CLIMATE RESILIENT DESIGN STANDARDS & GUIDELINES

FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

BOSTON PUBLIC WORKS DEPARTMENT

OCTOBER 17, 2018

SECTION 6.0
SAMPLE RAISED ROADWAY BARRIER

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6.1 DESCRIPTION AND ASSUMPTIONS

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

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

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

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

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

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

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

6.2 SAMPLE RAISED ROADWAY BARRIER DESIGN CONSIDERATIONS

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

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

DESIGN CONSIDERATIONS

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

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

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

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

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

6.3 OPERATIONS AND MAINTENANCE AND COST CONSIDERATIONS

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

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

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

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

Structure maintenance (wall and railings)

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

Vegetation maintenance

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

Stormwater maintenance

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

O&M Plan

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6.4 BARRIER SELECTION

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

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

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

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

6.5 SAMPLE DESIGN DRAWINGS AND FIGURES

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

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

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

DOWNLOADABLE FILES:

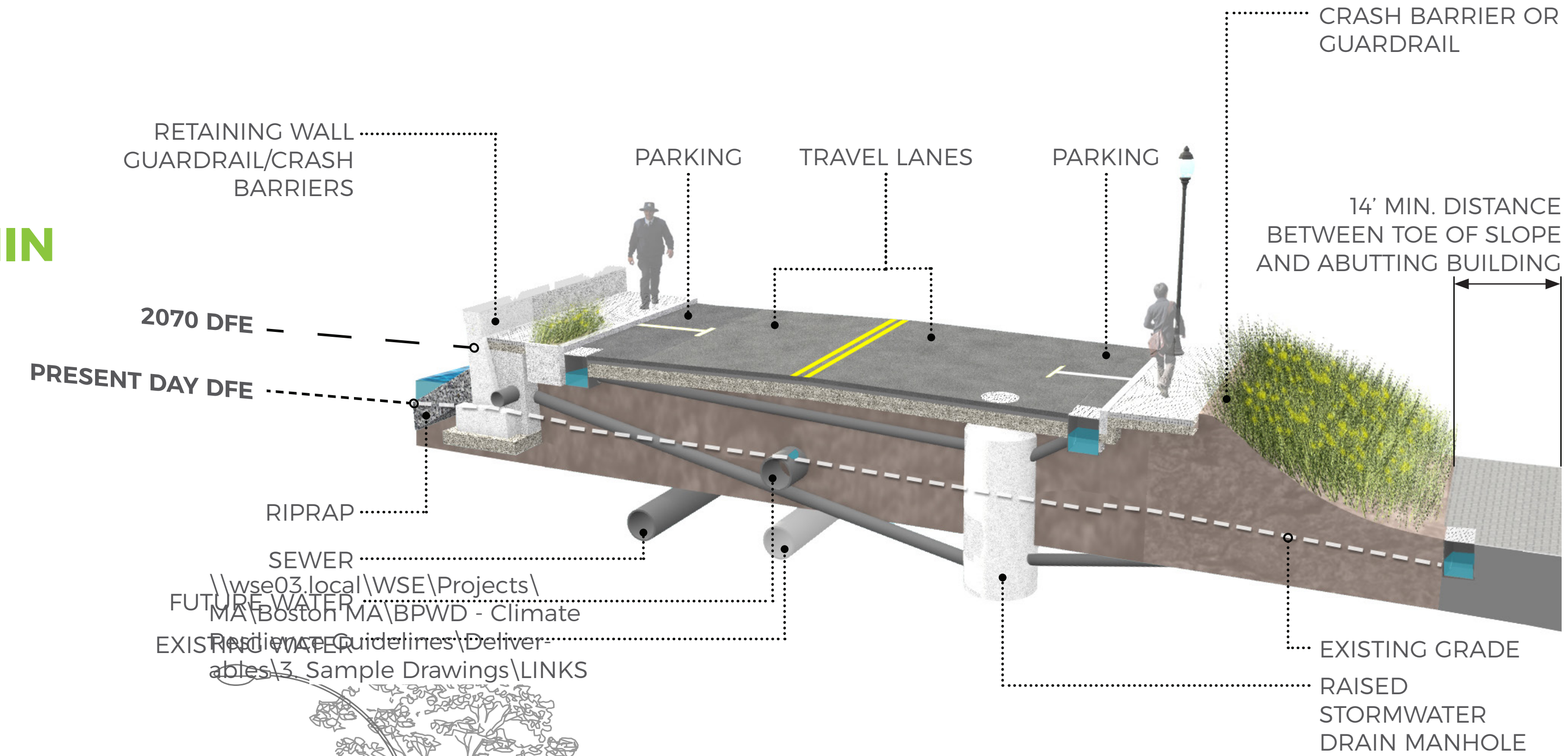
Standard PWD Details for reference and download can be found here

SAMPLE

B.3 SAMPLE RAISED ROADWAY- OPTION 1

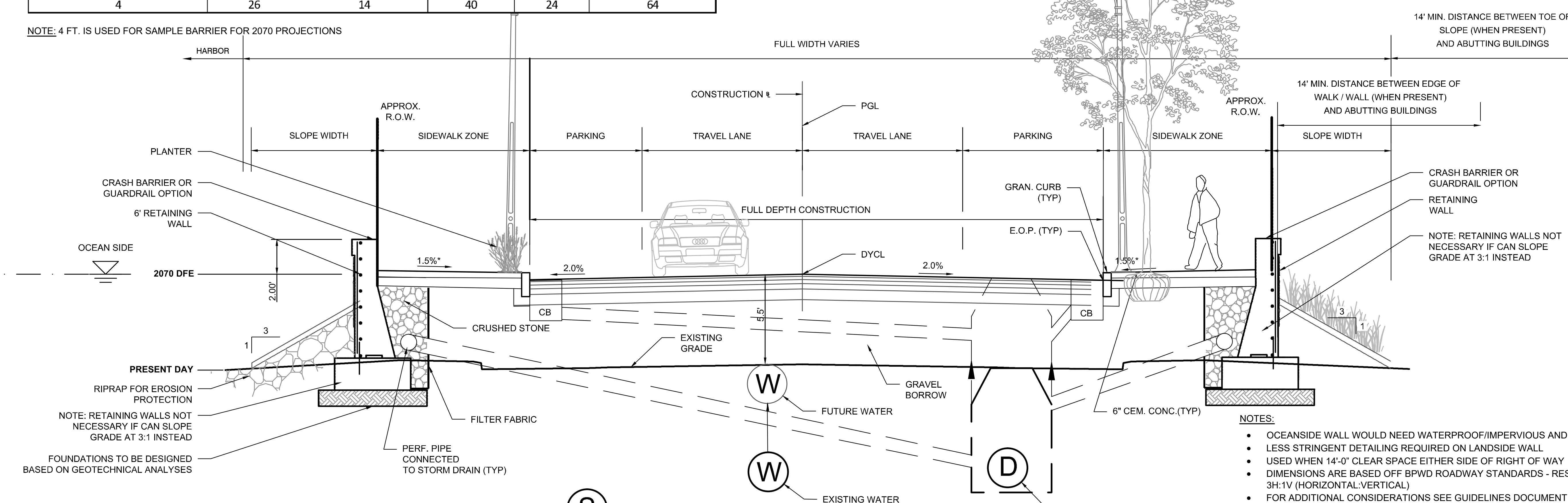
CAD

PDF



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

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



SAMPLE - NOT TO SCALE

SAMPLE SECTION

NOTES:

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

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

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

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

DOWNLOADABLE FILES:

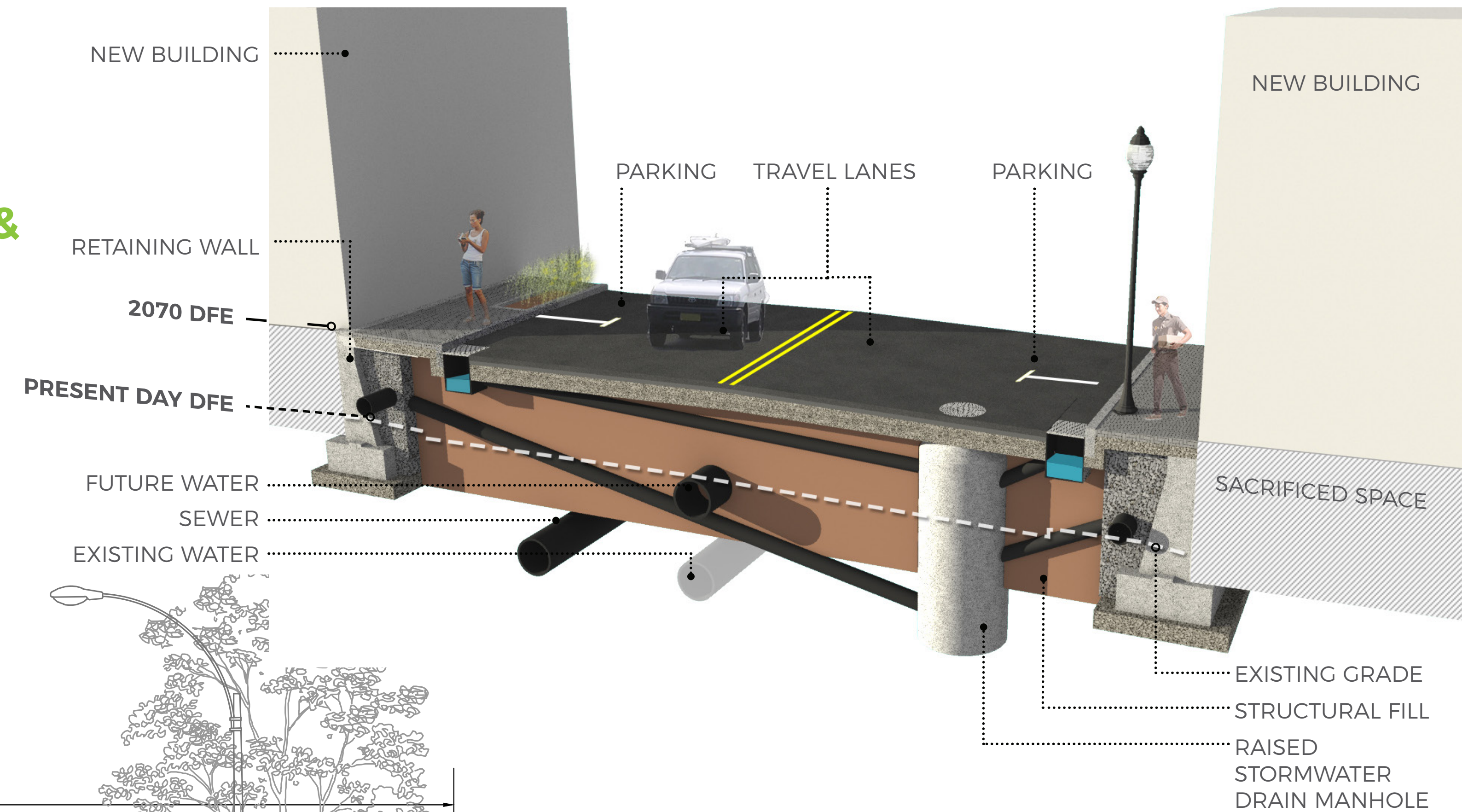
Standard PWD Details for reference and download can be found here

SAMPLE

B.4 SAMPLE RAISED ROADWAY- OPTION 2

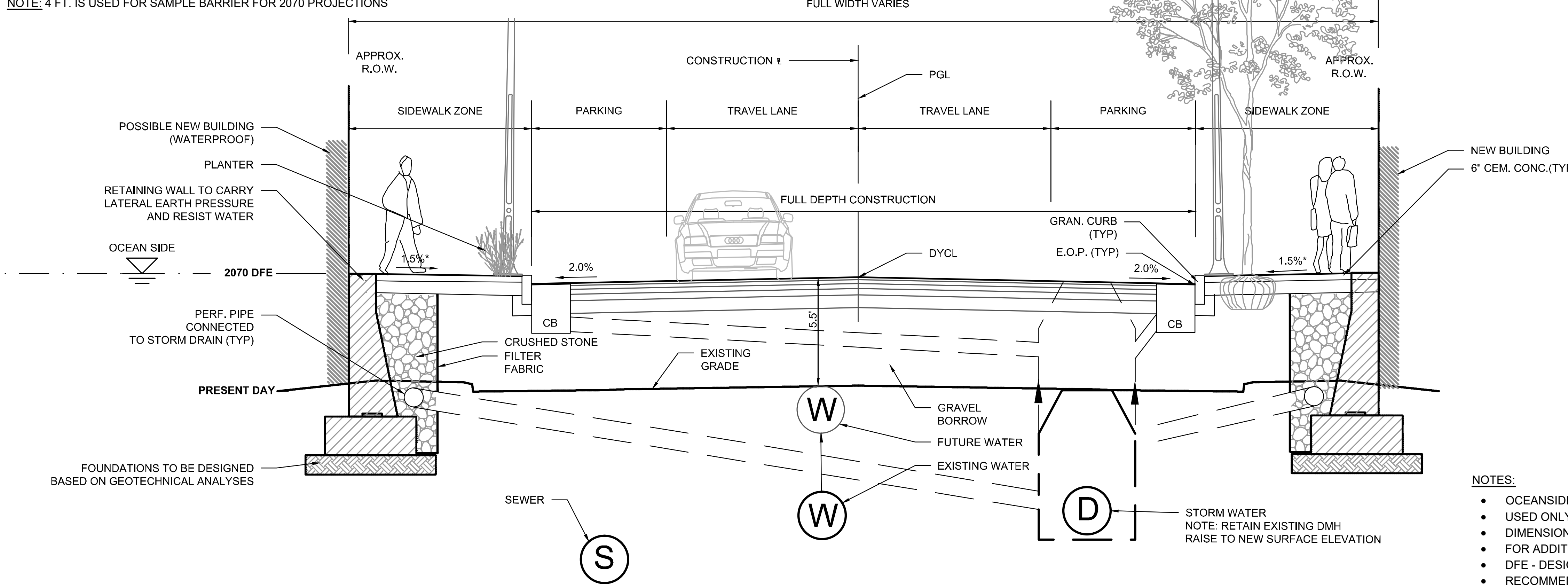
CAD

PDF



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

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



SAMPLE - NOT TO SCALE

SAMPLE SECTION

RECOMMENDED FOR NEW DEVELOPMENT ONLY

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

NOTES:

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

FIGURE 10

PROPERTIES IMPACTED BY SAMPLE RAISED ROADWAY BARRIER

- Proposed Barrier for the 2070 Design Flood Elevation (DFE)
- Buildings Impacted by Proposed Raised Roadway
- Parcels Affected by Proposed Buildout Area

250 0 250

Scale In Feet

Path: \\wse03.local\WSE\Projects\MA\Boston MA\BPWD - Climate Resilience Guidelines\Deliverables\7. Final Guidelines Document\GIS Figures\Build out Considerations - Border Street.mxd **User:** LambertD **Saved:** 10/3/2018 10:37:14 AM **Opened:** 10/3/2018 10:37:45 AM

FIGURE 11

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

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

250 0 250
Scale In Feet

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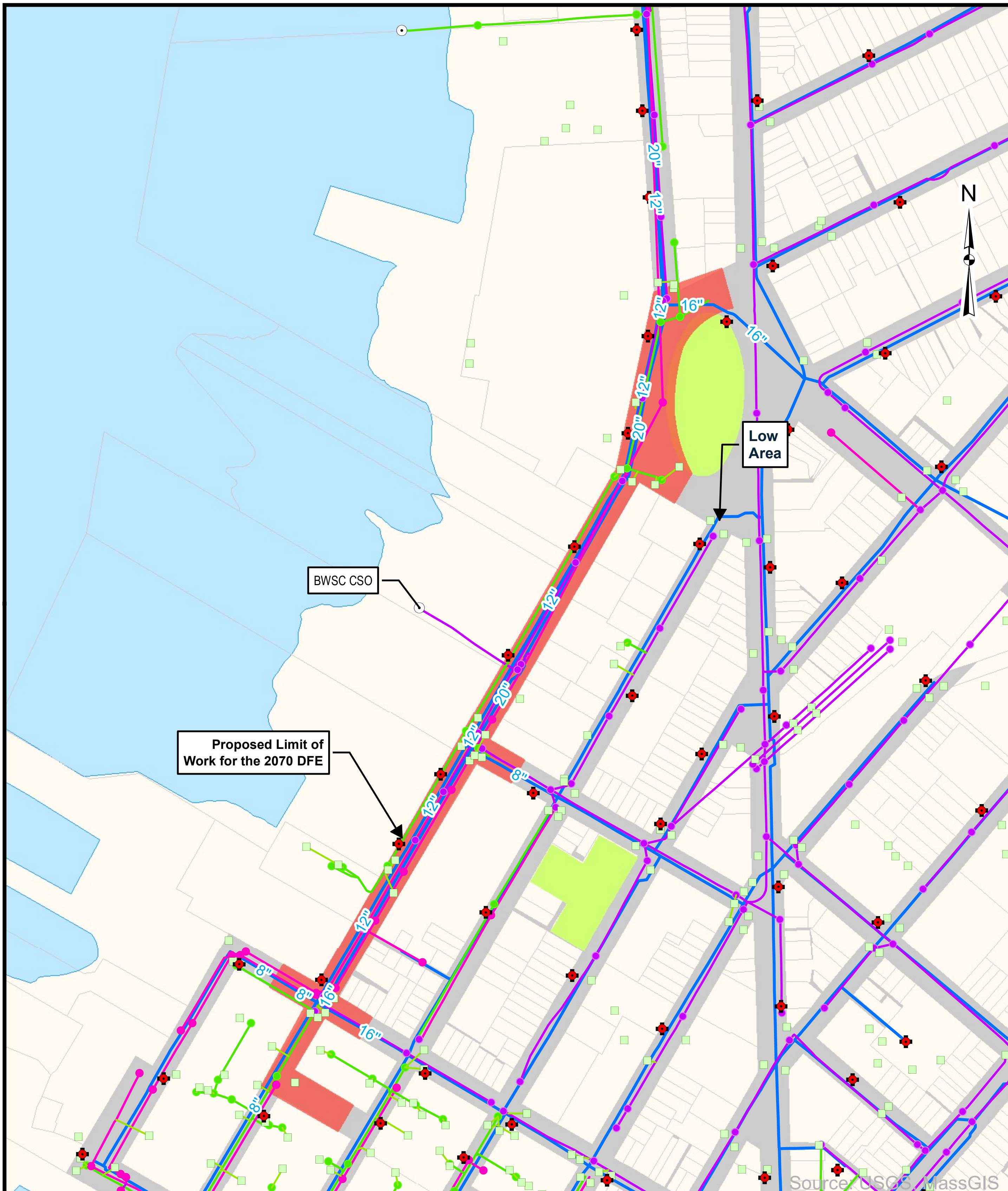

Outfall
Fire Hydrant
Catch Basin
Sanitary Manhole
Storm Manhole
Combined Manhole
Combined Sewer
Sanitary Sewer
Storm Sewer
Water Main

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

FIGURE 12

EXISTING UTILITIES IDENTIFIED IN SAMPLE RAISED ROADWAY BARRIER PROJECT AREA

250 0 250
Scale In Feet

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Path: \\wse03.local\WSE\Projects\MA\Boston MA\BPWD - Climate Resilience Guidelines\Deliverables\7. Final Guidelines Document\GIS Figures\Land Below 21.5 Border Street.mxd User: LambertD Saved: 10/3/2018 10:55:14 AM Opened: 10/3/2018 10:56:08 AM

FIGURE 13

PROPOSED LIMIT OF WORK FOR SAMPLE RAISED ROADWAY WITH TOPOGRAPHIC CONSIDERATIONS

Index Elevation Contour

Intermediate Elevation Contour

Proposed Barrier for the 2070 DFE

Land Below 21.5'

400 0 400

Scale In Feet

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

APPENDIX E. SAMPLE RAISED ROADWAY DESIGN CONSIDERATIONS

APPENDIX E. RAISED ROADWAY DESIGN CONSIDERATIONS

This section provides additional design considerations for a sample raised roadway barrier as provided in **Section 6.0 Sample Raised Roadway Considerations** 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 designing raised roadways.

E1. 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 greater than 50 years, so the 2070 time horizon is anticipated. Time horizons to consider include the present, 2030, 2050 and 2070 time horizons.

Sea Level Rise (BH-FRM)	• The sample site is within the Boston Planning & Development Agency (BPDA) “SLR-BFE” zone via the zoning viewer.
	• The 2030 1% annual flood pathway originates at an intersection around the midway point of the sample roadway.
	• The 2070 1% annual flood pathway originates at an intersection to the southeast of the barrier (around the midway point) and at an intersection at the northern end of the sample roadway barrier site. The total flood path extends between the northern and southern limits of the sample barrier. See Figure 13 in Section 6.5.
	• The BH-FRM results include the base flood elevation (BFE) of 19.4 ft. and 19.3 ft. Boston City Base (BCB) varying throughout the sample site for the 2070 time horizon.
	• 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 site for each time horizon.
	    ◦ Projected wave and wind impacts from the 1% annual flood event for each time horizon.
	• The design flood elevation should be 20.4 ft. at a minimum. Additional studies and the sub-model BH-FRM results are required for final design elevation. The design may select a 0.2% annual flood for the design storm, since roadways are less feasible to adjust and adapt over time.

Extreme Precipitation	• Select design storm events for analysis (10%, 4%, 2%, and/or 1% annual design storm events). ◦ The Massachusetts Stormwater Manual currently provides the design storm volumes for analysis of stormwater treatment and conveyance systems.

Extreme Precipitation (continued)	• 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, especially volumes now trapped behind the barrier. • Refer to Section 2.0 of the guidelines for Extreme Precipitation Adjustments identified by Climate Ready Boston. • 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 1% annual chance precipitation event and the sensitivity of the design to accommodate higher volumes. Refer to Section 2.0 of the guidelines for Extreme Precipitation Adjustments identified by Climate Ready Boston. • Assess high intensity rainfall events (cloudbursts) in the design and modify designs to safely convey the discharge without causing downstream/upstream flooding. • *"From 1958 to 2010, there was a 70% increase in the amount of precipitation that fell on the days with the heaviest precipitation. This increase is greater in the Northeast than for any other region of the country." (Climate Ready Boston)*. • The study for drainage on the site should include a comprehensive review of the drainage area/watershed and identify opportunities for stormwater management inland. 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
	  • Increased failure/reduced efficiency of electrical/mechanical systems (power outages and pumps).
	• Consider winter storm impacts including:
	  • Health and Safety
	  • Snow and ice ground cover
	  • Plowing and snow removal
	  • Snow storage on-site/off-site
	  • Drainage and infiltration impacts
	  • Ice jams.

Incremental Considerations	• An incremental approach for raising roadways would be difficult and highly disruptive to the surrounding neighborhoods and businesses. Designers may select a useful life greater than 50-years used for other barriers, as well as more conservative flood estimates, such as the 0.2% or 0.1% annual flood. • Climate design criteria will be updated regularly in the City of Boston. Plans should reference the most recent data and include the option to add 2 ft. of additional flood protection.

E2. SITE SPECIFIC AND BOUNDARY CONSTRAINTS

The sample site is an approximately 2,000 ft. long section of urban roadway near a public park, affordable housing, and commercial businesses with garage entrances. The sample site is located within the public right-of-way.

The following site specific and boundary constraints shall be used as a guideline when evaluating if a raised roadway is appropriate for flood protection for a selected 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. 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.

Extent of Barrier (Current and Future)	• The sample site length is intended to protect the public right-of-way from flooding based on a 50-year useful life.
	• The length extends at least 20 ft. past the sample flood pathway on both sides to reduce flanking.
	• The sample drawings provided for the raised roadway include calculation tables showing required widths and slopes for various roadway height options. Refer to the City of Boston Complete Streets for roadway and sidewalk zone widths.
	• Based on preliminary LiDAR information, the 14 ft. minimum setback for the sample barrier is not present in this sample location, with the exception of the area by a park. See Figures 10 and 13 in Section 6.5 for build out and topographic considerations for the sample roadway site.
	• The layout of the sample roadway is such that access from residences and businesses are located at the back of existing sidewalk. Many businesses, such as auto shops, have garage entrances also located at the back of sidewalk. See Figure 11 in Section 6.5 for a proposed limit of work for the sample roadway site.
	    ◦ If future development is proposed adjacent to the barrier, it should be designed for the new roadway and utilities.
	    ◦ Properties on the flood side of the barrier would not be protected by the barrier.
	• 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.

Zoning	• Contact the Boston Planning and Development Agency (BPDA) to evaluate zoning regulations and requirements.
	• Identify any current regulations that may prevent the design and implementation of raised roadways.
	    ◦ There may be restrictions on structure heights, weights, locations, materials used, etc.
	• All sites should be compared to available Designated Port Area (DPA) maps. The sample site is located within a Designated Port Area (DPA).
	    ◦ DPAs have physical and operational features for water-dependent land use.
	    ◦ Flood barriers should be designed to mitigate the impact on DPAs.

Available Open Space	• Evaluate space available for construction and installation efforts. Consider space and access for operations and maintenance activities.
	• There is a sample public park near the northern end of the roadway that is available open space. The remaining alignment is heavily developed.
	• Optimize opportunities to connect to the waterfront wherever possible.
	  ◦ Floodwaters can be returned to waterways instead of pooling behind/around the barrier.
	  ◦ Waterfront access paths need to be maintained or created if not currently available.
	  ◦ The Harborwalk may be redeveloped in this sample area.
	• Using the sample drawings provided in Section 6.5, consider how a raised roadway will impact neighboring properties and buildings. The sample drawings show various options for roadway design, including: no buildings abut the walkway and new development areas.

Public Right-of-Way	• The sample raised roadway will prevent flooding into the public right of way (ROW) but flooding from nearby roadways and public open spaces is still possible. • Pedestrian ROWs must remain uninterrupted or become redirected. • Sample barrier design should include pedestrian access. ◦ All public ROW shall follow ADA requirements and guidance from the Massachusetts Office on Disability.

Private Properties	• The sample raised roadway barrier will impact multiple properties.
	  ◦ 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 roadway 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 roadway shall be easily accessed for maintenance and operation purposes. Improvements to the existing access conditions shall be included in the barrier design. • Responsibility shall be established for the barrier pertaining to operation and maintenance efforts, especially stormwater management. See stormwater section.
Off-Site Impacts (Adjacent and Downstream)	• 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 barrier may divert flood water to unprotected areas. • Drainage areas will be impacted, and additional/modified drainage systems may need to be implemented to accommodate higher inflow rates. Figure 11 in Section 6.5 shows the impacted drainage area for the sample site. • Stormwater runoff must be considered when selecting and designing barrier types. The implementation of barriers may change existing stormwater flow regime, which could lead to overloading of stormwater systems. Additionally,

	stormwater runoff may flood off-site areas and could create flooding situations in areas that otherwise might not be within the flood pathway.

Climate Ready Boston Criteria	• Climate Ready Boston (CRB) created criteria to identify resilient design opportunities. In general, these guidelines address effectiveness, feasibility, and design life and adaptability. However, the following CRB criteria should be considered for the sample site:
	  • Social Impacts
	    • The roadway will continue to provide access for recreational and cultural opportunities in the area around the site.
	    • The aesthetic impact of the raised roadway will include vegetation, trees, and lighting along the side of the roadway and sidewalks.
	  • Equity
	    • The raised roadway will continue to provide equitable access to the waterfront.
	    • Additional benefits for vulnerable populations should be considered.
	    • Community partnerships may be equitable investments.
	    • The raised roadway protects affordable housing.
	    • Flood reduction behind the barrier will improve local economics and property values.
	  • Value Creation
	    • A raised roadway can help to create opportunities for public green space and passive recreation adjacent to the roadway.
	    • There may be opportunities for future funding and investment.
	  • Environmental Impact
	    • Due Diligence (evaluate soil/groundwater quality prior to construction)
	    • Consider impacts to water and air quality.
	    • Consider human health benefits and impacts.
	    • Consider mitigation of other climate hazards.

Incremental Considerations	• As sea level rises, the flood path will change and grow to include more impacted properties. Current barrier locations may need to change as sea level continues to rise and flood events increase in size and intensity.
	• The installation of a raised roadway barrier designed to current projections will not withstand flooding and sea level rise associated with future (2030, 2050, 2070) projections.
	  • When possible, barrier designs should be completed to accommodate up to the highest projection currently available.
	  • Incremental vertical adjustments will be incredibly difficult for a raised roadway. Designers should perform a cost-benefit analysis and evaluate opportunities to over-design the barrier.
	• Site specific incremental considerations, horizontal, are as follows:
	  • Boundaries – may change as sea level rises and flood events become more severe. New flood pathways may exist from other locations.
	  • Bridging Gaps –additional barriers may be needed in the future to bridge the gap between barriers.
	  • Barrier Modification – in addition to redesigning barriers to accommodate new boundaries, barriers may need to be modified to properly protect against flood levels. Barriers should be capable of supporting a

Incremental Considerations (continued)	supplemental protection method or be designed with conservative climate design adjustments. • Master Plans – roadways should be raised as part of a larger Master Plan for the neighborhood. This may result in sections of roadways being raised at different times and new development. • Planning – this project should be coordinated in conjunction with other flood protection projects in the area.
Operation & Maintenance	• Operation and maintenance (O&M) will be similar to levee, dam, dike and floodwall considerations. • Stormwater management will be a significant feature of O&M. See Stormwater Section. • The raised roadway sample site is located very close to the coastline/harbor and may result in larger operation and maintenance needs as weather/erosion may have a significant effect on the barrier.
Costs	• Operation and maintenance costs will be estimated by current and project future wage rates and the manpower estimated for regular maintenance associated with the selected barrier, including stormwater management. • Permitting costs 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. • Property acquisition may be considered.

E3. 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 raised roadways, such as the selected sample roadway site provides the opportunity to create a raised roadway barrier for coastal sea level rise protection, while protecting the right-of-way.

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 (BWSC) 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 the Massachusetts Stormwater Handbook Volume 2, Chapter 2, Stormwater BMPs. • Raised roadways will include space for required structural pretreatment BMPs such as deep sump catch basins, oil/grit separators, proprietary structures, and sediment traps. • Streetscapes and green spaces inland from the sample roadway site present opportunities to incorporate stormwater treatment GI designs including bioretention, media filters, tree box filters, and proprietary treatment devices. Opportunities for underground stormwater detention could be placed along many inland streets in and satisfy Boston's Complete Streets approach. • Winter weather may reduce the ability of stormwater to infiltrate into the ground (if frozen). Designs should account for freezing weather and associated de-icing materials that are used in the environment.
Volume Capture and Control	• Post-development stormwater discharge rates must not exceed pre-development rates. This standard may be waived for land subject to coastal storm flowage. The calculation is based upon any new impervious surfaces created from the design of the raised roadway, such as walkways, road surfaces, and potentially the slopes of the roadway if they 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. • Raised roadways will need adequately sized conveyance and, mechanical pumping systems to manage and release the stormwater on the inland side of

Volume Capture and Control (continued)	the new structure. Space is currently available in the sample park space 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 is an existing low point in the area behind the sample raised roadway where stormwater collection should be considered.
Off-Site Impacts & Flooding	• Barrier designs should have no significant off-site impacts. • The end points of the sample raised roadway shall be tied in to elevations that will not cause bypass and diversion of floodwaters onto adjacent properties.
Water Quality	• The stormwater design associated with a barrier project should incorporate the appropriate stormwater treatment measures in accordance with the Massachusetts Stormwater Handbook. 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 discharges. • Boston contains vast amounts of urban fill, known oil/hazardous material sites, and containers/tanks of petroleum and/or hazardous materials. An evaluation should be completed to evaluate the potential for encountering these contaminants during construction. • Goal of no net increase in total petroleum (TP), total suspended solids (TSS) and volume of stormwater. • The proposed raised roadway 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. • ***Best Practices Example*:** The City of Miami Beach, FL has developed a 4-stage stormwater treatment system that consists of debris capture using trash racks, swirl-concentrators to reduce turbidity, sumps to separate lighter oils and greases, and finally aeration of the discharge to the receiving water.
Watershed Approach	• Studies should look within the drainage basin to identify open spaces in the watershed up-basin where additional storage and delay can be created, therefore reducing flooding at the site. These measures may not be implemented during design of a specific flood protection project, but should be identified for future consideration. • Assess watershed conditions to incorporate a comprehensive delay, store and discharge approach for managing stormwater with a drainage basin study. • The sample drainage area to the sample roadway site has several green and open space opportunities available to accommodate detention storage for stormwater during precipitation events, including a local public open space area.

Watershed Approach (continued)	• Identify potential inland stormwater management approaches to delay, store, and discharge stormwater trapped by the barrier (sample site drainage area is 19.2 acres). See Figure 11 in Section 6.5.
Incremental Considerations	• Adaptive management approach can be considered for GI stormwater controls in the watershed. • Consider property acquisition and creating new public space on flood side of barrier for use between flooding events. • Evaluate current zoning and new development/redevelopment potential in the inland watershed and the need for land use controls/change. • Reduction in inland risk can be achieved over time by removing low-lying structures, incorporating climate resiliency into building renovations and codes, and instituting a retreat program that could be implemented far into the future. • Build flooding resilience into new construction/development in the watershed.
Operation & Maintenance	• Refer to the Utility Considerations for Stormwater Utility Management and Maintenance. • Gray stormwater infrastructure will require sediment, debris, and potentially pollutant filtering systems that will require and O&M plan. • Green stormwater infrastructure will require an O&M plan for removal of trapped sediment and debris, and annual vegetation assessment and replacement of dead or dying plants. • Follow General Permits for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems in Massachusetts (2016). • 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 catch basin sump reaches 50% of the available volume. • Streets, with the exception of high speed limited access highways shall be swept and/or cleaned a minimum of once per year in the spring (following winter activities such as sanding). • Establish and implement inspection and maintenance frequencies and procedures for stormwater treatment structures such as water quality swales, retention/detention basins, infiltration structures, proprietary treatment devices or other similar green infrastructure. Inspect stormwater treatment structures annually at a minimum or according to manufacturer recommendations for proprietary devices. • Sediment, trash and debris captured in urban stormwater treatment systems will require removal as frequently as weekly to prevent clogging or bypass during precipitation events. • Pump stations for detained stormwater should be inspected monthly and following precipitation events when they are activated. • Keep a hardcopy/electronic record of activities including but not limited to maintenance activities, inspections and training. • Special considerations for maintenance of green infrastructure should be identified and documented.

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. • Stormwater GI BMPs range from \$15/sq. ft. to \$175 per sq. ft. installed. Sizing depends on the drainage area that is captured and treated. Annual O&M costs for GI range from \$2,000 - \$7,800 /year /acre of impervious cover treated. • Typical catch basin cleaning costs are \$200/structure/cleaning. • Pump stations will require frequent maintenance to remove debris and remain operational during flooding events. They will require monthly inspections as well as inspections following each activation. Costs for these activities should be assessed on a site-specific basis.

E4. UTILITY CONSIDERATIONS FOR FLOOD PROTECTION

This section will evaluate issues relative to water, sewer, and drain utilities, which are owned and operated by the Boston Water and Sewer Commission (BWSC), and privately owned electric, gas, and communications utilities. Collected wastewater/sewage is discharged to the MWRA system. The following utility considerations for the sample roadway site provide detailed information regarding raising the roadway 4 ft. and should be used to develop appropriate engineering guidelines and directives to adhere to, regardless of the roadway section. Raised roadways will affect existing underground utilities. 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. All work shall be in accordance with federal, state, and local regulations.

Studies and Investigations Required:

- Data collection for underground and overhead utilities, including materials, dimensions, year of installation.
- Data on utility service connections.
- Jurisdictional requirements for materials (for example, MWRA or BWSC standards for installation of water mains and appurtenances).
- Utility conflict investigations.
- Utility penetrations through flood barriers provide a pathway for floodwater – either in the conduit (piping), in the bedding material surrounding the conduit, or along the outside walls of the conduit. Where a structure or utility passes through a flood barrier, precautions shall be taken to prevent passage of water through the barrier.
- Any utility that crosses a raised roadway shall be assessed carefully for the potential to pass sea water through or under the barrier, thereby adding to flooding behind the barrier. Wherever possible, no utilities should cross the barrier. Passage of sea water through or under a raised roadway shall be prevented.

Survey	• Several known utilities exist in the sample raised roadway 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 early in the design process. • A professional surveyor shall conduct a site survey and identify 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 utilities (known and abandoned) within the project area. • Use Boston City Base datum on elevation survey work. • Identify flood zones on any mapping efforts, overlay utility survey with flood maps.

Survey (continued)	• Identify mechanical assets and their elevation relative to the design flood elevation.

Water Utilities	• Contact Boston Water and Sewer Commission (BWSC) for records including water mains, hydrants, valves, and services.
	  ◦ All materials and methods of installation shall be in accordance with BWSC standards.
	• Water mains passing under or through a barrier could fail leading to damage or failure of the barrier. Considerations include:
	  ◦ Eliminating perpendicular barrier crossing at ends of proposed barriers. If elimination is not feasible, consider placing the water main within a watertight sleeve to protect the barrier and the utility from movement.
	  ◦ Parallel water main in barrier, including a 12-inch and 20-inch water main along the roadway. Consider relocating the water main on the inland side of 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.
	  ◦ Evaluate the use of Horizontal Directional Drills (HDD) of water mains under flood barriers to minimize impacts.
	• Water mains outside of the barrier could be damaged by flood waters and/or storm surges, thereby compromising the integrity of the potable water system. Considerations:
	  ◦ Protect fire hydrants and vulnerable segments of water mains from impact and/or erosion damage. There are currently fire hydrants along the flood side of the barrier that should be addressed in design so that they are accessible in the future.
	  ◦ Provide valving within the barrier to shut off sections of pipelines outside of the barrier in case of failure.
	• Barriers built over water mains could impart additional detrimental loading on the water main, leading to premature failure. Considerations:
	  ◦ Replace sections under barriers with new water main using more durable materials (ductile iron with corrosion protection).
	  ◦ Set new main in a sleeve and at a depth which allows for optimum access and operation.
	• Fill placed over water mains could result in pipes deeper than acceptable, leading to premature failure and difficulty with maintenance and operation. Consideration:
	  ◦ Replace water mains at depths where they are accessible, typically at five feet of cover. In raised roadways, where new water mains are installed, the main could be installed at four feet of cover initially and when an additional two feet of road elevation is added, the water main would then be at six feet of cover. This would reduce overall cost, since the water main would not need to be replaced twice.

Sewer Utilities	• Sewer mains and manholes exist in the sample roadway. There is a sewer outfall (CSO) that cross the sample barrier.
	• Sewers that are outside of a barrier can become pathways for flooding within the barrier. Consideration:
	  ◦ If possible, sewer structures that cross the flood barrier shall be eliminated.
	  ◦ Sewer manhole covers should be protected from damage and water intrusion using reinforced concrete around the top section and frame where appropriate.
	  ◦ Covers should be bolted with stainless steel bolts and waterproof gaskets to prevent dislodging.
	• For sewers adjacent to the barrier, but not crossing it:
	  ◦ Consider relocating the sewer main and structures further from the barrier so that it cannot adversely impact the barrier integrity, and/or install a structural liner in sewer main to minimize the possibility of sewer main failure.
	• Building service connections to sewers, including bathroom facilities and floor drains in low elevation areas can also become conduits for intrusion of floodwaters. Considerations:
	  ◦ Building inspections should be performed in areas outside of the barrier to identify these situations and remedial actions should be taken.
	  ◦ Consider installing backflow valves in sewer gravity main which can be closed to prevent flood waters from back feeding into buildings.
	• Sewers shall be assessed for structural integrity in response to the additional grade changes and loads.
	  ◦ If a sewer is assessed to be structurally insufficient, a structural liner shall be installed.
	  ◦ Sewer mains shall normally be left at their existing elevations. A change in elevations may affect the gravitational direction of flow.
	  ◦ Sewer structures (manholes, catch basins, etc.) shall be raised to accommodate new grade elevations.

Combined Sewers and Combined Sewer Overflows (CSO's)	• The design for the sample raised roadway should consider the BWSC CSO and related facilities. The sample project area includes combined sanitary and stormwater flows, which means stormwater discharges into the combined sewer main. • 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. • All catch basins on the flood side of the raised roadway shall be removed from the combined sewer main and diverted to a dedicated drain line. The drain can be pumped via force main or released to the ocean via outfall. • Off-site flooding may back up combined sewers on the inland side of the barrier. Study the extent of the stormwater system to the critical nodes and identify preliminary vulnerability of these locations. Design with this vulnerability in mind.

Combined Sewers and Combined Sewer Overflows (CSO's) (continued)	• Combined sewers discharge to the MWRA sewer system. When flows exceed the local BWSC system capacity or the MWRA interceptor sewer capacity, overflows 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.
	• Most existing BWSC CSO's have tide gates installed on them. Considerations:
	  • Install tide gates on outfalls that can act as conduits to flood protected areas.
	  • 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 sample roadway and cross the barrier.
	• Stormwater (or drain) pipes that are on the flood side of a barrier can become pathways for flooding within the barrier. Consideration:
	  • Storm drains that cross the barrier should be eliminated where possible or reduced to increase the reliability of the system.
	  • Disconnected storm drains behind the barrier would need to be reconnected to new storm drains, typically installed parallel to the barrier to central collection points. At these central points, a storm drain would pass through or under the barrier to discharge to an existing or new stormwater outfall.
	  • Where space allows, swales, open channels, detention basins and other storage solutions should be evaluated to attenuate peak storm flows and to reduce infrastructure size and cost.
	  • Tide gates on outfalls will be necessary to prevent backflow of sea water to the area behind the barrier.
	  • Pumping will be necessary when sea level is higher than the ground surface elevation behind the barrier, such as during extreme high tides and storm surges. Pumping will become more frequent as sea levels rise. Pumping will also be required when the projected higher intensity rainfall events overwhelm undersized pipe networks.
	  • Drain manhole covers should be protected from damage and water intrusion using reinforced concrete around the top section and frame where appropriate.
	  • Covers should be bolted with stainless steel bolts and waterproof gaskets to prevent dislodging.
	• Stormwater (or drain) pipes on the dry side of the barrier may be retained without change, however, provisions should be made for upsizing pipes as infrastructure is replaced/upgraded to accommodate increased storm intensity.

Stormwater Utilities (continued)	• For stormwater pipes adjacent to the barrier, but not crossing it:
	  ◦ Consider relocating the stormwater pipes and structures further from the barrier so they cannot adversely impact the barrier's integrity, and/or install a structural liner in stormwater pipe to minimize the possibility of pipe failure.
	• Building connections to stormwater systems, including downspouts and building drains in low elevation areas can also become conduits for intrusion of floodwaters. Considerations:
	  ◦ Building inspections should be performed in the areas outside of the barrier to identify these situations and remedial actions should be taken, such as installation of backflow prevention devices.
	• Stormwater (or drain) pipes shall be assessed for structural integrity in response to the additional grade changes and load.
	  ◦ If drain is assessed to be structurally insufficient, a structural liner shall be installed.
	  ◦ Drains shall be left at their existing elevations.
	  ◦ Drain structures (manholes, catch basins, etc.) shall be raised to accommodate new roadway elevations.
	• Capacity (size) of existing stormwater pipes may be inadequate with proposed grade changes and flood elevations. New pipes and culverts should be resized as required with proposed grade changes and flood elevations.
	• Pumping stations may be necessary to manage stormwater. The following should be considered:
	  ◦ Pump redundancy, over-design of wet-well capacity (future flow volumes), pump approaches, trash accumulation and removal, on-site generators and power supply;
	  ◦ Install water level sensors to monitor rise and fall of water surface elevations and connect them to a supervisory control and data acquisition (SCADA) system. This information is helpful measuring storm impacts and calibrating storm water models;
	  ◦ Pump Stations shall be designed to withstand flooding. Elevations of power supplies, motor starters, 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 raised roadway project area are unknown. • Electric utilities (duct banks and conduits), allow pathways for significant flows through any flood barrier. Consideration: ◦ Identify utilities crossing the barrier and identify ownership, construction methods and likelihood of an existing flow path. If yes, seal ducts to create watertight barriers. • Consider overhead utility clearance, power poles and overhead wires shall be relocated. • 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.

Electric Utilities (continued)	• 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 gas utilities in the sample raised roadway 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
	  • 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.

Communications Utilities	• Locations of communication utilities in the sample raised roadway project area are unknown. • Communication utilities (duct banks and conduits), allow pathways for significant flows through any flood barrier. Consideration: • Identify utilities crossing the barrier and identify 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.
Other Utilities	• Other utilities (such as City owned or private fiber optic cable, Massachusetts Bay Transportation Authority (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. • Traffic signals, traffic signal conduits, and street lighting will need to be replaced and interconnected systems will be disrupted. • Consider using a subsurface utility engineering firm to identify and locate utilities within project area.
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

Incremental Considerations (continued)	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. • 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. • Utilities buried deeper than 4 ft. below grade will require additional considerations to access and maintain, such as dewatering and excavation stabilization. Where possible, raising utilities with raised grades will facilitate operations and maintenance practices. • Higher groundwater tables and increased salinity due to sea level rise may reduce the life-cycle of buried utilities and increase maintenance requirements. Refer to groundwater guidance for additional information. • Standard stormwater infrastructure (inlets, catchbasins, 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 SEARATE STORM SEWER SYSTEMS IN MASSACHUSETTS, Final 2016) • Streets, with the exception of rural uncurbed roads with no catch basins or high-speed limited access highways, shall be swept and/or cleaned a minimum of once per year in the spring (follow winter activities such as sanding). (GENERAL PERMITS, Final 2016) • Establish and implement inspection and maintenance frequencies and procedures for stormwater assets. Inspect stormwater assets annually at a minimum or according to manufacturer recommendations for proprietary devise. Include Asset Management appropriate for the asset and connect with the GIS system for optimization and management of maintenance and operation records, O&M manuals and work order management. • Trash and debris captured in urban stormwater assets will require removal as much as weekly to prevent clogging or bypass during precipitation events. • Pump stations for detained stormwater should be inspected monthly and following precipitation events when they are activated. • Keep a hardcopy or electronic record of required activities including but not limited to maintenance activities, inspections and training or utilize a work order management system for tracking trends and managing efficiently. • Refer to the stormwater guidance for additional information related to pump station operations and maintenance.

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 (CZM). • A perpendicular utility crossing a barrier (water, sewer, and drain 18” or less in diameter) may cost between \$10k - \$25k per utility per crossing • Stormwater pump stations can vary in costs considerably depending upon their capacity. • Typical cost variations can be between \$500k and \$20M • A typical 36”-48” tide gate and structure on a stormwater outfall may cost \$200k -\$500k. • A typical 72-inch tide gate (or dual tide gate equivalent) and structure on a stormwater outfall may cost \$450k -\$500k.

E5. STRUCTURAL CONSIDERATIONS FOR FLOOD PROTECTION

The functionality of existing structures will be impacted by changes in climate and need to be evaluated for the ability to manage changes in climate and capacity requirements. Structures are designed for a range of loading conditions (including temperature) based on current design standards. Projected precipitation, snowfall, and temperature increases may exceed current design standards—Refer to Section 2.0 of the guidelines for climate design adjustments. Furthermore, the function of a structure may differ from its original purpose as needs change based on evolving conditions; for example: existing walls may not have been designed for hydrostatic pressure but are now located within a flood pathway. Structures that fail to meet the proposed loads must be modified to accommodate them or be protected by external measures if still serving or intended to serve a vital function.

There are several types of structural considerations related to raised roadway flood protection. The primary concerns involve the proposed flood protection elements designed to resist increased climate loads. The following considerations should be used for the sample raised roadway site to develop appropriate engineering guidelines and directives to adhere to, regardless of the roadway section.

Studies and Investigations Required:

- Condition Assessment of Existing Buildings, Utility Structures, and Roads
- Design of Proposed Walls and Connections to Existing Structures
- Analysis of Existing Buildings for Modified Conditions.

Anticipated Loads	• Increased temperature and heat waves may impact performance of thermally sensitive materials, such as steel. Designers should look at design considerations for warmer climates in addition to considering how extreme cold temperatures may impact operations and maintenance. • Flooding conditions will result in increased hydrostatic and uplift pressures on structures, dependent on tides and groundwater. • Flood protection structures are expected to encounter impact forces from wind, waves, ice, and debris. • The self-weight of new and existing structures must be accounted for. • Earth pressures on existing structures may change depending on the type of flood protection selected and must be included in analysis of both new and existing structures to remain. • Structures with roadways, walkways, or with unrestricted access behind them must be evaluated for live load surcharge. The design live load surcharge will vary based on access restrictions and can include pedestrians, snow removal equipment, emergency vehicles, or truck traffic.
Condition Assessment – Existing Structures	• Take inventory of existing structures (retaining walls, utility structures, roadways and sidewalks) and gather available information from existing contract, record, or as built drawings. Note materials used, design criteria at time of construction, and intended use/functionality. • If the above information is unavailable or to supplement the above information, perform exploratory testing such as probes, test pits, and borings.

Condition Assessment – Existing Structures (continued)	• Assess the condition of existing structures by performing a hands-on field inspection of accessible areas and performing material sampling or testing as required.
	  ◦ Take cores of existing concrete and test for compression and contamination.
	  ◦ Take section property measurements and coupons of existing steel and test for tensile strength.
	• Assess the capacity of existing structures utilizing data gathered from available plans and the existing condition assessment. Perform capacity calculations for the proposed modified condition and for future anticipated loadings.
	• Analyze existing structures, mainly retaining walls, adjacent to the roadway on the flood side for increased hydrostatic pressure due to flooding and impact forces from floating debris.
	• Identify necessary repairs to existing structures that need to be made to improve water tightness and structural capacity.

Walls	• Structures intended to act as flood protection barriers must be impervious to water. This should be considered when selecting proposed materials and developing modifications required for existing structures. Consider adding a waterproofing membrane to decrease permeability. • Secondary walls and elements not acting as a flood protection barrier can be free draining and do not need impervious detailing. • Mechanically Stabilized Earth (MSE) walls are not recommended for the flood side of barriers due to susceptibility to scour and erosion.

Materials	• Material selection can have a significant impact on the capacity of structures exposed to extreme environmental conditions. The following considerations and suggestions apply to structures which will act as a flood protection barrier:
	  ◦ Use air-entrained concrete with low permeability to minimize damage caused by freeze-thaw cycles and the absorption of salt
	  ◦ Consider adding pozzolans, such as fly ash, to the concrete mix. Pozzolans increase strength while reducing alkali-silica reaction, permeability, and cost of replacing cement
	  ◦ Use corrosion-resistant reinforcing steel with a minimum of 3 in. concrete cover
	  ◦ Use corrosion-resistant metals, such as steel or an aluminum alloy, for any exposed metal.
	• Secondary walls and elements not acting as a flood protection barrier may not require specialized materials or detailing.

Connections	• Connection elements must be designed for above mentioned intended loads. • Connection elements must be watertight/impervious to maintain the impermeability of the flood barrier. • Corrosion resistance must also be considered when selecting connection elements.
Durability	• Consider implementing erosion control mechanisms, such as riprap, for the slopes on either side of the raised roadway (for options with slopes as part of the

Durability (continued)	design). Natural plant materials and turf reinforcement mats may be feasible in areas with low erosion forces. • Damage resistance to tear, puncture, debris impact, excessive deformation must be considered in the design of flood protection structures. The ability to repair future damage should also be examined during the design process. • Damage to existing structures intended to support flood protection structures must be repaired and actions for preventing future damage should be considered. • Though above-mentioned damage may not lead to structural failure, it may render the element functionally obsolete if the structure no longer retains water.
Failure Mechanisms	• Failure mechanisms for structures will vary based on structure type and intended function. • Vertical components should be analyzed for shear, bending, and axial failure mechanisms. • Walls should be analyzed for sliding, overturning, overtopping, and bearing failures due to proposed conditions and loads. • Analyze connections for shear, tensile, breakout, pullout, blowout and splitting.
Constructability	• Consider time and budget constraints associated with permitting. • Site conditions can impose access restrictions or limitations on potential construction methods which may be required for various structural options. Restrictions and limitations must be considered in the design phase such that a buildable solution is chosen. • Construction of various components could require work within an active waterway or within a natural resource area. These types of construction may require extensive permitting, increasing the time and cost associated with a project that could render the selected option infeasible. This must be considered during the planning phase when choosing between potentially feasible options.
Incremental Considerations	• A plan of incremental increase in flood protection must be included as part of the design. Elements must be designed and constructed with the ability to accommodate future changes and additions that provide supplementary protection. • Retaining walls adjacent to the sample roadway could be raised in the future to provide additional flood protection. This condition should be considered when assessing loads and demands on elements to be analyzed and designed. • Loading in the future configuration must be included in design. Though adequate for demands from the present configuration, a member may not meet requirements for future conditions; therefore, analysis and design of the initial structural element must take into account future loading conditions.
Operations & Maintenance	• Raised roadway structures must be inspected and maintained regularly to remain functional efficient pieces of infrastructure. The type and frequency of inspections and maintenance should be developed for each roadway to be implemented. Structures should be inspected at least annually and after each flood event. General structural operations and maintenance considerations are introduced in this section.

Operations & Maintenance (continued)	• Structures containing steel elements are subject to the following maintenance procedures:
	  ◦ Exposed surfaces should be washed to remove debris buildup, deicing salts, ocean spray, vegetation growth, and pigeon guano
	  ◦ The paint and/or coating system protecting exposed steel should be regularly inspected and replaced if deteriorating
	  ◦ Steel elements should be regularly inspected for corrosion and any structural members exhibiting corrosion should be repaired/replaced
	  ◦ Steel elements should be inspected for signs of failure including cracking, denting, deflection, and missing connection elements and repaired accordingly.
	• Structures containing concrete elements are subject to the following maintenance procedures:
	  ◦ Exposed surfaces should be washed to remove debris buildup, deicing salts, ocean spray, vegetation growth, and pigeon guano
	  ◦ The waterproofing membrane and/or coating on exposed concrete should be regularly inspected and reapplied if deficiencies are present
	  ◦ Concrete structures must be regularly inspected for cracking and spalling. Cracks should be sealed, and spalls repaired. Any exposed reinforcing steel should be checked for corrosion and repairs made accordingly.
	• Structures containing stone elements are subject to the following maintenance procedures:
	  ◦ Exposed surfaces should be washed to remove debris buildup, deicing salts, ocean spray, vegetation growth, and pigeon guano
	  ◦ Stone elements should be routinely inspected for surface damage, including chinking, cracking, and failure in joint material, and repaired accordingly.

Costs	• Availability of existing structure information can have large cost implications. It is much more cost effective to review a set of plans than to perform an exploratory and materials testing program. • The condition of existing structures can dramatically impact cost. Depending on the current condition, an existing structure may require no work, may need rehabilitation, or may need to be replaced. • The suitability of soils for foundations can make the use of shallow (inexpensive) foundations infeasible requiring the need for deep (expensive) foundations. • Access to the site can impact costs for exploratory and materials testing, as well as construction, or can eliminate flood protection options. ◦ Access to the sample roadway site appears to be good, but access for portions of the work may be challenging due to nearby residences and businesses within close proximity to the street. • Consider an investigation of ownership of surrounding properties, as well as the anticipated limits of work that will need to be defined prior to determining project permitting requirements. • Depending on the temporary and permanent impacts of the chosen flood protection measure on the surrounding environment, many different permitting requirements can be triggered. Creating permit applications and attending

Costs (continued)	approval meetings can be expensive and may initiate long delays in the project which can further impact costs. • Operations and Maintenance costs vary by chosen flood protection measure and material type.

E6. GEOTECHNICAL CONSIDERATIONS FOR FLOOD PROTECTION

Geotechnical design for flood protection barriers should consider global stability, settlement, seepage conditions, and effects on adjacent structures—such as existing foundations and utilities. Earthen flood barriers, such as raised roadways and vegetative berms, are essentially levees and 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. Retaining walls designed to function as floodwalls should be designed in accordance with USACOE EM-1110-2-2502, Retaining and Flood Walls. Design will depend on the site-specific subsurface soil and groundwater conditions, as well as spatial constraints and future flood protection needs. A professionally licensed Geotechnical Engineer must be engaged to conduct 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 feet along the alignment of the barrier. 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 feet into natural bearing soils or to 50 feet 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. • Test pits should be conducted, as necessary, to evaluate existing structure condition and geometry. • The geotechnical exploration and testing program should be defined by a professionally licensed Geotechnical Engineer based on the unique geotechnical characteristics of each site and the proposed flood barrier. • Observation trenches should be excavated under the centerline of 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 feet.
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 two feet from the edges of the barrier, and then downward and outward at a slope of 1H:1V (Horizontal:Vertical). Identify existing subsurface structures, such as basements and utilities, that will be located within the zone-of-influence. There are below ground structures (basements and garages) at the sample site. • Prior to increasing grades, the load carrying capabilities of structures within the zone-of-influence of the proposed barrier must be evaluated. • Prior to increasing grades, settlement potential of structures within the zone-of-influence of the proposed barrier must be evaluated. • Plan and design for future anticipated loading conditions.

Global Stability	• Flood barrier structures shall be designed to meet minimum factors of safety against global stability failure during end-of-construction, steady-state seepage (during design flood), rapid drawdown, and seismic conditions as described in USACE guidelines EM 1110-1913 and EM 1110-2502. • Where walls are used, check lateral sliding and overturning for the proposed wall during end-of-construction, steady-state seepage (during design flood), rapid drawdown, and seismic conditions as described in USACE guidelines for floodwalls. It may be necessary to include grid reinforcement within backfill to provide additional stability. • 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 pathways through the barrier. See vegetative considerations.
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. Check the effect of settlement on existing structures within the zone of influence below the new load. Consider supporting existing structures sensitive to movement by underpinning, bridging the loads, or relocating the structures.
Seepage/ Groundwater	• Raised roadways must be designed to prevent through seepage from emerging on the landside slope. 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 as described in EM 1110-2-1913. • All seepage shall be managed to prevent sediment transport. • The roadway barrier shall 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 hydrology 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	• <u>Flood side</u>: 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, natural planting or paving may be sufficient. • Turbulence should be considered when assessing scour susceptibility on the flood side. Turbulence can be minimized by avoiding short-radius bends, and providing smooth transitions where levees meet land and structures. • <u>Dry side</u>: Erosion protection should be provided on the crest and dry side of the flood barrier to minimize erosion due to possible overtopping or heavy rain during storm events. Consider use of riprap, hardscape, or a turf reinforcement mat below vegetated surfaces and walking paths.
Materials	• Ideally, embankments should be constructed of well-graded gravel borrow material (MassDOT M1.0.3.0). Material should be selected, placed, and compacted as required to prevent detrimental seepage and maintain overall stability of the roadway. • 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. • 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. • Embankment materials should consist of readily available earth materials. The use of concrete and wood should be minimized. • Impervious material should not be used as embankment fill within 4 feet of paved roadway surface for better roadway performance. • Where a retaining wall is used as part of the raised roadway flood barrier, wall types can include gravity walls, soldier pile and lagging walls, and sheetpile walls. If the new flood barrier is constructed atop an existing wall, assess whether the wall can be raised with in-kind wall material. Refer to structural guidance for additional information. • Materials and vegetation must be able to withstand wave action and saltwater/corrosion.
Drainage	• Provide free-draining material and place filter fabric behind floodwalls to prevent soils migration from land to water. Evaluate stability of the wall with crushed stone behind the wall and drainage pipes if on the flood-side of the wall.

Drainage (continued)	• Seepage can be collected in designed collection systems (often in toe drains) and drained off-site on the dry side of the barrier to reduce penetrations through the barrier.
Foundations	• Foundations to support flood barrier structures may include shallow footings, driven piles, drilled piers, or other systems as appropriate based on the subsurface conditions and loads. Foundations should be selected based on existing subsurface materials, with considerations for settlement, movement, bearing, earthwork requirements, and other geotechnical considerations. • If raising the height of an existing wall, evaluate the supporting capacities of the existing wall foundation and bearing soils. Underpinning or modifications to the existing foundations may be required if the new loads exceed the existing capacity of the foundation system. • Design analyses should consider wall movement under flood load conditions, and the seepage pathway that may be created around the foundation and wall as a result of wall movement. • 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 embankment or wall heights. • Roadway widths should be designed to accommodate future wall heights and anticipated increased loading while maintaining acceptable side slopes. • For the sample raised roadway site, the roadway is sufficiently wide enough for necessary grade changes. • The initial width of the sample raised roadway should allow for additional fill to be placed over time to raise grades while maintaining a minimum 3H:1V slope on both sides.

Operation and Maintenance	• Inspect the raised roadway after flood events, and at least once per year to assess if the system will continue to function as intended. Some general geotechnical operation and maintenance considerations are as follows:
	    • Check for signs of erosion due to precipitation and overtopping. Signs of erosion include gullies, caving, or scarps. Repair eroded areas. Consider providing increased erosion protection in areas where ongoing erosion is observed.
	    • Check for 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 as needed to prevent ponding of water and maintain design crest elevation.

Operations & Maintenance (continued)	• 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 Geotechnical/ Structural 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. • Adjacent structures requiring protection of adverse effects related to the construction of a flood barrier may impart large costs to the project. • Existing conditions of topography (cut/fill volumes), and structures can have large cost implications on proposed designs. Availability of existing structure and foundation information will reduce the need for exploring to find the information. • Access to the site can impact exploratory and construction cost. • Depending on the temporary and permanent impacts of the chosen flood protection measure on the surrounding environment 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 impact costs. • Operations and Maintenance costs vary by chosen flood protection measure and material type. Annual inspections and maintenance costs are estimated to range between about $10,000 to $20,000 per site. Maintenance costs of repairs will vary. Minor repairs, such as filling erosion gullies and replacing riprap can range from about $10,000 to $40,000.

E7. ACCESSIBILITY AND TRANSPORTATION CONSIDERATIONS FOR FLOOD PROTECTION

Accessibility and transportation should be considered when identifying and designing flood protection. This includes considering pedestrian and vehicle access, as well as connectivity with the rest of built environment. Public health and safety are paramount and maintaining the right of way and emergency evacuation routes is essential. These routes must be designed to be kept clear of flood debris, water, ice, and snow. Coordination with local, state, and federal transportation and rail agencies are essential in planning changes to any roadways. The City of Boston requires that barrier designs maintain accessibility to the waterfront and neighborhood. The design should meet Boston Public Works Department Roadway Design Standards and Boston's Complete Streets guidelines: http://bostoncompletestreets.org/guidelines/

The following considerations for the sample roadway site provide detailed information regarding raising a roadway 4 ft. for flood protection. The considerations should be used to develop appropriate engineering guidelines and directives to adhere to, regardless of the roadway section selected.

Sidewalks	• The sample street has sidewalks on both sides of the street and buildings entrances are adjacent to the sidewalk, with the exception of a public park.
	• All pedestrian access to buildings, sidewalks and roadways shall be ADA compliant (per Massachusetts Architectural Access Board MAAB).
	• It is unacceptable to raise the roadway four to six feet and leave existing sidewalks and entries at grade if there is less than 14 ft. between the back of the existing sidewalk and a building. The 14 ft. setback assumes that an emergency vehicle can access the lower properties while still maintaining ADA accessibility, appropriate drainage and lighting is provided, snow storage and removal efforts are feasible, utility access is feasible, and Boston's Complete Streets standards are maintainable. The setback is a minimum value and additional studies are required in design to assess if more clearance is necessary for public health and safety and regular operations and maintenance.
	• A lower sidewalk without the minimum 14 ft. setback presents public health and safety risks including, but not limited to the following:
	  ◦ The sidewalks would function as storm gutters, with debris and roadway runoff collecting in them.
	  ◦ Poor lighting and personal safety concerns.
	  ◦ If vehicles were to swerve off the road, they would end up in the gutter.
	  ◦ Emission pipes from cars would be at head (breathing) level for pedestrians.
	  ◦ The lower sidewalks would have poor air quality.
	  ◦ Snow removal would be difficult, and snow would end up stored in lower sidewalk gutters.
	  ◦ Concerns over stormwater drainage and runoff from adjacent properties.
	  ◦ Concerns over maintaining ADA compliance.
	  ◦ Concerns over business and community health and growth.
	  ◦ Concerns over emergency vehicle and response access to areas left at grade. 14 ft. is the minimum required width behind the barrier for buildings to be present if they are left at grade.

Sidewalks (continued)	• Split sidewalk systems may be viable for grade changes of 2 ft. or less where there is room behind the back of curb but should be evaluated for public health and safety considerations, not just transportation and access.
Intersections	• There are four intersections in the sample street that will be impacted by the raised roadway, as well as several driveways with access to private properties. • When intersections are being raised as part of a project, a design study should be conducted to identify the best possible solution. Solutions may include stop conditions, signals or roundabouts. • Design the connection to side streets, driveways and parking lots in such a way that the approach grades are not excessive. Changes in slope shall not exceed 15% so vehicles do not bottom out. Proposed connections to side streets, driveways, and sidewalks shall be ADA compliant. • Proper sight distance shall be maintained from the side street to the new raised roadway such that safe passage of pedestrians, bicycles and other vehicles is established. • Intersections with rail crossings must be analyzed to evaluate if it is feasible to remove the tracks or raise them and how far the track modifications would need to extend.
Bridges/ Underpasses	• Bridges and underpasses within 500 feet of a barrier should be analyzed for clearance. The studies shall review appropriate bridge clearances. • Where roadways are proposed to be raised and there are adjacent tunnels, feasibility studies should be performed to assess the impact on tunnel.
Abutters	• Coordinate with property owners and stakeholders, including but not limited to MassDOT, MBTA, community organizations, and private property owners. • Raising roadways will impact the public and stakeholders beyond the immediate street scape. A full transportation study and analysis of impacted properties shall be performed to understand the appropriate scale and sequence of the project (i.e. communication, public outreach, acquisition.) • Existing 1st floor entrances and commercial property entrances (garages and doorways) may prevent raising full roadway profiles. • It may be possible to coordinate a larger scale redesign of the neighborhood that would enable raising the full profile of the sidewalk and raising/rebuilding the existing properties and existing building utility connections.
Accessibility and ADA	• Split sidewalks, immediate stairways or ADA compliant ramps will need to be constructed to provide access from the raised roadway sidewalk elevation to existing sidewalk elevations. • Future buildings should be designed to access at higher points, either with a taller first floor (1 ½ height) or entrance on the second floor. • Where there are no buildings adjacent to back of the existing sidewalk, access to any set back buildings will be constructed by providing a retaining wall with a height to support the raised roadway or sloping to existing grades. ADA compliant access to any buildings may be necessary depending on distance from back of the proposed sidewalk to the existing buildings.
Roadway Base Construction/ Materials	• Increased temperatures may impact the performance of pavement and steel. New technologies for heat mitigation should be considered, but pilot sites are recommended to test performance before implementing on a large scale. • Winter weather shall be evaluated in design, including freeze-thaw and drainage.

Materials (continued)	• If the roadway is intended to block the flood pathway, an impermeable layer of material may be required to be constructed in the core of the roadway to reduce seepage through the barrier. Typical base and subbase materials for roadways are otherwise recommended. • Refer to the geotechnical considerations for base material recommendations.
Parking	• It may be necessary to remove on-street parking from the roadway or eliminate two-way traffic to design a raised roadway with the necessary minimum setback of 14 ft. for public health and safety. For the sample site, this may not be feasible as an alternative location for parking may not be available. • Parking feasibility studies should be completed prior to raising a roadway to assess the impacts on residential, commercial and industrial developments. Some of those impacts may be the loss of revenue for businesses and also adverse impacts on residents who use on street parking to access their residence. Alternative parking options shall be assessed.
Grading	• The raised roadway/sidewalk must ramp to meet existing conditions at intersections and the ends of roadways. This ramp must be designed to transition such that there are no adverse effects like bumper grinding and lack of sight distance. The designed slope shall be appropriate for the design speed of the roadway and sidewalk.
Signage, Pavement Markings and Traffic Signals	• All existing signs and posts shall be removed and reset or replaced with new posts and signs compliant with the latest Manual on Uniform Traffic Control Devices (MUTCD). https://mutcd.fhwa.dot.gov/ • Proposed pavement markings shall replicate the layout of existing pavement markings, unless otherwise altered to provide bike lanes and parking lanes. • All existing street lights and traffic signals shall be replaced with new foundations, posts, mast arms, conduit/wire, signal heads and vehicle detection loops. This will impact interconnected systems beyond the sample site location. • White paint on roadways is being examined as an alternative to reduce the heat island effect in cities, like Los Angeles. Snow removal practices, such as plowing, has historically stripped paint from roadways in New England. Where there is snow and ice, roadway paint will require additional maintenance and may not be feasible.
Bike Lanes	• New raised roadways should have bike lanes and adhere to Boston's Public Works Department Roadway Design Standards, Complete Streets Guidelines, and the latest Manual on Uniform Traffic Control Devices (MUTCD). https://mutcd.fhwa.dot.gov/
Incremental Considerations	• Raised roadways will substantially impact existing urban environments. Due to the large impact on the public, raising a full or partial roadway incrementally would increase costs for both the city and developers and is not recommended unless incremental amounts are considered feasible during regularly scheduled roadway repaving. • An additional 2 ft. of flood protection may be feasible by constructing a small wall at the flood side barrier. The retaining wall (if used) should be designed to accommodate the additional load. For example, in areas where there are no buildings within 14 ft. of the back of sidewalks and the roadway is being raised 4 ft., 6 ft. retaining walls may be installed at the flood side with the intent for future flood protection.

Incremental Considerations (continued)	• In areas where new developments are proposed, private buildings and infrastructure elevations shall meet (or be designed to meet) the proposed elevations of the raised roadway. • Developers should show how proposed developments can raise grades above existing roadway elevations over time.

Operation & Maintenance	• Once raising a roadway is implemented, the water will no longer discharge into the street and will become trapped on either side of the barrier. There will be the cost of maintaining a stormwater pump system (i.e. pumps, generators). There may be the need for additional staff to maintain the systems. Maintenance crews and equipment may need to be added to existing personnel. For example, the City of Miami Beach created (two) crews with (two) personnel to provide maintenance of the new stormwater pump systems for projects already completed:
	  • West Avenue at 14th Street.
	  • Northwest side of Palm Avenue on Palm Island.
	  • Hibiscus Island.
	  • Sunset Harbour.
	  • City Center/Convention Center.
	• If any underground structures are installed for a particular pump system, they should be inspected at least once per month and cleaned as needed.
	• Sweeping of roadways should happen 1 to 2 times per year dependent upon deicing operations.
	• Replacement of existing pavement should be considered 15-20 years after initial installation dependent upon traffic volumes and vehicular types using the roadway.
	• Replacement of existing sidewalks should be considered 25-30 years after initial installation dependent upon sidewalk material and condition.
	• When raising a roadway, there may be the potential to install large capacity drainage structures (CB's, DMH's) so that they can handle a larger storm event. This may reduce O&M costs for those structures.

Costs	• Significant costs will be added with future stormwater pump systems, including generators. The stormwater management and construction costs are very difficult to estimate without doing engineering analyses, since the system demands will vary based on volume, debris capture in the watershed, number of pumps, type of pumps, water quality processes, discharge options, etc. • When raising a roadway, there may be the potential to install large capacity drainage structures (CB's, DMH's) so that they can handle a larger storm event. This would increase costs for the installation of the structures, but may reduce the costs for O&M. • Costs for future replacement of pavement and sidewalk materials, street lighting, traffic signals, and traffic signal conduit shall be considered. • Neighborhood redevelopments costs vary widely and are not estimated in these guidelines.

E8. GROUNDWATER CONSIDERATIONS FOR FLOOD PROTECTION

Changes in sea level can lead to changes in 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, and more. These impacts are addressed in more detail in the following section. 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 Pressure	• 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 roadway that depend on fresh groundwater. • Identify existing wells near the sample roadway 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. • Steam utilities should be evaluated for impact of salinity in the groundwater.
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.

Drainage (continued)	• 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. • 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 and dewatering during excavations, 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. These practices will vary based on the subsurface conditions at a site.
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 (volatilized 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. • A search should be conducted within the project area to check for releases of oil/hazardous materials to evaluate if groundwater table increase may pose unacceptable exposures.
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. However, costs for groundwater management related to groundwater table increases will be elevated and need to be developed on a case by case basis and on a community/city wide basis.

E9. 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 barrier functions today and in the future. Each barrier design will create challenges and opportunities for plant material selections and performances. The challenges are further addressed in the following sections.

The following considerations for the sample raised roadway site provide detailed information regarding raising a roadway. The considerations should be used to develop appropriate landscape and engineering guidelines and directives to adhere to, regardless of the roadway section selected.

Studies and Investigations Required:

- Utility Conflict Investigations and Stormwater Capacities
- Existing Soil Porosity and Nutritional Make-Up
- Environmental and Permitting Requirements
- Landmark Requirements
- Native Tree Species.

Tree/Root Systems	• Current USACOE setbacks and easements do not allow for trees to be within 15 feet of dams or levees. Trees are not permitted on flood barriers because of their root systems. If trees are uprooted during a storm event, the barrier may result in a breach. Tree root systems also pose a risk as a flood pathway; roots rot over time and can provide pathways for animals to burrow. If trees are desired, a root barrier system may be designed for the inland side of the barrier (waterfront side is a higher risk of breaching the structure). A structural wall may be designed in the embankment to reduce the impact of a breach. The wall should consider groundwater, geotechnical, and structural considerations. • Tree and woody vegetation growth near hard barrier structures such as concrete dams or seawalls is undesirable and not recommended. At a minimum trees and large shrubs will over time, cause some level of detrimental impact upon barrier integrity, operation, inspection, performance, and safety of the barrier. Tree roots cause serious structural damage, including damage to concrete joints and other problems that will be very costly to repair or detrimental to the structural integrity of the barrier. • Streetscape planting provides an opportunity to incorporate stormwater collection and treatment GI designs, such as subsurface stormwater collection and retention. GI developed solutions will enhance urban forests and surrounding watersheds including adjacent streets, parking lots, properties and other impervious area. Using an open cell system or similar engineered products will allow for an implemental framework that contains engineered soils that will support street trees and absorb runoff from storm events, increasing air and water quality, reducing energy loads, mitigating heat island effect and nurturing urban trees for an extended life within the urban environment. • 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 recommended to reduce root systems from growing into and beneath the barrier.

Tree/Root Systems (continued)	• It may be necessary to maintain a greater distance such that 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 roadway 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
	  ◦ A major factor to consider is insects and disease resistance.
	• Aesthetic considerations for plant selection include:
	  ◦ Growth habit (height, shape, spreading)
	  ◦ Season and color of bloom
	  ◦ Foliage texture, color and shape
	  ◦ Winter interest, fruits and seeds
	  ◦ Benefits to wildlife
	  ◦ Fall color
	  ◦ Longevity.
	• 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, 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	• 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. • 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

Open Space (continued)	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.
	  ◦ 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 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. • 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 plants require some routine care to thrive. 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 provide 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.