The Rose Kennedy Greenway

Climate Change Vulnerability Assessment & Asset Management Plan

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Prepared by Kleinfelder Northeast, Inc.
One Beacon Street, Boston, MA

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Executive Summary

The Rose Kennedy Greenway is a 1.5 miles long urban park consisting of programming including public art, event spaces, landscaping, fountains, and a one-of-a-kind carousel. These assets, and the utilities, systems, and operations that serve them, face growing risks of damage and disruption from climate change and extreme storm events. This plan presents a roadmap for the Rose Kennedy Greenway Conservancy (Conservancy) to protect vulnerable assets and manage risks from current and future effects of climate change, and to adopt more sustainable practices to reduce its greenhouse gas footprint.

This *Rose Kennedy Greenway Climate Change Vulnerability Assessment and Asset Management Plan* gives an overview of the climate risks that the City of Boston is already facing and will continue to face with increasing severity. A methodology is outlined regarding how relevant hazards were selected, which climate scenarios were utilized to analyze risk, a description of the data sources used to conduct the analysis, and recommendations for short-term and longer-term resiliency improvements.

Each of the Greenway's assets were evaluated based on their sensitivity and exposure to each climate hazard, including coastal flooding, stormwater flooding, groundwater flooding, winter weather and extreme heat. Each hazard subsection includes a table describing each at-risk asset. The analysis results are summarized in a prioritization section which aims to inform the reader of priority actions based on likelihood of occurrence and exposure and consequence of damage.

The report concludes with prioritized recommendations for how the Conservancy can protect the Rose Kennedy Greenway and its cherished assets. The Greenway serves as a great public space connector for Bostonians and tourists that come to Boston. Without taking actions to protect these assets, the Greenway may accrue significant damage costs and service disruptions from the effects of long-term climate change impacts. However, with a few targeted actions, the Greenway can enhance its resiliency contributing to a sustained quality of life for citizens and the protection of this landmark public space.

The recommendations will help the Conservancy to allocate near-term capital resources earmarked for climate resiliency to specific, cost-effective, risk-reduction projects. The Conservancy will also be able to integrate the recommendations into ongoing and future design, programming, and maintenance activities for which climate risk-reduction is not the primary driver.

Finally, the Conservancy will be able to engage and coordinate with partners to advance larger-scale strategies for protecting the Greenway over the longer-term and potentially leveraging co-benefits the Greenway could generate to enhance the resiliency of the I-93 tunnel infrastructure and the Downtown Boston community.

The sensitivity and exposure analyses were performed in a vulnerability assessment database. This database, which contained a detailed list of Conservancy assets, was developed under a separate State of Good Repair asset management project. Additional data columns were added to the data base for the climate change analyses. The database is in Excel format.

Prioritized Recommendations:

The following table summarizes the proposed prioritized recommendations to help the Conservancy address and adapt to present and future exposures to changing climate conditions. The recommendations are prioritized based on sensitivity and exposure of the assets, and in some cases by grouping of similar construction trades to take advantage of efficiencies in construction.

Asset	Parcel	Action	Estimated Cost
Carousel	14	Install deployable flood barriers around the perimeter of the carousel and ticket booth	$ 84,000
Carousel	14	Seal electrical and telecommunications conduits into the flood protected area that could carry water from flooded electrical or telecommunications manholes outside the protected area	$ 3,000
Carousel	14	Purchase a deployable gasoline-powered pump and hoses to be able to pump out water within the flood protected area	$ 4,000
Rings Fountain Vault Access Hatch	15	Replace existing hatch with flush-mounted floodproof hatch	$ 45,000
Rings Fountain Vault Ventilation Louvers	15	Install deployable flood shields across ventilation louvers	$ 20,000
Harbor Fog Fountain Vault Access Hatch	17	Replace existing hatch with floodproof hatch	$ 40,000
Rings Fountain Vault Electrical and Telecommunications Conduits	15	Seal any electrical and telecommunications conduits entering the vault that could flood from flooded manholes with expandable foam plugs	$ 3,000
Harbor Fog Fountain Vault Electrical and Telecommunications Conduits	17	Seal any electrical and telecommunications conduits entering the vault that could flood from flooded manholes with expandable foam plugs	$ 3,000
Performance Panel	15	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Performance Panel	13	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000

Asset	Parcel	Action	Estimated Cost
Performance Panel	17	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Performance Panel	14	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Performance Panel	16	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Irrigation Controller	14	Elevate existing irrigation contoller box on new reinforced concrete pad to EL. 14.0 NAVD88	$ 20,000
Irrigation Controller	16	Elevate existing irrigation contoller box on new reinforced concrete pad to EL. 14.0 NAVD88	$ 20,000
Electrical Cabinet (Power Supply to Visitor Center)	14	Elevate existing electrical cabinet on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Water Meter Hot Box	14	Elevate existing water meter hot box on new reinforced concrete pad to EL. 14.0 NAVD88	$ 20,000
Irrigation Hot Box	17	Elevate existing irrigation hot box on new reinforced concrete pad to EL. 14.0 NAVD88	$ 20,000
Stone Dust Paths	8	Replace existing stone dust paths with porous pavement such as Porous Pave	$ 36,000
Stone Dust Paths	10	Replace existing stone dust paths with porous pavement such as Porous Pave	$ 41,600
Stone Dust Paths	19	Replace existing stone dust paths with porous pavement such as Porous Pave	$ 132,000
Stone Dust Paths	21	Replace existing stone dust paths with porous pavement such as Porous Pave	$ 60,000

Risk & Resilience

Introduction

The coastal floods of winter 2018 were a wake-up call for all of Boston - the risks of climate change became more real, present, and growing. Prior to this event, planning for coastal flooding in Boston became a priority following the devastation and loss observed in New York City during Superstorm Sandy in 2012, which narrowly missed Boston. Realizing the growing need to plan for an inevitable large-scale coastal flood event, MassDOT with Woods Hole Group Inc. and UMass Boston developed a predictive coastal flood model, called the Boston Harbor - Flood Risk Model (BH-FRM) to understand the vulnerability of the Central Artery Tunnel and other infrastructure to current and future coastal flooding.

The BH-FRM became publicly available in 2015, which prompted the City of Boston to undertake its Climate Ready Boston planning efforts beginning in 2016. In 2018, the MBTA experienced damage at the Aquarium Station East Headhouse on Long Wharf during two major coastal flooding events. The MBTA has since undertaken a project to protect the station from overland coastal flooding using a deployable flood barrier system. In 2020, the City released a neighborhood plan to specifically identify actions to minimize damage from coastal flooding in the Downtown and North End neighborhoods. The plan's concluded action is a district-scale infrastructure project to block flood pathways at the harbor edge to provide flood protection for 100-year flood events in 2070. The massive undertaking will likely take many years to complete and cost billions of dollars. Climate change was 'made real' by the impacts of the flooding in 2018, and it became apparent that these events would become increasingly common, jeopardizing Boston's building stock, historic landmarks, and public spaces in addition to putting the life safety of people at risk.

Figure 1 Flooding at MBTA Aquarium Station, January 2018 (Source: Rose Kennedy Greenway Twitter)

In addition to coastal flooding, changing and more extreme patterns are emerging in rainstorms, winter weather, and heat and humidity. Short duration precipitation events can result in a fast accumulation of rainwater that over-washes main arterial roadways, public transportation lines, and basements and first floors of buildings. This type of flooding often has nowhere to go when stormwater systems cannot handle large volumes of water over a brief timespan.

Extreme heat is a growing concern, particularly for an outdoor public space such as the Greenway. It is important that visitors have safe, shaded areas to enjoy as heat-stress is the leading cause of climate-related health emergencies and fatalities in the United States according to the World Health Organization. While Boston has relatively comfortable summer temperatures compared with more southern regions of the United States, the average annual temperature and number of heat waves appear to be increasing.

To better prepare for the future, The Rose Kennedy Greenway Conservancy (Conservancy) developed an asset management plan called “The State of Good Repair” to baseline the condition of existing assets within the direct control of the Conservancy. Horticultural assets (trees, shrubs, groundcover), MassDOT infrastructure such as tunnel egresses and ventilation shafts, Conservancy leased office space, and Armenian Heritage Foundation assets were not included in the study.

Building on this baseline of assets, the Conservancy retained Kleinfelder Northeast, Inc. (Kleinfelder) to develop a climate vulnerability assessment and adaptation plan to analyze the risks to these assets from various climate hazards over time and provide recommendations for managing these risks. The recommendations in this adaptation plan will help the Conservancy to allocate near-term capital budgets earmarked for climate resiliency to specific, cost-effective, risk reduction projects. The Conservancy will also be able to integrate the recommendations into ongoing and future design, programming, and maintenance activities for which climate risk reduction is not the primary driver.

Finally, the Conservancy will be able to engage and coordinate with partners to advance larger-scale strategies for protecting the Greenway over the longer-term and potentially leveraging co-benefits the

Figure 2 - Rings Fountain

Greenway could generate to enhance the resiliency of the I-93 tunnel infrastructure and Downtown community.

Data and Selected Hazards

Geospatial and general information were received for 1,078 assets owned by the Greenway from the State of Good Repair Asset Management Plan project team. This data set included asset categories and sub-categories, asset descriptions, replacement values (for many assets), and condition information which then was evaluated with climate hazard data based on spatial location, information from Conservancy staff, and site visit observations. Climate hazards identified as being relevant for the Greenway assets were coastal flooding, groundwater, extreme precipitation, winter weather, and extreme heat and humidity. The best available projections for these climate hazards, consisting of geospatial hazard exposure data sets and other information were identified. Assets were then assessed for risks of damage and deterioration considering sensitivity and exposure to the selected climate hazards. The full Excel database is maintained by the Conservancy.

Sensitivity

Sensitivity to a climate hazard is defined by the characteristics of an asset that would make it more likely to be damaged or impacted by exposure to the hazard. For the purpose of this analysis, these characteristics included whether:

- the asset's material is flood resistant, impervious to water penetration or damage,
- the asset relies on power that could face outages during a climate-related event,
- the asset serves a critical function to maintain operations of the Greenway, or
- the asset is 'operational' (involving movement or mechanics) or 'fixed' (anchored to the ground and without moving parts).

The sensitivity analysis was qualitative in nature and did not involve computation in ArcMap. To evaluate sensitivity, the asset's 'sub-category' from the asset management database, which describes its general functioning, was used to evaluate the characteristics described to determine their sensitivity. Assets that were deemed sensitive to coastal and stormwater flooding were largely those that involved mechanical operation, electricity, or were important components of the Greenway's infrastructure or public operations. The only assets potentially sensitive to groundwater would be underground assets such as the fountain vaults. As these structures are designed and waterproofed to function underground, they were deemed not to be sensitive to groundwater.

There were fewer assets overall that were sensitive to heat. The assets identified as being sensitive are ones that may be inoperable in the case of an electrical outage caused by a grid overload. This can occur during heatwaves when there is an abnormally high usage of air conditioning units and HVAC systems.

Finally, while wind and snow can cause secondary impacts such as flooding from snowmelt, for the purpose of the sensitivity analysis, this hazard category refers directly to the impacts of wind and snow. Assets sensitive to these hazards included fixtures on site that could be covered or damaged due to snow and ice buildup, or could be displaced by strong winds, causing potential damage due to impact.

The results of the sensitivity analysis are listed in Table 1 below.

Table 1: Sensitivity Analysis

O = Sensitive, x = Not Sensitive

Category	Sub-Category	Coastal	Stormwater	Groundwater	Heat/ Humidity	Wind/ Snow
1. Carousel	Carousel Parts	O	O	x	x	O
2. Fountains	Pumps/Compressors	O	O	x	O	x
	Water Purification System	O	O	x	x	x
	Fans/ HVAC	O	O	x	O	x
	Controllers/ Cabinets	O	O	x	O	x
	Basin Elements	O	O	x	x	x
	Security/ Safety	O	O	x	x	x
	Sensors	O	O	x	x	x
	Lighting	O	O	x	x	x
	Basin Piping	O	O	x	x	x
3. Park	Special Features	O	O	x	x	O
	Pavers	O	x	x	O	x
	Furniture Fixed	x	x	x	x	x
	Furniture Moveable	O	x	x	x	O
	Signs	x	x	x	x	x
	Lighting	O	O	x	x	x
4. Infrastructure	Outlets	O	O	x	x	x
	Drainage	x	x	x	x	x
5. Vehicles	Trucks	O	O	x	x	x
	Ride-On Equipment	O	O	x	x	x

Exposure Analysis

Exposure refers to the physical location of the asset located in an impacted area. Because the Greenway runs parallel to the coastline of Downtown Boston, its probable exposure to sea level rise and storm surge flooding is significant.

Using the State of Good Repair asset management database, an exposure analysis was conducted for each of the assets. This was a spatial analysis conducted in ArcMap using data outlined in Table 2 below.

To understand future flood-risks, data was utilized from the most recent Massachusetts Coastal Flood Risk Model (MC-FRM) developed by Woods Hole Group for MassDOT. This model expanded on the original BH-FRM for the entire Massachusetts coastline using updated storm and climate data.

There was no quantitative data available for groundwater flooding, winter weather, or wind. For these assets the sensitivity of the asset is the sole indicator of vulnerability.

All Greenway assets are considered 'exposed' to extreme heat during a heat wave, though geolocated surface temperature data was available. A more granular analysis could be conducted looking at localized urban heat island impacts. However, this was not done as a part of this climate vulnerability assessment. The best available climate hazard exposure data is listed in Table 2.

Table 2: Data Used for Analysis

Data	Description	Source, Year	Application
Ground Elevation	Elevation of asset	LiDAR, 2013	The elevation of each asset will help determine its vulnerability to different hazards.
Critical Elevation	Elevation of critical component of asset	Kleinfelder, 2020	Based on site walks, some assets have critical components that are at a higher elevation than the ground elevation of the asset. This is the elevation at which inundation would compromise the functionality of the asset, and therefore this is the elevation at which the asset would become vulnerable.

Stormwater Depth	Average stormwater depth, 10% 2030 and 10% 2070	Boston Water and Sewer Commission, 2015	The depth of stormwater at each asset in both a 10% 2030 and a 10% 2070 storm event will determine an asset's vulnerability when compared to the asset's critical elevation.
Heat	Average land surface temperature	Metropolitan Area Planning Council, 2012	The land surface temperature of each asset will help determine the vulnerability of the asset to heat impacts.
Coastal Flooding Probability	Average coastal flooding probability (Present day, 2030, 2050, and 2070)	Massachusetts Coastal - Flood Risk Model (MC-FRM) via Woods Hole Group (WHG), 2020	The probability of a present-day, 2030, 2050, or 2070 flood occurring in the location of each asset.
Coastal Flooding Elevation	Average coastal flooding elevation (Present day, 2030, 2050, and 2070)	Massachusetts Coastal - Flood Risk Model (MC-FRM) via Woods Hole Group, 2020	The flood elevation associated with the probability of the asset flooding as a result of a present-day, 2030, 2050, or 2070 flood.

Data was extracted from GIS data within ArcMap to obtain asset-level information relevant for the exposure assessment, including ground elevation, coastal flooding probability and depth, and stormwater flooding depth, and land surface temperature.

Coastal Flooding

Coastal storm events pose the most significant risk of flooding and damage to the Rose Kennedy Greenway's assets. Many of the Greenway's most vulnerable assets are located in vaults below ground or are located at grade.

The analysis for coastal flooding was completed using the Massachusetts Coastal - Flood Risk Model, which provides flooding elevations and probability of exceedance. The probability of exceedance curves for coastal flooding were based on locations ("nodes") within the Greenway parcels. Assets were assigned a node ID based on proximity to the nodes. Using the critical elevation of each parcel and the data for an asset's corresponding node, each asset was assigned a coastal flood probability for present day, 2030, 2050, and 2070 and the associated flood elevation under that probability. For example, an asset with an elevation of 10.57 feet with a node assigned the following data would be assigned a flood probability of 50% elevation of 11.15 feet in 2070, as shown in Table 3 below.

Table 3: Example Node Data for 2070

Probability of Flood	Elevation of Flood
0.1%	15.49
0.2%	15.05
0.5%	14.47
1%	14.03
2%	13.58
5%	12.99
10%	12.52
20%	12.01
25%	11.84
30%	11.68
50%	***11.15***
100%	9.96

Field Verification

After the sensitivity and exposure were understood, the Conservancy led the Project Team on a guided site visit to verify on-the-ground conditions.

During the site visit, entrances to vaults, ventilation louvers, and electrical cabinets, among other assets were evaluated. A critical elevation was determined during the site visit for assets located at grade to identify when the trigger is met which could damage an asset. The most vulnerable assets are electrical and mechanical, which if flooded would require replacement.

Assets at Risk

During the present timeframe, Parcel 15 is the only parcel with assets at risk of flooding from a flood with a 1% probability of exceedence (equal to a 100-year recurrence storm event), though the assets are pavers and the likely damage might only be minor undermining of pavers.

During the 2030 timeframe, the overall risk to Greenway assets increases significantly. High-value assets are exposed to damaging levels of flooding in the 100-year event, including fountain systems stored in underground vaults, performance panels (electrical cabinets used to power equipment used for events), and the carousel. In addition, less valuable but similarly vulnerable assets are at risk, including light poles, furniture, trash receptacles, etc. The total replacement value of sensitive assets exposed in the 2030 100-year recurrence coastal flooding event is estimated to be $3,953,394. It is important to note that the estimated replacement value of all assets is not the same as estimated damages - all exposed and sensitive assets would not necessarily require full replacement. In 2070 the replacement value jumps significantly to $5,509,134 of the total replacement value portfolio of $14,775,732.

Figure 3 – Assets at Risk in 2030 from Coastal Flooding

Figure 4 – Greenway Assets at Risk in 2070 from Coastal Flooding

The parcels with assets at risk during the 100-year coastal flood and the highest value vulnerable assets located within them are shown in Table 4.

Table 4 – Highest Value Assets at Risk During a 2030 100-year Flood Event

Parcel	Asset	Asset Critical Elevation	Probability	Replacement Value
14	Carousel	10.2 ft	2%	$446,271
	Performance Panel	10.4 ft	1%	$30, 000
	Storage	10.4 ft	1%	$50,000
15	Rings Fountain Vault	9.7 ft	5%	$2,120,646
	Performance Panel	10.4 ft	1%	$30, 000
17	Harbor Fog Vault	9.8 ft	2%	$656,686

Groundwater

The Boston Groundwater Trust has monitoring wells, which have collected some groundwater information over different time periods. The data was reviewed to determine whether any of the wells are tidally influenced and therefore more susceptible to increases in Sea Level Rise. However, the only locations close to the Greenway, particularly on the Downtown waterfront and near Chinatown where potential tidal influence was identified, are no longer in operation. The Greenway mostly sits on top of the Central Artery tunnel system complicating things further. To be conservative, we assume that groundwater levels will tend to rise.

The assets considered at the greatest risk to groundwater intrusion are the underground fountain vaults, as they are the only subsurface structures on the Greenway. Groundwater intrusion into vaults through leaky through-wall connections (i.e. HVAC, electrical conduits) has been observed in the past, but is considered a minimal threat as the quantities of flow are minimal and can be easily managed by sump pumps. The underground vaults are designed and waterproofed to prevent groundwater seeping in through the walls. Therefore, none of the underground vaults are considered sensitive to groundwater.

Stormwater

In ArcMap, the ground elevation and projected flood elevations were analyzed for each asset. In order to obtain data from raster layers, a 3D spatial analysis tool was used. This tool assigns the ground elevation for the stormwater flooding time horizons (2030, 2070) for each asset based on the raster's value in that location. To obtain stormwater depth at each asset, the spatial join tool was used in ArcMap to combine the information contained in the stormwater layer to the asset.

As air temperatures rises, the air holds more water which leads to more intense precipitation events. Over time, extreme precipitation events will become more frequent and the City of Boston's drainage infrastructure will not be able to manage the amount of water, causing localized flooding. Assets at risk from a 10-year extreme precipitation flooding event in 2030 and 2070 are minimal. Currently, during a 10-year precipitation event, the Greenway experiences erosion of the crushed stone pathways due to runoff on the pathways. No additional assets were identified to be at risk during the 2030 and 2070 predicted extreme precipitation events.

Note that these findings are limited by the available scenarios. While coastal flood maps and data are available across a broad spectrum of probabilities, precipitation was only available for the 10-year storms. As additional scenarios become available from ongoing work at the Boston Water and Sewer Commission (BWSC), these findings should be revisited.

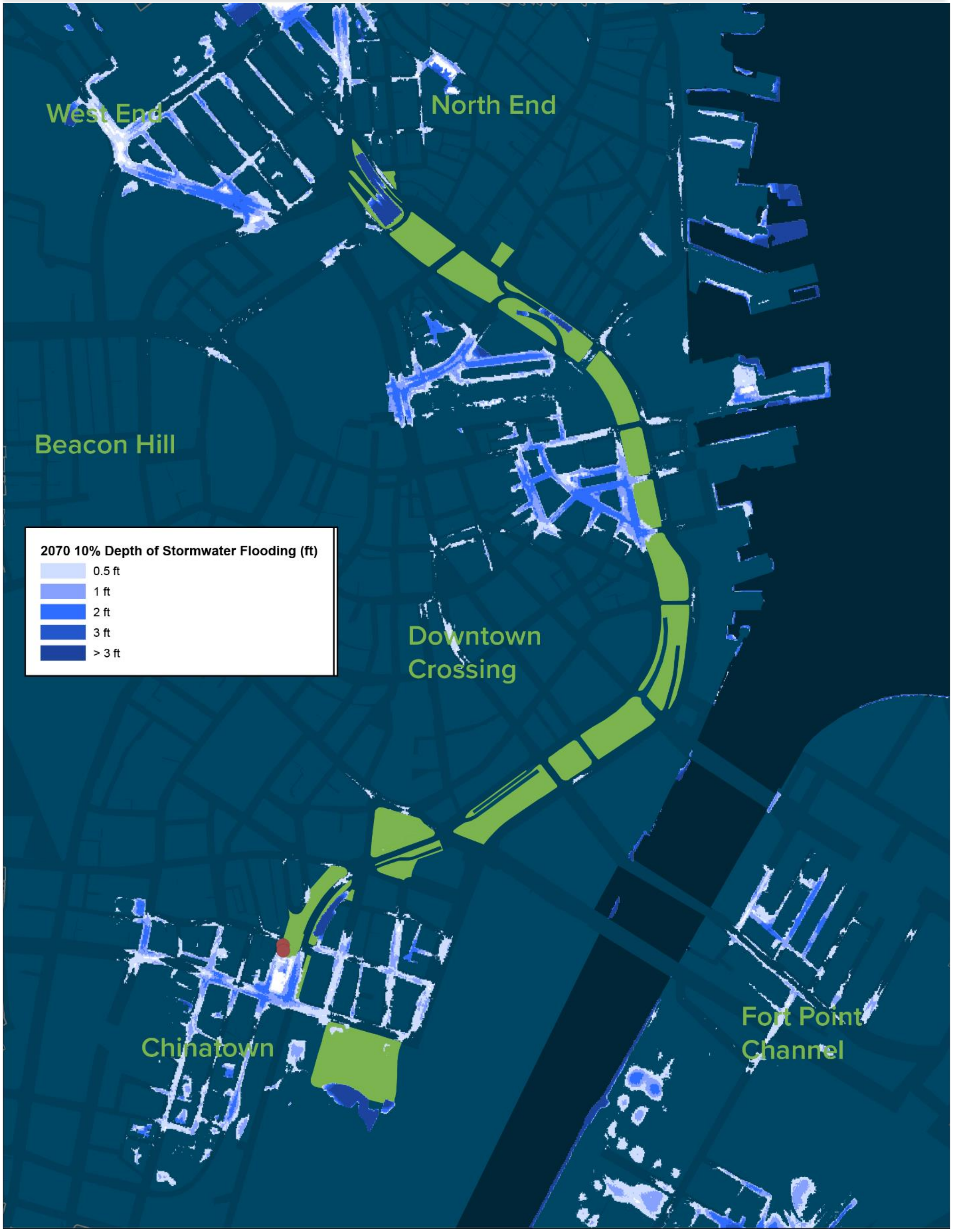

Figure 5 - Stormwater Flooding in 2070

Heat and Humidity

Assets sensitive to extreme heat and humidity are electrical and mechanical equipment such as fans, compressors, and pumps which are primarily located in the underground fountain vaults. Outdoor electrical equipment, such as performance panels, are also sensitive. These assets are susceptible to deterioration and damage from moisture and overheating. Because sensitive assets are primarily underground, their exposure to extreme temperature is relatively low. However, the equipment in the vaults generates significant heat. which is why the vaults are already equipped with air conditioning and ventilation systems. In the future, as extreme heat and humidity increase due to climate change, air conditioning and ventilation systems in vaults will likely need to run more frequently and for longer durations, accelerating their deterioration from wear and tear. Outdoor electrical equipment may also be subject to premature failure.

A high-level qualitative analysis was performed to evaluate the Greenway's potential role in contributing to or mitigating the impacts of urban heat island for its users and adjacent neighborhood residents.

Parcels were evaluated for their potential risk to users and to adjacent neighborhood areas based on land surface temperature data, satellite and site visit observations regarding the prevalence of materials with a high or low Solar Reflectance Index (SRI), and park uses. SRI is the combination of the measurement of solar reflectance or albedo and thermal emittance and is demonstrated on a scale of 0=black to typically 100=white. Material SRI was considered as a factor in potential contribution to or mitigation of urban heat island effects. This does not take into account humidity, which will be higher on mostly planted parcels. A summary of the findings by parcel is included in Table 5.

Table 5: Typical Material SRI

Material Surface	Solar Reflectance	Thermal Emittance	SRI
Black	0.05	0.9	0
New asphalt	0.05	0.9	0
Aged asphalt	0.1	0.9	6
"High albedo" asphalt shingle	0.21	0.91	21 to 30
Aged concrete	0.2 to 0.3	0.9	19 to 32
Grass	.25	.98	78
Brick	0.2 to 0.6	0.9	19 to 65
New concrete (ordinary)	0.35 to 0.45	0.9	38 to 52
New white Portland cement concrete	0.7 to 0.8	0.9	86 to 100
White	0.8	0.9	100

Source: Kleinfelder for Cambridge Ecosystem Benefits Analysis for Inman Square Memo, 2017

In addition to being a pedestrian corridor and place for passive recreation, the Greenway hosts events and attractions where large numbers of people gather. Some of these activities generate revenue for the Conservancy. Attractions include the carousel, waterplay fountains, beer garden, food trucks, concerts, public art exhibits, and others. Park use is highest in the summer months when heat-related health risks are also highest. People are vulnerable to heat stroke and heat illness once air temperatures reach 90 degrees and more so when humidity is also high. In the future, as extreme heat and humidity become more prevalent, park users may face greater health risks from being outdoors. In addition, uncomfortable ambient temperatures may discourage or depress use of the Greenway during typical peak use and tourism seasons. Some parcels, such as Parcel 17, have features that may mitigate exposure to high ambient temperatures, including large lawns and planted areas, shade trees, shade structures, and fountains. Other areas are primarily impervious pavement and offer limited shade.

The Greenway is a large open space that is easily accessible to residents and workers in Chinatown and the North End. Residents of both of these neighborhoods tend to be more socially vulnerable than residents of Boston on average, including having higher proportions of people over 60 years old, with disabilities, medical illness, limited English, non-white race (Chinatown only), and low income. Chinatown and the North End have active service industries as well, and workers in these industries may also be socially vulnerable. In terms of heat exposure, these neighborhoods have higher land surface temperatures than other neighborhoods, due primarily to the prevalence of dark, flat, impervious surfaces like rooftops, brick walls, and brick pavements. These factors put them at greater risk of heat-related health impacts. Cooler areas of the Greenway, highlighted below in a heat map produced by the Metropolitan Area Planning Commission (MAPC) Figure 6, may serve as important refuges for these residents and workers. Parcels with large, vegetated areas may also have a cooling effect on adjacent neighborhood areas. However, some areas of the Greenway, such as Parcel 23, include large areas of brick pavement and other impervious pavements which may contribute to the urban heat island effect in adjacent areas. Average temperature per parcel, extracted from the MAPC map, is shown in Table 6.

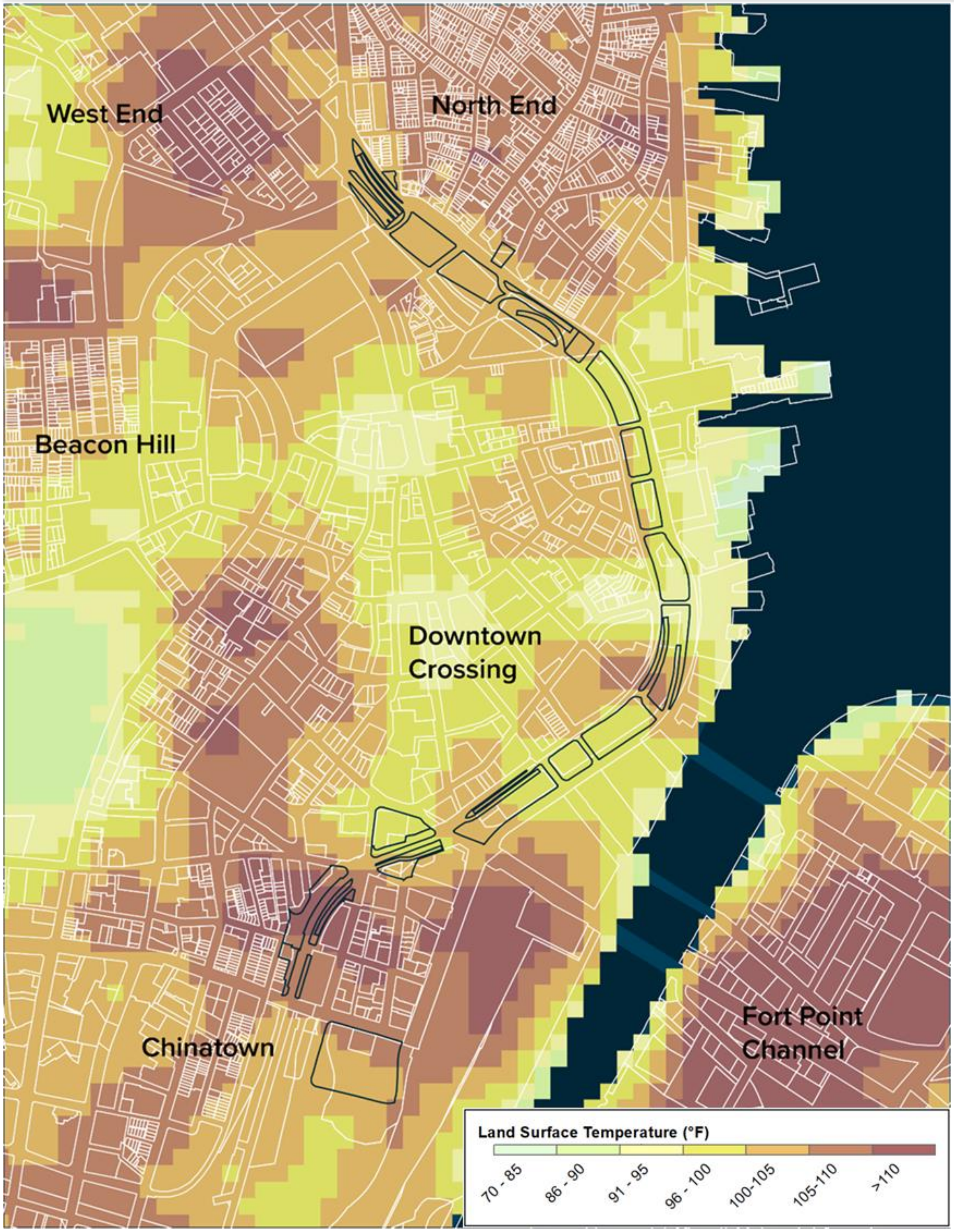

Figure 6 - Urban Heat Map (Source MAPC)

Table 6: Heat-Related Risks of Major Parcels (Source: MAPC)				
Parcel #	**Average Extreme Temp**	**Ground Material**	**High Pedestrian Traffic / Used for Events (Yes/No)**	**Determined at risk following site visit (Yes/No)**
8	101.5	Granite pavers, grass, plantings, stone dust, trees	Yes	Yes
10	102.8	Granite pavers, grass, plantings, stone dust, trees	Yes	Yes
12	101.9	Grass, plantings	No	No
13	101.2	Red brick, plantings, trees	No	No
14	99.8	Granite pavers, light colored pavers, grass, plantings, trees	Yes	Yes
15	99.9	Granite pavers, light colored pavers, grass, plantings, trees	Yes	Yes
16	99.7	Granite pavers, light colored pavers, grass, plantings, trees	Yes	Yes
17	95.9	Granite pavers, light colored pavers, grass, plantings, trees	Yes	No
18	97.7	Trees, brick, grass, plantings,	Yes	No
19	99.9	Grass, trees, brick, stone dust	Yes	No
21	97.8	Grass, trees, brick, stone dust	No	No
22	100.6	Pavers, Grass, stone dust, trees, brick	Yes	Yes

23	111.9	Concrete unit pavers, concrete sidewalks, trees,	Yes	Yes

Winter Weather

Winter weather hazards such as snow, ice, and wind are likely to be impacted by climate change. The frequency and quantity of snowfall is generally expected to decrease as fewer days are projected to have temperatures below freezing. However, extreme precipitation events are expected to increase in frequency and quantity, including over winter months, and some of those events could come in the form of snow or ice. The science of projecting the impact of climate change on wind, particularly from extratropical storms like nor'easters is not conclusive. The Conservancy has few assets that are potentially vulnerable to extreme winter weather, namely the carousel canopy, paths that need to be plowed and de-iced, and trees.

Prioritization

To identify priority assets, a score was assigned to assets for criticality, sensitivity, and exposure. When the scores were summed, a pattern emerged to help identify priority assets. Prioritization was ranked base on the following scores:

Ranking	Low	Medium	High
Points	1-4	5-9	10-14

Complete results of the prioritization scoring are available in the Climate Change Vulnerability Assessment Excel database.

Asset Management Plan and Climate Change Recommendations

Implementation Strategy

The Conservancy should focus on implementing priority resilience recommendations that will have near term (through 2030s) benefits in terms of avoided damages and operational disruptions. The highest priority recommendations from this perspective are those to increase resilience of critical and high value assets to coastal flooding. Resilience projects implemented in the near term should be designed to provide lasting benefits through the long term (2050, 2070) by incorporating forward-looking design criteria based on the best available science. Further, the Conservancy should incorporate lower-cost resilience measures into maintenance practices and implement them through ongoing maintenance activities. Lower priority resilience recommendations should also be integrated to the extent feasible with future planned improvements as part of the normal capital improvement process.

Coastal Flooding

Long Term Recommendations

Preventing coastal flooding risks to the Greenway in 2050 and 2070 are beyond the Conservancy's financial, legal, and technical capacity to address on its own. To be independently resilient to long-term coastal flooding risks, the entire Greenway landscape or each of its parcels would need to be redesigned as islands of resilience - elevated or walled off from the adjacent rights of way or primarily under water. Even if the Conservancy and its stakeholders wanted to pursue these strategies, they are not likely to be feasible without exceedingly high costs due to the presence of the highway tunnels below. But an independently resilient Greenway is not a functional solution to long term coastal flooding risks. The park is not an independently functioning system – it depends on the viability of the surrounding neighborhoods, business districts, and their infrastructure for access, utilities, and most importantly people.

The City of Boston has developed the *Coastal Resilience Solutions for Downtown Boston and North End (2020)* plan that would protect the Greenway from coastal flooding risks projected for the mid to late century. A similar plan for South Boston would protect Greenway parcels south of the Northern Avenue bridge. The City and Conservancy share a critical stake in the successful implementation of the coastal flood resilience infrastructure systems envisioned in these plans, along with the many property owners and interest groups with which the Greenway engages through its programming and community involvement – the Greenway Business Improvement District members, Wharf District Council members, neighborhood associations, community-based organizations, transportation agencies, utility companies, and more.

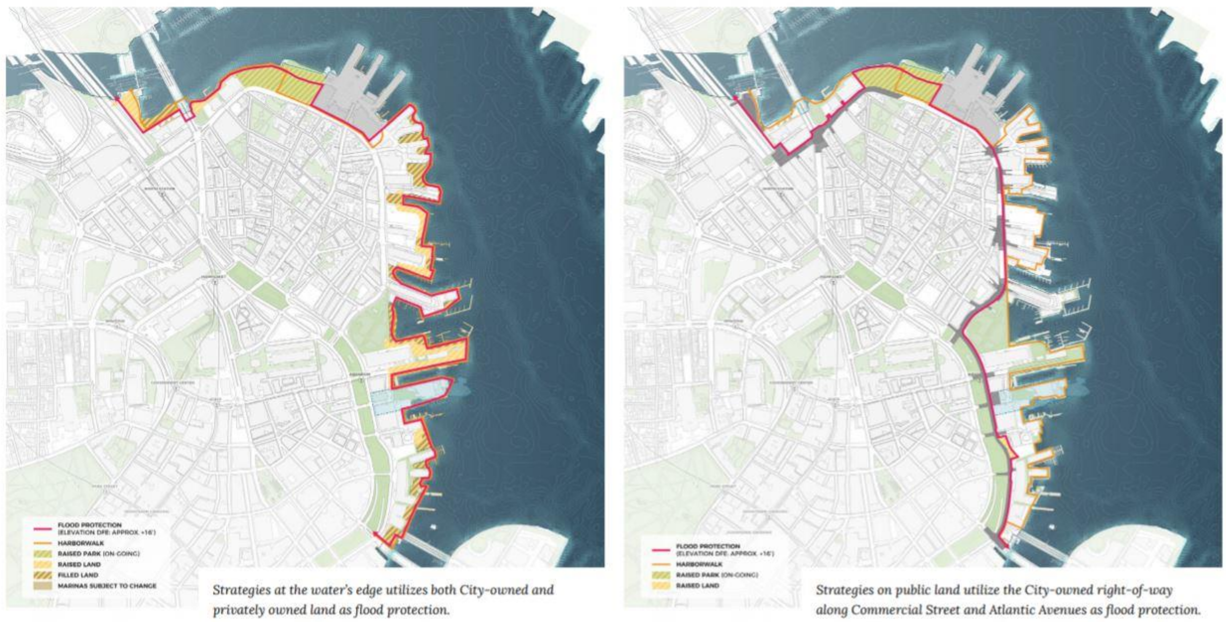

Figure 7 – Two Alternatives from Coastal Resilience Solutions for Downtown and North End - City of Boston 2020

The Conservancy should apply all available resources and do everything in its power to advocate, with others, for the City and other responsible entities to implement projects designed to protect the Greenway from long term coastal flooding risks. As those projects move forward, the Conservancy should lean on its mission to advocate for "vibrant, inclusive, and evolving" open space solutions that enhance or are compatible with the Greenway's function. These are likely to follow the waterfront alignments defined in the *Coastal Resilience Solutions for Downtown Boston and North End* plan. An alternative inland alignment protection plan, following the Atlantic Ave and Commercial St rights-of-way, would likely have a detrimental effect to the Greenway in terms of connectivity with the waterfront. Figure 7 shows the two concept plans.

Near Term Recommendations

Performance Panels

Five performance panels on Parcels 13-17 are vulnerable to coastal flooding in 2030. To protect them, equipment cabinets should be elevated on concrete pads to be above their respective base flood elevations. The cabinets are currently minimally elevated above the surrounding grade, making them susceptible to coastal flood exposure and potential future increases in flooding from extreme precipitation. Their low elevation also makes them physically awkward to access for operations and maintenance. Raising the cabinets on concrete pads would address each of these issues. However, if cabinets are raised too high, they will be even more difficult to access, possibly requiring platforms and stairs to meet code. Based on the base flood elevations and height required to meet them (Table 7), we recommend that the 2070 1% annual chance flood elevation be selected as the design flood elevation. For planning purposes, the estimated cost of elevating each performance panel is $25,000. (Note: Performance panels and other electrical panels are not included in the asset management data base.)

Table 7 – Performance Panel Flood Elevations and Heights

Parcel	Critical Elevation (ft NAV88)	2050 1% Annual Chance Flood Elevation (ft NAVD88)	2070 1% Annual Chance Flood Elevation (ft NAVD88)	Height to 2050 1% Annual Chance Flood Elevation (ft)	Height to 2070 1% Annual Chance Flood Elevation (ft)
Parcel 15	9.5	12.3	14.0	2.8	4.5
Parcel 13	10.0	12.3	14.0	2.3	4.0
Parcel 17 (Harbor Fog)	10.0	12.3	14.0	2.3	4.0
Parcel 14	10.4	12.3	14.0	1.9	3.6
Parcel 16	10.4	12.3	14.0	1.9	3.6

These improvements may need to be prioritized due to the high cost. Assuming all performance panels are of equal importance, prioritization should be based on exposure, with the priority being assigned in ascending order from lowest to highest critical elevation (i.e., Parcel 15 as top priority, then Parcels 13 and 17, and so on). Improvements should also be implemented opportunistically as part of the natural capital improvement cycle (i.e., a panel should be elevated when it needs to be replaced or undergo significant maintenance).

Rings Fountain

The Rings Fountain vault and basin have a relatively high probability of being exposed to coastal flooding in 2030 (5-10% annual chance).

The underground vault contains most of the highest value assets that require protection, including electrical, mechanical and HVAC equipment. The elevation of the existing vault access hatch is approximately 9.78 NAVD 88, which is below the 2070 flood elevation of 14.0 NAVD 88. Therefore, flood water could enter the vault structure through the non-floodproof hatch. The vault itself is designed and waterproofed to function under water. To protect against the possibility of water entering the vault through the hatch, we recommend replacing the hatch with a flush-mounted floodproof sidewalk hatch. There are also side louvers that are below the 2070 flood elevation that would be conduits for flood water to enter the vault below. These louvers need to be sealed during a flood. In addition, to protect against the possibility of flooding through conduits from flooded nearby electrical and telecommunications manholes, we recommend sealing potential water pathways through conduits entering the vault using expandable foam sealant conduit plugs.

Based on costs and least amount of disruption, we recommend the following floodproofing strategies described in Table 8 to protect the Rings Fountain from coastal flooding.

Table 8 – Resilience Recommendations and Costs for Rings Fountain Vault

Action	Description	Order of Magnitude Construction Cost Estimate
1 – Replace existing access hatch with a flush-mounted floodproof access hatch (Recommended)	The at-grade hatch used to access the underground vault should be replaced with a floodproof hatch. This is a passive protection measure requiring no pre-flood action, aside from a check to make sure it is closed for it to be effective. Floodproof hatches can be manufactured in a variety of sizes and configurations. A hatch type that installs flush with grade is preferable to minimize tripping hazards at this high pedestrian traffic site. The selected hatch should be designed to withstand the design flood and an HS 20 truck wheel load (not simultaneously). Gaskets should be inspected and maintained according to manufacturer's instructions. PS Flood Barriers (psfloodbarriers.com) manufactures flush-mounted floodproof sidewalk hatches designed for HS 20 loading. Their designs are custom designed to fit the existing opening, meet required design loading and can be manufactured in either aluminum, steel or stainless steel.	$45,000
2 – Install deployable flood shields across ventilation louvers (Recommended)	Deployable flood shields can be temporarily affixed to the walls and pavement surrounding the vault's ventilation louvers to form a watertight seal around them in advance of a potential coastal flood. A deployment plan should be developed and annual training and inspection conducted to minimize risks of human error and equipment failure. In addition, equipment should be labelled that should be shut down in advance of a flood while ventilation is blocked by the flood shields.	$20,000
3 - Seal electrical and telecommunications conduits (Recommended)	Watertight foam sealant should be injected into any conduits that penetrate the vault floor, ceiling, and walls where water could enter from flooded exterior electrical or telecommunications manholes. The foam expands and fills spaces between wires and gaps to prevent water from flooded manholes from leaking into the vault.	$3,000
Total		$68,000

The Rings Fountain vault can also be protected with a perimeter flood barrier system. There are permanent and deployable flood barrier types (Actions 1A and 1B in Table 9) that could be considered for selection and design, with different associated costs, operational, and storage requirements. The flood barriers should be designed to meet an effective base flood elevation of 12.3 ft (NAVD88) for 2050, or 14.0 ft (NAVD88) for 2070. The longer-term 2070 flood elevations should be used if a permanent wall is selected as the preferred flood barrier type. Ground elevations along the perimeter are approximately 9.9 ft (NAVD88). Additional measures are required to address leakage and rainfall accumulation. The options shown in Table 9 are shown as possible solutions to protect the Rings Fountain vault from coastal flooding but are not recommended as they are less cost effective that the recommendations shown in Table 8.

Table 9 – Resilience Recommendations and Costs for Rings Fountain Basin

Action	Description	Order of Magnitude Construction Cost Estimate
1A – Install deployable flood barriers around the perimeter of the fountain basin (Alternate floodproofing concept)	Deployable flood barriers, such as AquaFence or stop logs are faster to install and much more effective than sandbags at stopping flooding. Space is required for large storage containers containing equipment, tools, and supplies. Storage should be as close to the fountain as possible. A deployment crew of four people should be available for at least four hours prior to potential flooding events. The barrier should be 2.4 or 4.1 ft tall to provide protection up to the 1% annual chance flood in 2050 or 2070 respectively. AquaFence comes in standard 4.0 ft tall panels. Approximately 325 lf is needed for the basin perimeter. A deployment plan should be developed and annual training and inspection conducted to minimize risks of human error and equipment failure.	Range: $154,000 (AquaFence) to $276,000 (Stop Logs)
1B – Construct permanent concrete flood wall around the perimeter of the vault, with deployable barriers at entry/exit points (Alternate floodproofing concept)	Permanent flood walls are more costly and complex to design and construct than deployable flood barriers but have several advantages. Most importantly, they minimize the time and labor needed prior to potential flooding events to make the system effective. They allow little to no leakage, though conduits still must be sealed to minimize leakage and pumping is still needed to remove accumulated rainfall (see Actions 2-3). Permanent flood walls can serve as seating benches with low backs. The barrier, including the back, should be at least 2.4 ft tall to provide protection up to the 1% annual chance flood in 2050. Approximately 285 lf is needed for the basin perimeter. At least 40 lf of deployable barrier is needed for access openings to minimize the impact of the permanent obstructions to circulation.	$462,000 (assuming stop logs are used at openings)
2 - Seal electrical and telecommunications conduits (Recommended for both recommended options and alternate options)	Watertight foam sealant should be injected into conduits that penetrate the ground within the protected perimeter. The foam expands and fills spaces between wires to prevent water from flooded manholes and high groundwater from leaking into the area.	$3,000

3 - Purchase and deploy portable pump (Alternate floodproofing concept)	A gasoline-powered pump with debris filters and hoses should be deployed within the protected perimeter to collect accumulated water from rainfall and leakage and discharge over the flood barrier wall.	$4,000
Total	1A + 2+3 or 1B+2+3	$161,000 to $469,000

Harbor Fog Fountain

The Harbor Fog Fountain vault and performance panel are vulnerable to coastal flooding exposure in 2030 (0.2% annual chance), but at a lower probability than the Rings Fountain vault or performance panels described in prior sections. Therefore, resiliency improvements recommended here are of lower priority. The Harbor Fog sculptures are unlikely to be damaged from flood exposure, and associated mechanical and electrical components mounted on the sculptures are above the 2030 0.1% annual chance flood elevation, therefore, no actions are recommended for these assets at this time.

The underground vault contains most of the highest value assets that require protection. The elevation of the existing vault access hatch is approximately 9.82 NAVD 88, which is below the 2070 flood elevation of 14.0 NAVD 88. Therefore, flood water could enter the vault structure through the non-floodproof hatch. The vault itself is designed and waterproofed to function under water. To protect against the possibility of water entering the vault through the hatch, we recommend replacing the hatch with a flush-mounted floodproof sidewalk hatch. In addition, to protect against the possibility of flooding through conduits from flooded nearby electrical and telecommunications manholes, we recommend sealing potential water pathways through conduits entering the vault using expandable foam sealant conduit plugs.

We recommend the following floodproofing strategies described in Table 10 to protect the Harbor Fog Fountain vault from coastal flooding.

Table 10 – Resilience Recommendations and Costs for Harbor Fog Vault

Action	Description	Order of Magnitude Construction Cost Estimate
1 – Replace existing access hatch with a floodproof access hatch (Recommended)	The at-grade hatch used to access the underground vault should be replaced with a floodproof hatch. This is a passive protection measure requiring no pre-flood action, aside from a check to make sure it is closed for it to be effective. Floodproof hatches can be manufactured in a variety of sizes and configurations. A hatch type that installs flush with grade is preferable to minimize tripping hazards at this high pedestrian traffic site. The selected hatch should be designed to withstand the design flood	$45,000

	and an HS 20 truck wheel load (not simultaneously). Gaskets should be inspected and maintained according to manufacturer's instructions. PS Flood Barriers (psfloodbarriers.com) manufactures flush-mounted floodproof sidewalk hatches designed for HS 20 loading. Their designs are custom designed to fit the existing opening, meet required design loading and can be manufactured in either aluminum, steel or stainless steel.	
2 - Seal electrical and telecommunications conduits (Recommended)	Watertight foam sealant should be injected into any conduits that penetrate the vault floor, ceiling, and walls where water could enter from flooded exterior electrical or telecommunications manholes. The foam expands and fills spaces between wires and gaps to prevent water from flooded manholes from leaking into the vault.	$3,000
Total		$48,000

North End Fountains

The North End Fountain vault in Parcel 8 is vulnerable to coastal flooding exposure in 2070 (0.1% annual chance). The vault hatch is at elevation 15.14 NAVD 88 and the 2070 0.1% chance flood elevation is 15.49 NAVD 88. As the probability of flooding is very low and far in the future, we do not recommend any capital improvements to change the hatch to a floodproof hatch at this time or in the near future. With such a low probability and only 4 inches of flood water projected, a more realistic option might be to sandbag the hatch in the event of a major flood to prevent water from entering the underground vault. The fountain vault located in Parcel 10 is not subject to flooding through 2070 and no floodproofing recommendations are included for this vault.

Chinatown Fountain

The Chinatown Fountain vault in Parcel 23 is vulnerable to coastal flooding exposure in 2070 (0.2% annual chance). The vault hatch is at elevation 14.09 NAVD 88 and the 2070 0.2% chance flood elevation is 14.45 NAVD 88. As the probability of flooding is very low and far in the future, we do not recommend any capital improvements to change the hatch to a floodproof hatch at this time or in the near future. With such a low probability and only 4 inches of flood water projected, a more realistic option might be to sandbag the hatch in the event of a major flood to prevent water from entering the underground vault.

Carousel

We recommend protecting the Carousel from coastal flooding using a perimeter flood barrier system. There are both permanent and deployable flood barrier types that can be considered for selection and design, with different associated costs, operational, and storage requirements. The flood barrier should be designed to be effective up to the base flood elevation of 12.3 ft (NAVD88) for 2050, or 14.0 ft (NAVD88) for 2070. The longer-term 2070 flood elevations should be used if a permanent wall is selected as the preferred flood barrier type, due to its longer design life and higher upfront cost. Ground elevations along the perimeter range from 10.0-11.0 ft (NAVD88). Additional measures are required to address leakage and rainfall accumulation.

Table 11 – Resilience Recommendations and Costs for the Carousel

Action	Description	Order of Magnitude Construction Cost Estimate
1A – Install deployable flood barriers around the perimeter of the carousel, and if desired, the ticket booth (Recommended)	Deployable flood barriers, such as AquaFence and stop logs are faster to install and much more effective than sandbags at stopping flooding. Space is required for large storage containers containing equipment, tools, and supplies. Storage should be as close to the carousel as possible. A deployment crew of four people should be available for about 4 hours prior to potential flooding events. The barrier should be 2.5 or 3.0 ft tall to provide protection up to the 1% annual chance flood in 2050 or 2070 respectively. AquaFence comes in standard 4.0 ft tall panels. Approximately 150 lf is needed for the carousel and an additional 30 lf for the ticket booth. A deployment plan should be developed and annual training and inspection conducted to minimize risks of human error and equipment failure.	$70,000 (AquaFence) to $130,000 (stop logs) Add $14,000 to $26,000 if ticket booth is included
1B – Construct permanent glass or concrete flood wall around the perimeter of the carousel, with deployable barriers at entry/exit points, and if desired, around the ticket booth. (Alternate floodproofing concept)	Permanent flood walls are more costly and complex to design and construct than deployable flood barriers but have several advantages. Most importantly, they minimize the time and labor needed prior to potential flooding events to make the system effective. They allow little to no leakage, although conduits must still be sealed to minimize leakage and pumping is still needed to remove accumulated rainfall (see Actions 2 & 3). Permanent flood walls can serve as security walls, seating benches, and aesthetic features. The barrier should be 2.5 or 3.0 ft tall to provide protection up to the 1% annual chance flood in 2050 or 2070 respectively. Additional security fencing could be included at additional cost. Approximately 140 lf of permanent barrier and 10 lf of deployable barrier is needed for the carousel and an additional 30 lf of deployable barrier for the ticket booth.	$220,000 (assuming stop logs are used at openings) Add $14,000 to $26,000 if ticket booth is included
2 - Seal electrical and telecommunications conduits (Recommended)	Watertight foam sealant should be injected into conduits that penetrate the ground. The foam expands and fills spaces between wires to prevent water from flooded manholes and high groundwater from leaking into the protected area.	$3,000
3 - Purchase and deploy portable	Gasoline-powered pumps with debris filters and hoses should be deployed within the protected perimeter to	$4,000

pumps (Recommended)	collect accumulated water from rainfall and leakage and discharge back over the flood barrier wall.	
Total	1A + 2+3 or 1B+2+3	$91,000 to $241,000

Irrigation Systems

Irrigation systems will be critical for flushing salts from soils to minimize damage to lawns, plantings, and trees immediately after a coastal flooding event. Irrigation controllers on Parcels 14 and 16 are vulnerable to coastal flooding in 2030 (1% annual chance), as are the water meter hot box on Parcel 14 and irrigation hot box on Parcel 17 (0.2% annual chance). To protect them, equipment cabinets can either be elevated on concrete pads to be above their respective base flood elevations in 2050 or 2070 or equipment cabinets could be replaced with taller cabinets with sensitive components rewired and mounted higher in the cabinet. The cabinets are currently minimally elevated above the surrounding grade, making them susceptible to coastal flood exposure and potential future increases in flooding from extreme precipitation. Their low elevation also makes them physically awkward to access for operations and maintenance. Raising the cabinets on taller concrete pads or mounting them within taller cabinets would address each of these issues. Once a decision is made to elevate the equipment, we recommend that they be elevated to withstand the 2070 flood elevation of 14.0 NAVD 88. For planning purposes, the cost of elevating each asset is $20,000.

Table 12 – Irrigation Equipment Flood Elevations and Heights

Parcel	Critical Elevation (ft NAV88)	2050 1% Annual Chance Flood Elevation (ft NAVD88)	2070 1% Annual Chance Flood Elevation (ft NAVD88)	Height to 2050 1% Annual Chance Flood Elevation (ft)	Height to 2070 1% Annual Chance Flood Elevation (ft)
Parcel 14 Irrigation Controller	10.2	12.3	14.0	2.1	3.8
Parcel 16 Irrigation Controller	10.3	12.3	14.0	2.0	3.7
Parcel 14 Water Meter Hot Box	11.1	12.3	14.0	1.2	2.9
Parcel 17 (Harbor Fog) Irrigation Hot Box	11.2	12.3	14.0	1.1	2.8

These improvements may need to be prioritized due to the high cost. Assuming all irrigation assets are of equal importance, prioritization should be based on exposure, with the priority being assigned in ascending order from lowest to highest critical elevation (i.e., Parcel 14 irrigation controller as top priority, then Parcel 16 controller, and so on). Improvements should also be implemented opportunistically as part of the natural capital cycle (i.e., an asset should be elevated when it needs to be replaced or undergo significant maintenance).

Other Assets on Parcel 14

Two additional assets located at Parcel 14 are vulnerable to coastal flooding in 2030 and may warrant protection.

The storage container, with lawn mowing and trash removal equipment and supplies, has a 1% annual chance of flooding in 2030. While this level of flooding may not cause significant damage, a 0.1% annual chance flood in 2050 would results in 1.4 ft of inundation within the container. To achieve protection, we recommend that any equipment that could be damaged by flooding be moved to higher ground in advance of a large storm event. This operational solution would be significantly lower cost than raising the container on a new elevated platform above the flood level. The recommended solution has no capital cost, only future operational costs.

The other asset is an electrical cabinet that serves as a junction box for the Boston Harbor Islands Welcome Center power supply. It is not clear how damage to this asset would affect the Conservancy's operations on the Greenway. The electrical cabinet has a 0.5% annual chance of flooding in 2030. We recommend that the bottom of electrical cabinet be raised to at least the 1% annual chance flood elevation in 2070 base flood elevation of 14.0 NAVD 88 (3.2 ft higher than current top of pad). The approximate cost of elevating this asset is $25,000.

There are 40 light pole assets that are vulnerable to coastal flooding in 2030 and many more beyond that time horizon. A low-cost measure that should be taken programmatically as part of the capital renewal cycle to minimize damage to lighting assets is to replace traditional wiring splice caps and connectors located in the light pole bases with watertight splice caps. Refer to the climate change asset management database to determine if a particular asset is vulnerable, warranting replacement.

Stormwater

Stormwater flooding represents a limited risk for critical assets on the Greenway based on the available 10% annual chance 24-hour rainfall modeling scenarios from Boston Water and Sewer Commission (BWSC). These were the scenarios used for the City of Boston's Climate Ready Boston vulnerability assessment. More extreme precipitation scenarios, such as a 1% annual chance 24-hour rainfall, were not modeled or not available, so the potential risks to critical assets on the Greenway may not be captured by the present vulnerability assessment. A key recommendation is for the Conservancy to update the vulnerability assessment in the future if additional stormwater modeling scenarios, particularly more extreme ones, are made available.

The assets most impacted by extreme rainfall are the unpaved stone dust paths on Parcels 19 and 21. During heavy rainstorms, water ponds in some areas, the stone dust and underlying soil is eroded, and material is deposited in stormwater catch basins. Both the surface and the drainage infrastructure impacts result in ongoing maintenance costs, and the Conservancy has experimented with different approaches to mitigating these impacts, including grading, adhesive additives, and catch basin protection. However, these measures have had limited success. To minimize ongoing maintenance costs and impacts to pedestrian access from stormwater flooding, we recommend that the paths on Parcels 19 and 21 be reconstructed with a porous rubberized pavement, such as manufactured by Porous Pave (porouspaveinc.com). The total estimated cost for pathway replacement is $269,600 (based on $20.00/sf) based on the following pathway areas: 1800 sf for Parcel 8, 2080 sf for Parcel 10, 6,600 sf for Parcel 19, and 3,000 sf for Parcel 21. While this change in design will technically result in increased impervious area on these parcels, the reality is that the existing stone dust paths have minimal permeability as evidenced by the stormwater sheet flow and ponding that is observed during heavy precipitation events. The above costs do not include any allowance for drainage improvements that might be required by regulatory agencies. There are added costs for maintenance with pervious materials due to the need for seasonal “vacuuming”. The added cost is either through hiring an outside vendor to vacuum the surface or through the purchase of equipment. Purchasing the equipment may prove to be a prudent investment if the Conservancy chooses to replace more pavers or paves surfaces with porous pavers or pervious asphalt.

Stakeholders may have an interest in enhancing the stormwater management performance of the Conservancy’s parcels, in support of broader City-wide or district-scale stormwater flood mitigation or water quality goals. There is limited open space in Boston to use for managing stormwater due to the high concentration of buildings and other impervious surfaces. While there are large pervious areas on the Greenway, including lawns, landscaped areas, and planters and tree pits, there are also large areas of impervious materials, including concrete, brick, and stone pavement. Stormwater infiltration could potentially be increased by replacing impervious surface materials with previous ones, including hardscape alternatives like porous pavers. Technical analysis of soils, groundwater levels, drainage infrastructure, and other factors are critical for assessing the feasibility and effectiveness of these measures at a site level.

Increasing stormwater infiltration on Greenway parcels is generally complicated by the presence of highway tunnels beneath the surface which causes a need to minimize potential leakage into those structures from excessive infiltration. Stormwater detention, retention, and storage are also a challenge due to potential impacts of additional loading (i.e., the weight of the water) on the underground tunnel structures. Each tunnel section has a different available loading capacity. While there may be specific parcels or parcel areas where such capacity could be utilized for holding stormwater, such an analysis was beyond the scope of the present study. Due to these sensitivities, it is recommended that, should such opportunities become of interest to BWSC, the City of Boston, MassDOT, regulatory agencies, or others, that the Conservancy defer primary responsibility for further study to MassDOT with the Conservancy participating as a key stakeholder.

Groundwater

Underground fountain vaults are at limited risk from groundwater intrusion due to resiliency measures already implemented in the design of the vaults. All of the existing underground fountain vaults are designed and waterproofed to function underground, and there are no obvious signs of groundwater intrusion problems indicating that the waterproofing systems are not functioning as designed. Therefore, no specific recommendations are made to address future groundwater intrusion problems.

Heat and Humidity

As described in the vulnerability assessment section of this report, the Conservancy's critical assets that are sensitive to heat and humidity are primarily located in underground vaults and are generally resilient to these hazards due to measures already taken by the Conservancy. Above ground assets, such as electrical equipment cabinets, are also generally located in cooler vegetated areas with some tree cover. No recommendations are provided for protecting critical assets from heat and humidity, other than continuing to maintain mitigative measures such as air conditioning systems.

The vulnerability assessment also describes potential urban heat island risks and benefits of the Greenway for park users and adjacent neighborhoods. There are several recommendations that the Conservancy can implement as part of the capital renewal cycle to increase the heat island mitigation benefits and reduce the heat island impacts of the Greenway. The priority locations for the implementation of these recommendations are the Mary Soo Hoo Park and Chinatown Park (Parcels 23) which are used extensively by neighborhood residents and which has the highest land surface temperature exposure of all the Greenway parcels. Other higher risk areas are noted in Table 6 of the vulnerability assessment section.

- Replace dark colored hardscapes, particularly brick pavements, with vegetated surfaces, concrete, or other high SRI pavements, including porous alternatives.
- Plant additional canopy trees and install permanent or temporary shade structures.
- Install permanent misting stations and additional drinking water fountains and bottle filling stations. Coastal flood exposure should be taken into account in the siting and design of new infrastructure.

Winter Weather

As noted in the vulnerability assessment section of this report, the Conservancy has few assets that are potentially vulnerable to increases in extreme winter weather caused by climate change, namely the carousel canopy, paths, and trees. Trees are not included in the scope of the present study.

The Conservancy has already implemented measures to increase the resilience of the carousel canopy, replacing it with a more durable material and more robust fastening system. Current building code incorporates a robust model for wind and snow loads. In the future, codes may be updated to reflect observed changes in these hazards, and if so, the Conservancy should follow the latest codes.

Unpaved stone dust paths on Parcels 8, 10, 19, and 21 are a challenge for the Conservancy to maintain during winter months due to the unevenness and erodibility of the path materials. As recommended in the stormwater section of this report, these paths can be reconstructed with concrete pavements to mitigate this maintenance and safety issue.

Summary of Prioritized Recommendations

Table 13 summarizes the prioritized proposed recommendations in descending order of priority to help the Conservancy address and adapt to present and future exposures to changing climate conditions.

All of the assets described in Table 13, with the exception of the stone paths, are affected by potential coastal flooding in 2030. Therefore, the recommendations are prioritized based on sensitivity and exposure of the assets, and in some cases by grouping of similar construction trades to take advantage of efficiencies in construction. The recommendations for the stone paths are based on an on-going maintenance problem due to stormwater runoff.

Table 13 – Summary of Prioritized Recommendations

Asset	Parcel	Action	Estimated Cost
Rings Fountain Vault Access Hatch	15	Replace existing hatch with flush-mounted floodproof hatch	$ 45,000
Rings Fountain Vault Ventilation Louvers	15	Install deployable flood shields across ventilation louvers	$ 20,000
Rings Fountain Vault Electrical and Telecommunications Conduits	15	Seal any electrical and telecommunications conduits entering the vault that could flood from flooded manholes with expandable foam plugs	$ 3,000
Carousel	14	Install deployable flood barriers around the perimeter of the carousel and ticket booth	$ 84,000
Carousel	14	Seal electrical and telecommunications conduits into the flood protected area that could carry water from flooded electrical or telecommunications manholes outside the protected area	$ 3,000
Carousel	14	Purchase a deployable gasoline-powered pump and hoses to be able to pump out water within the flood protected area	$ 4,000
Harbor Fog Fountain Vault Access Hatch	17	Replace existing hatch with floodproof hatch	$ 40,000
Harbor Fog Fountain Vault Electrical and Telecommunications Conduits	17	Seal any electrical and telecommunications conduits entering the vault that could flood from flooded manholes with expandable foam plugs	$ 3,000
Performance Panel	15	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Performance Panel	13	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000

Asset	Parcel	Action	Estimated Cost
Performance Panel	17	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Performance Panel	14	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Performance Panel	16	Elevate base of existing performance panel on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Irrigation Controller	14	Elevate existing irrigation contoller box on new reinforced concrete pad to EL. 14.0 NAVD88	$ 20,000
Irrigation Controller	16	Elevate existing irrigation contoller box on new reinforced concrete pad to EL. 14.0 NAVD88	$ 20,000
Electrical Cabinet (Power Supply to Visitor Center)	14	Elevate existing electrical cabinet on new reinforced concrete pad to EL. 14.0 NAVD88	$ 25,000
Water Meter Hot Box	14	Elevate existing water meter hot box on new reinforced concrete pad to EL. 14.0 NAVD88	$ 20,000
Irrigation Hot Box	17	Elevate existing irrigation hot box on new reinforced concrete pad to EL. 14.0 NAVD88	$ 20,000
Stone Dust Paths	8	Replace existing stone dust paths with porous pavement such as Porous Pave	$ 36,000
Stone Dust Paths	10	Replace existing stone dust paths with porous pavement such as Porous Pave	$ 41,600
Stone Dust Paths	19	Replace existing stone dust paths with porous pavement such as Porous Pave	$ 132,000
Stone Dust Paths	21	Replace existing stone dust paths with porous pavement such as Porous Pave	$ 60,000