Memorandum

To : Andrew Brennan, Sr. Director of Energy and the Environment, Department of Environmental Affairs, MBTA

From : M.V. Martello, EIT, Climate Change Resiliency Intern, Department of Environmental Affairs, MBTA

Re : MBTA Bus Facilities

Subject : Climate Change Coastal Flood Vulnerability Summary

Date : September 15th, 2020

Dear Mr. Brennan,

Climate change and subsequent sea level rise (SLR) will increase the coastal flood vulnerability of existing transit assets in Greater Boston, including bus garages and maintenance facilities. 11 bus facilities (9 existing bus garages, 1 maintenance facility, and 1 proposed bus garage/maintenance facility) were identified and ranked based on expected frequency of coastal flooding and impact to the overall bus network performance based on passenger flow data. Two of these facilities, the Lynn Garage and the proposed site of the New Quincy Garage and Maintenance Facility lie within the current FEMA 1-100 year coastal floodplain and are therefore considered to be highly vulnerable. Other facilities which are projected to be vulnerable under higher (+41 in.) SLR scenarios include the Everett Maintenance Facility, Southampton Garage, Albany Street Garage, and Cabot Yard Garage.

As requested, attached please find a report summarizing the current and projected coastal flood vulnerabilities for MBTA bus facilities. This analysis is based on existing FEMA flood maps and data obtained from the Boston Harbor Flood Risk Model (BH-FRM). Please let me know if you have any questions or comments regarding this report.

Thank you,

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martello@mit.edu

CC:

Hannah Lyons-Galante, Climate Change Resiliency Specialist, Department of Environmental Affairs, MBTA
Scott Hamwey, Director of Bus Modernization, Office of Chief Engineer, MBTA
Alexandra Markiewicz, Manager of Bus Modernization, Office of the Chief Engineer, MBTA

Climate Change Coastal Flood Vulnerability Summary

of

MBTA Bus Facilities

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The future flood projections shown within this report derive from the Boston Harbor Flood Risk Model (BH-FRM) (Bosma et al., 2015). The BH-FRM was created for MassDOT in 2015 in order to assess the long-term flood vulnerability of the central artery tunnel (CA/T). Despite being commissioned to focus largely on the Downtown Boston and the South Boston neighborhoods, the extents of the flood model results roughly coincide with the urban core of Greater Boston.

It is important to note that the hazards mapped by this model exclusively reflect anticipated coastal flood risk, meaning precipitation-based or drainage-based flooding is not reflected in this study. The model simulated a suite of 40,000 storms (both tropical and extratropical) under 2013 sea level conditions, as well as for sea level rise (SLR) projections for the years 2030 (+8.2 in. of SLR), and 2070 (+41 in. of SLR). These sea level rise projections reflect the fourth assessment report (AR4) high scenario given in the NOAA Technical Report OAR CPO-1 (Parris et al. 2012). This AR4 high scenario predates but roughly corresponds to the more current relative concentration pathway (RCP) 8.5 scenario, which reflects a "business-as-usual" scenario in which economic growth is projected to increase and there are no substantive attempts to curtail CO2 emissions. Figure 1 below shows the sea level rise values used in the BH-FRM compared to estimates based on RCP scenarios, as well as those being used in the ongoing development of the Massachusetts Coastal Flood Risk Model (MC-FRM; not available at the time of this report).

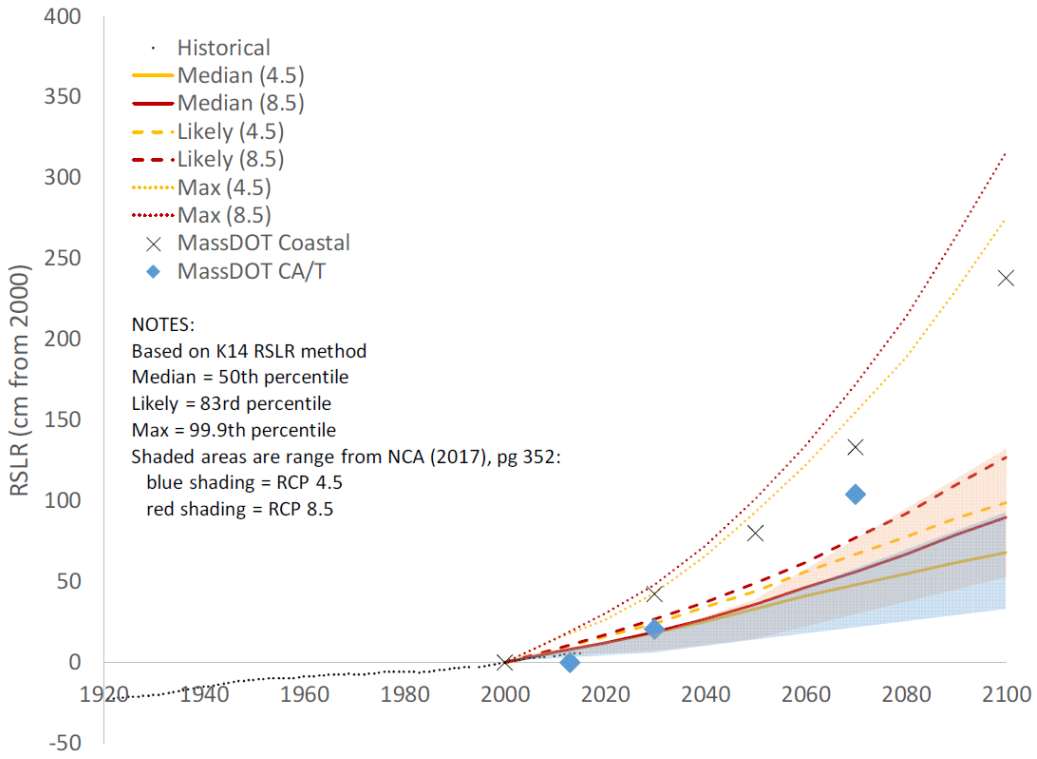

Figure 1: Sea level rise projections used in the BH-FRM compared to RCP projections (Miller, 2019)

When superimposing the BH-FRM flood maps onto MBTA system assets or potential project locations, there are two important caveats to consider. First, unlike FEMA flood maps, which calculate flood risk retrospectively based on prior events, the flood maps produced by the BH-FRM reflect the probabilistic average of simulated flooding events. It is the understanding of the author at the time of writing that because of this distinction, these results cannot legally be used as the basis for project design

requirements. Second, the spatial resolution of the BH-FRM is at best 5 meters (16.4 feet). As a result of this limitation, some flood pathways that would arise in reality are not shown in the BH-FRM, while other areas are shown to flood, that in fact would not likely be flooded. For example, the South Boston Bypass Road is not shown to flood in the BH-FRM, but does based on FEMA flood maps, while the bridge abutment at Wellington Yard along the Orange Line is shown to flood when it does not based on FEMA flood maps, as shown in Figure 2.

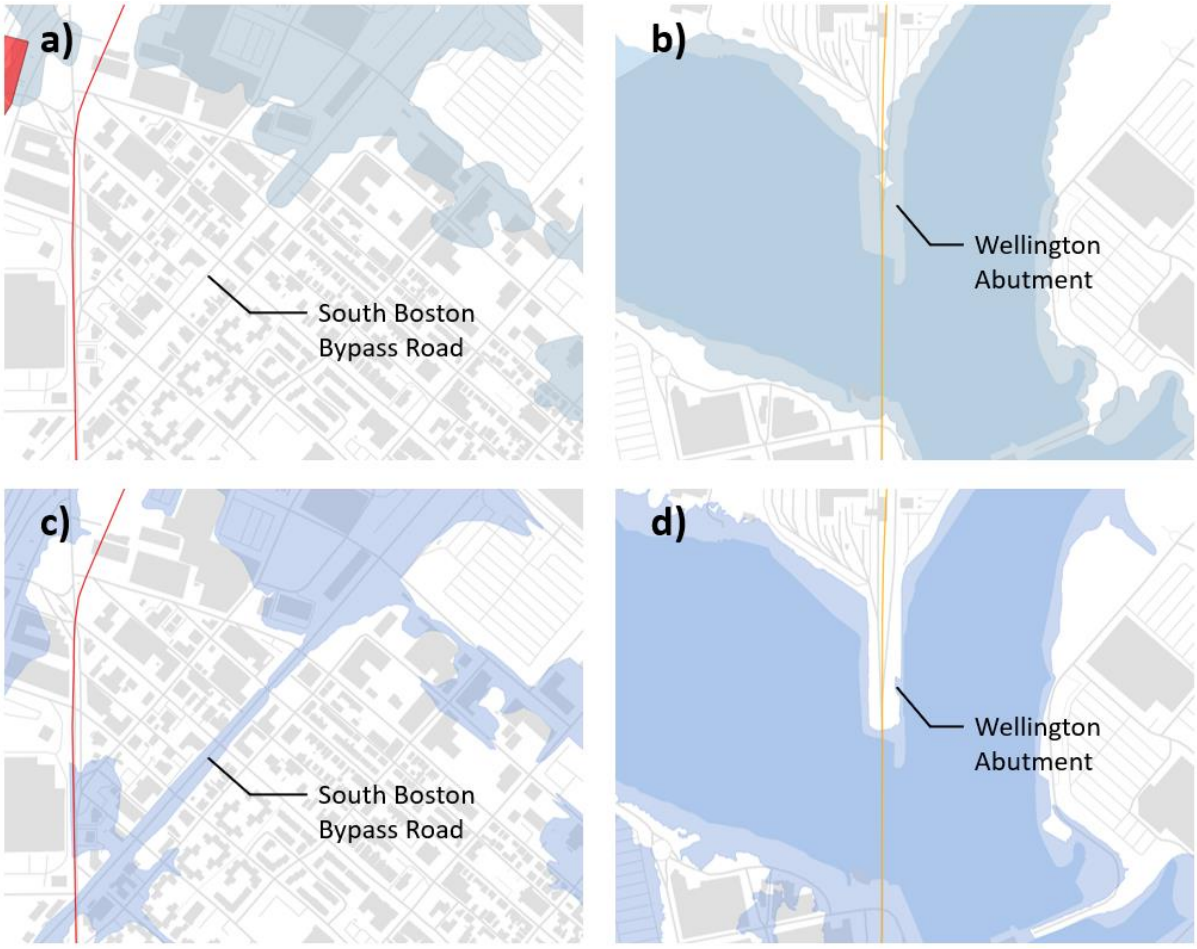

Figure 2: Discrepancies between the BH-FRM 2030 1% CFEP (a, b) and the FEMA 1-500 year floodplain (c, d). A flood path along the South Boston Bypass Road not captured by the BH-FRM (left). An area of inundation along the Orange Line ROW in Wellington shown in the BH-FRM that is not congruent with historic FEMA data (right).

However, despite the inherent limitations of this data, in the absence of alternative risk projections, they still have the potential to provide useful insights for planning purposes and design guidance, particularly when considering capital investment projects whose design lifespan is greater than 10 years. For such projects, it is both sensible and prudent to ensure they will not be exposed to excessive flood risk prior to their projected end of useful life.

MBTA Bus Network and Facilities Overview

The MBTA bus network consists of 170 routes and services approximately one third of trips across all public transit modes in the Greater Boston area, with an average of 392,000 trips recorded during typical weekday service in February 2020 (MBTA, 2020c). Compared to other service modes, the bus network services a larger proportion of low income and minority residents; according to recent MBTA (2020b) data, 41.5% of bus riders are low-income and 48.0% are minority.

Shown in Figure 3, the MBTA bus network is supported by a fleet of 1051 buses housed at 9 facilities across Greater Boston. An additional facility, the Everett Maintenance Facility (Figure 3) does not dispatch or permanently house buses, but is a critical component of the bus network, as it regularly services and repairs buses. Figure 4 shows the relative percentage of the bus fleet located at each facility.

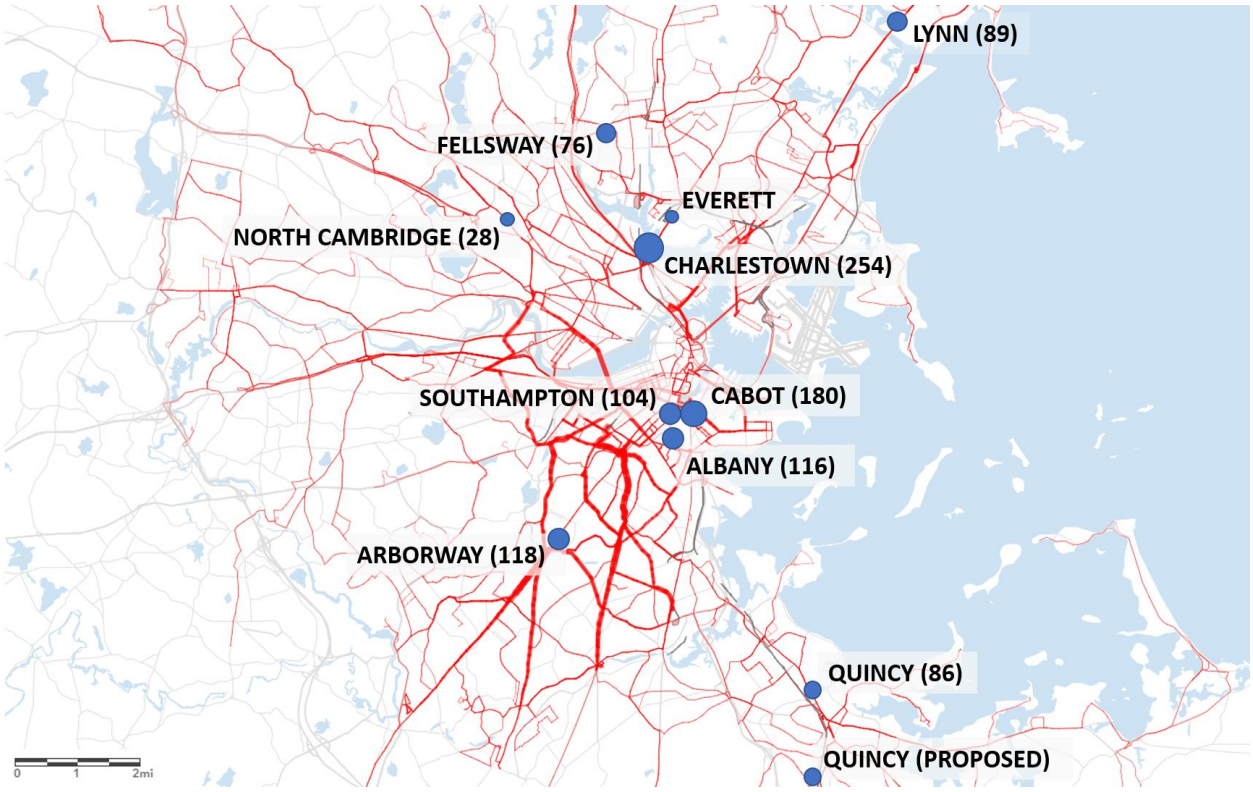

Figure 3: MBTA bus network and facility locations (with the number of buses currently housed at each facility; MBTA, 2020a). Note that the thickness of bus routes corresponds to average daily passenger flows during October 2019 (Caros, 2020).

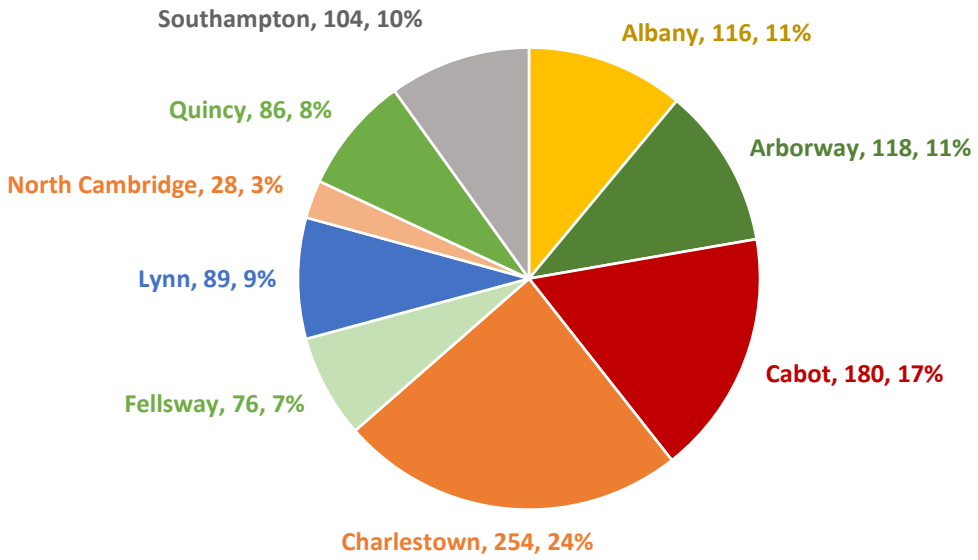

Figure 4: Number of buses and percentage of the bus fleet housed at each facility based on data from the MBTA (2020a).

The percentage of the bus fleet located at each garage can serve as a proxy for the relative importance of each facility to bus network operations. However, the relative importance of each facility can also be characterized on the basis of passenger flows. Knowing the typical dispatch location for each bus route (Zimmer, 2020) and the average number of weekday passengers for each segment of all bus routes (Caros, 2020), a relative importance based on passenger flows was determined, shown in Figure 5. This relative importance captures both ridership and length of passenger trips (i.e., number of stops travelled) for each bus route, rather than simply ridership alone. It should be noted that the passenger flows for the Silver Line were estimated based on ridership data from February 2020 (MBTA, 2020c).

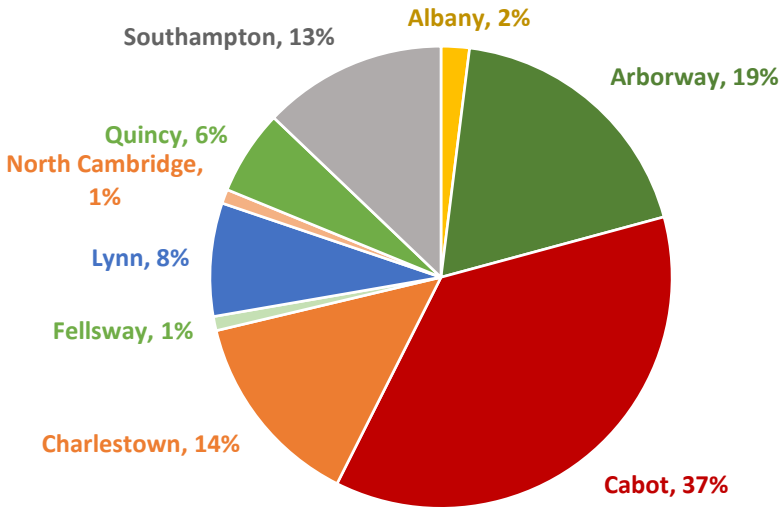

Figure 5: Percentage of passenger flows reliant upon buses dispatched from each facility based on the data from Caros (2020) and Zimmer (2020).

High Vulnerability Locations

The following facilities are currently within the FEMA 1-500 year floodplain and may be inadequately protected from flooding under current conditions. For each of these locations, further study using the anticipated MC-FRM data and a more detailed vulnerability assessment are recommended. These locations have been ranked by severity of flooding and relative importance based on passenger flow:

Figure 6: Lynn Garage

Figure 7: Proposed Quincy Garage

Lynn Garage

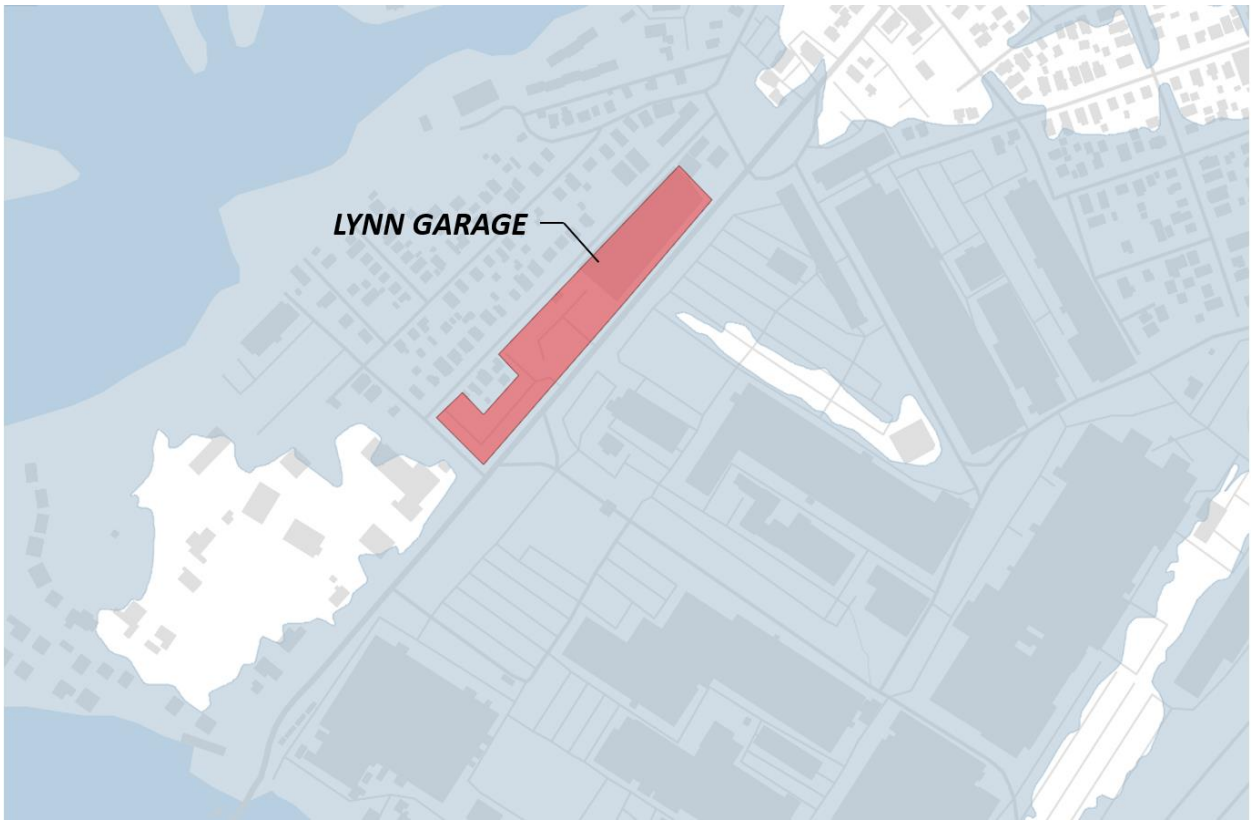

Figure 6: Lynn Garage and extent of FEMA 1-500 year flood map. Note that the bus garage lies within the 1-100 year floodplain

The entirety of the Lynn Garage lies within the current 1-100 year floodplain, as designated by FEMA and shown in Figure 6. The garage lies within an AE flood zone, and therefore could expect up to 3 feet of coastal flooding (Hatheway, 2005). The Lynn Bus Garage houses 89 buses (9% of the MBTA's total bus fleet) and its service area represents 8% of the bus network based on passenger flow data.

Proposed Quincy Garage and Maintenance Facility

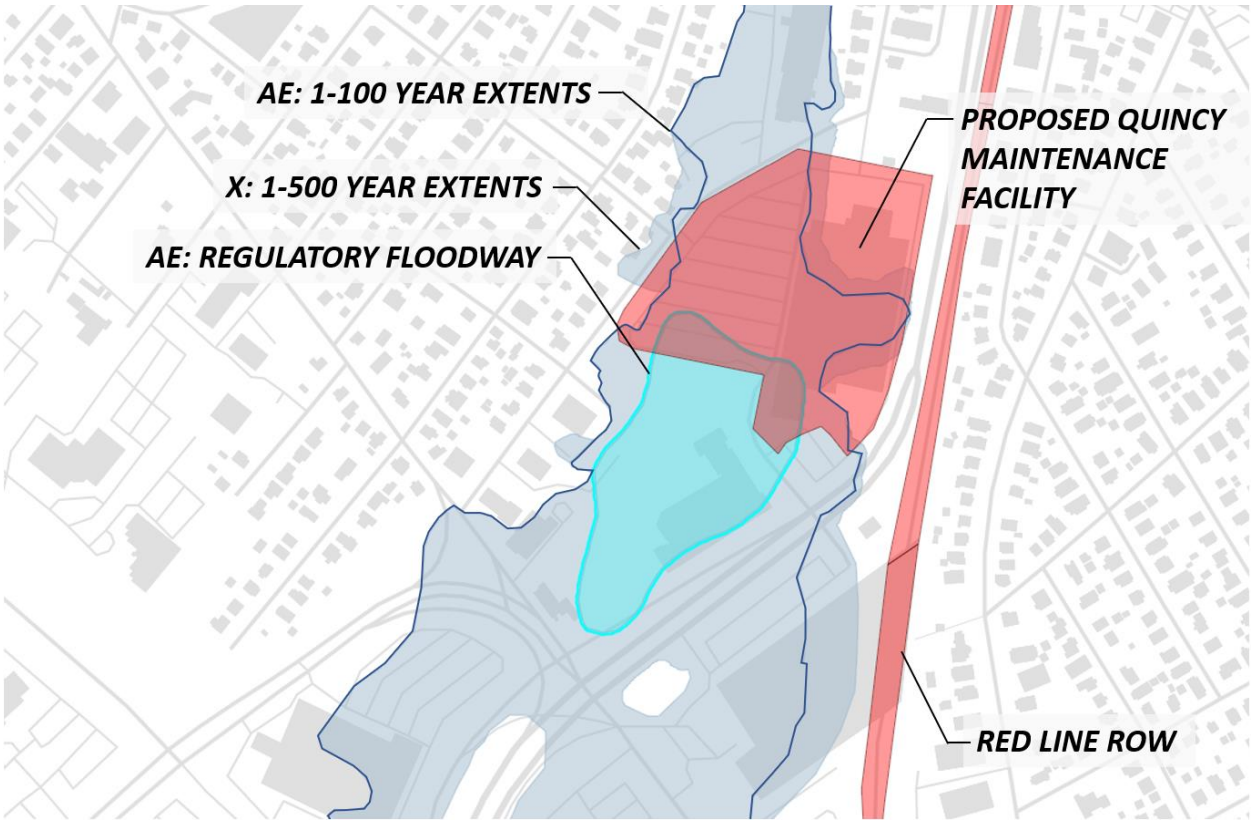

Figure 7: Proposed Quincy Maintenance Facility and the current FEMA flood map. A large portion of the proposed facility lies within the current 1-100 year flood plain; a portion of the proposed facility also lies within a current regulatory floodway.

Also vulnerable according to current FEMA flood maps is the proposed site for the New Quincy Garage and Maintenance Facility. Shown in Figure 7, the site lies within the 1-100 year and 1-500 year flood plain extents. Similar to the Lynn Garage, the site is located in an AE flood zone, and therefore could experience up to 3 feet of coastal flooding (Hatheway, 2005), with an additional portion of the site within a FEMA designated floodway. However, Tetra Tech Rizzo (2007) notes that the FEMA flood maps at this location do not reflect floodway improvements to Town Brook implemented by DCR since 1980. Further analysis conducted by Tetra Tech Rizzo (2007) determined that these improvements resulted in a 4.2 foot reduction in 1-100 year flood elevation at this site, reducing projected flood extents to only a small portion of the parking lot. However, conditions have changed since this assessment, as additional portions of Town Brook were culverted north of the site and the Tetra Tech Rizzo (2007) study may not reflect current flood exposure.

This site will replace the current Quincy Garage, which houses 86 buses (8% of the MBTA's total bus fleet) and services 6% of the bus network based on passenger flow data. Additionally, this is the first MBTA facility designed to support and house an electric bus fleet as the MBTA moves towards its bus facilities modernization goals (MBTA; 2020b). Flooding of this facility may also damage electric charging infrastructure, which could greatly increase the costs and service impacts associated with flooding.

Long-Term Vulnerable Locations

The following facilities lie within the projected 1-100 year floodplain, based on the BH-FRM 2070 projections, with 41 inches of SLR. Locations within this section are anticipated to be exposed to significant coastal flood risk in 50 years. For each of these locations, it may be sensible to include climate resilience improvements as part of any current or future facility capital improvement projects. These locations have been ranked by severity of flooding and relative importance based on passenger flow:

Figure 8, Figure 9, Figure 10: Everett Maintenance Facility

Figure 11: Southampton Garage

Figure 12: Albany Street Garage

Figure 13: Cabot Yard Garage

Figure 14: Charlestown Garage

Everett Maintenance Facility

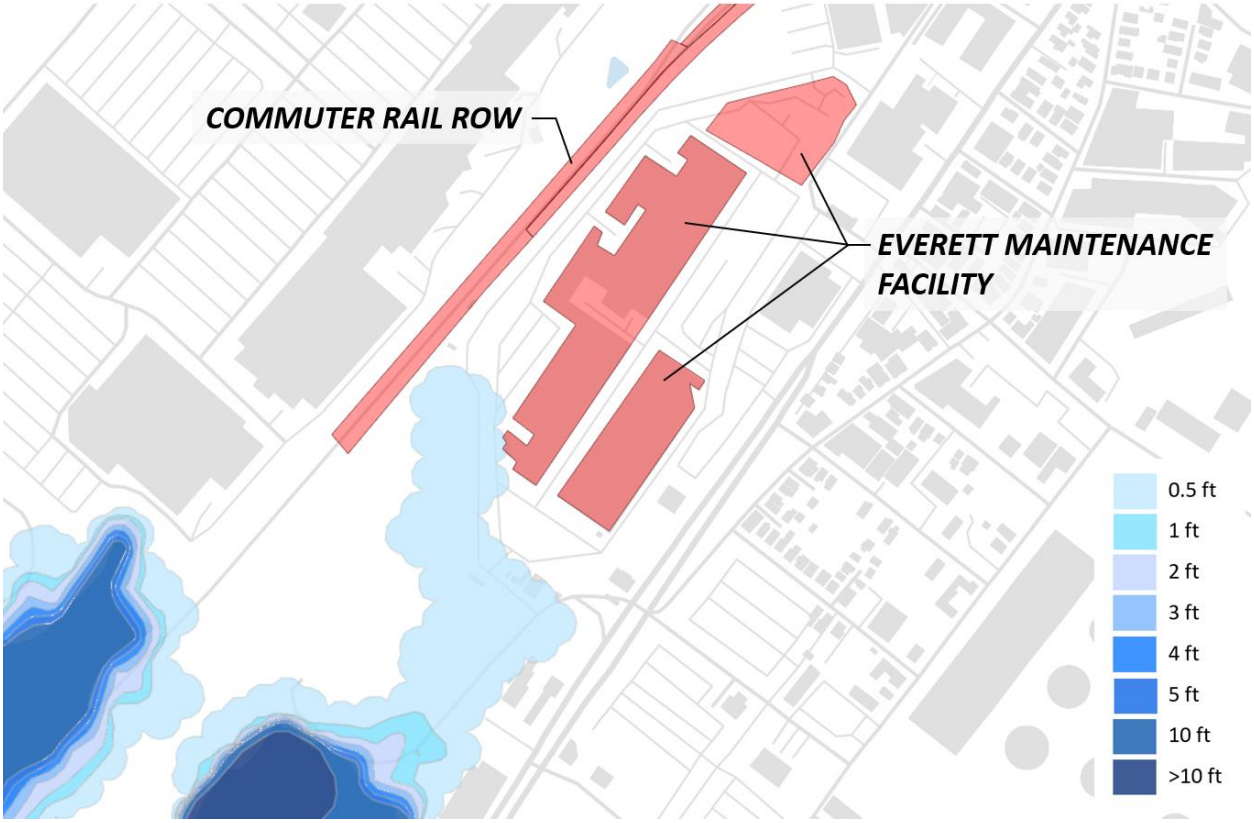

Figure 8: Everett Maintenance Facility exposure to projected 1-100 year flood event with +8.2 in. of SLR (projected 2030; Bosma et al., 2015). Note that the shades of blue reflect the depth of projected flooding

A small portion of the Everett Maintenance Facility is projected to be exposed to coastal flooding (to a depth of 0.5 ft) under the 1-100 year coastal flood event with +8.2 in. of SLR (projected 2030) shown in Figure 8. The flood extents shown would likely result in little to no damage at the facility. However, under the 1-100 year coastal flood event with +41 in. of SLR, the majority of the Everett Maintenance Facility is projected to be exposed to coastal flooding (projected 2070). A maximum flood depth of 4 feet is projected under this scenario, as shown in Figure 9. Further analysis by the Woods Hole Group released as part of a study by the City of Chelsea et al. (2019) shows this location floods also from the northeast via the Newburyport/Rockport Line, shown in Figure 10. While the Everett Maintenance Facility does not permanently house buses and therefore is not the origin of any routes (or passenger flows) its operation is critical to regular bus service.

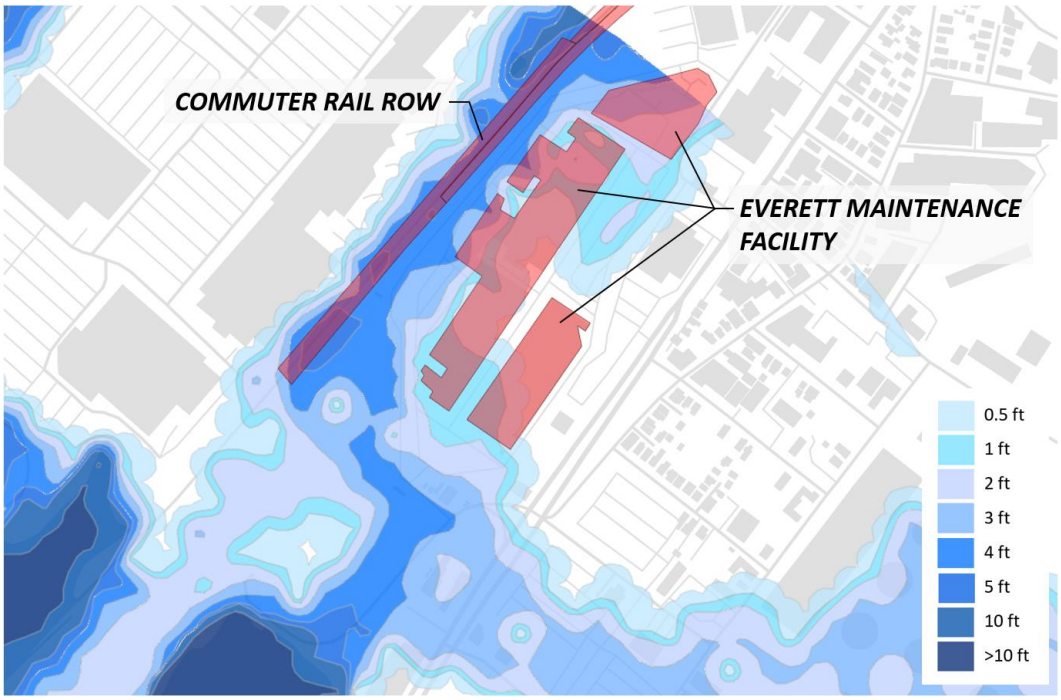

Figure 9: Everett Maintenance Facility exposure to projected 1-100 year flood event with +41 in. of SLR (projected 2070; Bosma et al., 2015). Note that the shades of blue reflect the depth of projected flooding

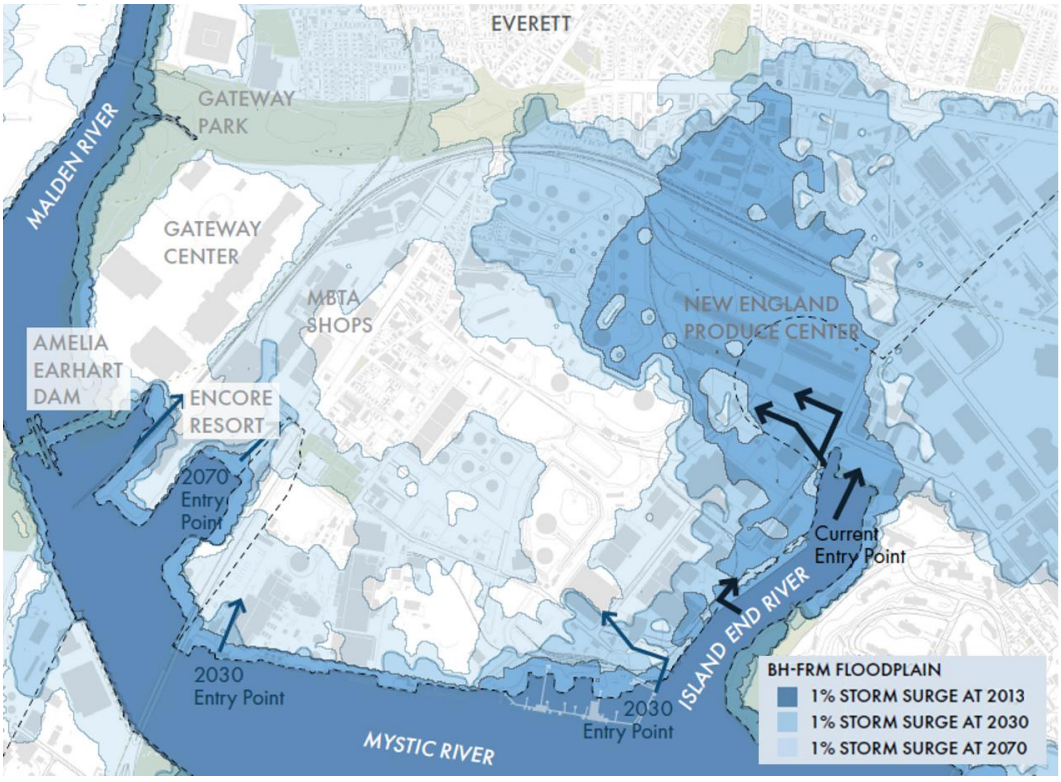

Figure 10: Summary of 1-100 year (1%) storm surge inundation extents in proximity of Island End River under +0in SLR (2013), +8.2in SLR (2030), +41in SLR (2070). Note that the Everett Maintenance Facility is labeled "MBTA Shops" (City of Chelsea et al., 2019)

Southampton Garage

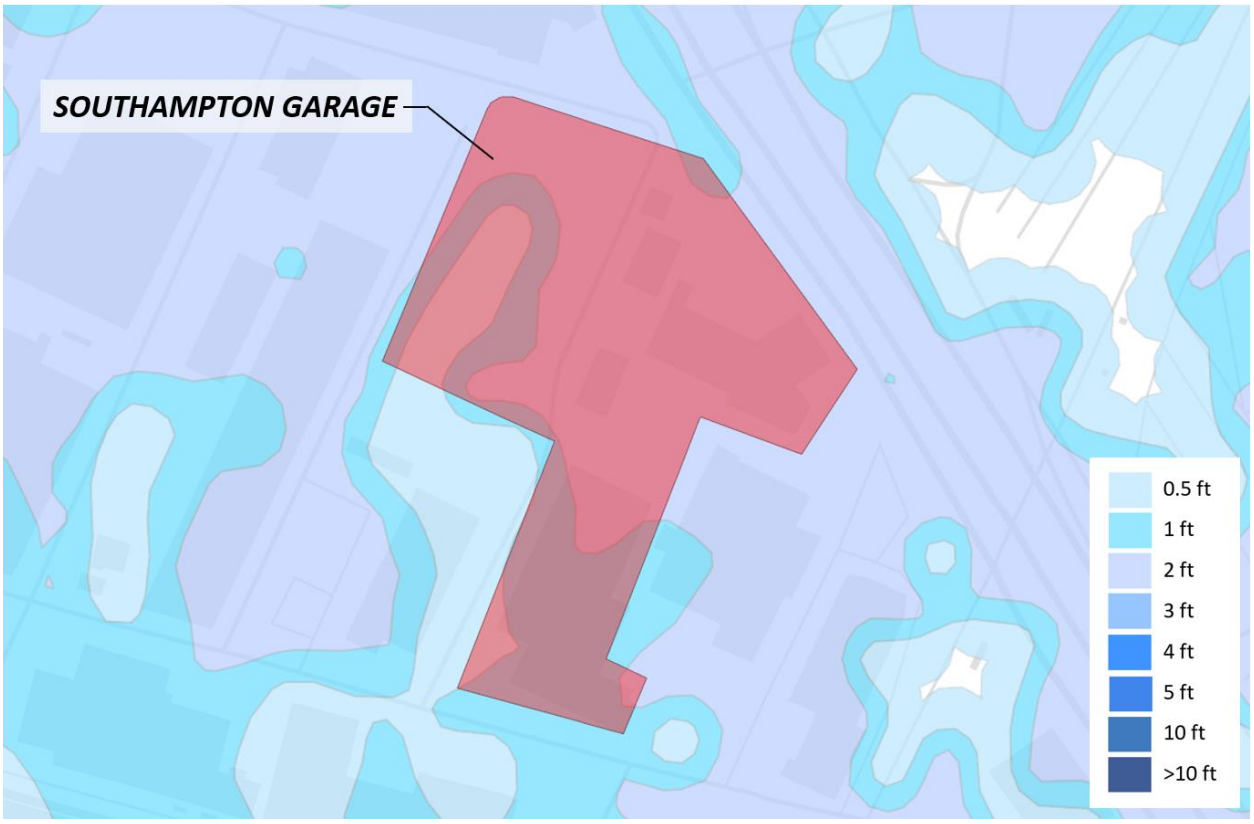

Figure 11: Southampton Garage exposure to projected 1-100 year flood event with +41 in. of SLR (projected 2070; Bosma et al., 2015). Note that the shades of blue reflect the depth of projected flooding

Southampton Garage is projected to be exposed to coastal flooding under the 1-100 year coastal flood event with +41 in. of SLR (projected 2070). Shown in Figure 11, a maximum flood depth of 2 feet is projected across the majority of the facility under this scenario. The Southampton Garage houses 104 buses (10% of the MBTA's total bus fleet) and its service area represents 13% of the bus network (including the Silver Line) based on passenger flow data.

Albany Street Garage

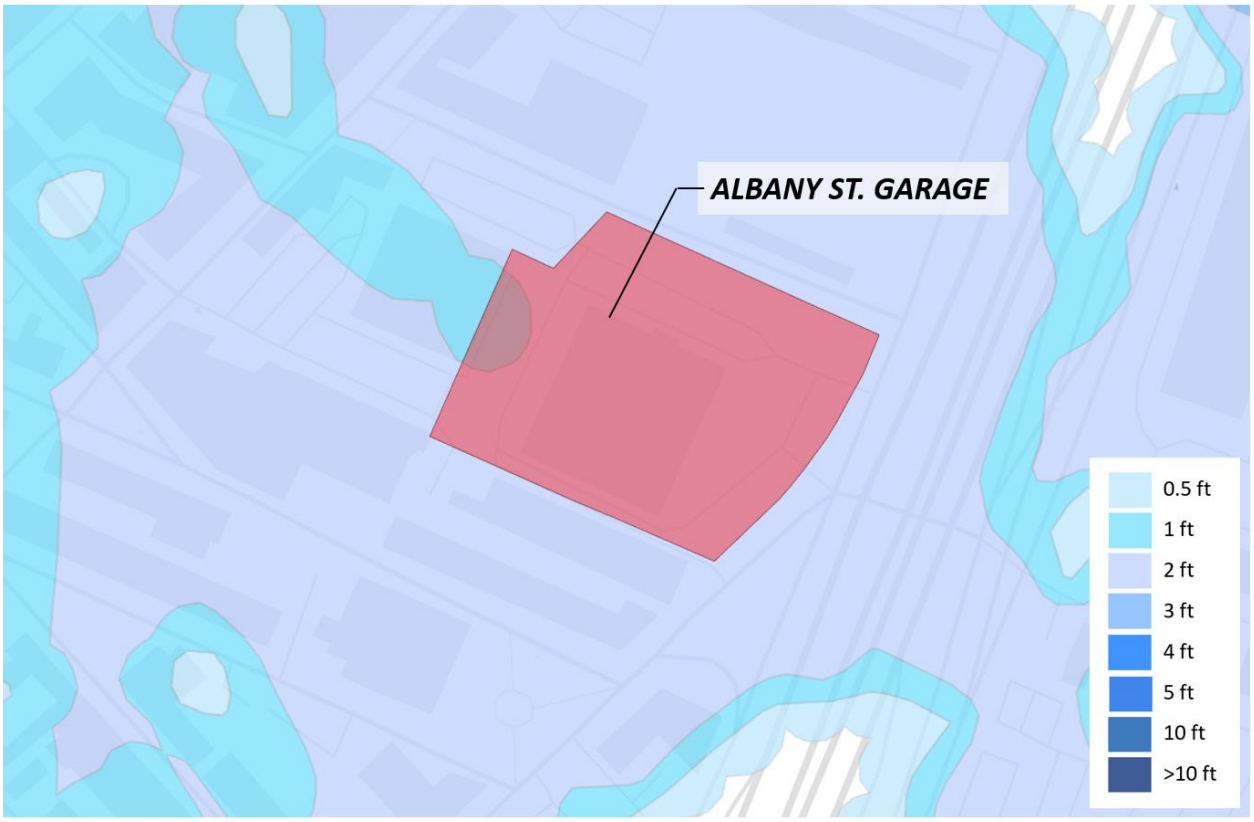

Figure 12: Albany Street Garage exposure to projected 1-100 year flood event with +41 in. of SLR (projected 2070; Bosma et al., 2015). Note that the shades of blue reflect the depth of projected flooding

Albany Street Garage is projected to be exposed to coastal flooding under the 1-100 year coastal flood event with +41 in. of SLR (projected 2070). Shown in Figure 12, a maximum flood depth of 2 feet is projected across nearly the entire facility under this scenario. The Albany Street Garage houses 116 buses (11% of the MBTA's total bus fleet) though its service area only represents 2% of the bus network based on passenger flow data.

Cabot Yard Garage

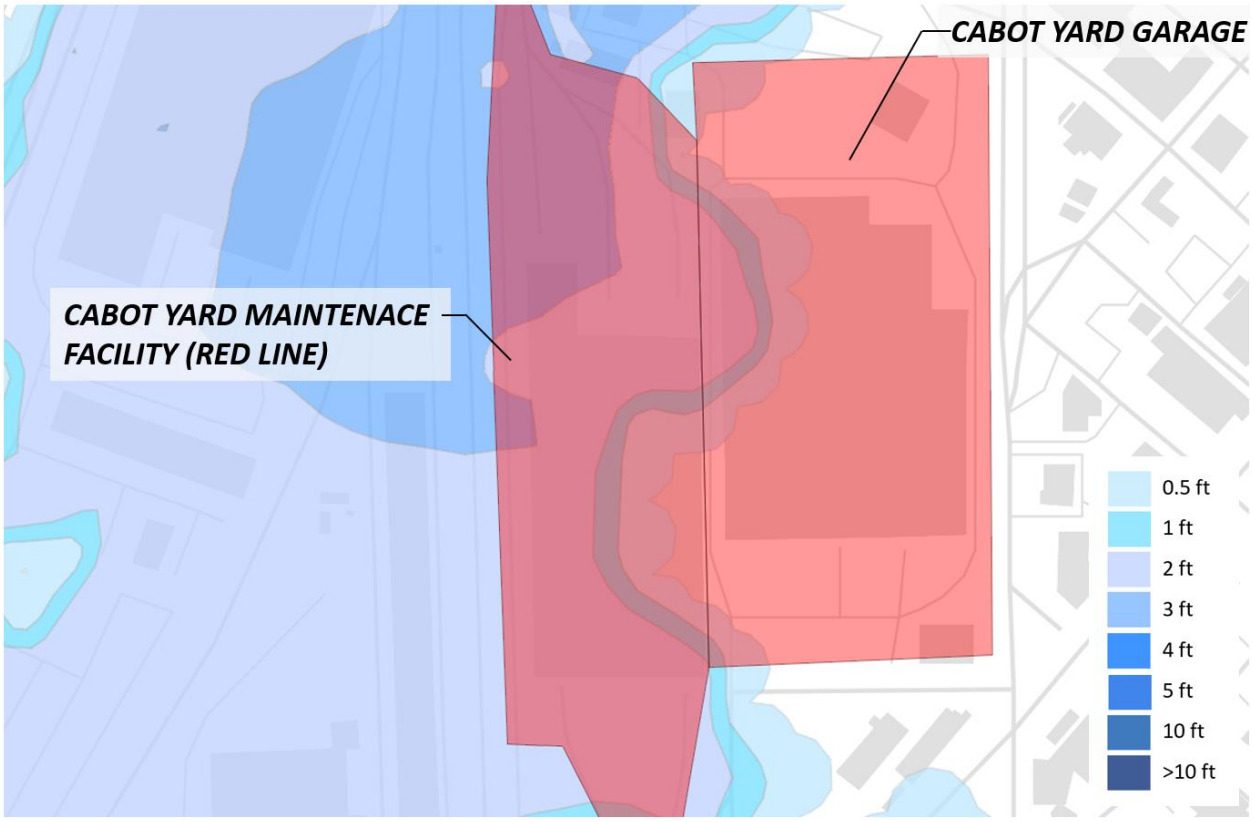

Figure 13: Cabot Yard Garage exposure to projected 1-100 year flood event with +41 in. of SLR (projected 2070; Bosma et al., 2015). Note that the shades of blue reflect the depth of projected flooding

Cabot Yard Garage is projected to be minimally exposed to coastal flooding under the 1-100 year coastal flood event with +41 in. of SLR (projected 2070). Shown in Figure 13, a maximum flood depth of 2 feet is projected across only a small portion of the facility under this scenario, with much more severe flooding expected for the adjacent Red Line facility. The Cabot Yard Garage houses 180 buses (17% of the MBTA's total bus fleet) and its service area represents an even greater 37% of the bus network based on passenger flow data. Since the projected flood pathways affecting this facility arise from the Fort Point Channel and flow through the rail yard northwest, coastal resilience improvements at this facility should be coordinated with the adjacent Red Line facility.

Charlestown Garage

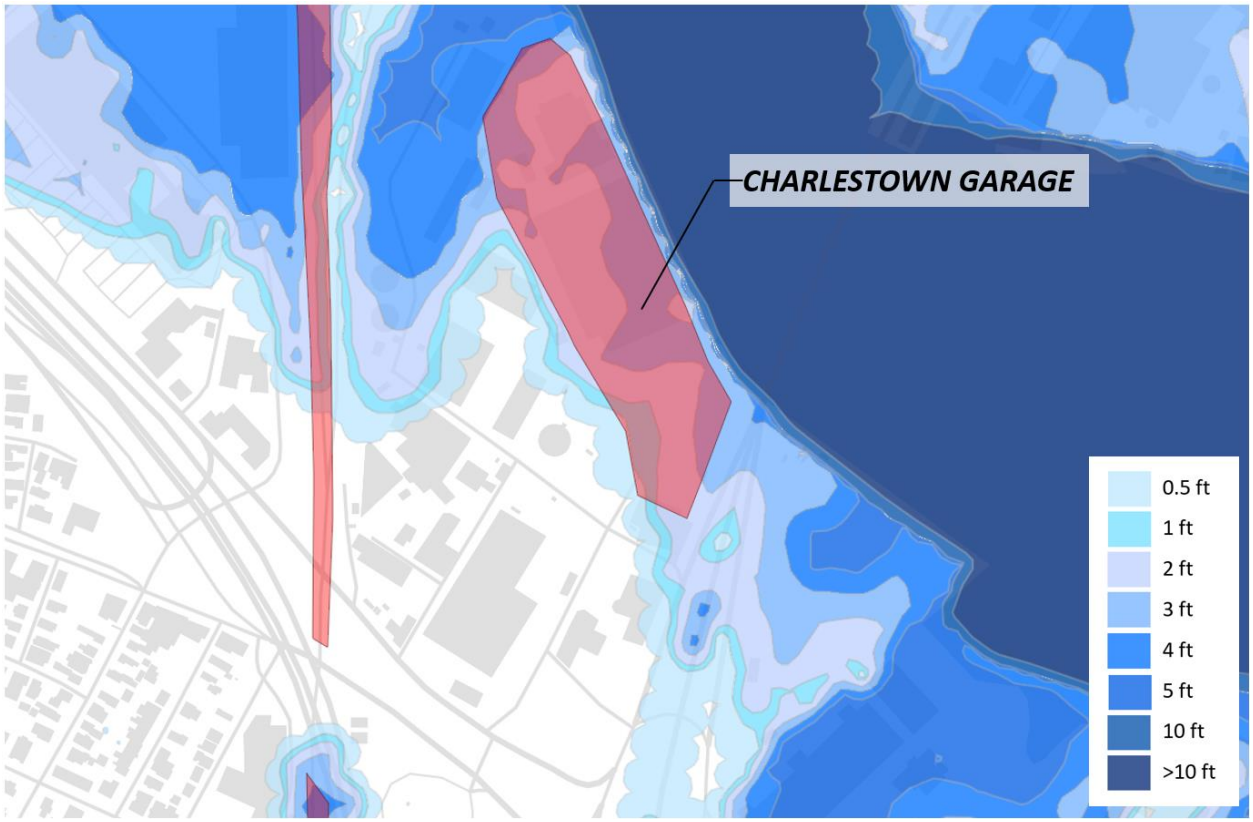

Figure 14: Charlestown Garage exposure to projected 1-100 year flood event with +41 in. of SLR (projected 2070; Bosma et al., 2015). Note that the shades of blue reflect the depth of projected flooding

Under the available BH-FRM results, the Charlestown Garage is projected to be exposed to coastal flooding under the 1-100 year coastal flood event with +41 in. of SLR (projected 2070). Shown in Figure 14, a maximum flood depth of 3 feet is projected across a large portion of the facility under this scenario, with more severe flooding expected for adjacent facilities. **However, these flood projections do not reflect the recently upgraded seawall along the garage's boundary with the Mystic River. As a result of these improvements, projected flooding under the aforementioned SLR condition is expected to be minimal (Bosma, 2020; Figure 15).** The Charlestown Garage is the MBTA's largest bus facility and houses 254 buses (24% of the MBTA's total bus fleet) and its service area represents 14% of the bus network based on passenger flow data. Because of the recent improvements to the seawall, no further coastal resilience actions are likely required at this time.

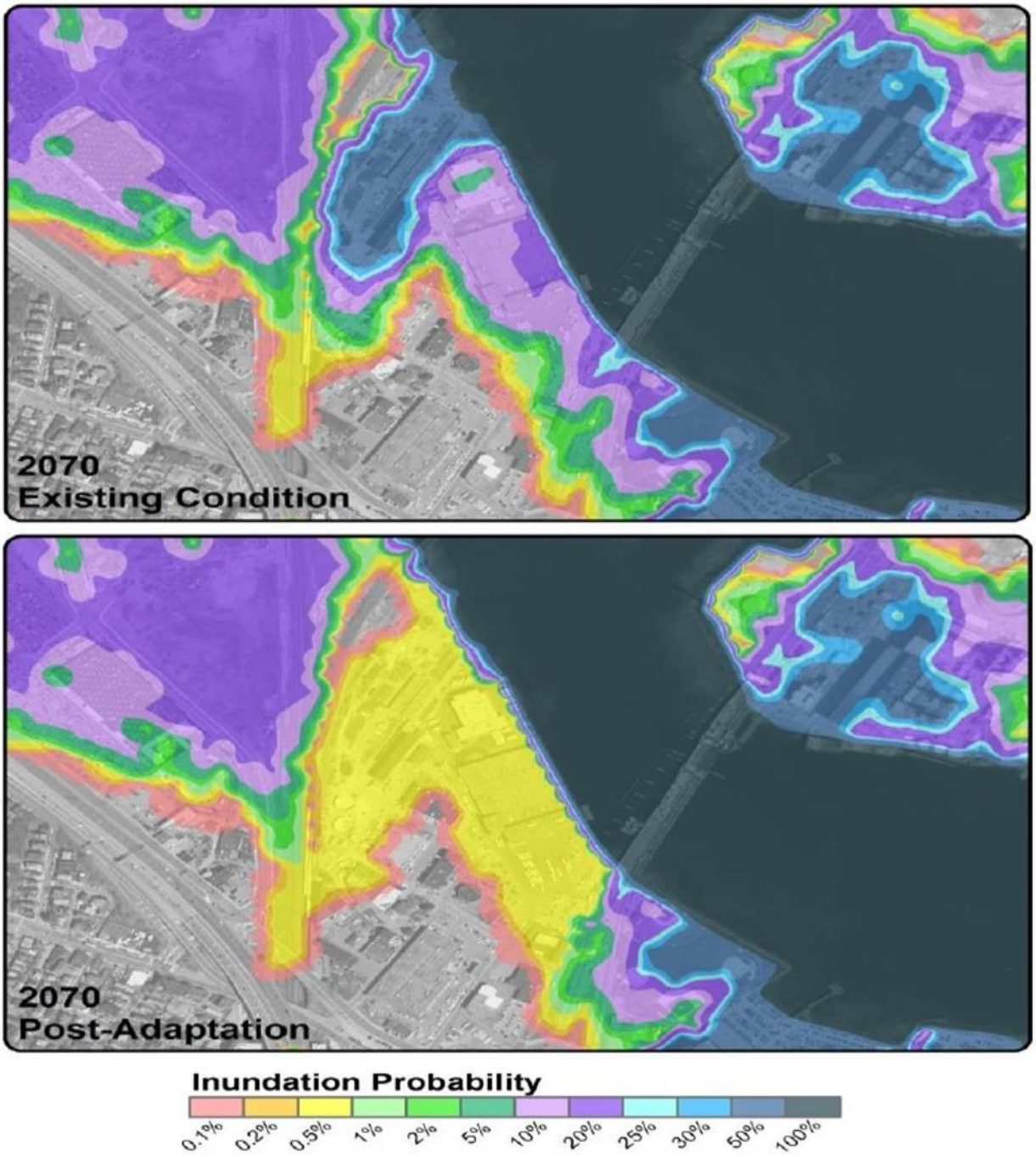

Figure 15: Changes in inundation probability under +41in SLR (2070) regime resulting from recent improvements in the Charlestown Bus Garage seawall (Bosma et al., 2020)

Unexposed Locations

The following facilities have not been found to lie within any BH-FRM projected 1-100 year floodplain, or the current FEMA 1-500 year floodplain. Locations within this section are not anticipated to be exposed to significant coastal (or precipitation-based) flood risk in the foreseeable future given currently available information. No climate resilience improvements are currently recommended for these locations, though further study investigating other climate change effects, such as changes in extreme precipitation, extreme heat, and projected changes in design win loads may be prudent to pursue in future. These locations have been ranked by potential for flooding and relative importance based on passenger flow:

Figure 16: Quincy Garage

Figure 17: Arborway Garage[1]

Figure 19: North Cambridge Carhouse

Figure 20: Fellsway Garage

[1] Note that while Arborway Garage is not currently vulnerable according to FEMA flood maps, the site lies in the original stream bed for Stony Brook (Wightman, 1863) which has since been culverted.

Quincy Garage

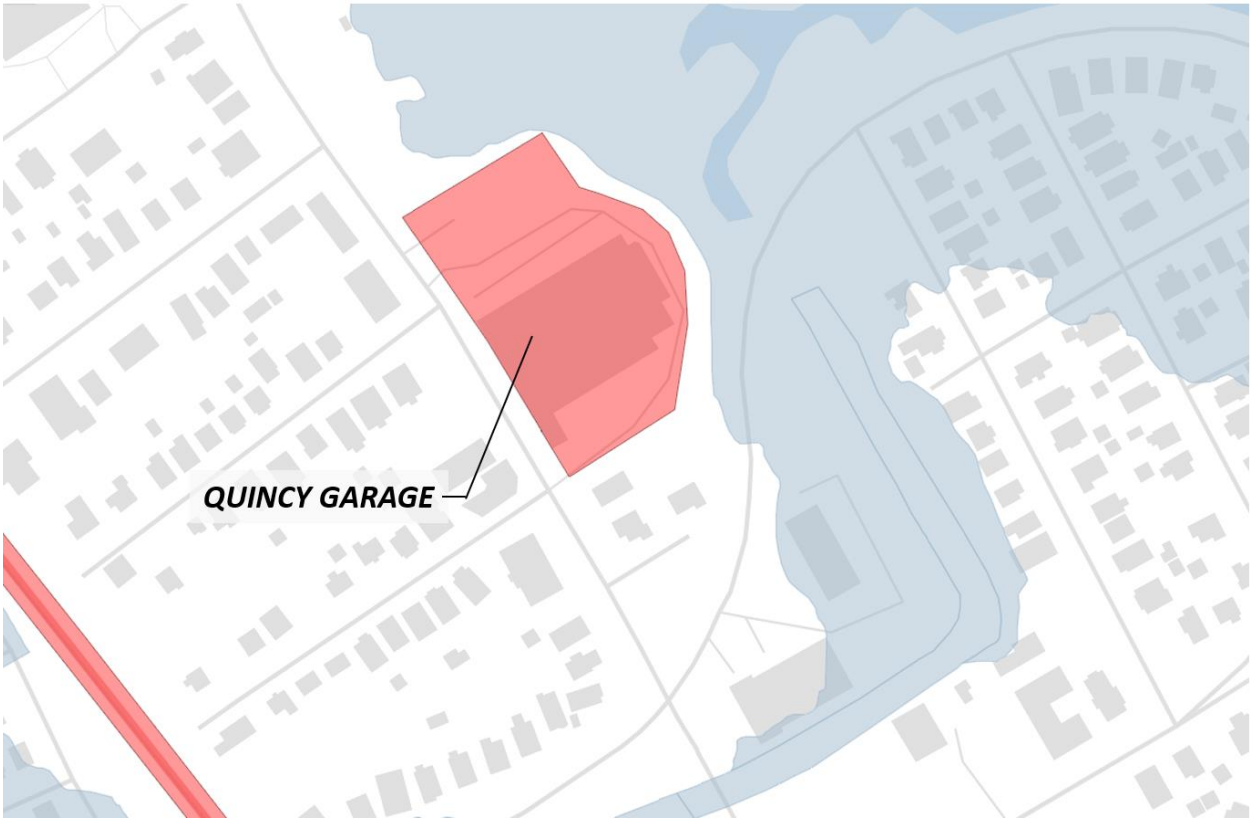

Figure 16: *Quincy Garage and the current FEMA 1-100 year floodplain. Note the close proximity of the floodplain to the boundaries of the facility.*

The Quincy Garage lies outside the current 1-100 year floodplain, as designated by FEMA and shown in Figure 16. Based on this flood map, the facility is minimally exposed to coastal flooding, though it is likely that under future SLR projections the site would be vulnerable. While this facility is expected to be replaced in the near-term with the proposed facility shown previously (Figure 7), should the MBTA retain this facility, further investigation of this site using MC-FRM is recommended. The Quincy Bus Garage houses 86 buses (8% of the MBTA's total bus fleet) and services 6% of the bus network based on passenger flow data.

Arborway Garage

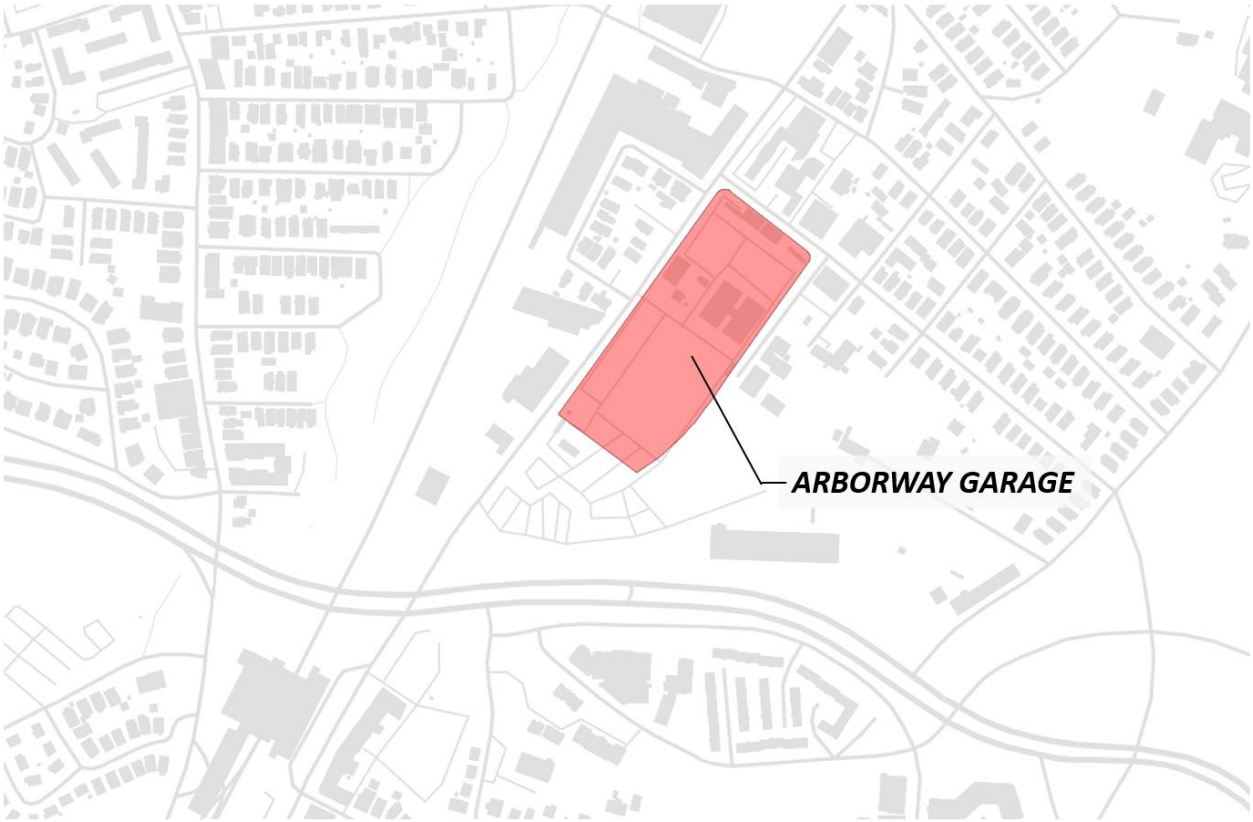

Figure 17: Location of the Arborway Garage. Note that current FEMA flood maps do not indicate any significant flood risks at this location.

The Arborway Garage lies outside the current FEMA 1-500 year floodplain, shown in Figure 17. Based on available information, the facility is minimally exposed to coastal or precipitation-based flooding. However, the location is roughly coincident with the original stream bed of Stony Brook (Wightman, 1863) and lies adjacent to the existing Stony Brook culvert (Weiskel et al., 2005) shown in Figure 18. The proximity to the culverted Stony Brook and historic streambed may be indicative of some degree of flood risk, however further study would be required to fully understand the flood risk at this location. The Arborway Garage houses 118 buses (11% of the MBTA's total bus fleet) and services 19% of the bus network based on passenger flow data.

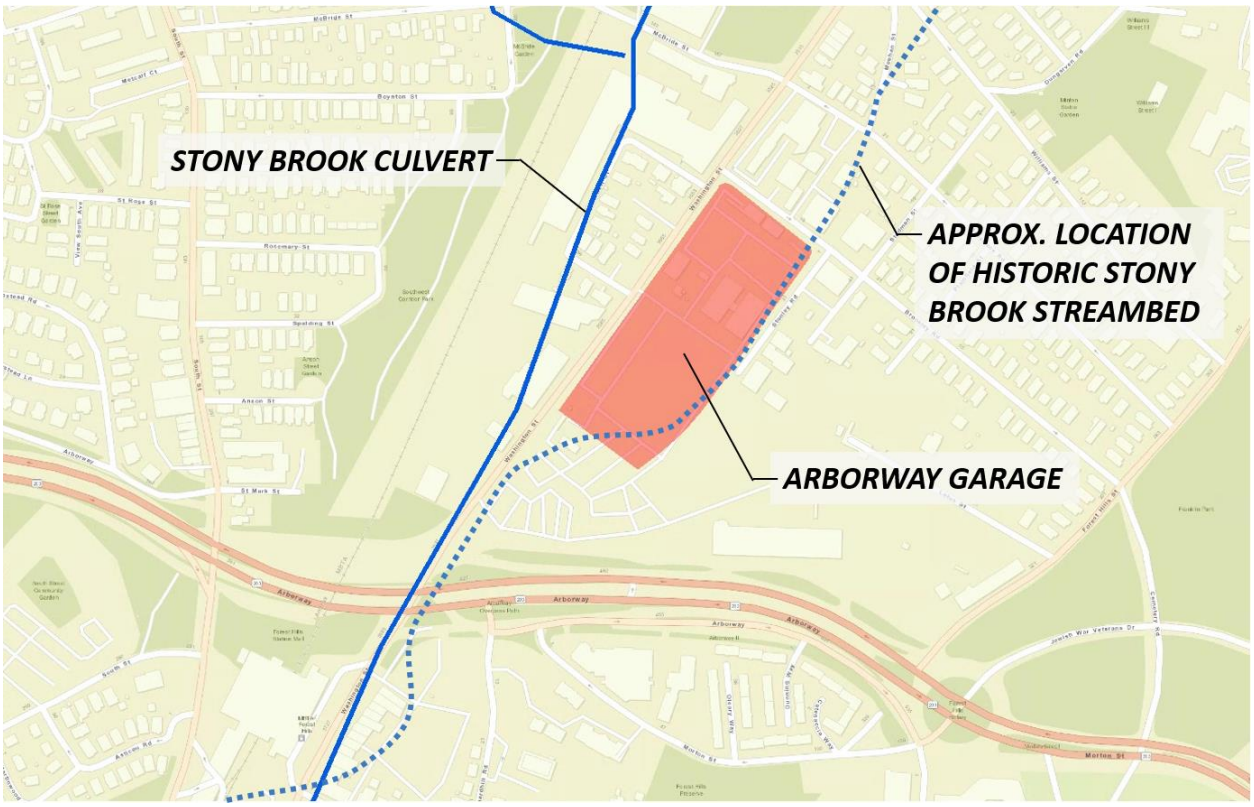

Figure 18: The Stony Brook culvert and approximate location of its historic streambed in the proximity of the Arborway Garage (after Weiskel et al. 2005; Wightman, 1863).

North Cambridge Carhouse

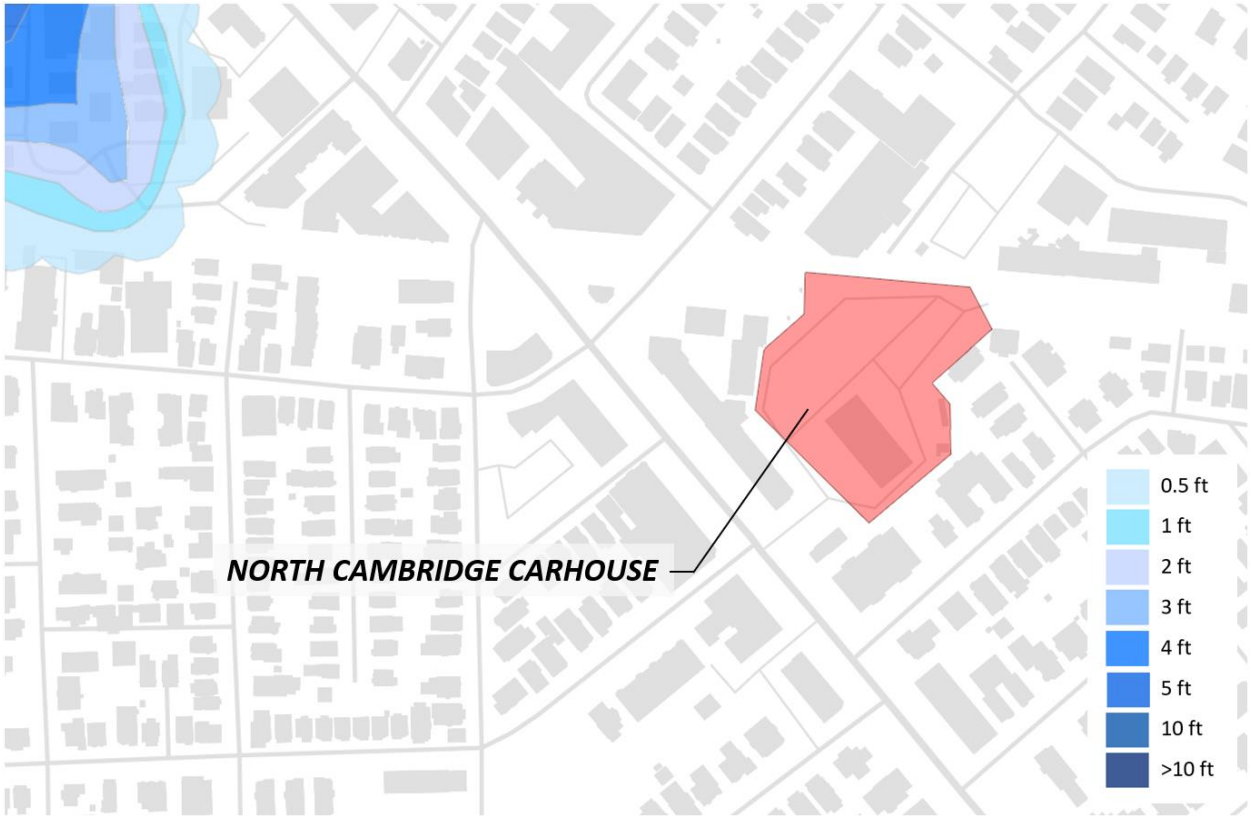

Figure 19 : Location of the North Cambridge Carhouse. Note that projected 1-100 year coastal flood under +41 in. SLR (projected 2070; Bosma et al., 2015) does not reach the facility

The North Cambridge Carhouse lies outside the projected 1-100 year coastal floodplain under +41 in. of SLR (projected 2070; Bosma et al., 2015) as shown in Figure 19. Based on available information, the facility is minimally exposed to coastal or precipitation-based flooding, though further investigation of this site using MC-FRM is recommended. The North Cambridge Carhouse stores 28 buses (3% of the MBTA's total bus fleet) and services 1% of the bus network based on passenger flow data.

Fellsway Garage

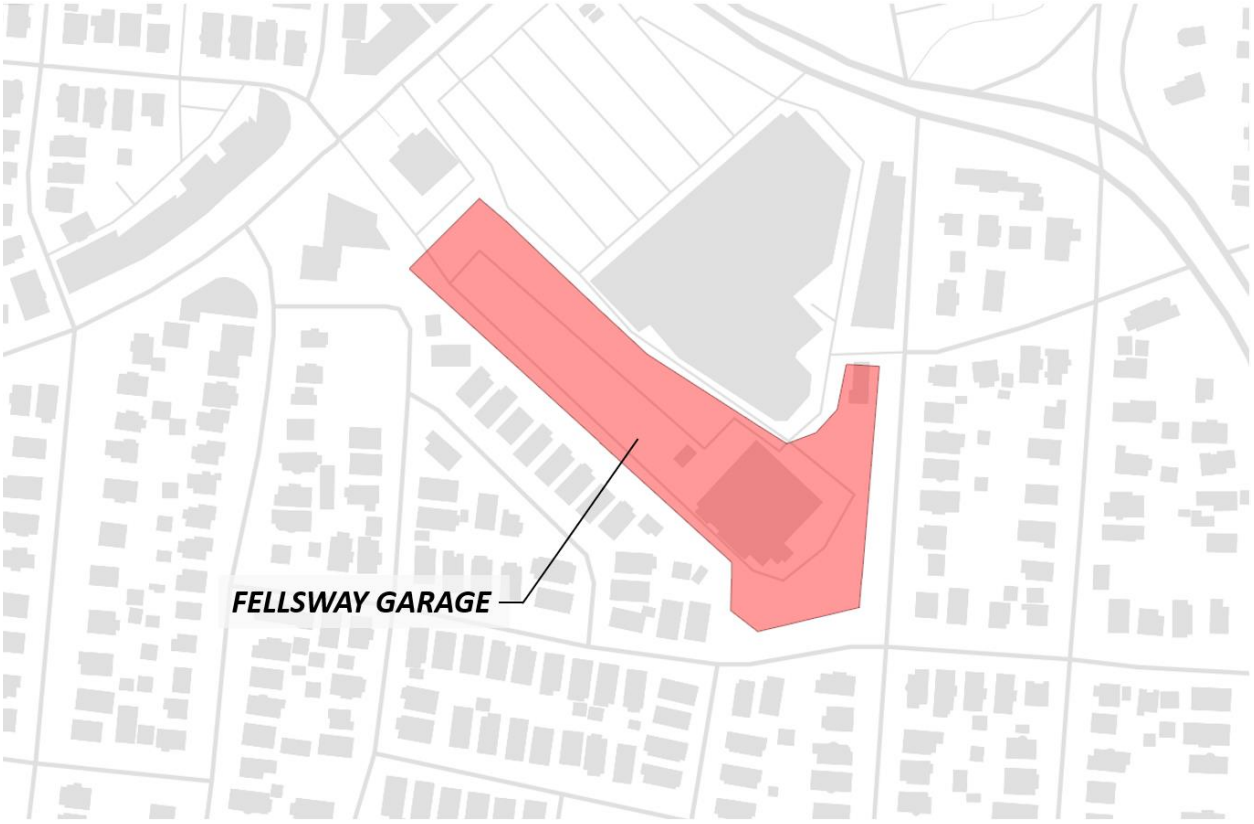

Figure 20: Location of the Fellsway Garage. Note that current FEMA flood maps do not indicate any significant flood risks at this location.

The Fellsway Garage lies outside the current FEMA 1-500 year floodplain, as shown in Figure 20. Based on available information, the facility is minimally exposed to coastal or precipitation-based flooding. However, limited coastal flood projection information (Mystic River Watershed Association, n.d.) indicates that this location may be exposed under expected 2070 conditions. Further investigation into this location with MC-FRM data when available is recommended. The Fellsway Garage houses 76 buses (7% of the MBTA's total bus fleet) and services 1% of the bus network based on passenger flow data.

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