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

APPENDIX B. GENERAL DESIGN CONSIDERATIONS

BOSTON PUBLIC WORKS DEPARTMENT

APPENDIX B. GENERAL DESIGN CONSIDERATIONS

This appendix provides detailed design considerations related to **Section 3.0 Climate Resilient Flood Barrier Design Process** of the guidelines. This section provides a wide range of design considerations but is not a comprehensive list of all potential considerations. Engineers and designers should use these considerations to assess the existing standard of care provided in projects and identify opportunities to create value wherever feasible. The design considerations and recommended additional studies may be used to tailor climate resilience options to individual projects based on site-specific information.

B1. 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 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) and Storm Surge	• Evaluate if the site is within the BPDA's "SLR-BFE" zone via the zoning viewer. Identify if the site is within a major flood pathway**.** Refer to Phase I - Initial Decision on Use for guidance. • Identify if the site should be designed for the 1%, 0.2%, or 0.1% annual flood event. • Using the BH-FRM model and sub-model results, identify for each time horizon the: ▪ base flood elevation for the selected flood event; ▪ associated flood depth with the selected flood event; ▪ flood duration or residence time for the selected flood event; ▪ flood pathways for the selected flood event that pass through the site and/or flood the site; and ▪ projected wave and wind impacts from the selected event for each time horizon. • BH-FRM sub-model results listed above may not be available for the 2050 time horizon yet. Conservatively use the 2070 time horizon where 2050 data are not available. • A minimum freeboard of 1 ft. should be added to base flood elevations (BFE). If the site is considered "critical" based on Section 2.0 of the guidelines, a minimum freeboard of 2 ft. should be selected. The freeboard is the difference between the design flood elevation (DFE) and the BFE.
Extreme Precipitation	• Determine design storm events for analysis (10%, 4%, 2%, and/or 1% annual design storm events). ▪ The Massachusetts Stormwater Manual currently provides the design storm volumes for analysis of stormwater treatment and conveyance systems. ▪ Boston Water and Sewer Commission (BWSC) uses NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES for design of stormwater systems. ▪ The barrier and upgradient stormwater features should also be designed to handle increases in future design storm volumes.

Extreme Precipitation (continued)	▪ Refer to **Section 2.0 Climate Design Adjustments for Useful Life** of the guidelines for Extreme Precipitation Adjustments identified by Climate Ready Boston. ▪ Suggest increase in current 24 hr. volume 1% annual chance event to address future climate conditions. A risk-based alternatives analysis should be considered in the design to evaluate a future condition 1% annual chance precipitation event and the sensitivity of the design to accommodate higher volumes. Refer to Section 2.0 of the guidelines. • Assess high intensity rainfall events (cloudbursts) in the design and modify designs to safely convey the discharge without causing downstream/upstream flooding. ▪ *"From 1958 to 2010, there was a 70% increase in the amount of precipitation that fell on the days with the heaviest precipitation. This increase is greater in the Northeast than for any other region of the country." (Climate Ready Boston)*. • The study for drainage on the site should include a comprehensive review of the drainage area/watershed and identify opportunities for stormwater management up-gradient. Refer to the stormwater considerations for more details.
Extreme Temperatures	• Consider extreme heat impacts to: ▪ Health and Safety; ▪ Thermal expansion; ▪ Material degradation from excessive heat; ▪ Pavement softening; and ▪ Increased failure/reduced efficiency of electrical/mechanical systems (power outages and pumps). • Consider winter storm impacts including: ▪ Health and Safety; ▪ Snow and ice ground cover; ▪ Plowing and snow removal; ▪ Snow storage on-site/off-site; ▪ Drainage and infiltration impacts; and ▪ Ice jams.
Incremental Consideration	• If the site is unable to accommodate the design values for the 2070 time horizon, an incremental approach may be selected to currently meet the 2030 and/or 2050 time horizons and incrementally adapt to 2070. • This may include, but is not limited to, raising grades over time to achieve design flood elevations, drainage improvements, pump stations, generators, property acquisition/managed retreat, etc. • All approaches must be documented with a timeline and plan to achieve 2070 flood protection in the future, including operation and maintenance roles and responsibilities. • Climate projections will be updated regularly in the City of Boston. All plans should reference the most recent data and include the option to add 2 ft. of additional flood protection.

B2. SITE SPECIFIC AND BOUNDARY CONSTRAINTS

The following site specific and boundary constraints for flood protection measures are to be used as a guideline when evaluating flood barrier selection at a particular site. The guidelines provided are not comprehensive and are designed to be context driven to encourage flexibility and balance in flood protection efforts. These considerations will aide in understanding how various barriers could interact with the site, as certain barriers may not be suitable for a site. The ultimate goal is to protect sites from flooding and achieve climate preparedness, and to do so, neighboring context must also be considered to aide in contributing to a highly functioning public realm. With this, it is important to carefully identify the constraints and limitations that may impact barrier selection.

Extent of Barrier (Current and Future)	• Using projections for current and future flood paths, identify how far the barrier would need to extend to fully protect the site and not result in flanking (i.e. water going around the sides of the barrier).
	  ▪ Keep in mind that sea level will continue to rise, so what works at the time of installation may not protect the site beyond the useful life.
	• Design to reduce flanking, overtopping, and alternate/unplanned flood pathways.
	  • Barriers should tie into higher elevations or structures to effectively protect the site without directing water to neighboring sites.
	  • There may be some sites where barriers do not tie into higher elevations or structures. Where it is not feasible to close off the flood pathway on your site without extending onto other sites/properties, an incremental approach should be considered. Refer to Section 7.0 for guidance on temporary and deployable flood barriers.
	• The minimum cross-section of the barrier should consider (at least):
	  ▪ Current elevation and grading of the site;
	  ▪ Space for slopes (horizontal extent should be 3 times longer than the vertical extent per slope) and/or retaining walls;
	  ▪ Freeboard to reduce risk of overtopping; and
	  ▪ Size of future “final” barrier if incremental approach.
	• Downstream encroachment considerations
	  ▪ If future development is proposed immediately downstream of the barrier, it may “encroach” on the barrier and increase risk for failure mechanisms, such as piping (a serious structural-integrity problem due to internal erosion and loss of embankment fill), and damages.
	• Consider the impacts of neighboring properties:
	  • Lack of protection of neighboring properties could impact the effectiveness of barrier protection at the site.
	  • Installation of a barrier alters the flood path and could result in neighboring properties becoming more susceptible to flood waters diverted from the site.
	• A Phase I Environmental Site Assessment should be conducted to assess if the potential exists for Recognized Environmental Conditions including soil and/or groundwater impacts.

Zoning	• Contact the Boston Planning and Development Agency (BPDA) to evaluate zoning regulations and requirements. • Identify any current regulations that may prevent the design and implementation of certain barrier types.

Zoning (continued)	▪ There may be restrictions on structure heights, weights, locations, materials used, etc.
	• Identify the Designated Port Areas (DPA)s in Boston and assess the site location for proximity to DPAs to ensure proper design features are incorporated.
	  • 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	• A large amount of space is required to construct most barrier types. Evaluate space available for construction and installation efforts. Consider space and access for operations and maintenance activities.
	• Optimize opportunities to connect to the waterfront wherever possible.
	  ▪ Flood waters can be returned to waterways instead of pooling behind/around barriers.
	• Sample design drawings are provided in Section 4.0, Section 5.0, and Section 6.0 that help to identify sample space requirements for barriers.
	  • Prior to design, refer to the slope tables and design drawings to assess that there is a sufficient amount of space available.

Public Right-of-Way	• The intent of the guidelines is to protect the public right of way (ROW) from flooding. • Pedestrian ROWs should remain uninterrupted or be redirected. • Emergency access must be maintained for all barrier types. • Barrier design should include pedestrian access. • All public ROW shall follow ADA requirements and guidance from the Massachusetts Office on Disability.

Private Properties	• Barriers may extend across multiple properties.
	  • Coordination is necessary between property owners if barriers are to encroach upon neighboring properties.
	  • Design requirements shall remain the same with the addition of properties.
	  • Barrier selection may change based on constraints of additional properties.
	• Easements may pass through the site, or the barrier may encroach onto nearby easements with proper land planning and legal agreements.
	  • Coordination will be necessary between the owners of the site and the easement.
	  • Easement access shall be maintained at all times and may need to be relocated upon implementation of barriers.

Operational Capacity	• The barrier shall be easily accessed for all maintenance and operation purposes. If access to the site is currently limited, improvements to the existing access conditions shall be included in the barrier design. • Responsibility shall be established for the barrier pertaining to all operation and maintenance efforts. • Maintenance shall include all necessary cleaning (removal of debris and sediment) and upkeep of the barrier to ensure the barrier performs as designed in flood events.

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 flood path may change with the addition of a flood barrier, as the barrier could 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. • 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 the opportunities for resilient design. In general, the BPWD *Climate Resilient Design Standard and Guidelines* address effectiveness, feasibility, and design life and adaptability. However, the following CRB criteria should be considered for the site:
	  • Social Impacts
	    o Recreational and cultural opportunities
	    o Aesthetic impact of the barrier
	  • Equity
	    o New & equitable access to waterfront
	    o Additional benefits for vulnerable populations
	    o Community partnerships may be equitable investments
	    o Protection of affordable housing
	  • Value Creation
	    o Opportunities for new value creation on sites and/or adjacent sites
	    o Capacity to catalyze future funding and investment
	  • Environmental Impact
	    • Due Diligence (evaluate soil/groundwater quality prior to construction)
	    • Impacts to water and air quality
	    • Habitat value
	    • 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. • If an incremental approach is required, barriers should be designed with the knowledge that additional height/loading will be added in the future. • Evaluate design opportunities and challenges to limit preclusion of future climate adaptation measures. • When possible, barrier designs should consider designing beyond the 50-year useful life based on projections currently available. • Site specific incremental considerations, both vertical and horizontal, are as follows: o Boundaries – may change as sea level rises and flood events become more severe. Barriers may not be able to be relocated and will need to be redesigned in the case of a decrease in protection capability.

Incremental Considerations (continued)	○ Bridging Gaps – the implementation of barriers will be necessary to combat flooding and the impacts of climate change. Additional barriers may be needed in the future to bridge the gap between what may currently be protected, and what will need further protection measures. ○ Barrier Modification – in addition to redesigning barriers to accommodate new boundaries, barriers may need to be modified to properly protect against flood levels. Barriers should be capable of increasing the protection height, or supporting a supplemental protection method. ○ Master Plans – shall be changed according to the locations and sizes of barriers. ○ Planning – as time continues, areas along the coast may become more susceptible to flooding and storm events. This may lead to needed protection of these areas and provide physical and operational constraints regarding development and use.
Operation & Maintenance	• Operation and maintenance will vary based on the flood barrier selected. Refer to Phase III of Section 3.0 for additional information. • Proximity to the coastline/harbor may result in larger operation and maintenance needs as weather/erosion may have a significant effect on the barrier. • Site locations that encroach into public or pedestrian rights-of-way may need more operation and maintenance efforts to ensure that all City of Boston requirements are met.
Costs	• Refer to sample barriers in Section 4.0, 5.0, and 6.0 for an opinion of probable cost for sample barrier approach. • Operation and maintenance costs will be determined by current and project future wage rates and the manpower estimated for regular maintenance associated with the selected barrier, including stormwater management. • Permitting costs will 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 need to be considered. • Addition of barrier height in the future should be considered.

B3. 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. Sample flood protection measures provided in these guidelines must be designed to address stormwater discharge control and quality treatment. Each barrier will create challenges for stormwater management.

Green Infrastructure (GI)	• Urban stormwater management has improved rapidly in the last 15 years to embrace blue-green infrastructure in cities. Boston Water and Sewer Commission (BWSC) has published a Low Impact Development (LID) Stormwater Design Manual to provide guidance and promote green infrastructure (GI). • 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.
	• Assess high intensity rainfall events (cloudbursts) in the design and modify designs to safely convey the discharge without causing downstream/upstream flooding.
	• Raised structures and barriers will need adequately sized conveyance and, possibly, mechanical pumping systems to manage and release the stormwater on the upgradient side of any new structure.
	• Any type of shoreline or sea level rise barrier will create obstacles to the passage and management of entrapped stormwater. The concepts of safe stormwater passage, and upgradient stormwater management through delay, storage and discharge measures are appropriate considerations in the design of flood barriers.
	• ***Best Practices Example***: The City of Hoboken, NJ suffered considerable flooding damages from Super Storm Sandy that resulted from both shoreline storm surge and inland precipitation-induced flooding. Hoboken is now embarking on a comprehensive water management approach where stormwater management behind the shoreline barriers and linkage to up-basin solutions are just as important as the barrier itself. The process includes elements of Resist, Delay, Store and Discharge.
	  • Resist: combination of hard infrastructure (such as bulkheads and floodwalls) and soft landscaping features (such as berms and/or levees which could be used as parks) that act as barriers along the coast during exceptionally high tide and/or storm surge events;
	  • Delay: policy recommendations, guidelines and urban green infrastructure to slow stormwater runoff;
	  • Store: green and grey infrastructure improvements, such as bioretention basins, swales, and green roofs, that slow down and capture stormwater,

Volume Capture and Control (continued)	and which will complement the efforts of the City of Hoboken's existing Green Infrastructure Strategic Plan; and • Discharge: enhancements to Hoboken's existing stormwater management system, including the identification and upgrading of existing stormwater/sewer lines, outfalls and pumping stations. http://www.nj.gov/dep/floodresilience/rbd-hudsonriver.htm
Off-Site Impacts & Flooding	• Barrier designs should mitigate significant off-site impacts. • The potential exists for barriers to divert floodwaters to other adjacent, unprotected properties and to cause damage. Each proposed barrier should be evaluated for potentially causing damage on adjacent properties. Where it is assessed that the barrier will cause flooding damage to adjacent property that would not occur without the barrier construction, the project must provide flood protection for affected properties or approximate compensation to property owners.
Water Quality	• The stormwater design associated with a barrier project should incorporate the appropriate stormwater treatment measures in accordance with the Massachusetts Storm Water Manual. Design the project associated stormwater best management practices (BMPs) using GI or LID approaches as the first try – then non-GI approaches or combinations. • Designs must address appropriate MS4 pollutants including sediment, nutrients, metals, oils, greases, etc. The City of Boston must address urban stormwater pollution in all discharges. • Boston contains vast amounts of urban fill, known disposal sites impacted by oil/hazardous materials, and bulk storage of petroleum and/or hazardous materials. An evaluation should be completed to assess the potential for encountering these contaminants during construction. • Goal of no net increase in Total Phosphorus (TP), Total Suspended Solids (TSS) and volume. • The proposed barriers should consider a range of options that are appropriate to treat the expected pollutants. From roadway runoff these are primarily sediment, turbidity, metals, and oils and greases. If there is available space, GI/LID infrastructure should be considered first for stormwater treatment. Proprietary stormwater treatment designs may be necessary in ultra-urban settings with little space available for green solutions. • ***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.

Incremental Considerations	• Take an adaptive management approach to the implementation of GI/LID controls upgradient of the barrier. Delay, store and discharge facilities can be designed and constructed in a planned fashion over several years/decades. It is possible to implement a portion of the upgradient stormwater controls as the barrier is implemented and delay future implementation to a later date. Actual experience from flooding and high precipitation events can help to inform where and when other GI/LID controls are necessary. • Land use change. Reduction in upgradient risk can be achieved over time by removing low-lying structures, incorporating climate resiliency into zoning ordinances, building renovations and codes, and instituting a retreat program that could be implemented far into the future.
Operation & Maintenance	• 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. • With the exception of high speed limited access highways, city streets 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 all stormwater treatment structures such as water quality swales, retention/detention basins, infiltration structures, proprietary treatment devices or other similar green infrastructure. Inspect all 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 much as weekly to prevent clogging or bypass during precipitation events. • Pump stations for detained stormwater should be inspected monthly and following all precipitation events when they are activated. • Keep a written (hardcopy/electronic) record of all activities including but not limited to maintenance activities, inspections and training. • Special considerations for maintenance of green infrastructure should be identified and documented.
Costs	• 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 ensure proper operation during flooding events. They will require monthly inspections as well as inspections following each activation. Costs for these activities should be determined on a site-specific basis.

B4. UTILITY CONSIDERATIONS FOR FLOOD PROTECTION

This section will evaluate design considerations relative to water, sewer, and drainage utilities, which are owned and operated by the Boston Water and Sewer Commission (BWSC), and privately owned electric, gas, and communications utilities. Flood barriers 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. Utility owners will need to be involved in the design of flood protection measures.

Survey	• Records for existing utilities, both overhead and underground, shall be requested early in the design process. • A professional surveyor shall conduct a site survey and identify 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.). Considerations should be given to the use of a professional subsurface utility engineering firm to identify utilities in 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. • Identify mechanical assets and their elevation relative to the design flood elevation.

Water Utilities	• Water mains are pressure pipes and therefore do not provide conduits for passage of flood water though any barrier.
	• Water mains passing under or through a barrier could fail leading to damage or failure of the barrier. Considerations include:
	  ○ Eliminating perpendicular barrier crossing. 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 (typically a raised roadway or berm) – consider relocating the water main outside 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.
	  ○ Provide valving within the barrier to shut off sections of pipelines outside of the barrier in case of failure.

Water Utilities (continued)	• 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	• Sewers are gravity pipe systems that can allow wastewater to flow in either direction depending on hydraulic conditions. Force main sewers are not dependent on gravity to convey wastewater.
	• 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;
	  ○ Consider eliminating manholes within the flood path; and
	  ○ 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 determined 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 Utilities (continued)	○ Sewer structures (manholes, catch basins, etc) shall be raised to accommodate new grade elevations.
Combined Sewers and Combined Sewer Overflows (CSO's)	• 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. • Off-site flooding may back up combined sewers onto the site. 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 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 assess that MWRA interceptors do not surcharge into the areas behind barriers. ○ Coordinate with MWRA to assess 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	• Stormwater (or drain) pipes are gravity pipe systems that can allow water to flow in either direction depending on hydraulic conditions. • Stormwater (or drain) pipes that are on the flood side of a barrier can become pathways for flooding within the barrier. Considerations: ○ 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.

Stormwater Utilities (continued)	◦ 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 • For stormwater pipes adjacent to the barrier, but not crossing it: ◦ Consider relocating the stormwater pipes and structures further from the barrier so that it 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 pipes, 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. Pipes and culverts should be resized as required. • 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 sensor to monitor rise and fall of water surface elevations to be tied to a supervisory control and data acquisition (SCADA) system. Information is very helpful with 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. ◦ Discharge or pump station flows should consider treatment and scour protection.
Electric Utilities	• Electric utilities (duct banks and conduits), allow pathways for significant flows through any flood barrier. Consideration: ◦ Identify utilities crossing the barrier and determine ownership, construction methods and likelihood of an existing flow path. If utility crosses barrier, ducts shall be sealed to create a watertight barrier.

Electric Utilities (continued)	• Consider overhead utility clearance, power poles and overhead wires shall be relocated. All work shall be in accordance with state and local regulations. • Owners of electrical utilities shall be notified of the project and should be notified of proposed locations for water, sewer, and storm water utilities. Coordinate utility locations with private utility owners. • Electrical substations and ground mounted transformers shall be designed to withstand flooding. These facilities should be installed above, or protected, from the design flood elevation.

Gas Utilities	• 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. Considerations:
	  ○ Maintain the ability to investigate gas leaks; and
	  ○ Valve boxes and vaults need to remain accessible, as well as the gas mains themselves.
	• Owners of gas utilities shall be notified of the project and should be notified of proposed locations for water, sewer, and storm water utilities. Coordinate utility locations with private utility owners.
	• Gas regulator stations shall be designed to withstand flooding. Elevations of power supplies, stand-by generation or any electrical or mechanical equipment should be above the design flood elevation.
	• Customer gas meter sets shall be designed to withstand flooding. The vents on service regulators should be piped to an elevation above the design flood level. Electronic instrumentation and equipment locations should also be evaluated.
	• All work shall be in accordance with federal, state and local regulations.

Communications Utilities	• Communication utilities (duct banks and conduits), allow pathways for significant flows through any flood barrier. Consideration: ○ Identify utilities crossing the barrier and determine ownership, construction methods and likelihood of an existing flow path. If a utility crosses the barrier, ducts shall be sealed to create a watertight barrier. • Consider overhead utility clearance, power poles and overhead wires shall be relocated if necessary. All work shall be in accordance with state and local regulations. • 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. • Consider using a subsurface utility engineering firm to identify and locate all 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 accommodate future changes and additions that provide supplementary protection. • Access to utilities must be maintained with consideration for future changes. • Loading in the future configuration must be included in design. Though adequate for demands from the present configuration, a utility may not meet requirements for future conditions; therefore, analysis and design of the utility must take into account future embankment loading conditions; this may mean future increased loads by additional roadway or barrier height. • In general, it is difficult to modify below grade structures. It is recommended that designers be conservative with selecting pipes and materials to avoid the need for frequent reinvestment.
Operation & Maintenance	• Utility infrastructure shall be maintained with the typical frequency according to each utility owner. • 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. • 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. • Explore grant opportunities that may exist for utility improvement projects. • 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. o 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

B5. 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 as identified in Phase I of the guidelines. Structures that fail to meet the proposed loads must be modified to accommodate 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 flood protection. The primary concerns involve the proposed flood protection elements designed to resist increased climate loads. Structural factors concerning surrounding and secondary structures that were designed for an initial set of conditions, but now need to assist the proposed flood protection elements must also be considered. Finally, the protection of existing structural infrastructure must be examined. (i.e. will their conditions or functions change because of the flood protection measures?) Each type of structural consideration is discussed in this section to provide a set of guidelines for addressing the structural factors associated with flood protection.

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 (aka dead-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 remaining structures. • 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 and gather available information such as 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. • Assess the condition of existing structures by performing a field inspection of accessible areas and performing material sampling or testing as required.

	• 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.
Walls	• Walls intended to act as flood protection barriers must be impervious to water. This should be taken into account when selecting proposed materials and determining modifications required for existing structures. The addition of a waterproofing membrane should be considered. • Secondary walls and elements not acting as a flood protection barrier can be free draining. • 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. o Use air-entrained concrete with low permeability to minimize damage caused by freeze-thaw cycles and the absorption of salt. o 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. o Use corrosion-resistant reinforcing steel with a minimum of 3 in. concrete cover. o 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, such as bolts, fasteners, adhesives, etc. must be designed for all 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	• 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 the above-mentioned damage may not lead to structural failure, it may render the element functionally obsolete if the structure no longer retains water.
Failure Mechanism	• Failure mechanisms for structures will vary based on structure type and intended function. • Walls should be analyzed for sliding, overturning, overtopping, and bearing failures due to proposed conditions and loads.

	• Connections should be analyzed for shear, tensile, breakout, pullout, blowout and splitting.
Constructability	• Site conditions can impose access restrictions or limitations (such as proximity to the harbor, buildings, and utilities) on potential construction methods which may be required for various structural options. Restrictions and limitations must be considered in the design phase to ensure 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. • 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. For example, building on an existing wall is a popular option for incrementally increasing flood protection. The original wall foundation should be initially designed and analyzed for the anticipated final conditions.
Operations & Maintenance	• Flood protection structures must be inspected and maintained regularly to remain functional, efficient pieces of infrastructure. The type and frequency of inspections and maintenance should be determined for each type of structural flood barrier. All resilience structures should be inspected at least annually and after each flood event. General structural operations and maintenance considerations are introduced in this section. • Structures containing steel elements are subject to the following maintenance procedures. o Exposed surfaces should be washed to remove debris buildup, deicing salts, ocean spray, vegetation growth, and pigeon guano. o The paint and/or coating system protecting exposed steel should be regularly inspected and replaced if deteriorating. o Steel elements should be regularly inspected for surface corrosion and any structural members exhibiting corrosion should be repaired/replaced. o Steel elements should be inspected for signs of failure including cracking, denting, deflection, and missing connection elements and repaired or replaced accordingly. • Structures containing concrete elements are subject to the following maintenance procedures. o Exposed surfaces should be washed to remove debris buildup, deicing salts, ocean spray, vegetation growth, and pigeon guano. o The waterproofing membrane and/or coating on exposed concrete should be regularly inspected and reapplied if deficiencies are present.

Operations and Maintenance (continued)	◦ 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. • 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 may initiate long delays in the project which can further impact costs. • Operations and Maintenance costs vary by chosen flood barrier and material type.

B6. 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. Harborwalks retrofitted 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 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 all embankments during construction to evaluate foundation conditions and assess for undesirable underground features such as old utilities, organics, permeable material or other unsuitable materials. Observation trenches should extend to a minimum depth of 6 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). • 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 for incremental raise in grade. 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 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.
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	• Where berms or embankments are used, they must be designed to prevent 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. • Flood Protection Systems must be designed to prevent excessive hydraulic gradients, internal erosion and loss of material (piping), and/or sand boils caused by excessive hydraulic gradients and underseepage. • Underseepage control may need to be accomplished by cutoff walls such as steel sheeting or an impervious trench, flood-side or dry-side blankets, dry-side seepage berms, pressure relief wells, and/or pervious toe trenches as described in EM 1110-2-1913 and EM 1110-2-2502. • The type of underseepage control used will be site specific and will depend on the nature of the foundation soils and toe conditions. • Cutoff walls or trenches, if used, shall consider area groundwater 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	• Flood side: 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 high erosional wave forces and currents. In areas shielded from higher erosional forces, lower cost methods such as grass cover, gravel, nature 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. • Dry side: 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). • 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. • Care should be given to the placement of pervious soil layers such as gravel and crushed stone (sometimes used as utility bedding) 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. • Where a wall is used as part of the flood barrier, wall types can include gravity walls, MSE 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. • 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 site specific subsurface conditions and loads.

Foundations (continued)	• 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 berm or wall heights. • Berm widths should be designed to accommodate future berm heights while maintaining acceptable side slopes. Where berm widths are constrained by existing buildings, roadways, etc, design of berms should take into account potential need for retaining walls to support future berm heights. Consider incorporating retaining wall foundation elements for future use to reduce the amount of earthwork required when raising the embankment.
Operation and Maintenance	• Perform inspections of flood barriers after flood events, and at least once per year to help ensure the system will continue to function as intended. Some general geotechnical operation and maintenance considerations are as follows: o Check for signs of erosion due to precipitation and overtopping. Signs of erosion include gullies, caving, or scarps. Repair eroded areas. Consider providing increased erosion protection in areas where ongoing erosion is observed. o Check for and remove encroachments into the flood barrier. These may include trees and other woody vegetation, debris, animal nests, animal burrows or unapproved manmade elements such as fencing, irrigation systems, gardens, etc. o 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. o 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. o 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. o Check for leakage or seepage around non-earthen structures, such as pipes, gates, and walls passing through and adjacent to the flood barrier. o 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. o Check for clogging of drainage pipes.

	○ Check for tilting, sliding, or settlement of wall structures. If movement is considerable, repair as directed by a licensed engineer.
Costs	• The design requirement for seepage control is site specific. The suitability of soils can make the use of shallow trenches (inexpensive) infeasible, requiring cut-off wall (expensive). • The unsuitability of soils for foundations can make the use of shallow (inexpensive) foundations infeasible requiring the need for deep (expensive) foundations. • 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. • Site accessibility 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.

B7. ACCESSIBILITY AND TRANSPORTATION CONSIDERATIONS FOR FLOOD PROTECTION

The City of Boston desires to maintain access to the waterfront by constructing flood barriers. 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 the built environment. Public health and safety is paramount, and maintaining the right of way and emergency evacuation routes are 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.

Sidewalks	• 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. A lower sidewalk presents a public health and safety risk.
	  ◦ The sidewalks would end up functioning as storm gutters, with debris and roadway runoff collecting in them.
	  ◦ Poor lighting and personal safety concerns.
	  ◦ If vehicles were to swerve off road, they could end up in the gutter.
	  ◦ Emission pipes from cars would be at head 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.
	  ◦ Stormwater drainage and runoff from adjacent properties concerns.
	  ◦ 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.
	• 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	• With the increase in elevation care must be taken to 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 side street or driveway sidewalk access shall be ADA compliant. • Proper sight distance must be maintained from side streets to the new raised roadway to ensure safe passage of pedestrians, bicycles and other vehicles. • When intersections are being raised as part of a project, a design study should be conducted to provide the best possible solution. Solutions may include stop conditions, signals or roundabouts. • 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	• If grades are changed on transportation routes, vertical clearance beneath overpasses (bridges) and tunnels will decrease. • Impacts to bridge abutments and tunnels should be identified during a feasibility study.
Abutters	• Coordinate with all property owners and stakeholders, including but not limited to City of Boston, MassDOT, MBTA, community organizations, utility companies, and private property owners. • Raising roadways will impact the public and stakeholders beyond the immediate streetscape. A full transportation study and analysis of impacted properties should be performed to understand the appropriate scale and sequence of the project (i.e. communication, public outreach, acquisition.) • Existing first floor entrances and commercial property entrances (garages and doorways) may prevent raising full roadway profile without sacrificing the first floor use. • Consider 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	• Future buildings should be designed with access at higher elevations, either with a taller first floor (1 ½ height) or an entrance on the second floor. • Where there are no buildings adjacent to the back of existing sidewalk, access to any setback 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 should still be evaluated in design. • 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.
Parking	• In raising roadways, if the existing distance between building faces is not sufficient to fit the proper cross section it may be necessary to remove on-street parking from the roadway or eliminate two way traffic. • 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.
Grading	• The raised roadway/sidewalk must ramp to meet existing conditions. This ramp must be designed to transition in such a way that there are no adverse effects such as bumper grinding or lack of sight distance and that the designed slope is 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.

Signage, Pavement Markings and Traffic Signals (continued)	• All existing traffic signals shall be replaced with new foundations, posts, mast arms, conduit/wire, signal heads and vehicle detection loops. • White paint on roadways is being examined as an alternative in cities, like Los Angeles, to reduce the heat island effect. 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 the latest Boston's Complete Streets and 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. • 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	• If grades are changed, such as in raising roadways 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 each 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 occur 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) to handle large storm events. This may reduce O&M costs for those structures.
Costs	• Significant costs will be encumbered with future stormwater pump systems, including generators. They will need to be cleaned, maintained and replaced as necessary to handle the high flood elevations. • 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 should be considered. • Costs, including neighborhood redevelopments vary widely and are not estimated in these guidelines.

B8. GROUNDWATER CONSIDERATIONS FOR FLOOD PROTECTION

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

Uplift 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 areas that depend on fresh groundwater.
Utilities	• Saltwater intrusion into water treatment facilities may result in death of bacteria used for biological treatment of water. • Higher salinity may result in faster corrosion of buried utilities. Chloride concentrations due to salinity may corrode drinking water pipes and result in public health impacts (A. Brooks et. Al, 2011). Corrosion of buried electrical pipes may impact power distribution and public health and safety. • New utilities should use salt-water resistant materials to reduce risk of damage.
Seepage	• Timber piers supporting historic structures in Boston rely on the groundwater to prevent dry rot and support historic structures. Before a sheet pile or cutoff wall is designed to reduce seepage through the flood barrier, a study should consider impacts to nearby foundations. • Seepage from higher groundwater tables may result in more frequent groundwater intrusion in below grade structures. Preliminary studies in Hawaii indicate that changes in tide levels due to sea level rise may cause widespread groundwater intrusion. (Rotzoll and Fletcher, 2013). • Soil conditions will impact groundwater seepage. For example, gravel will have a higher rate of flow through the material than a fine grained material, such as silt or clay. Refer to geotechnical section for additional considerations.
Drainage	• Higher groundwater levels may result in reduced stormwater infiltration and affect stormwater drainage systems. Refer to stormwater considerations for additional guidance on stormwater drainage. • Groundwater pumps should consider back-up generation and redundancy. Power generation may be compromised due to climate impacts. • In projects with dewatering, consider reducing the rate of extraction for well fields near the coast and increasing the rate of discharge for wells in other areas to manage groundwater in areas near the coast. • Pumping groundwater may result in land subsidence. See below.

Land Subsidence	• 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. 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. Consult with environmental professionals such as Licensed Site Professionals 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 fluctuations 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 utilities. 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 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.

B9. 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.

Tree / Root Systems	• Trees are not permitted on levees or earthen embankments 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.
	• 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.
	• Woody vegetation and brush can also prevent observation of deficiencies forming that increase the risk of failure.
	• It is recommended that an offset area of at least 20 feet from the toe of the barrier be maintained free of trees and large woody shrubs. This is necessary to reduce root systems from growing into and beneath the barrier.
	• In some cases it may be necessary to maintain a greater distance to avoid roots adversely impacting barrier components such as utilities. For example, do not allow tree growth in areas located above buried conduits/pipes unless root barrier guards are considered where contact between tree root systems may impact adjacent pavements and underground utilities.
	• Reference guides and sources of information related to tree impacts on levees:
	  • https://www.mass.gov/files/documents/2016/08/wn/fema-publication-l-263.pdf
	  • https://www.mass.gov/files/documents/2016/08/pl/fema-publication-534.pdf

Plant Performance Goals	• When selecting climate resilient vegetation materials for a flood barrier project, consider protocols to increase open space benefits for each site and to quantify the net climate resilient benefits including but not limited to stormwater mitigation, carbon reduction, reduction in heat island and infrastructure resilience within an urban environment.
	• Choosing the correct plants is an important consideration at any location particularly in the urban environment and within densely populated suburbs. Selecting the incorrect plants may lead to increased maintenance, failure of plants to thrive or loss of plant material altogether. Careful planning and site analysis are important first steps. It is critical for plant selection to align with the proposed growing conditions, adjacent use area activities, and enhance their landscape value. Some site conditions to keep in mind when selecting plants include:
	  • Light availability, intensity and duration (full sun to deep shade).
	  • Water availability, both quantity and quality.

Plant Performance Goals (continued)	◦ 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 in all infiltration and discharge flows. The plant materials associated with a barrier design should consider the stormwater treatment strategies according to the Massachusetts Storm Water Manual.
Open Space	• 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 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 Citywide protection.
Conservation Commission	• The City of Boston Conservation Commission (BCC) safeguards the open space and the City's natural areas and, in particular, wetlands. The City also protects several areas of natural open spaces known as Urban Wilds. Wetlands are vital to the City's natural environment as they provide a habitat for fish, shellfish and other wildlife. Wetlands also maintain groundwater and water quality and mitigate the impacts of flooding, storm event damage and pollution. The BCC administers the following: ◦ Massachusetts Wetland Protection Act; and ◦ Massachusetts Rivers Protection Act. • Coordinate with the BCC for permitting barriers that impact wetlands or wildlife resource areas. • Refer to relevant publications, such as the 2018 "Design Guidelines for Urban Stormwater Wetlands," prepared by the MIT Norman B. Leventhal Center for Advanced Urbanism for more information.

Invasive Plants & Native Plants	• Known invasive plant materials should never be used. See list of Massachusetts invasive plants: https://www.mass.gov/service-details/invasive-plants. • There are many advantages to growing native plants. Being already adapted to the local ecosystem, they are better able to withstand climate changes and invasions from insects and diseases. Natives require low maintenance once established and also are not invasive. They have evolved a delicate balance with other plants, pests, and diseases so they don't overwhelm an ecosystem, but remain an essential part of it. Because they are so well adapted to a specific region, they provide reliable food and shelter to local wildlife. Refer to the list of native plants recommended by Boston Parks Department and BWSC: http://www.bwsc.org/notices/public_notices/.NE.NATIVEPLANTS.PDF
Incremental Considerations	• Take an adaptive management approach when selecting plant materials for the implementation of GI/LID control practices. It is possible to establish portions of the plant materials as the barrier is constructed and delay future planting to a later date. • Evaluate current zoning and new development/redevelopment codes for landscape and open space requirements.
Operation & Maintenance	• Low-maintenance landscaping does not mean no maintenance will be required as all plants require some routine care to succeed. In addition to plant selection, the proper planting practices and grouping of plant types according to their needs for water, fertilizer and maintenance will go a long way to ensure good plant health. With good site evaluation and proper plant selection, plants will thrive and enhance the open space and usability of the berms as a public asset for many years. • In general, routine maintenance activity does not typically require a permit. Coordinate with the proper regulatory agencies and the BCC for permits associated with operations and maintenance. • Prepare an operation and maintenance program associated with plant material management including 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.