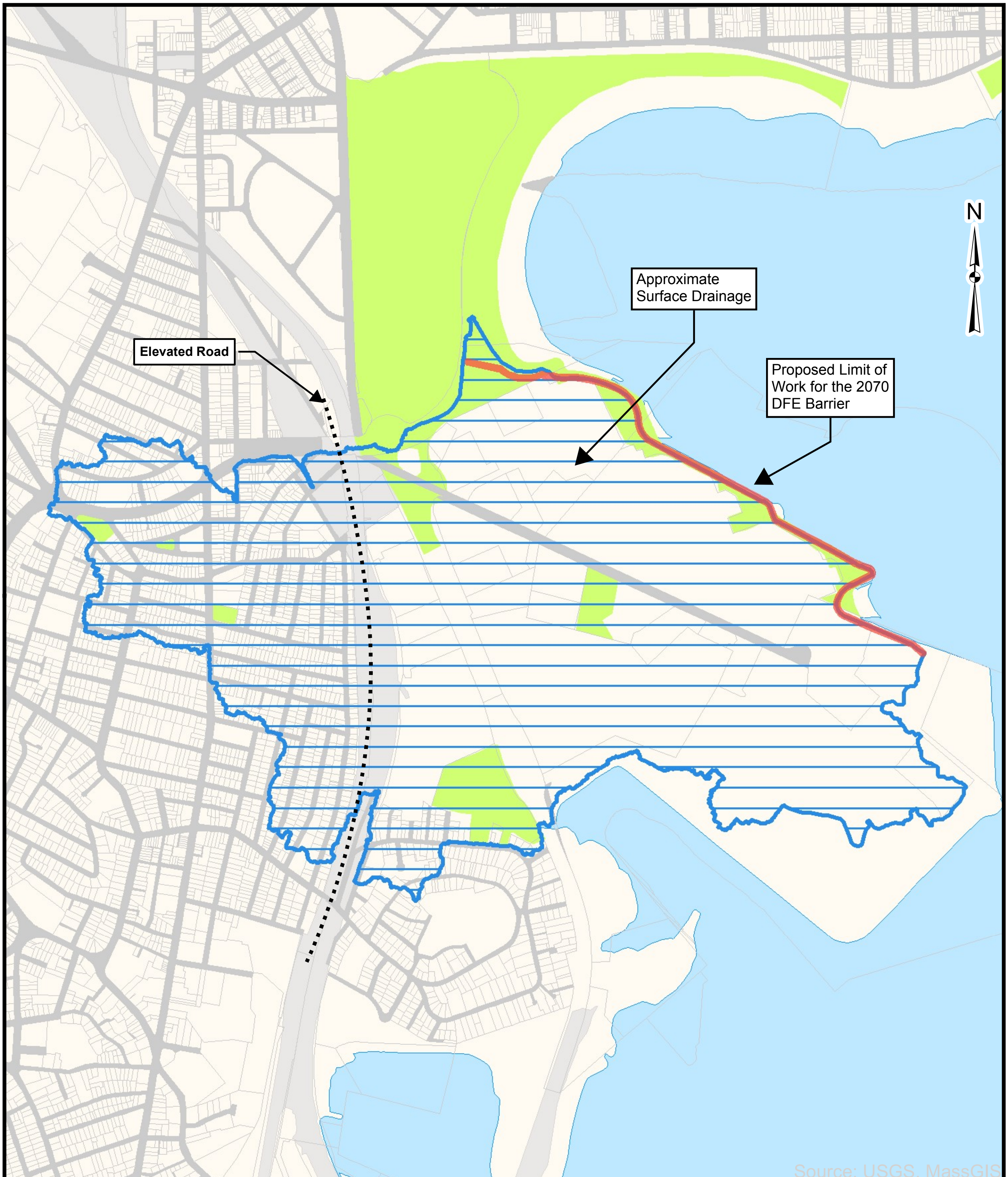

FIGURE 3

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

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

Drainage Area (422.3 acres)

Protected Open Space (34.18 acres In Drainage Area)

1,000 0 1,000

Scale In Feet

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Proposed Limit of Work fro the 2070 Design Flood Elevation (DFE)
PS Pump Station
Outfall
Catch Basin
Sanitary Manhole
Storm Manhole
Combined Manhole
Combined Sewer
Sanitary Sewer
Storm Sewer
Water Main
Protected Open Space

FIGURE 4

EXISTING UTILITIES IDENTIFIED IN SAMPLE VEGETATED BERM BARRIER PROJECT AREA

1,000 0 1,000
Scale In Feet

FIGURE 5

- Index Elevation Contour
- Intermediate Elevation Contour
- Proposed Barrier for the 2070 Design Flood Elevation (DFE)
- Land Below 21.5'

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

650 0 650

Scale In Feet

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

APPENDIX C. SAMPLE VEGETATED BERM DESIGN CONSIDERATIONS

APPENDIX C. SAMPLE VEGETATED BERM DESIGN CONSIDERATIONS

This section provides additional design considerations for designing a sample vegetated berm as provided in **Section 4.0 Sample Vegetated Berm 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 should be used by engineers and design professionals to understand the process of advancing conceptual design to implementation.

C1. 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 useful life of 50 years, so the 2070 climate adjustment 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 within a flood pathway that impacts a college and roadway. The present 1% annual flood pathway originates at the north tip of the sample site. Additional 1% annual storm entry points based on the 2030, 2050, and 2070 time horizons occur south of the sample site. • The BH-FRM model results include the base flood elevation of 19.3 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 20.3 ft. at a minimum. Additional studies and the sub-model BH-FRM results are required for final design elevation.
Extreme Precipitation	• Determine 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 inland 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 event to address future climate conditions. A risk alternative analysis should be considered in the design to evaluate a future condition 1% annual 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 future barrier: 0.6 sq. miles. Refer to the stormwater considerations section 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; and ▪ Increased failure/reduced efficiency of electrical/mechanical systems (power outages and pumps). • Consider winter storm impacts to: ▪ Health and Safety; ▪ Snow and ice ground cover; ▪ Plowing and snow removal; ▪ Snow storage on-site/off-site; ▪ Drainage and infiltration impacts; and ▪ Ice jams.
Incremental Consideration	• If the site is unable to accommodate the design values for the 2070 climate adjustments, an incremental approach may be selected to meet the 2030 and/or 2050 time horizons. • An incremental approach may be feasible to extend the flood barrier to block the pathway over time. See Figure1 in Section 4.5. • This may include, but is not limited to, raising grades 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.

C2. SITE SPECIFIC AND BOUNDARY CONSTRAINTS

The sample site is part of a DCR reservation and is located to the east of college campus exposition center, residential neighborhoods, and a parking lot. It is located south of a beach and public park. The sample site is located along the Boston Harborwalk and within the public right-of-way.

The following site specific and boundary constraints for the vegetated berm are to be used as a guideline when evaluating if a berm is an appropriate flood protection barrier for a sample 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 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.

<table>
<tr>
<td>Extent of Barrier (Current and Future)</td>
<td>

Using projections for current and future flood paths, identify how far the barrier would need to extend to fully protect the site and not result in flanking (floodwaters flowing around the barrier).

The barrier would need to be approximately 2000 ft. long for current flood protection, and increase to approximately 1-mile for 2070 flood protection.

The minimum cross-section of the barrier should consider (at least):

Current elevation and grading of the site;
Space for slopes (horizontal extent is approximately 3 times longer than the vertical extent per slope) and/or retaining walls;
Freeboard to reduce risk of overtopping;
Size of future “final” barrier for incremental approach; and
The sample drawing provided includes a table with the height differential and minimum widths for berm designs. For the example site, in this case, a 4 ft. berm would need to be at least 57 ft. wide with an inland access path (15 ft. wide) that connects the inland property to the top of the berm. This is not to suggest that hybrid barriers with walls or steeper slopes are not appropriate. The final geometry of the vegetated berm should meet the intentions of the guidelines. The sample is designed to provide an example to consider.

The final barrier for a 50-year useful life will be approximately 1 mile long and should extend a minimum of 20 ft. into the abutments (higher grades at 20.3 ft. BCB) to reduce risk of flanking and failure at abutments. The final proposed alignment is shown in attached Figures 2 through 6 in Section 4.3.
Downstream encroachment considerations:

If future development is proposed immediately downstream of the barrier, it may “encroach” on the barrier and increase risk for failure mechanisms, such as piping, and damages.

Consider the impacts of neighboring properties:

Figure 3 in Section 4.3 shows the extent of impacts to neighboring properties for the final phase of the berm implementation at the example site location.

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. The

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	vegetated berm ties into higher elevations at both ends in its final phase.
Zoning	• Contact the Boston Planning and Development Agency (BPDA) to evaluate zoning regulations and requirements. • Identify any current regulations that may prevent construction of the vegetated berm. • 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	• Easements may be necessary along the dry-side (inland side) of the barrier based on actual property line survey data (not performed for this sample). This includes O&M access routes to the berm. See Figure 2 in Section 4.3. • The existing harborwalk alignment has space for the sample berm to be constructed. The parking lot could be used as a space for construction and installation efforts. Space and access for operations and maintenance activities should be considered. • Optimize opportunities to connect to the waterfront wherever possible. ▪ An access road provides connection from the protected side to the waterfront.
Public Right-of-Way	• The sample barrier will prevent flooding into the public right of way (ROW), but flooding from roadways and public open spaces is still possible. • Pedestrian ROWs will be re-established along the top of the sample berm. • Sample barrier design includes 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 at the sample site.
	    ○ Coordination is necessary between property owners if barriers are to encroach upon neighboring properties.
	    ○ Design requirements shall remain the same with the addition of properties.
	    ○ Barrier selection may change based on constraints of additional properties.
	• The barrier may encroach onto nearby properties.
	    ○ Coordination will be necessary between the owners of the property and of the easement.
	    ○ Easement access shall be maintained at all times and may need to be relocated upon implementation of barriers.

Operational Capacity	• The berm shall be easily accessed for all maintenance and operation purposes. The sample berm is accessible near a beach, a college, and a public open space. • Responsibility shall be established for the barrier pertaining to all operation and maintenance efforts. • Maintenance shall include all necessary cleaning and upkeep of the barrier to ensure the barrier performs as designed in flood events.

Off-Site Impacts (Adjacent and Downstream)	• 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 within the project area. • Similar to the considerations for the overall extent of the barrier with impacts to neighboring properties, the installation of a flood barrier has off-site impacts to both adjacent and downstream areas. • The flood path may change with the addition of a flood barrier, as the barrier could divert flood water to unprotected areas. This study has not been completed. • Drainage areas will be impacted, and additional/modified drainage systems may need to be implemented to accommodate higher inflow rates. Figure 4 shows the impacted sample drainage area. • 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.

Climate Ready Boston Criteria	• Climate Ready Boston created criteria to identify the opportunities of resilient design. In general, the Public Works Department's Climate Resilient Design Standard and Guidelines address effectiveness, feasibility, and design life and adaptability. However, the following CRB criteria should be considered for the sample site:
	• Social Impacts
	  ◦ The berm should include recreational and cultural opportunities.
	  ◦ The berm should be aesthetically pleasing.
	• Equity
	  ◦ Creates equitable access to waterfront in South Boston.
	  ◦ Additional benefits for vulnerable populations should be considered.
	  ◦ Community partnerships may be equitable investments.
	  ◦ The barrier protects affordable housing.
	  ◦ Flood reduction behind the barrier will improve local economics and property values.
	• Value Creation
	  ◦ A Vegetated Berm in this location will create the opportunity to construct new public green space and passive recreation on the berm and adjacent to the berm.
	  ◦ Vegetated berms can be designed with pedestrian walkways, which can provide access to the waterfront that may not have been previously available.
	  ◦ The berm creates new opportunities to revitalize the waterfront.
	  ◦ There may be opportunities for future funding and investment.
	• Environmental Impact
	  ◦ Water and air quality are not impacted.
	  ◦ There may be opportunities to create habitat value upstream of the riprap slope.
	  ◦ Consider human health benefits and impacts.

Climate Ready Boston Criteria (continued)	• Creating salt and freshwater stormwater treatment marshes will improve wildlife habitat in the area. • More green space will help to reduce urban heat island. • Creating stormwater detention in the watershed behind the berm will result in improved wildlife habitat, reduction in stormwater flooding, improved air quality, and passive recreation creation.

Incremental Considerations	• As sea level rises, the flood path will change and grow to include more impacted properties. The barrier may need rise in height as sea level continues to rise and flood events increase in size and intensity.
	• The barrier is designed to be implemented incrementally and accommodate up to 2 ft. of additional height without steepening the slopes.
	• Site specific incremental considerations, both vertical and horizontal, are as follows:
	  ○ Boundaries – full barrier will extend as shown in Figure 6 and tie into existing higher grades.
	  ○ Bridging Gaps – there are no gaps that will not be covered by the berm.
	  ○ Barrier Modification – the barrier is designed to increase in height as needed.
	  ○ Master Plans – shall be changed according to the locations and sizes of barriers.
	  ○ Planning – this project should be coordinated in conjunction with other flood protection projects in the area.

Operation & Maintenance	• Operation and maintenance will be similar to levee, dam, and dike considerations.
	• The berm is located along the harbor and may result in more operation and maintenance needs as weather/erosion may have a significant effect on the barrier.
	• Access paths to and along the berm will need to be considered for all maintenance and emergency needs.
	  ○ Vehicles will need to be supported by the berm for any short-term travel.
	  ○ The berm should not be designed for full time vehicle use.

Costs	• Operation and maintenance costs will be determined by current and project future wage rates and the manpower estimated for regular maintenance associated with the selected barrier, including stormwater management. • Permitting costs may be required for implementation of barriers in certain 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.

C3. 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 today and, in the future, to safely convey, treat, and manage stormwater. Stormwater Management controls for vegetated berms such as the selected sample site location would provide the opportunity to create a raised berm for coastal sea level rise protection that could also serve as space for stormwater management and new public open space.

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;
- Water Quality Modeling of Stormwater Control Measures; and
- Pump station feasibility analysis.

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 infrastructure.
	• 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.
	• Vegetative berms will include space for required structural pretreatment BMPs such as deep sump catch basins, oil/grit separators, proprietary structures, sediment forebays and vegetative filter strips
	• Vegetative raised berms can also incorporate stormwater treatment GI designs such as bioretention/raingardens, constructed stormwater treatment wetlands, media filters, tree box filters, sand and organic filters and wet basins.
	• GI designs at this vegetated berm location can include management of stormwater generated by the vegetated berm and stormwater generated nearby from the college, and local streets leading to improved local stormwater treatment.
	    • Vegetation for berm GI stormwater designs should include salt tolerate grasses and shrubs. Trees are excluded. See New England Wetland Plants (www.newp.com) for salt tolerant native grasses, shrubs and seed mixes and also Massachusetts Stormwater Handbook Volume 2, Chapter 2 for plants suitable for use in bioretention. Dry sections of the Vegetative berm should be planted with species following Coastal Landscaping Plant List for Massachusetts
	    • http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/coastal-landscaping/plants.html

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

Volume Capture and Control (continued)	of the vegetated berm such as walkways, road surfaces and potentially the sides of the berm 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. • The vegetative berm will need adequately sized conveyance and potential mechanical pumping systems to manage the stormwater on the upgradient side of any new structure. Space is currently available along the dry side of the Harbor Walkway 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.
Off-Site Impacts & Flooding	• Barrier designs should have no significant impacts off-site. • The end points of the sample Vegetated berm must be tied into elevations that will not cause bypass and diversion of floodwaters onto adjacent properties. Tie into high points to the north and south.
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 City of Boston must address urban stormwater pollution in all discharges. • Goal of no net increase in total petroleum (TP), total suspended solids (TSS) and volume. • The proposed barriers should consider a range of options that are appropriate to treat the expected pollutants. From roadway runoff these are primarily sediment, turbidity, metals, and oils and greases. If there is available space, 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 sample drainage area has possible green and open space available to accommodate detention storage for stormwater during precipitation events. • Identify potential inland stormwater management approaches to delay, store, and discharge stormwater trapped by the barrier (sample site drainage area is 0.6 sq. miles). See Figure 4 in Section 4.3.
Incremental Considerations	• Adaptive management approach can be considered for GI stormwater controls in the watershed. • Evaluate current zoning and new development/redevelopment potential ion the inland 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. • Special considerations for maintenance of green infrastructure should be identified.
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.

C4. UTILITY CONSIDERATIONS FOR FLOOD PROTECTION

A raised vegetated berm may not require significant utility modifications at the sample site. A Boston Water and Sewer Commission (BWSC) storm outfall crosses the sample berm to the waterfront. Multiple utilities exist within 100 ft. of the sample berm. The goal is to 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 conduits, or along the outside walls of the conduit (a serious structural-integrity problem often referred to as “piping”). As part of flood protection design, utility penetrations through any barrier should be minimized, however, where a structure or utility passes through a flood barrier, precautions must be taken to prevent passage of flood water through the barrier.

Studies and Investigations Required:

- Data Collection for all underground and overhead utilities, including materials, dimensions, year of installation;
- 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; and
- Pump station feasibility assessment.

Survey	• Several known utilities exist in the vegetated berm project area. An in-depth survey shall be performed at the project area to best address utility conflicts. • Records for existing utilities, both overhead and underground, shall be requested and reviewed thoroughly early in the design process. • A professional surveyor shall conduct a site survey and identify all public and private utilities, both overhead and underground land. The survey shall include elevation data for utilities when possible (for example, clearance for overhead wires and depth of underground utilities.) In addition, consideration should be given to hiring a professional subsurface utility engineering firm to locate all utilities (known and abandoned) within the project area. • Use Boston City Base datum on all elevation survey work. • Identify flood zones on any mapping efforts, overlay utility survey with flood maps. • Identify all mechanical assets and their elevation relative to the design flood elevation.

Water Utilities	• Approximately 30-feet of 8-inch water main appears to cross the sample vegetated berm at the north side of the barrier.
	  o Consider placing the water main within a watertight sleeve to protect the barrier.
	  o Install a gate valve on the 8-inch water main on the dry side of the vegetated berm to isolate the potable water system from the system on the wet side of the barrier, which may become compromised from flooding.
	• Less than 200-feet of existing 8” water main runs parallel to the vegetated berm area.

Water Utilities (continued)	○ Consider relocating the water main further from the barrier so that it cannot adversely impact the barriers integrity, and/or construct the pipeline 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	• Sewer mains, manholes, and catch basins exist on the dry side of the vegetated berm. There are no sewer outfalls or utilities that cross the barrier. • Sewer mains shall be left at their existing elevations. A change in elevations may affect the gravitational direction of flow. • Consider relocating the sewer main and structures further from the barrier so that it cannot adversely impact the barriers integrity, and/or construct install a structural liner in sewer main to minimize the possibility of sewer main failure.
Combined Sewers and Combined Sewer Overflows (CSO's)	• The design of the vegetated berm should consider the nearby storm outfalls and related facilities. • The sample project area includes combined sanitary and storm water flows. This means all catch basins discharge into the combined sewer main. However, all catch basins are on the dry side of the barrier. • Combined sewers include sanitary and storm water flows and are gravity pipe systems that can allow water to flow in either direction depending on hydraulic conditions. • 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. It is possible that CSO's on the dry side of the barrier can create flooding behind the berm. • Combined sewers discharge to the MWRA sewer system. When flows exceed the local BWSC system capacity or the MWRA interceptor sewer capacity, CSO's occur through overflow pipes to the local receiving water. Considerations: ○ Coordinate with MWRA to assure that MWRA interceptors do not surcharge into the areas behind barriers; ○ Coordinate with MWRA to assure that 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; and ○ One 72-inch storm outfall exists at the south end of the sample site. No tide gate exists on the outfall. A tide gate should be installed to prevent water from flowing backwards to the dry side of the vegetated berm. • If the outfall is extended to discharge on the flood side of the vegetated berm, it will need to cross under the barrier. The combined sewer main crossing the barrier shall be assessed for structural integrity in response to the additional material and weight of the vegetated berm. ○ Sewer outfall shall be left at their existing elevations. • Most existing BWSC CSO's have tide gates installed on them. Considerations:

CSOs (continued)	○ Install tide gates on outfalls that can act as conduits to flood protected areas. ○ There is currently no tide gate on the outfall that crosses the berm. ○ Installation and management of possible pumping systems to move the accumulated stormwater during high tides and storm surges.
Stormwater Utilities	• Several stormwater conflicts exist in the vegetated berm project area, particularly on the north side of the berm. • An in-depth analysis of stormwater infrastructure needs to be performed in this project area in order to address stormwater needs such as stormwater separation, relocation of stormwater assets, re-grading ground surface, and pump station design. • Drain utilities belonging to BWSC and the MWRA both exist in the vegetated berm project area. • The majority of catch basins discharge to the combined sewer. • See notes in “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 proposed grade changes and flood elevations. • Pumping stations maybe necessary to manage stormwater behind the vegetated berm. 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; ○ Install water level sensor to monitor rise and fall of water surface elevations to be tied to SCADA. Information is very helpful with measure storm impacts and calibrating 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; and ○ 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 all utilities crossing the barrier and determine ownership, construction methods and likelihood of an existing flow path. If yes, require sealing of ducts to create watertight barriers. • Consider overhead utility clearance, power poles and overhead wires shall be relocated. All work shall be in accordance with state and local regulations. • Owners of electrical utilities shall be notified of the project and should be notified of proposed 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 flood water though any barrier. However, low pressure gas mains that operate at ¼ to ½ psi can be susceptible to water infiltration from floods. Consideration:
	  ○ Maintain the ability to investigate gas leaks; and
	  ○ 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 proposed 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.
	• All work shall be in accordance with federal, state and local regulations.

Communications Utilities	• Locations of communications utilities in the vegetated berm project area are unknown. • Communication utilities (duct banks and conduits), allow pathways for significant flows through any flood barrier. Consideration: ○ Identify all utilities crossing the barrier and determine ownership, construction methods and likelihood of an existing flow path. If yes, require sealing of ducts to create watertight barriers. • Consider overhead utility clearance, power poles and overhead wires shall be relocated if necessary. • Owners of communication utilities shall be notified of the project and should be notified of proposed locations for water, sewer, and storm water utilities. Coordinate utility locations with private utility owners. • All work shall be in accordance with state and local regulations.
Other Utilities	• Other utilities (such as City owned fiber optic cable, MBTA owned utilities, 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 flood water though any barrier. However, low pressure steam pipes can be susceptible to water infiltration from floods.
Incremental Considerations	• A plan of incremental increase in flood protection must be included as part of the design. Utilities must be designed and constructed with the ability to accommodate future changes and additions that provide supplementary protection. • Access to utilities must be maintained with consideration for future changes. • Loading in the future configuration must be included in 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 must take into account future embankment loading conditions; this may mean future increased loads by 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. • 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 all stormwater assets. Inspect all 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 all precipitation events when they are activated. • Keep a written (hardcopy or electronic) record of all required activities including but not limited to maintenance activities, inspections and training or utilize a work order management system for tracking trends and managing efficiently.
Costs	• Costs for each utility shall be coordinated with the utility owner. • Grant opportunities may exist for utility improvement projects including dam, levee and seawall grants from the Massachusetts office of coastal zone management. • A perpendicular utility crossing a barrier (water, sewer, and drain 18” or less in diameter) may cost between $10k - $25k per utility per crossing. • Installation of an 8-inch gate valve on the 8-inch water main on the dry side of the barrier may cost $5,000. • Stormwater pump stations can vary in costs considerably depending upon their capacity. o Typical cost variations can be between $500k and $20M • A typical 72-inch tide gate (or dual tide gate equivalent) and structure on a stormwater outfall may cost $450k -$500k.

C5. STRUCTURAL CONSIDERATIONS FOR FLOOD PROTECTION

Structural considerations will most likely not apply to the vegetated berm design since the sample design is a vegetated earthen embankment. However, in the event that unfavorable site conditions, such as poor-quality soil and/or limited space, are encountered, a retaining wall may be required. The design and construction of a retaining wall should reference general structural considerations in **Appendix B. General Design Considerations**. Refer to geotechnical considerations for embankment considerations.

C6. GEOTECHNICAL CONSIDERATIONS FOR FLOOD PROTECTION

Primary geotechnical considerations for the vegetated berm at this location include global stability, potential for settlement, seepage, and scour. The berm should be designed in accordance with United States Army Corps of Engineers (USACOE) guidance provided in EM 1110-2-1913, Design and Construction of Levees. A licensed Geotechnical Engineer must 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, potential contamination, under-seepage conditions, slope stability, foundation conditions for structures and potential for settlement. • Explorations should consist of borings spaced every 100 to 500 ft. along the alignment of the berm. Borings should be performed in phases when possible, initially conducting widely spaced “pilot” borings during conceptual design, followed by closer spaced final 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. • Observation trenches should be excavated under the centerline of all embankments during construction to evaluate foundation conditions and assess for undesirable underground features such as old utilities, organics, permeable material or other unsuitable materials. Observation trenches should extend to a minimum depth of 6 ft.
Impacts to Existing Structures	• Flood barriers can impart significant surcharge on the underlying utilities or adjacent structures 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 proposed berm location. The parking lot at the college may be near the sample site. • Identify whether existing utilities or below grade structures are located beneath or near the proposed berm. If so, evaluate the load carrying capacities of the existing structures and compare with the anticipated surcharge load from the weight of the berm. • 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 berm can be constructed with 3H:1V (Horizontal: Vertical) slopes on either side, which is considered stable against global stability failure and preferable for maintenance activities. • The natural growth of trees and other woody vegetation is not permitted within 20 ft of flood barriers, as trees may become uprooted during storm events and roots create seepage paths through the barrier.

Settlement	• Flood barrier construction will result in an increase in vertical stress within the underlying soils and subsequent settlement. The amount of settlement will depend on the magnitude of the load and the subsurface conditions. • Settlement may result in loss of freeboard or damage to structures within and around the flood barrier. • Flood barrier design should account for estimated settlement. It may be necessary to overbuild the barrier, over excavate and replace compressible foundation material, or practice staged construction techniques. • Depending on subsurface conditions, long-term settlement may impact existing structures within the zone of influence. Consider supporting existing structures sensitive to movement by underpinning, bridging the loads, or relocating the structures.
Seepage/ Groundwater	• Design the berm to prevent seepage through the berm and emerging on the landside. This may be achieved by constructing the berm to be sufficiently wide to prevent seepage during flood events, and/or by inclusion of a pervious toe, toe trench, and/or vertical or horizontal drainage layers in accordance with USACE design guidance. • All 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 underseepage. • 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 1110-2-1913 and EM 1110-2-2502. • The type 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 hydrogeology and its effects on area foundations, particularly in areas where buildings are supported on timber piles, implications to area groundwater levels, and fresh/saltwater interaction.
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 below vegetated surfaces and walking paths to minimize erosion due to berm overtopping or heavy rain during storm events.
Materials	• Ideally, embankments should be constructed of well-graded gravel borrow material (MassDOT M1.0.3.0). • If ordinary borrow or onsite material is used, the more impervious materials should be placed toward the floodside of the embankment and the more pervious material to the landside.

Materials (continued)	• Embankment material should be placed in lifts and compacted to 95% maximum dry density. • Designers should consider placement of pervious soil layers such as gravel and crushed stone (sometimes used as utility bedding) so that they do not provide a seepage path for flood waters. • Pervious layers of material should not extend completely through or beneath the embankment or wall. • Consider the use of lightweight aggregates and geogrids to increase stability. • Materials and vegetation must be able to withstand wave action and saltwater/corrosion.
Drainage	• Seepage can be collected in seepage collection systems (toe drains) and drained off-site.
Foundations	• Possible future wall foundations on the berm should be designed with future surcharges (soil and water) in mind. • 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	• When designing any flood protection barrier, plan for increased loading due to future berm or wall heights. • Berm widths should be designed to accommodate future berm heights while maintaining acceptable side slopes. Where berm widths are constrained by existing buildings, roadways, etc, design of berms should take into account potential need for retaining walls to support future berm heights. Consider incorporating retaining wall foundation elements for future use to reduce the amount of earthwork required when raising the embankment. o In this sample site, the berm is sufficiently wide for increased grade changes without steepening the slope.

Operation and Maintenance	• Inspect the berm after flood events, and at least once per year to help ensure the system will continue to function as intended. Some general geotechnical operation and maintenance considerations are as follows:
	    o 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.
	    o Check for and remove encroachments into the flood barrier. These may include trees and other woody vegetation, debris, animal nests, animal burrows or unapproved manmade elements such as fencing, irrigation systems, gardens, etc.

Operations & Maintenance (continued)	○ Check embankments for signs of global instability, including slumping, longitudinal cracking along the crest, and bulging at the toe. Areas exhibiting signs of slope instability should be stabilized as directed by a licensed engineer. ○ Check for sinkholes, low areas or ruts on or near embankment crests due to settlement or pedestrian or vehicular traffic. Fill low areas as needed to prevent ponding of water and maintain design crest elevation. ○ Check for sandboils and turbid seepage through the barrier, and at or beyond the toe which may be indicative of internal erosion of the embankment or foundation material. ○ Check for leakage or seepage around non-earthen structures, such as pipes, gates, and walls passing through and adjacent to the flood barrier. ○ Where pressure relief wells are used, qualified well drillers should perform well testing to check for clogging of the filter or well screen, and clear wells as needed. ○ Check for clogging of drainage pipes. ○ Check for tilting, sliding, or settlement of wall structures. If movement is considerable, repair as directed by a licensed engineer.
Costs	• The design requirement for seepage control is site specific. The suitability of soils can make the use of shallow trenches (inexpensive) infeasible, requiring cut-off wall (expensive). • The unsuitability of soils for foundations can make the use of shallow (inexpensive) foundations infeasible requiring the need for deep (expensive) foundations. • Many different permitting requirements can be triggered. Creating permit applications and attending approval meetings can be expensive and can also initiate long delays in the project which can further impact costs. • Annual inspections and maintenance costs are estimated to range between about $10k to $15k. Costs of repairs will vary. Minor repairs, such as filling erosion gullies and replacing riprap can range from about $10k to $30k.

C7. ACCESSIBILITY AND TRANSPORTATION CONSIDERATIONS FOR FLOOD PROTECTION

The City of Boston desires to maintain access to the waterfront by constructing flood barriers. Accessibility should be considered when designing the vegetated berm. This includes considering pedestrian and vehicle access, as well as connectivity with the rest of built environment. Public health and safety are paramount. The ROW should be kept clear of debris, water, ice, and snow.

Sidewalks	• Pedestrian access to the berm shall be ADA compliant (per Massachusetts Architectural Access Board MAAB).
Intersections	• No intersections would be affected by the vegetated berm.
Bridges/ Underpasses	• There are no bridges or underpasses within 500 ft. of the sample site.
Abutters	• Coordinate with all property owners and stakeholders, including but not limited to the City, Boston Harbor Now, MassDOT, MBTA, community organizations, and private property owners.
Accessibility and ADA	• Sidewalks or pathways constructed along the vegetative berms 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 should be ADA compliant. Similar roadway base materials are recommended.
Parking	• Parking is not impacted by the berm.
Grading	• Proposed slopes are 3H:1V (horizontal:vertical) for the berm to satisfy global stability and facilitate maintenance activities and recreational opportunities.
Signage, Pavement Markings and Traffic Signals	• The signage for the harborwalk should continue on the access path on the vegetated berm. Informative signage is recommended to educate the public on the project and sea level rise. Coordinate with Boston Harbor Now.
Bike Lanes	• The vegetated berm crest should be designed with appropriate widths to maintain pedestrian and bike paths.
Incremental Considerations	• The vegetated berm is designed to be sufficiently wide as to accommodate grade changes without impacting the slope inclination or function of the berm.
Operation & Maintenance	• If the access path is stone dust, it shall be inspected at least monthly and after heavy rainfall for deterioration or washouts. • Grade and compact the stone dust path as necessary. Supplemental stone dust should be kept close to the site for efficient repairs.
Costs	• Regular maintenance costs associated with the stone dust path include the stone dust to supplement 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.

C8. GROUNDWATER CONSIDERATIONS FOR FLOOD PROTECTION

Changes in sea level can result in fluctuations of the coastal area's groundwater table, including depth to groundwater and depth of saltwater intrusion. The range of impacts resulting from changes to the groundwater table may include uplift damage, seepage, drainage, salinity increase, ecosystems, water quality, utilities, etc. The impacts of local sea level rise on groundwater levels in the Boston area are not yet well defined. That study is beyond the scope of any one barrier project, but a local groundwater study should be performed to identify impacts relative to the site and surrounding features.

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 elevation 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 berm that depend on fresh groundwater. • Identify existing wells near the berm site and perform groundwater sampling to characterize existing groundwater.
Utilities	• Saltwater intrusion into water treatment facilities may result in higher salinity 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. • Seepage from higher groundwater tables may result in more frequent groundwater intrusion in below grade structures. Preliminary studies in Hawaii indicate that changes in tide levels due to sea level rise may cause widespread groundwater intrusion. (Rotzoll and Fletcher, 2013). • Soil conditions will impact groundwater seepage. 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 geotechnical section for additional considerations.
Drainage	• Higher groundwater levels may result in reduced stormwater infiltration and affect stormwater drainage systems. Refer to stormwater considerations for additional guidance on stormwater drainage. • Groundwater pumps should consider back-up power generation and redundancy. Power generation may be compromised due to climate impacts; therefore, power generation should be considered during design.

Drainage (continued)	• 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 groundwater pumping may be required to reduce below ground flooding, which may exacerbate land subsidence. Groundwater pumping should be managed to avoid land subsidence. A thorough geotechnical and hydrogeological study should be performed if groundwater pumping is anticipated.
Pollutants	• 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. • Groundwater pollution can occur when contaminants are released at the ground surface and infiltrate through the soil to the groundwater table. Higher groundwater tables increase the risk of pollution and potential vapor intrusion (volatized contaminants entering into occupied indoor spaces). Consult with a Licensed Site Professional to identify risks at the site for spills and/or releases and identify if additional measures should be considered to protect the groundwater.
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 monitoring/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 based on the need to design for the considerations in this section.

C9. VEGETATIVE CONSIDERATIONS FOR FLOOD PROTECTION

The proper selection of trees and plants associated with any new vegetated barrier is key to its long-term viability and performance. As rainfall amounts and intensities increase, and weather patterns and temperatures change over time, it becomes necessary to consider how plant resilience can impact how the berm functions today and in the future. The challenges are further addressed in the following sections.

Tree / Root Systems	• Trees are not permitted on levees because of their root systems. If trees are uprooted during a storm event, the barrier may result in a breach. Tree root systems also pose a risk as a flood pathway; roots rot over time and can result in pathways through the soil. Tree root systems also provide pathways for animal burrows to create additional pathways in the soil and barrier.
	• Woody vegetation and brush can also prevent observation of deficiencies forming that increase the risk of failure.
	• It is recommended that an offset area of at least 20 feet from the toe of the barrier be maintained free of trees and large woody shrubs. This is necessary to reduce root systems from growing into and beneath the barrier.
	• In some cases it may be necessary to maintain a greater distance to ensure roots do not adversely impact barrier components such as utilities. For example, do not allow tree growth in areas located above buried conduits/pipes unless root barrier guards are considered where contact between tree root systems may impact adjacent pavements and underground utilities.
	• Reference guides and sources of information related to tree impacts on levees:
	  ◦ https://www.mass.gov/files/documents/2016/08/wn/fema-publication-l-263.pdf
	  ◦ https://www.mass.gov/files/documents/2016/08/pl/fema-publication-534.pdf

Plant Performance Goals	• When selecting climate resilient vegetation materials for a flood barrier project, consider protocols to increase open space benefits for each site and to quantify the net climate resilient benefits including but not limited to stormwater mitigation, carbon reduction, reduction in heat island and infrastructure resilience within an urban environment.
	• Choosing the correct plants is an important consideration at any location particularly in the urban environment and within densely populated suburbs. Selecting the 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 to align with the proposed growing conditions, adjacent use area activities, and enhance 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; and
	  ◦ A major factor to consider is insects and disease resistance.
	• Aesthetic considerations for plant selection include:

Plant Performance Goals (continued)	• 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; and • Longevity. • Plant varieties must address erosion control measures and appropriate pollutants including sediment, nutrients, metals, etc. The City of Boston requires that the GI/LID designs address urban stormwater pollution in all infiltration and discharge flows. The plant materials associated with a barrier design should consider the stormwater treatment strategies according to the Massachusetts Storm Water Manual.
Open Space	• A vegetated berm in this sample location will create the opportunity to construct new public green space and passive recreation on the berm and adjacent to the berm. Plant materials should complement passive recreational activities. • Green and public open space assets are the front line of defense for a multitude of flood protection issues within and outside of the communities they serve. From matters of health and wellness to social equity, conservation and sustainability, critical topics such as these must be considered across the city. Climate resilience must weave itself through all these matters. • Increasing foot and bike trail access benefits a population's health and wellness while cutting down on the need for driving. Increasing tree canopy and green space in otherwise urban landscapes provide communities with direct access to the physical and mental benefits of contact with nature. • Taking measures to mitigate the effects of natural disasters using plant selection strategies puts open spaces as major assets for neighborhood and city wide protection.
Conservation Commission	• The City of Boston Conservation Commission (BCC) safeguards the open space and the City's natural areas and, in particular, wetlands. The City also protects several areas of natural open spaces known as "Urban Wilds." Wetlands are vital to the City's natural environment as they provide a habitat for fish, shellfish and other wildlife. Wetlands also maintain groundwater and water quality and mitigate the impacts of flooding, storm event damage and pollution. The BCC administers the following: • Massachusetts Wetland Protection Act; and the • Massachusetts Rivers Protection Act. • Coordinate with the BCC for permitting barriers that impact wetlands or wildlife resource areas. • Refer to relevant publications, such as the 2018 "Design Guidelines for Urban Stormwater Wetlands," prepared by the MIT Norman B. Leventhal Center for Advanced Urbanism for more information.

Invasive Plants & Native Plants	• Known invasive plant materials should never be used. See list of Massachusetts invasive plants: https://www.mass.gov/service-details/invasive-plants. • There are many advantages to growing native plants. Being already adapted to the local ecosystem, they are better able to withstand climate changes and invasions from insects and diseases. Natives require low maintenance once established and also are not invasive. They have evolved a delicate balance with other plants, pests, and diseases so they don't overwhelm an ecosystem, but remain an essential part of it. Because they are so well adapted to a specific region, they provide reliable food and shelter to local wildlife. Refer to the list of native plants recommended by Boston Parks Department and BWSC: http://www.bwsc.org/notices/public_notices/.NE.NATIVEPLANTS.PDF
Incremental Considerations	• Take an adaptive management approach when selecting plant materials for the implementation of GI/LID control practices. It is possible to establish portions of the plant materials as the barrier is constructed and delay future planting to a later date. • Evaluate current zoning and new development/redevelopment codes for landscape and open space requirements.
Operation & Maintenance	• Low-maintenance landscaping does not mean no maintenance will be required as all 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 ensure good plant health. With good site evaluation and proper plant selection, plants will thrive and enhance the open space and usability of the berms as a public asset for many years. • In general, routine maintenance activity does not typically require a permit. Coordinate with the proper regulatory agencies and the BCC for any permits associated with operations and maintenance. • Prepare an operation and maintenance program associated with plant material management including regular observation, water requirements, pruning and mowing schedules. • Barrier areas and plant materials shall be kept free from refuse and debris. Plant materials shall be maintained in a healthy growing condition, neat and orderly in appearance in perpetuity from the time of the growth season. If any plant material required by this dies or becomes diseased, they should be replaced.
Cost	• Plant costs will vary based on the proposed landscaping. Coordinate with a landscape designer to identify costs relative to the initial construction and identify a plan for regular maintenance associated with the proposed landscaping.