

**Sea Level Rise/
Storm Surge
Flooding
Regional
Analysis
Technical
Report**

RESILIENT CAMBRIDGE

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Executive Summary

This study investigates the socio-economic implications of a coastal flooding event caused by sea level rise/storm surge (2070 SLR/SS 1% coastal flood event) in the Mystic River, Charles River, and North Coastal (i.e., Saugus and Revere) watersheds. This study estimates the potential social and economic benefits associated with implementing a portfolio of ten regional coastal flood interventions (the Regional SLR/SS Interventions), including estimates of protected real estate value, protected populations and socially vulnerable groups, and lessening potential impacts to regional economic “engines” and commercial/industrial/institutional economic hubs.

The technical analyses performed in this study find that over 7,550 acres of land are protected by these interventions, comparable to over 1.5 times the land area of the City of Cambridge. Across the 15 municipalities shown to benefit from these interventions, this protection extends to over 11,750 individual properties. While the actual cost of damages at the building scale was not assessed as part of these analyses, the portfolio of ten interventions analyzed mitigate flooding for over \$60 billion of exposed real estate value, according to recent municipalities’ assessors’ data. This region-wide total, representing total assessed building and land values, includes over \$58 billion within the Mystic River and Charles River watersheds. Another \$1+ billion of real estate value in flood exposed areas is mitigated in the North Coastal watershed (i.e., properties protected by eliminating Saugus-Malden-Revere coastal flood pathways).

For residential populations, it is estimated that the ten coastal flood interventions collectively protect over 108,000 people across 12 municipalities¹. These 108,000 people account for approximately 9% of the total population living in these 12 communities and more than the combined total population of Arlington and Medford. A demographic breakdown applied spatially at the census block scale indicates that areas protected by the interventions include many socially vulnerable populations, proportionally. Approximately 40% of the 108,000 people identify as minority, 33% are without vehicle access, 17% are low-income, 10% are elderly/age 65+, with 9% experiencing English language isolation (note: percentage values are not additive).

While a detailed study of *economic impacts avoided* as a result of the ten interventions (e.g., mobility, business, supply chain disruption, sector-by-sector impact, other indirect and long-term impacts on business and real estate) was beyond the scope of this analysis, a high-level overview of potential avoidance of impacts to key economic “engines” and regional hubs is provided. This analysis found that absent these interventions flooding from a 1% coastal SLR/SS event in 2070 would significantly impact key commercial hub areas (e.g., Kendall Square, Alewife Triangle/Quadrangle, Assembly Row, Kenmore Square/Fenway, Copley Square, Malden Center), as well as key institutional areas (e.g., Harvard University, MIT, Boston University, Longwood Medical Area, Mass General Hospital), knowledge economy, and research and development engines (e.g., core biotech, life sciences, finance hubs). Impacts would also be significant to low-lying critical infrastructure (e.g., Lower Mystic Generating Station, Vicinity Energy/Kendall Station) large fuel storage tanks, and other energy and utility infrastructure), at least ten MBTA public transit stations (e.g., Green, Orange, Red, and Silver subway and commuter rail lines), key local/state roadway mobility routes, a lengthy list of significant

¹ 12 municipalities of the 15 contain protected residents because the protected areas in Newton, Saugus, and Winchester are non-residential uses.

historic/cultural assets and drivers of regional tourism and recreational activity (e.g., 360+ locations on the National Register of Historic Places, including Fenway Park), and the New England Produce Center.

1 Introduction

1.1 Background & Purpose of Study

The City of Cambridge (the City) has previously conducted numerous analyses to assess its vulnerability to inland and riverine flooding, as well as sea level rise/storm surge (SLR/SS) coastal flooding. Prior analyses have been well-documented in the City's Climate Change Vulnerability Analysis (CCVA, 2014 and 2017), and past Resilient Cambridge/Climate Change Preparedness and Resiliency (CCPR) reports.

While past analyses have previously focused on SLR/SS vulnerabilities in the Mystic River Watershed (via Alewife Brook), coastal storm modeling from the Woods Hole Group Massachusetts Coast Flood Risk Model (MC-FRM) – generated after these prior reports – has shown that significant flood exposure can also occur in the Charles and Mystic River Watersheds via flood pathways at the Charles River Dam and the Schrafft's Center/Sullivan Square.

The City has been an active participant in the Resilient Mystic Collaborative (RMC) regional flood mitigation efforts, including its role as the host community for a recent Municipal Vulnerability Preparedness (MVP) program FY19 Action Grant (see **Appendix RA1**). The City is also spearheading conversations with Massachusetts Department of Conservation and Recreation (DCR; see **Appendix RA2**) and other municipalities and stakeholders in the region, regarding the potential for strategic interventions (i.e., specific coastal flood intervention projects) to reduce regional flood exposure, benefitting Cambridge and 14 other municipalities. The purpose of this study is to assess SLR/SS flood exposure, and specifically identify vulnerable real estate and populations benefitting from a select set of ten regional interventions implemented in the Mystic River, Charles River, and North Coastal watersheds. Planning and design is already in progress for several of the 10 interventions, led by the individual communities where they are located.

1.2 Summary of Key Data Sources, Interventions, and Flood Layers

The flood data used in the exposure analyses in this technical memorandum use coastal flood modeling data developed by the Woods Hole Group for the Massachusetts Coast Flood Risk Model, version 11 (MC-FRM v11). Prior to performing these technical analyses, the Kleinfelder team coordinated with the City of Cambridge and Woods Hole Group to produce a series of three (3) coastal flood maps for the 2070 SLR/SS 1% coastal storm event. [*Note: Coastal storm probability is based on thousands of modeled coastal storm path scenarios; unlike precipitation-based recurrence intervals, flood exceedance probability is based on the cumulative set of modeled scenarios and not past statistical analysis of observed storm intensity, depth, and duration data.*]

The select ten (10) coastal flood interventions (with their respective host communities or state owner) modeled by Woods Hole Group include:

Lower Mystic River

1. Raising the crest of Amelia Earhart Dam (DCR)
2. Draw 7 Park (DCR)
3. MBTA Bus Depot (MBTA)
4. Schrafft's Center (Boston)
5. East of Encore Casino (Everett)
6. Island End River (Chelsea / Everett)
7. Route 1 (Revere / Saugus / Malden)

Lower Charles River

8. Raising crest of Charles River Dam (DCR / Army Corp of Engineers)
9. Paul Revere Landing Park (Boston)
10. North End (Boston)

These three (3) GIS maps produced with the MC-FRM include:

1. Coastal flood exposure in the region (see **Figure 1**) based on a 1% chance SLR/SS coastal storm event in 2070 with no interventions

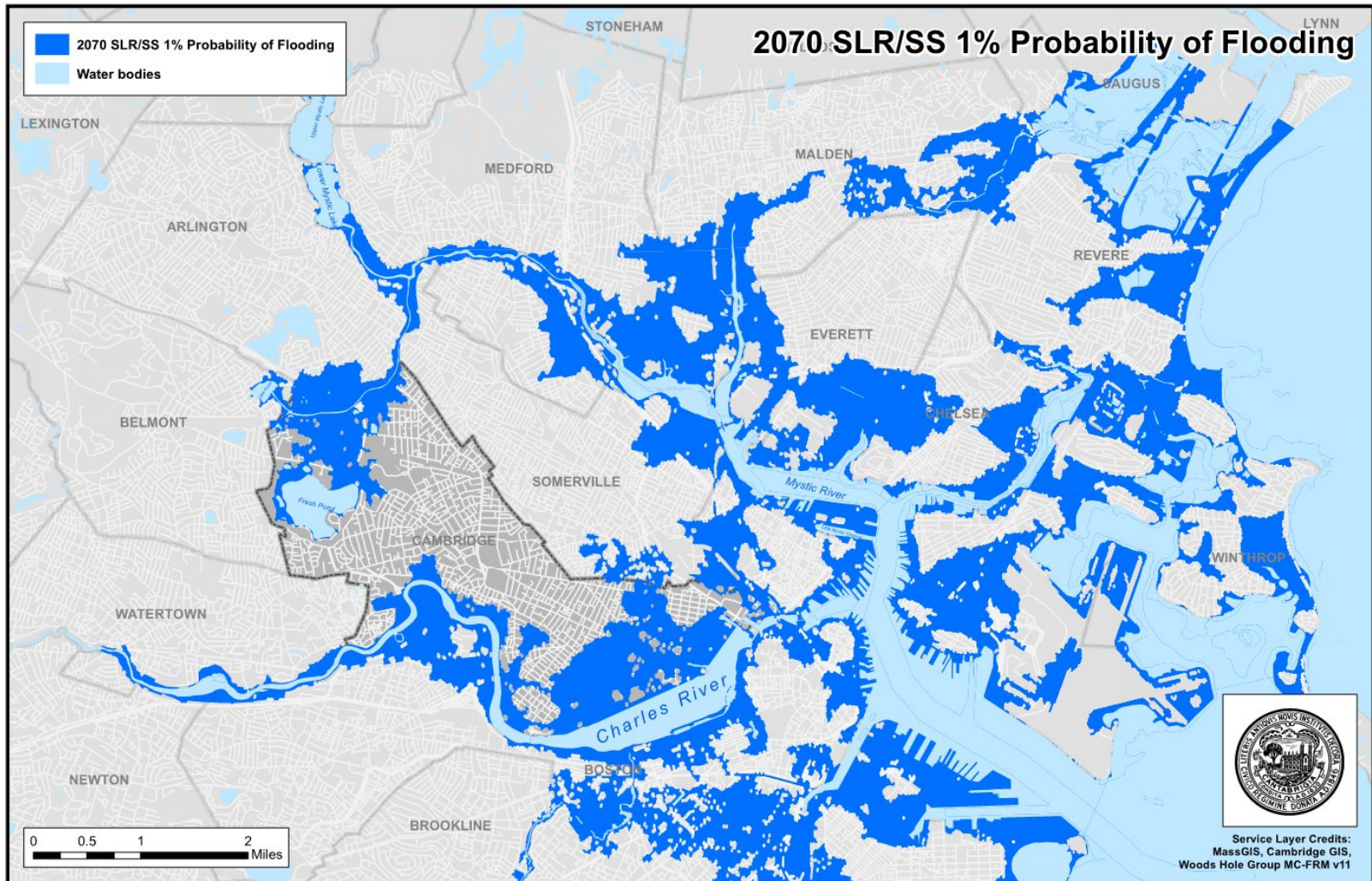


Figure 1 - Regional flood exposure from 2070 1% SLR/SS event (without interventions)

2. Coastal flood exposure in the region (see **Figure 2**) based on a 1% chance SLR/SS coastal storm event in 2070, with a select 10 regional storm surge interventions, as labeled:

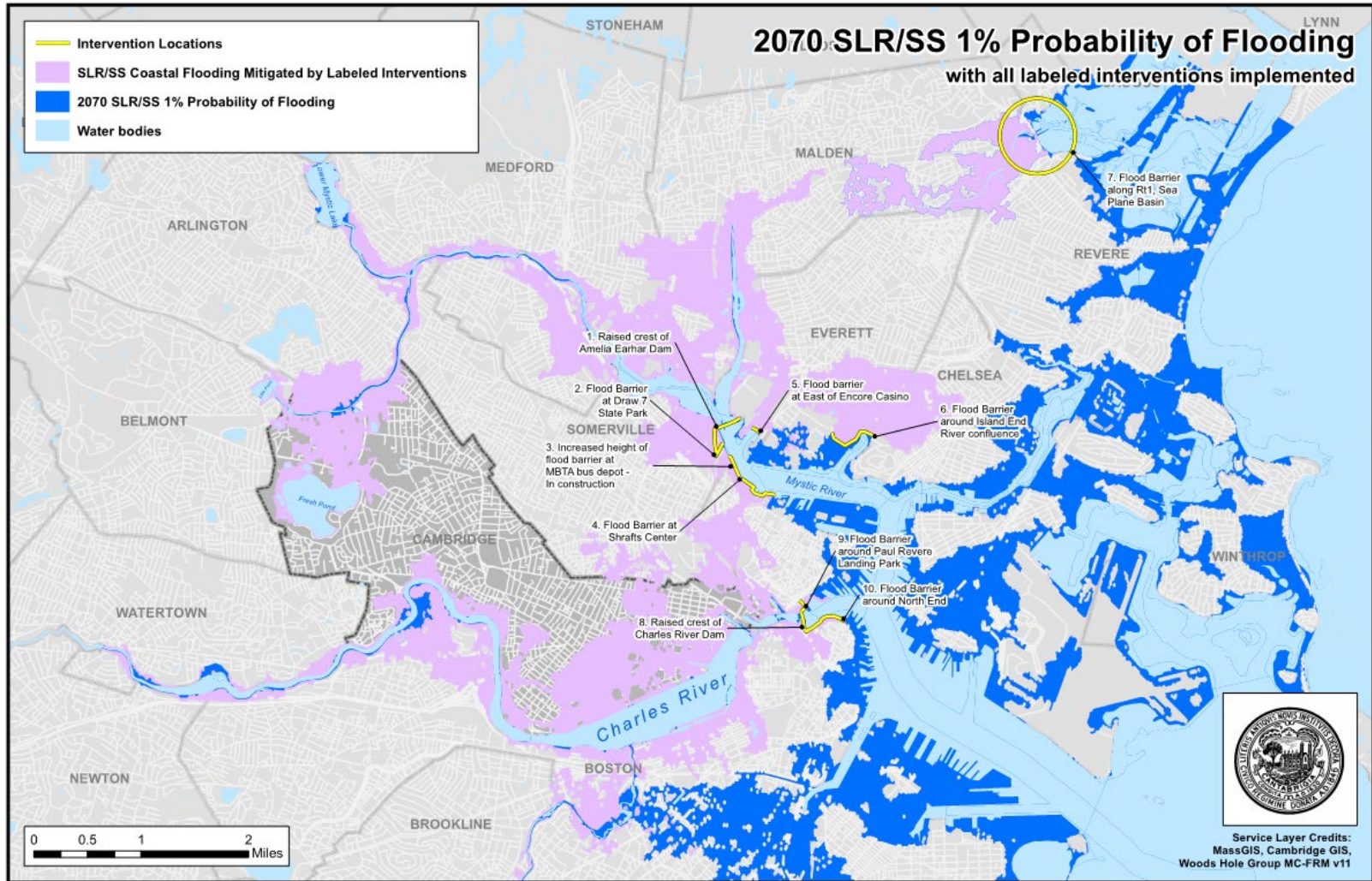


Figure 2 - Regional flood exposure from 2070 1% SLR/SS event (with select regional coastal flood interventions implemented)

3. Coastal flood exposure in the region shown alongside an area mask representing potential flood mitigation from others (i.e., data from masked areas shown in green within **Figure 3** are not included in the real estate, population, and economic exposure technical analyses in this report). [Note: The technical analyses in this report include only geographic areas where the 10 selected coastal flood interventions yield regional flood mitigation benefits. Other coastal flood interventions, such as proposed/ongoing projects via *Climate Ready Boston*² (or other coastal interventions not modeled by Woods Hole Group) are excluded but are shown in this map to reflect a fuller picture of regional flooding that could be mitigated in the future.]

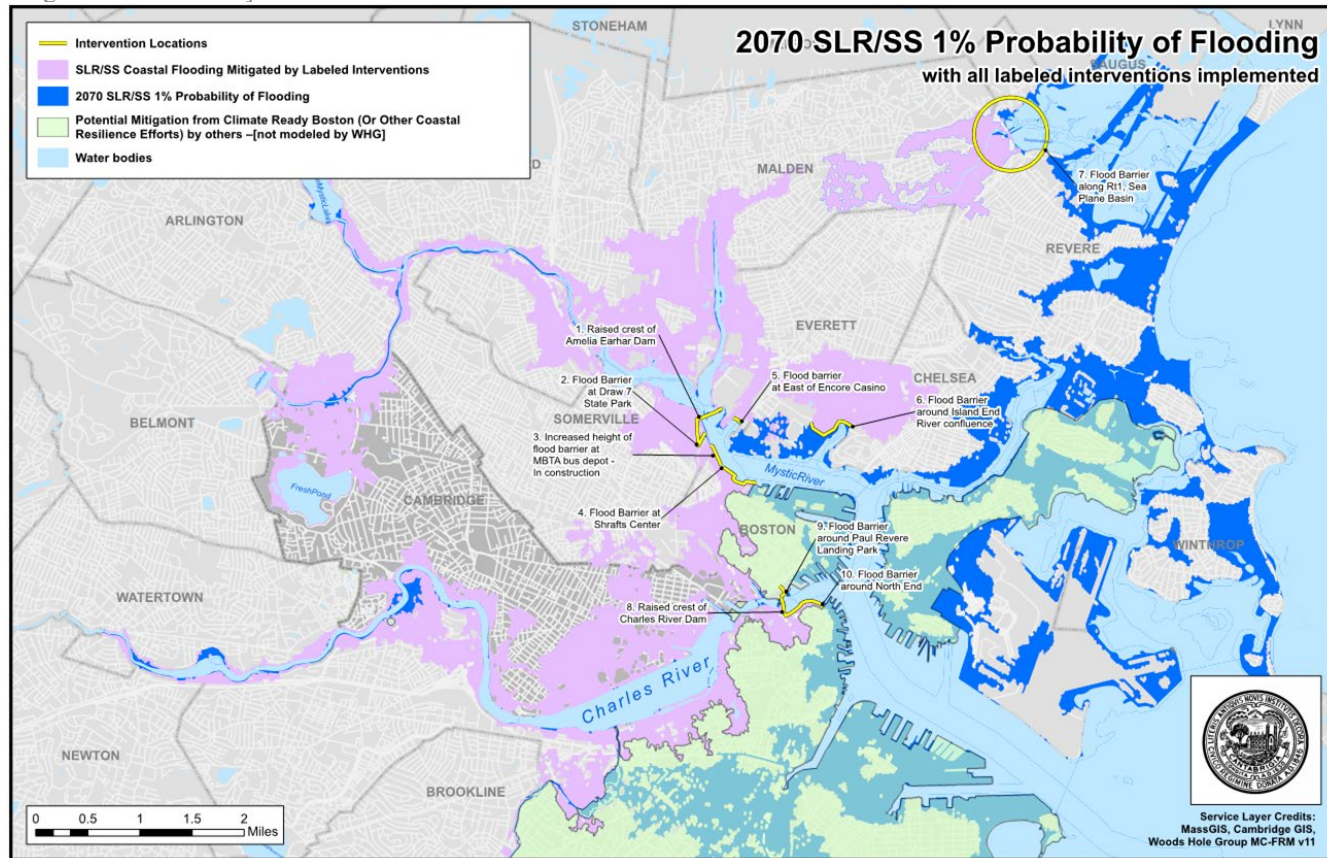


Figure 3 - Regional Flood Exposure - 2070 1% SLR/SS event (select interventions implemented; mask applied within City of Boston to show coastal flooding mitigated in future by Climate Ready Boston and coastal interventions modeled by others)

² https://www.boston.gov/sites/default/files/imce-uploads/2017-01/crb_-_focus_area_ri.pdf

1.3 Summary of Study Limitations

The real estate, population and social vulnerability, and economic exposure analysis (discussed in Sections 3 – 5) are based on the flood extents that would be directly prevented through at least 2070 shown in purple in **Figure 3**. Each of these analyses is therefore focused solely on the estimation of regional benefits provided cumulatively by the portfolio of 10 coastal flood interventions. The analysis includes only the 15 municipalities in the study area for which some flooding is mitigated by the regional coastal flood interventions. Despite its significant coastal flood exposure, this specific portfolio of 10 interventions does not result in any flood mitigation within the City of Winthrop, and it is thus excluded from these analyses.

At this time, the study is meant to provide high-level technical analyses only, with the intent that these will serve as a preliminary analysis, underpinning future conversations, follow-on analyses, and project prioritization impacting capital investments being made now and in the future.

2 Regional Real Estate Exposure Analysis

This analysis is a preliminary assessment of exposed real estate value in the Charles River, Mystic River, and North Coastal Watersheds that can be protected (i.e., where coastal flooding is mitigated) via the cumulative implementation of a select portfolio of 10 regional coastal flood interventions within these three watersheds.

2.1 Objectives

The primary objectives for the real estate exposure analysis are the following:

1. Quantitatively estimate the exposed total real estate value mitigated by the regional coastal flood interventions (as a proxy for direct loss/damage avoided by a 2070 1% SLR/SS coastal storm event)
2. Provide an estimate and breakdown of real estate exposed to flooding that may be mitigated by the regional coastal flood interventions, as classified by primary land use type (e.g., residential, commercial/industrial, institutional, critical infrastructure, open space/recreation uses)
3. Provide an estimate and breakdown of real estate exposed to flooding that may be mitigated by the regional coastal flood interventions, as classified by ownership (e.g., private, major institutional, municipal, State, or Federal entities)
4. Provide an estimate of potential benefits, assessed spatially by municipality, and broken down by ownership and primary land use.

2.2 Methodology

To assess the real estate value protected by the 10 interventions, some steps were undertaken in GIS to assign and sort primary land uses and ownership to all parcels benefitting from the interventions. The latest versions of municipal assessors' data (as made available on MassGIS) was downloaded to obtain assessed real estate values (i.e., total land and building values used for this analysis). Land use codes (i.e., three-digit numerical land use code classifications) are generally unified across the municipalities in this study and were sorted into ~30 subclasses of land uses/ownerships. Subjective decision-making regarding specific classifications was limited

to specific parcels for which data was inconsistent with the unified land use code system. In specific instances, other assessors' data attributes (owner, number of units, use descriptions, tax status) were used to classify specific parcels. For a smaller subset of parcels for which none of this data was not entered into the assessor's database, desktop methods (such as aerial imagery and web searches) were used to ascertain and assign land use/ownership types.

Once all the parcel data was unified with the buildings data (via GIS table join), the ~30 subclasses or land uses/ownership types were simplified into five (5) primary land use categories and five (5) primary ownership categories (see metadata crosswalk in **Appendix RA3**).

2.3 Results

The results of the real estate exposure analysis are presented in a series of ten (10) pie charts and bar graphs on the following pages. These figures are organized as follows:

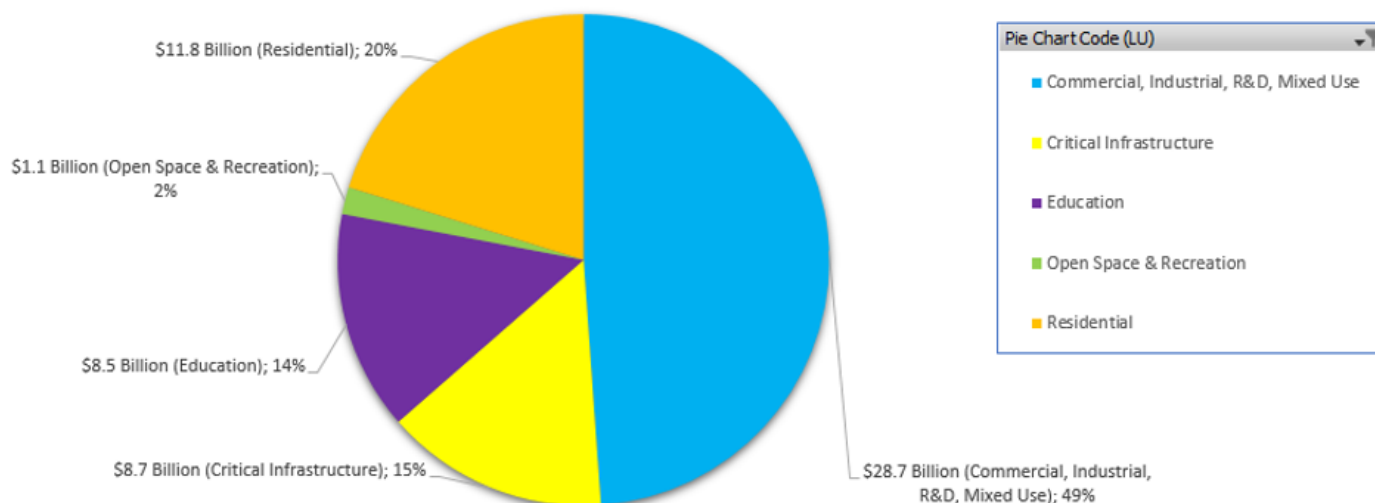
One set of five figures, each displaying data *by Land Use* type.

- **Figure 4** presents real estate value protection, comparing between primary land uses.
- **Figure 5** breaks down the flooded land area by primary land use
- **Figure 6** identifies the number of properties protected by interventions, characterized by primary land use.
- **Figure 7** provides a comparison of protected real estate value (i.e., differentiated benefits) resulting from the regional coastal flood interventions, characterized by primary land uses.
- **Figure 8** contains the same information as **Figure 7**, but now excludes data from the City of Cambridge and City of Boston.

A second set of five figures, each displaying the same data *by Ownership* type.

- **Figure 9** explores real estate value protection, comparing between key ownerships.
- **Figure 10** breaks down the flooded land area by primary ownership.
- **Figure 11** identifies the number of properties protected by interventions, characterized by primary ownership.
- **Figure 12** provides a comparison of protected real estate value (i.e., differentiated benefits) resulting from the regional coastal flood interventions, characterized by primary ownership.
- **Figure 13** contains the same information as **Figure 12**, but now excludes data from the City of Cambridge and City of Boston.

**Total Exposed Real Estate Value Mitigated (~\$60 billion) by Coastal Flood Interventions,
Approximate Values by Land Use
in Charles and Mystic River Watersheds
(2070 SLR/SS Coastal Event ~1% or Greater Frequency)**



Data Sources/Assumptions:

- **Real estate values** obtained from most recent Assessor's data (downloaded via MassGIS or directly from municipalities); Total values include assessed value for both Land and Buildings

Notes on category classifications:

"Residential" includes all residential uses including parcels owned by local housing authorities.

"Commercial, Industrial, R&D, Mixed Use" include all private businesses, industries, research and development (R&D; such as biotech) and all mixed use and multiple use parcels.

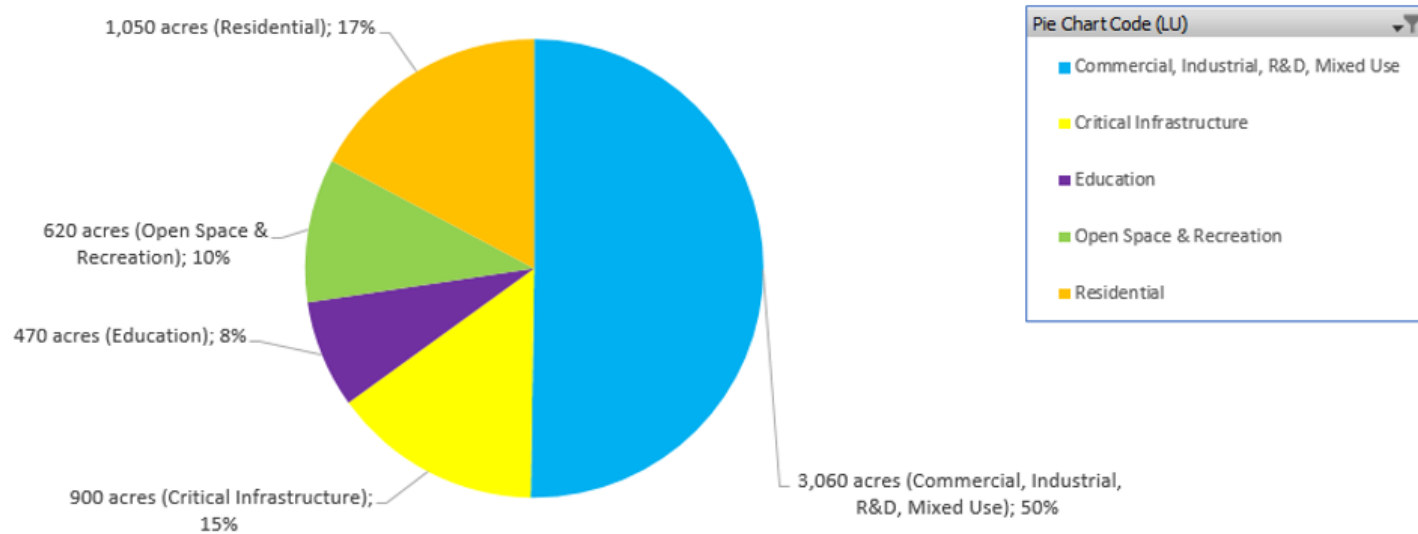
"Education" land use was limited to public K-8 schools and secondary education, public/private colleges, and universities.

"Critical infrastructure" is broadly defined as municipal government and State agency offices, operations and facilities, public health (hospitals), lands owned and operated by private/regional utilities, quasi-public and/or tax-exempt entities (i.e., community organizations, cultural or religious organizations).

"Open Space & Recreation" is limited to municipally-owned public open spaces, conservation parcels, undeveloped, and/or vacant lands owned by municipalities or protected by the State under Article 97.

Figure 4 - Exposed Real Estate Value Mitigated by Coastal Flood Interventions in Charles River and Mystic River watersheds (by Land Use)

Total Flooded Property Acreage (~6,100 acres, or 9.5 sq. miles) Mitigated by Coastal Flood Interventions, Approximate Values by Land Use in Charles and Mystic River Watersheds (2070 SLR/SS Coastal Event ~1% or Greater Frequency)



Data Sources/Assumptions:

- **Property acreage** is the flooded land area protected by SLR/SS interventions "delta" layer (per Woods Hole Group MC-FRM, v11)

Notes on category classifications:

"Residential" includes all residential uses including parcels owned by local housing authorities.

"Commercial, Industrial, R&D, Mixed Use" include all private businesses, industries, research and development (R&D; such as biotech) and all mixed use and multiple use parcels.

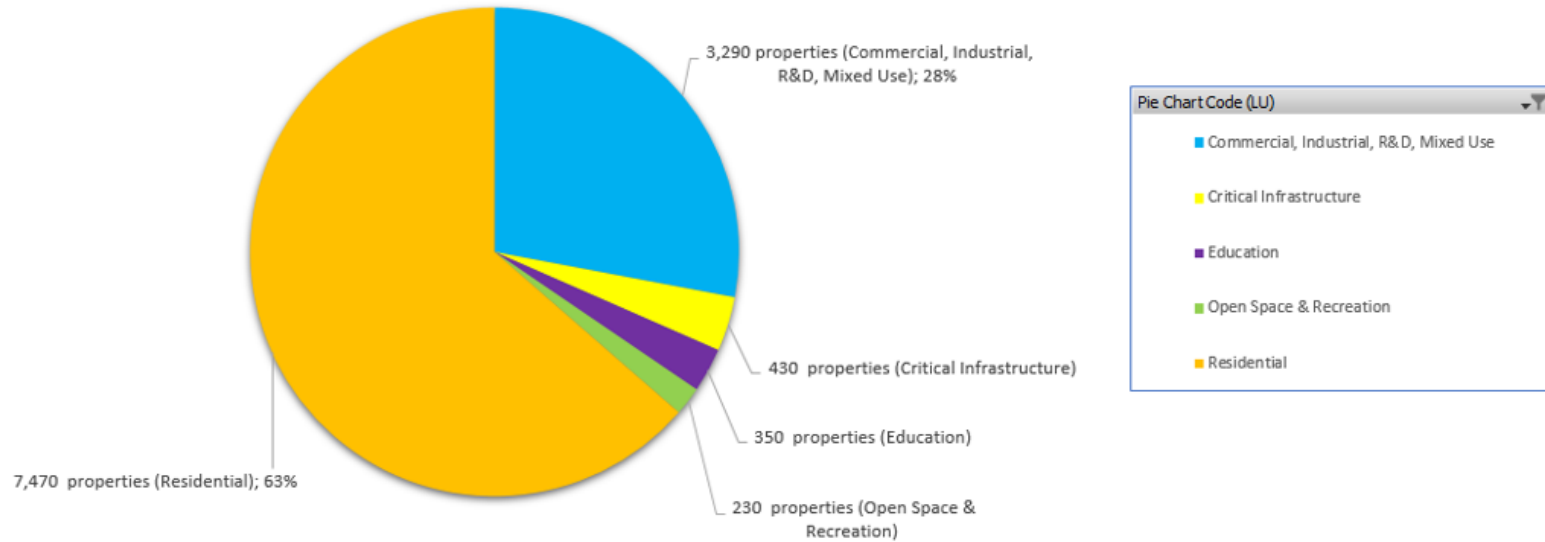
"Education" land use was limited to public K-8 schools and secondary education, public/private colleges, and universities.

"Critical infrastructure" is broadly defined as municipal government and State agency offices, operations and facilities, public health (hospitals), lands owned and operated by private/regional utilities, quasi-public and/or tax-exempt entities (i.e., community organizations, cultural or religious organizations).

"Open Space & Recreation" is limited to municipally-owned public open spaces, conservation parcels, undeveloped, and/or vacant lands owned by municipalities or protected by the State under Article 97.

Figure 5 - Flooded Land Area Mitigated by Coastal Flood Interventions in Charles River and Mystic River Watersheds (by Land Use)

Total Number of Properties (~11,750 properties) with Flooding Mitigated by Coastal Flood Interventions, Approximate Values, by Land Use in Charles and Mystic River Watersheds (2070 SLR/SS Coastal Event ~1% or Greater Frequency)



Data Sources/Assumptions:

- **Number of properties** obtained from most recent Assessor's data (downloaded via MassGIS or directly from municipalities); Total values based on overlap with the flooded land area protected by SLR/SS interventions "delta" layer (per Woods Hole Group MC-FRM, v11)

- **Notes on category classifications:**

"Residential" includes all residential uses including parcels owned by local housing authorities.

"Commercial, Industrial, R&D, Mixed Use" include all private businesses, industries, research and development (R&D; such as biotech) and all mixed use and multiple use parcels.

"Education" land use was limited to public K-8 schools and secondary education, public/private colleges, and universities.

"Critical infrastructure" is broadly defined as municipal government and State agency offices, operations and facilities, public health (hospitals), lands owned and operated by private/regional utilities, quasi-public and/or tax-exempt entities (i.e., community organizations, cultural or religious organizations).

"Open Space & Recreation" is limited to municipally-owned public open spaces, conservation parcels, undeveloped, and/or vacant lands owned by municipalities or protected by the State under Article 97.

Figure 6 - Number of Properties with Flooding Mitigated by Coastal Flood Interventions in the Charles River and Mystic River Watersheds (by Land Use)

**Total Exposed Real Estate Value Mitigated (~\$60 Billion) in Charles River, Mystic River, and North Coastal Watersheds
by Sea Level Rise/Storm Surge Interventions, all municipalities (n=15) with value protected
Approximate Values by Land Use**

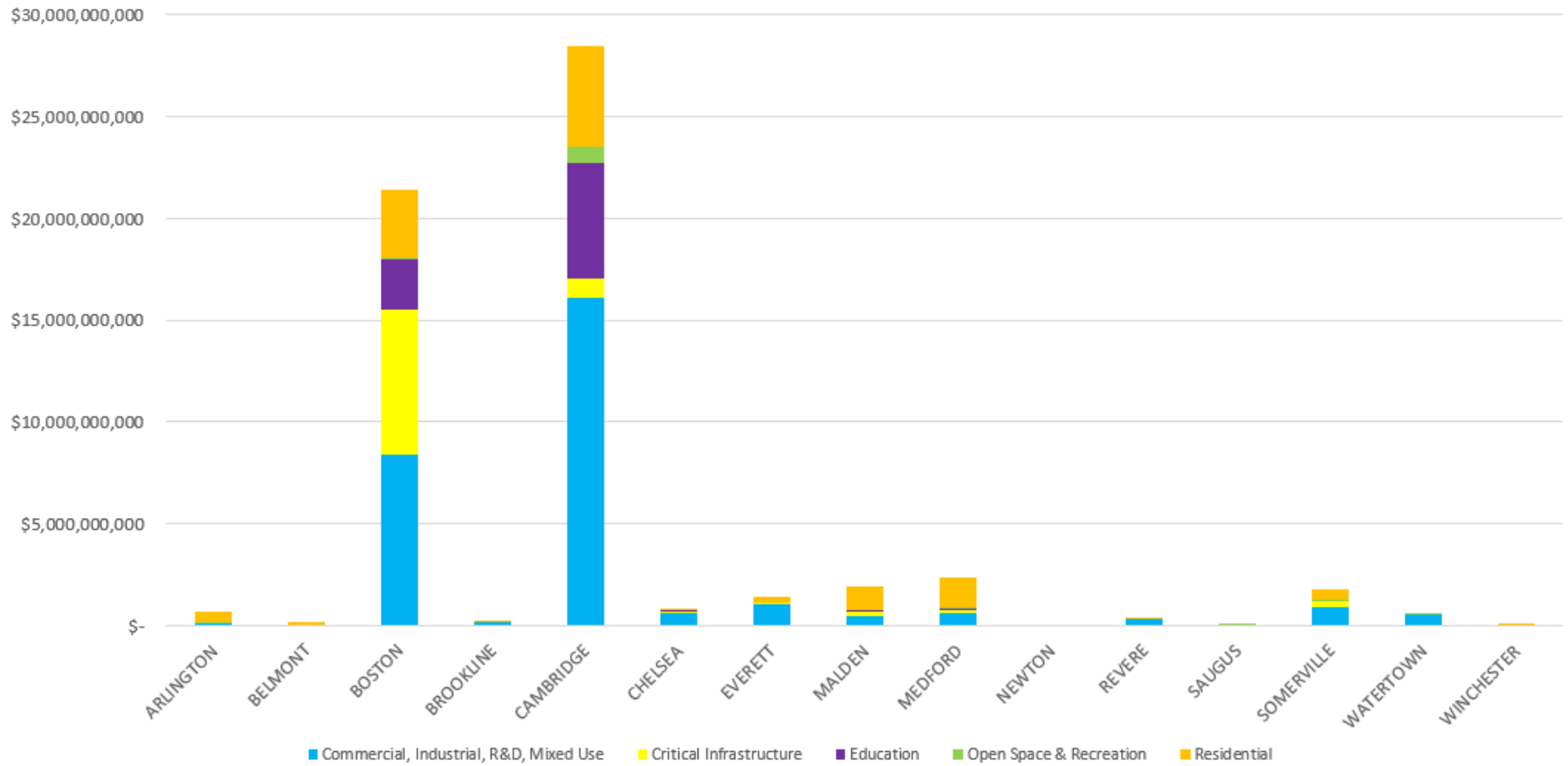


Figure 7 - Exposed Real Estate Value Mitigated by Coastal Flood Interventions per Municipality, Displayed by Land Use (2070 1% SLR/SS Event)

**Total Exposed Real Estate Value Mitigated (\$10.4 billion) in Charles River, Mystic River, and North Coastal Watersheds
by Sea Level Rise/Storm Surge Interventions, Excluding City of Boston and City of Cambridge
Approximate Values by Land Use**

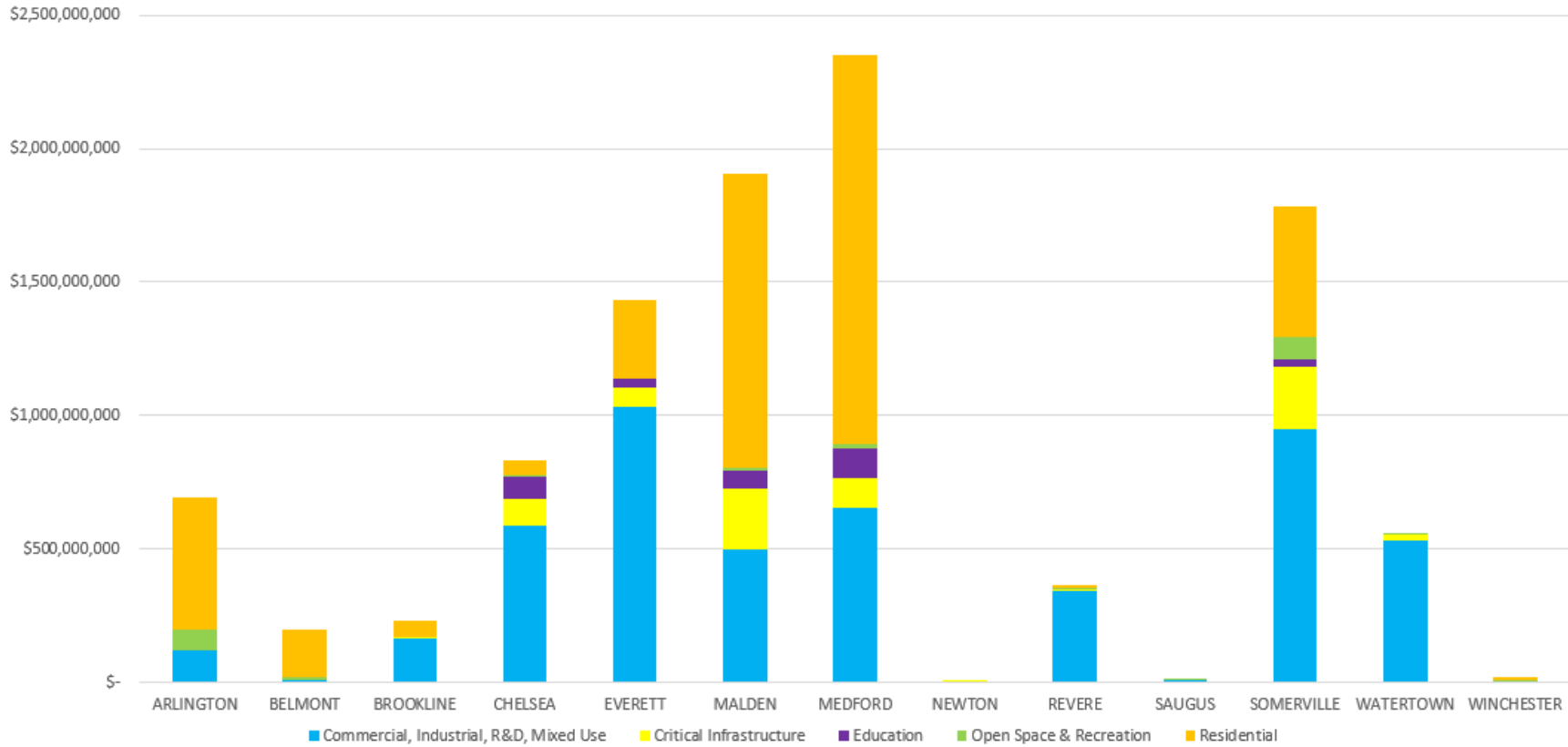
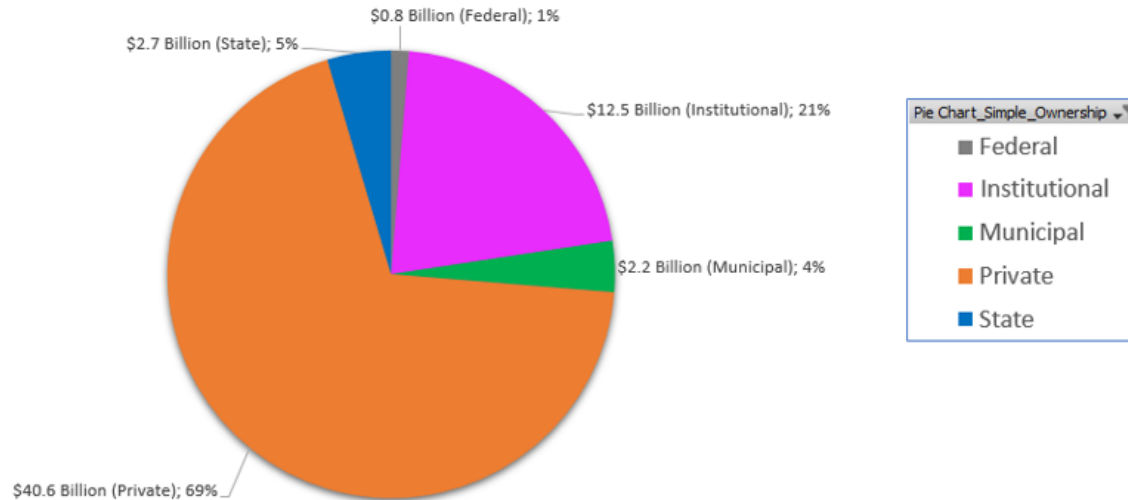


Figure 8 - Exposed Real Estate Value Mitigated by Interventions per Municipality, Displayed by Land Use (2070 1% SLR/SS Event) - Excluding City of Boston and City of Cambridge

Total Exposed Real Estate Value Mitigated (~\$60 billion) in Charles and Mystic River Watersheds
by Coastal Flood Interventions,
Approximate Values by Ownership
(2070 SLR/SS Coastal Event ~1% or Greater Frequency)



Data Sources/Assumptions:

- **Real estate values** obtained from most recent Assessor's data (downloaded via MassGIS or directly from municipalities); Total values include assessed value for both Land and Buildings

- Notes on ownership category classifications:

"Private" ownership includes commercial, industrial, R&D, all residential parcels and undeveloped and/or vacant lands owned by redevelopment authorities. This category also includes all mixed use or multiple use parcels and private utilities (e.g., Eversource, BWSC).

"Institutional" ownership is limited to major institutional entities, (i.e., public and private colleges, universities, and hospitals), quasi-public and/or tax-exempt entities (i.e., community organizations, cultural or religious organizations, housing authorities).

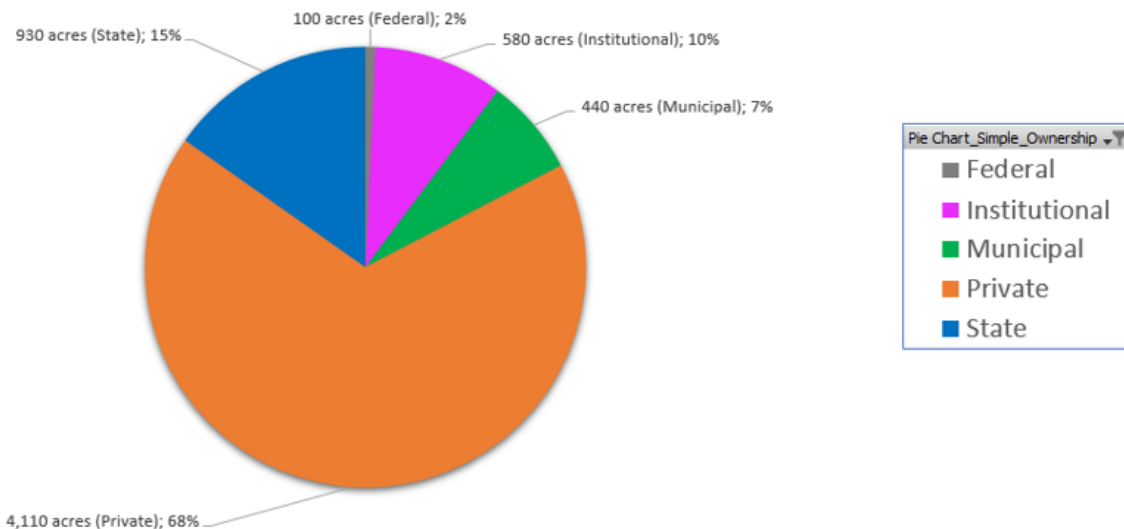
"Municipal" includes municipal critical infrastructure (i.e., municipal government offices, operations, and facilities), municipally-owned public open spaces and parking lots, public K-8 schools and secondary education, and other undeveloped land and/or vacant lots owned by municipalities.

"State" includes Massachusetts DCR parcels and facilities, as well as State transportation agencies (MassDOT, MBTA, Mass Transit Authority). It also includes specific public Open Spaces and conservation parcels that are designated as protected under Article 97.

"Federal" includes any Federal lands, including post offices, U.S. government offices and warehouse buildings.

Figure 9 - Exposed Real Estate Value Mitigated by Coastal Flood Interventions in Charles River and Mystic River watersheds (by Ownership)

Total Flooded Property Acreage (~6,100 acres, or 9.5 sq. miles) Mitigated by Coastal Flood Interventions, Approximate Values by Ownership in Charles and Mystic River Watersheds (2070 SLR/SS Coastal Event ~1% or Greater Frequency)



Data Sources/Assumptions:

- **Property acreage** is the flooded land area protected by SLR/SS interventions "delta" layer (per Woods Hole Group MC-FRM, v11)

- **Notes on ownership category classifications:**

"Private" ownership includes commercial, industrial, R&D, all residential parcels and undeveloped and/or vacant lands owned by redevelopment authorities. This category also includes all mixed use or multiple use parcels and private utilities (e.g., Eversource, BWSC).

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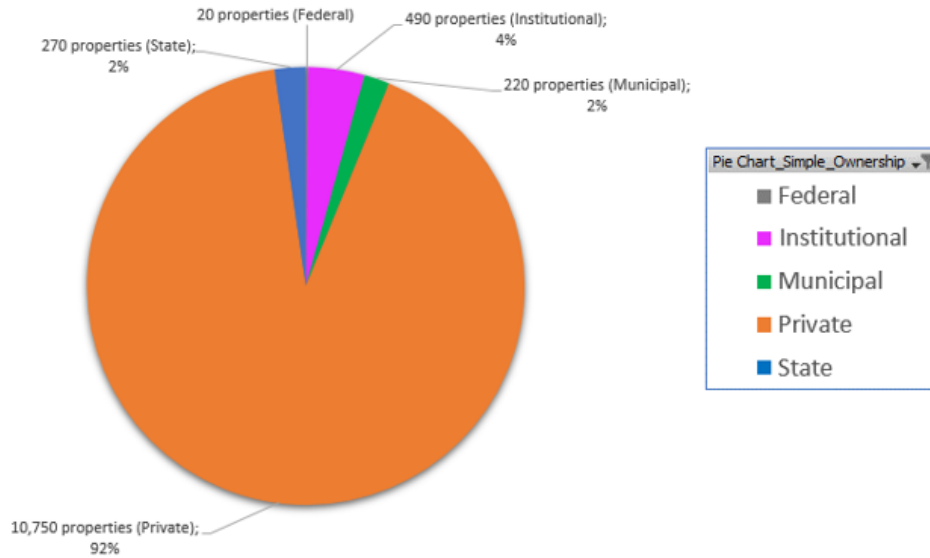
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"Federal" includes any Federal lands, including post offices, U.S. government offices and warehouse buildings.

Figure 10 - Flooded Land Area Mitigated by Coastal Flood Interventions in Charles River and Mystic River Watersheds (by Ownership)

Total Number of Properties (~11,750 properties) with Flooding Mitigated by Coastal Flood Interventions in Charles and Mystic River Watersheds
, Approximate Values, by Ownership
(2070 SLR/SS Coastal Event ~1% or Greater Frequency)



Data Sources/Assumptions:

- **Number of properties** obtained from most recent Assessor's data (downloaded via MassGIS or directly from municipalities); Total values based on overlap with the flooded land area protected by SLR/SS interventions "delta" layer (per Woods Hole Group MC-FRM, v11)

- **Notes on ownership category classifications:**

"Private" ownership includes commercial, industrial, R&D, all residential parcels and undeveloped and/or vacant lands owned by redevelopment authorities. This category also includes all mixed use or multiple use parcels and private utilities (e.g., Eversource, BWSC).

"Institutional" ownership is limited to major institutional entities, (i.e., public and private colleges, universities, and hospitals), quasi-public and/or tax-exempt entities (i.e., community organizations, cultural or religious organizations, housing authorities).

"Municipal" includes municipal critical infrastructure (i.e., municipal government offices, operations, and facilities), municipally-owned public open spaces and parking lots, public K-8 schools and secondary education, and other undeveloped land and/or vacant lots owned by municipalities.

"State" includes Massachusetts DCR parcels and facilities, as well as State transportation agencies (MassDOT, MBTA, Mass Transit Authority). It also includes specific public Open Spaces and conservation parcels that are designated as protected under Article 97.

"Federal" includes any Federal lands, including post offices, U.S. government offices and warehouse buildings.

Figure 11 - Number of Properties with Flooding Mitigated by Coastal Flood Interventions in the Charles River and Mystic River Watersheds (by Ownership)

Total Exposed **Real Estate Value Mitigated (~\$60 billion)** in Charles River, Mystic River, and North Coastal Watersheds
 by Sea Level Rise/Storm Surge Interventions, all municipalities (n=15) with value protected
 Approximate Values **by Ownership**

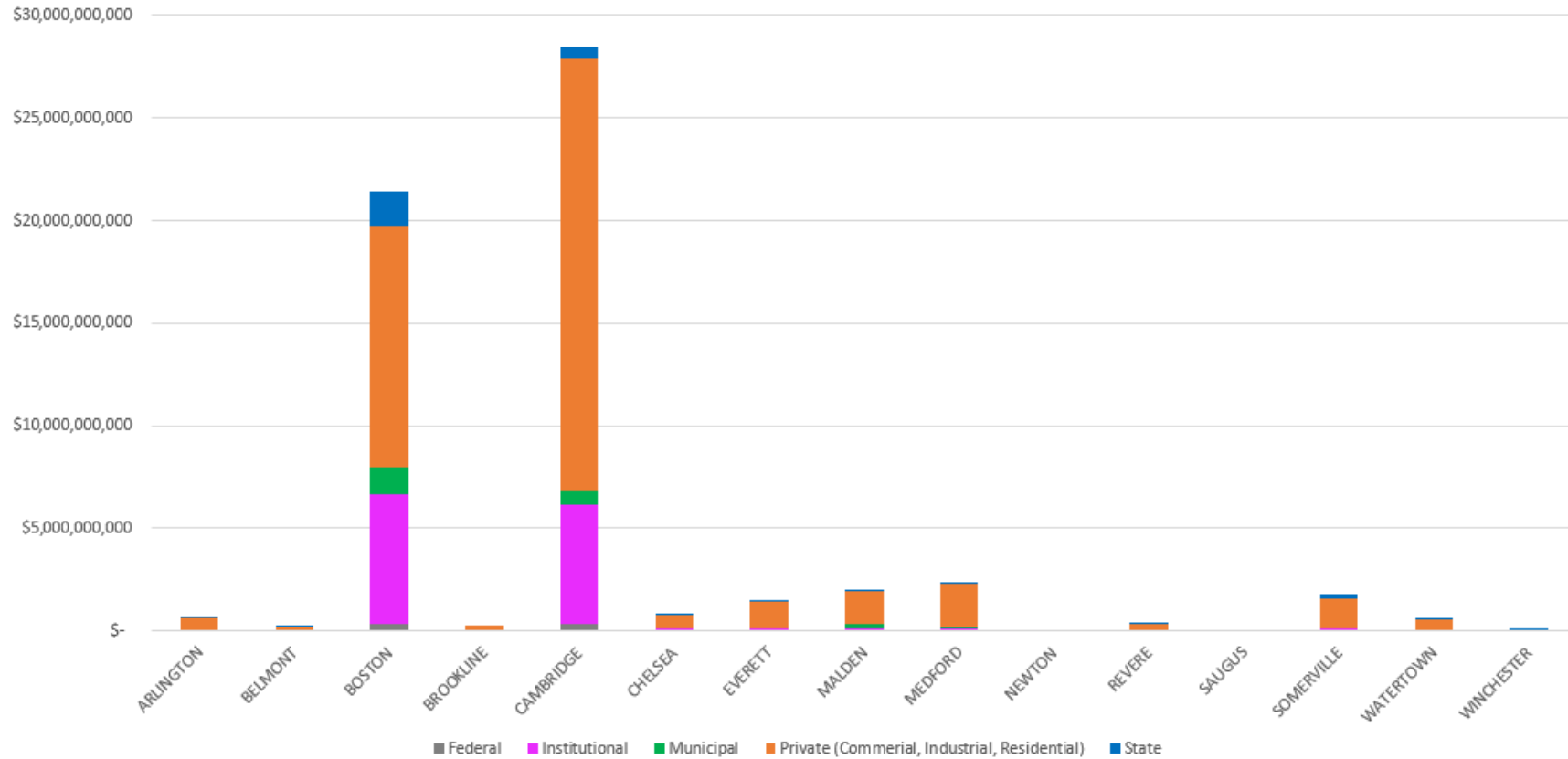


Figure 12 - Exposed Real Estate Value Mitigated by Coastal Flood Interventions per Municipality, Displayed by Ownership (2070 1% SLR/SS Event)

**Total Exposed Real Estate Value Mitigated (\$10.4 billion) in Charles River, Mystic River, and North Coastal Watersheds
by Sea Level Rise/Storm Surge Interventions, Excluding City of Boston and City of Cambridge
Approximate Values by Ownership**

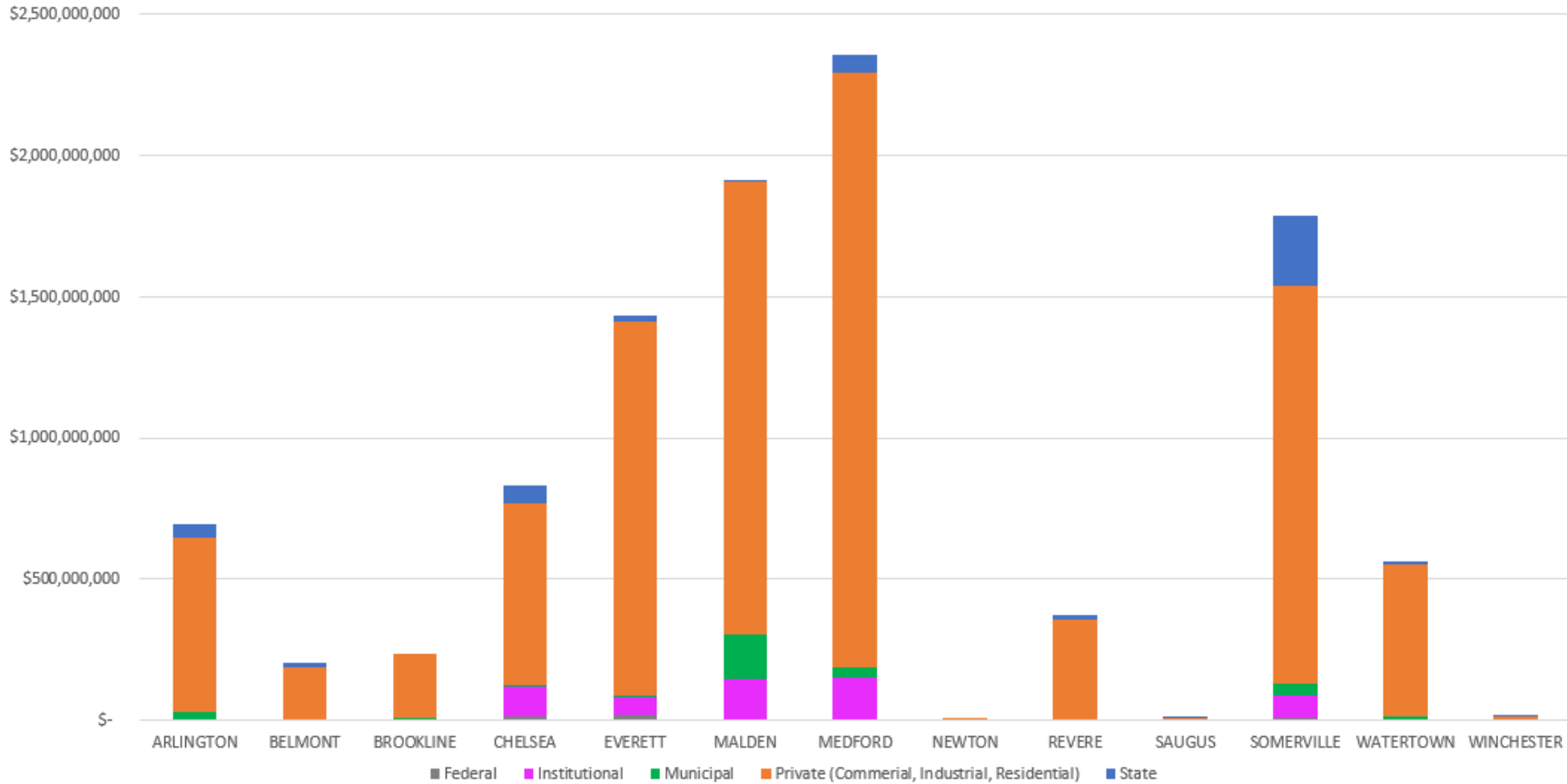


Figure 13 - Exposed Real Estate Value Mitigated by Coastal Flood Interventions per Municipality, Displayed by Ownership (2070 1% SLR/SS Event) - Excluding City of Boston and City of Cambridge

2.4 Key Limitations of Real Estate Exposure Analysis

The real estate exposure analysis is a high-level analysis and is limited to exposed total property value, which serves as a proxy for direct losses sustained during a 2070 SLR/SS 1% coastal storm event. “Total property value” in this analysis is simplified to assessed land value *plus* assessed building value. These data values were obtained from individual municipalities’ assessors’ datasets by downloading the latest database versions uploaded by the municipalities to the MassGIS clearinghouse (for assessor’s dataset metadata, refer to **Appendix RA3**). This analysis does not estimate the cost of property damage, nor does it estimate cost of economic disruption (which usually exceeds property damage). The analysis also does not capture the costs of disrupting infrastructure assets from coastal flooding, such as the MBTA transit system, energy distribution systems, or food distribution hubs.

The following simplifying assumptions were made for this analysis:

- For accounting purposes, this analysis assumes that the total property value (i.e., entire land and building value) is exposed to flooding if *any* part of the corresponding parcel is intersected by the modeled flood extents for the 2070 SLR/SS 1% coastal storm event. This assumption was made recognizing that there is uncertainty inherent in the Woods Hole Group flood layer (i.e., modeled flood extents in MC-FRM are limited to SLR/SS flooding and do not account for any compounded effects of propagated stormwater flooding of urban drainage systems), as well as uncertainty with respect to individual parcel-scale and building-scale flood protections.
- To further limit data review (and maintain consistent resolution across all communities):
 - No additional analyses were performed with respect to variable flood depths (i.e., the total real estate value was assumed fully exposed if there was any level of flooding at the respective parcel). More specifically, no specific depth-damage functions were developed for any assets as part of this analysis, nor were effective first floor elevations (FFE) explicitly accounted for.
 - No other adjustments were considered with respect to individual parcel-scale adaptations (e.g., seawalls, deployable barriers) and/or building-scale adaptations (e.g., floodable first floor and basement uses, wet floodproofing, or other retrofits to raise utilities and critical infrastructure elevations above FFE or any design flood elevations).
- For primary land use categorizations, a summary of parcel classification is provided below (for detailed metadata, refer to **Appendix RA3**):
 - “Residential” land use includes all residential uses (e.g., single and multi-family homes and apartments, condominiums, tower developments, dormitories, etc.), including parcels owned by local housing authorities.
 - “Commercial, Industrial, R&D, Mixed Use” land uses are primary self-descriptive, and include all private businesses, industries, research and development (R&D; such as biotech) and all mixed use and multiple use parcels.
 - “Education” land use was limited to public K-8 schools and secondary education, public/private colleges, and universities.
 - “Critical infrastructure” land use is broadly defined herein as municipal government and State agency offices, operations and facilities, public health (hospitals), lands owned and operated by private/regional utilities, quasi-public

- and/or tax-exempt entities (i.e., community organizations, cultural or religious organizations).
- “Open Space” land use was limited to municipality-owned public open spaces, conservation parcels, undeveloped, and/or vacant lands owned by municipalities or protected by the State under Article 97.
- For primary ownership categorizations, a summary of parcel classification is provided below (for detailed metadata, refer to **Appendix RA3**):
 - “Private” ownership categorization includes commercial, industrial, R&D, all residential parcels and undeveloped and/or vacant lands owned by redevelopment authorities. This category also includes all mixed use or multiple use parcels and private utilities (e.g., Eversource, Boston Water and Sewer Commission).
 - “Institutional” ownership categorization was limited to major institutional entities, (i.e., public and private colleges, universities, and hospitals), quasi-public and/or tax-exempt entities (i.e., community organizations, cultural or religious organizations, housing authorities).
 - “Municipal” ownership categorization includes municipal critical infrastructure (i.e., municipal government offices, operations, and facilities), municipality-owned public open spaces and parking lots, public K-8 schools and secondary education, and other undeveloped land and/or vacant lots owned by municipalities.
 - “State” ownership categorization includes Massachusetts DCR parcels and facilities, as well as State transportation agencies (MassDOT, MBTA, Mass Transit Authority). It also includes specific public Open Spaces and conservation parcels that are designated as protected under Article 97.
 - “Federal” ownership categorization includes any Federal lands, including post offices, U.S. government offices and warehouse buildings.

3 Regional Population & Social Vulnerability Exposure Analysis

3.1 Objectives

The primary objectives of this analysis are to:

1. Quantitatively estimate the total population of community residents protected by the regional coastal flood interventions (i.e., residential populations directly exposed to coastal flooding for a 2070 1% SLR/SS coastal flood event)
2. Provide a first order estimate of flood-exposed populations that would benefit from the regional coastal flood interventions, spatially characterized by municipality
3. Provide a high-level demographic breakdown of specific socially vulnerable populations exposed to flooding that would benefit from the regional coastal flood interventions, spatially characterized by municipality

3.2 Methodology

The technical analysis approach to estimate flood-exposed populations - and socially vulnerable groups - paired the same “delta” flood map as for the Real Estate analysis (Section 3) with census tract and census block datasets available through American Community Survey (ACS) and Boston’s Metropolitan Area Planning Council (MAPC).

Since there is a high degree of spatial heterogeneity in terms of demographic distribution within a single municipality (or even individual census tract), and because flooding can be limited to small sub-portions of these areas, the highest resolution data as available publicly was used, while being consistent across municipalities. The latest Demographic and Housing Dataset inclusive of Massachusetts data at the census block group level was downloaded from ACS (Table DP05 – 2019).

The 2070 1% SLR/SS flood extents that would be directly prevented at least through 2070 shown in purple in **Figure 3** was overlain with the census block group boundaries, and used to estimate the total population impacted by flooding within all census block boundaries:

$$\text{'2070 Total Population Flooded'} = [\text{ACS Census Block Group Population, 2019}] * [\text{2070 "Delta" Percentage of Land Area in that Census Block Group Flooded by 1\% SLR/SS event}]$$

To further assess the spatial distribution of flood-exposed populations and socially vulnerable the sub-groups that may be disproportionately impacted by this flood exposure, indicator data from MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis was spatially joined with the ACS census block group data.

[Note: Only census tract demographic data from MAPC's dataset were used as part of this analysis; Specific flooding and heat exposure analysis layers from MAPCs *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis were not used.]

For the purposes of this analysis, five key social vulnerability indicators from MAPC's dataset were used. These include: persons (residents) identifying as a minority, low-income (below poverty line), experiencing English language isolation, age 65 or above, and/or without access to a vehicle. For data quality control, the first three of these (minority, low-income, and English language isolation) were specifically chosen to allow for comparison against public data available through the Massachusetts Executive Office of Energy and Environmental Affairs' (EEA) Environmental Justice viewer (EJ Viewer)³.

These processing steps were performed to specifically estimate the number and proportion of these socially population sub-groups at high resolution. As indicator data (i.e., percentages for key socially vulnerable populations) was not available at the more-resolute scale of census block groups, the percentages from the census tract level (less resolute) were assumed to be representative across all census block groups within a given census tract.

To spatially analyze flood exposure of these socially vulnerable sub-groups, several calculations steps (shown below) were performed to estimate numbers and percentages of these populations at the census block group level. Specific MAPC data attributes are labeled in brackets (refer to metadata in **Appendix RA4**).

³ http://maps.massgis.state.ma.us/map_ol/ej.php

Minority population protected from flooding (%) =
'2070 Total Population Flooded' * { ([hisp⁴]+[nhbp⁵]+[nhasp⁶]+[nhothp⁷]) /100 }

Low-Income population protected from flooding (%) =
'2070 Total Population Flooded' * ([povp⁸]/100)

English language-isolated population protected from flooding (%) =
'2070 Total Population Flooded' * ([lngisop⁹]/100)

Age 65+ population protected from flooding (%) =
'2070 Total Population Flooded' * ([p65p¹⁰]/100)

Population with no access to vehicle protected from flooding (%) =
'2070 Total Population Flooded' * ([novehp¹¹]/100)

Lastly, as a quality control measure, the Massachusetts EEOEA Environmental Justice Layer, which uses population data from 2010 Census and is based upon 3 demographic criteria developed by EEOEA - was used to validate the population subgroup estimates via spot-checking GIS data in specific census tracts labelled as socially vulnerable with respect to the following indicators: Minority (M), Income (I), English (E), Minority and Income (MI), Minority and English (ME), Income and English (IE), and Minority-Income-English (MIE).

⁴ Proportion of population identifying as Hispanic, per MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis

⁵ Proportion of population identifying as Black or African-American, per MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis

⁶ Proportion of population identifying as Asian, per MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis

⁷ Proportion of population identifying as American Indian, Alaskan Native, Native Hawaiian, Pacific Islander, some other race, or two or more races, per MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis

⁸ Proportion of population below poverty rate, per MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis

⁹ Proportion of households experiencing linguistic isolation (i.e., no one over the age of 14 speaking English very well), per MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis

¹⁰ Proportion of population age 65 and up, per MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis

¹¹ Proportion of occupied housing units with no vehicle, per MAPC's *Climate Vulnerability in Greater Boston: MetroCommon x2050* analysis

3.3 Results

Table 1 - Estimated Exposure of Total Populations and Socially Vulnerable Populations Mitigated by Regional Coastal Flood Interventions (2070 1% SLR/SS Event)

Municipality	Area Protected from 2070 1% SLR/SS Coastal Flooding by Interventions (Acres) ²	Municipality Total Population ³ , 2019	Estimated Population Protected from 2070 1% SLR/SS Coastal Flooding ⁴	Estimated Population Protected, as % of Total Municipal Population	Demographic breakdown ¹ of populations protected by SLR/SS interventions (approximate)				
					Minority (%) ⁵	Low Income (%)	English Isolation (%)	Age65+ (%)	No Vehicle (%)
ARLINGTON	240	45,300	2,680	6%	23%	3%	3%	12%	7%
BELMONT	70	26,110	350	1%	26%	3%	3%	20%	3%
BOSTON	950 ^a	649,420	32,430 ^a	5%	29% ^a	22% ^a	6% ^a	9% ^a	50% ^a
BROOKLINE	50	59,180	80	<1%	38%	16%	12%	19%	34%
CAMBRIDGE	1,890	116,630	36,010	31%	45%	17%	7%	9%	35%
CHELSEA	350	39,990	3,570	9%	82%	22%	32%	8%	40%
EVERETT	890	46,120	3,400	7%	56%	16%	19%	10%	18%
MALDEN	830	60,980	9,090	15%	54%	16%	16%	12%	19%
MEDFORD	890	57,640	13,610	24%	34%	12%	11%	13%	12%
NEWTON	20	88,410	0	0%	-	-	-	-	-
REVERE	400	52,820	510	1%	37%	12%	10%	14%	14%
SAUGUS	260	28,220	0	0%	-	-	-	-	-
SOMERVILLE	500	80,910	5,830	7%	36%	15%	13%	12%	25%
WATERTOWN	160	35,400	680	2%	18%	6%	3%	16%	12%
WINCHESTER	50	22,740	0	0%	-	-	-	-	-
Grand Total	7,550	1,409,870	108,160						

¹ Percentages (per census tract) from MAPCs *Climate Vulnerability in Greater Boston : MetroCommon x2050* analysis (2019); <https://climate-vulnerability.mapc.org/>
² Flooded land area protected by SLR/SS interventions "delta" layer (per MC-FRM, v11)
³ Obtained from 2019 ACS Table DP05 census block group data
⁴ Estimated proportionally from census block group total populations and % flooded land area (per block group) protected by SLR/SS interventions "delta" layer (per MC-FRM, v11)
⁵ "Minority" percentages include those identifying as Hispanic, Black or African-American, Asian, American Indian, Alaskan Native, Native Hawaiian, Pacific Islander, some other race, or two or more races
^a Values noted above within City of Boston are limited only to areas protected via SLR/SS intervention at Charles River Dam
As flooded land areas in the City of Newton, Town of Saugus, Town of Winchester are all non-residential uses, population impacts were not considered for these communities

Additional tabular results - summarized at the individual census tract level - are provided in **Appendix RA4**. A series of municipal maps, highlighting census tracts where flooding is mitigated by the regional coastal flood interventions, is provided in **Appendix RA7**.

3.4 Key Limitations of Regional Population & Social Vulnerability Exposure Analysis

- This demographic analysis uses census data indicators, which are limited to residential populations documented by the U.S. Census. It does not consider movement of socially vulnerable populations within or between these communities (such as the commuting workforce, locations of community centers, and other supporting services used by socially vulnerable populations.)
- While using data at the census block group scale controls for some of variability in population density from neighborhood to neighborhood, the extents and magnitude of flood exposure can vary significantly from block to block. Further, variable zoning and building typologies (i.e., single-family homes vs. large tower condominiums) can result in denser clusters of vulnerable populations existing within smaller sub-areas of census block groups. This analysis did include any detailed analysis to identify specific high-occupancy residences.
- The five social vulnerability indicators included in this analysis (i.e., minority, low-income, English isolation, age 65 or above, no vehicle) are not the only indicators that are relevant to consider when planning equitable solutions for coastal flooding and SLR/SS.

4 Exposure Analysis of Key Regional Economic “Engines” & Hubs

4.1 Discussion

In addition to the significant amount of real estate and people that are protected by the regional coastal flood interventions, impacts of a large-scale coastal surge event could result in significant other direct and indirect costs to the region including: business disruption and reduced economic output, population and workforce displacement, decreased mobility and public transportation access, reduced service life of infrastructure assets, supply chain disruption, price spikes for goods and commodities, as well as many other insurable and uninsurable losses. There may also be significant longer-term effects, such as impacts to real estate valuation in flood zones, flood insurance premiums, or availability of flood insurance. Based on past extreme events in the United States, the indirect costs associated with coastal flooding events can be of a much greater magnitude than direct damages to infrastructure and real estate. For example, Hurricane Laura (which made landfall in Louisiana in August, 2020) amounted to \$20 billion to \$30 billion in total losses after accounting for many of the indirect losses^{12, 13}, as compared to estimates of \$9 to \$13 billion in insured losses for direct damages¹⁴.

In the Boston metropolitan area, where an outsized portion of the regional economy is driven by key economic “engines” (e.g., life sciences, biotech, technology R&D, healthcare, and educational institutions), the potential reach of coastal flooding is of particular importance. Since these sectors drive substantial employment and draw capital investment from well outside the downtown metro area, it is imperative that these anchoring services and sectors are protected. Examples of these – highlighted in **Figure 14** - include college and university campuses, and the

¹² <https://www.cnn.com/2020/08/28/business/hurricane-laura-economic-impact/index.html>

¹³ <https://www.accuweather.com/en/hurricane/record-breaking-2020-hurricane-season-caused-60-billion-to-65-billion-in-economic-damage/858788>

¹⁴ <https://www.rms.com/newsroom/press-releases/press-detail/2020-09-03/rms-estimates-that-total-onshore-us-insured-losses-from-hurricane-laura-will-be-between-us9bn-us13bn>

associated internationally-renown research centers and institutes (e.g., Harvard University, MIT, Boston University). Other key commercial and industrial sectors (finance, commercial fishing, historic site tourism) could also face acute and long-term impacts as a result of a significant coastal flood event.

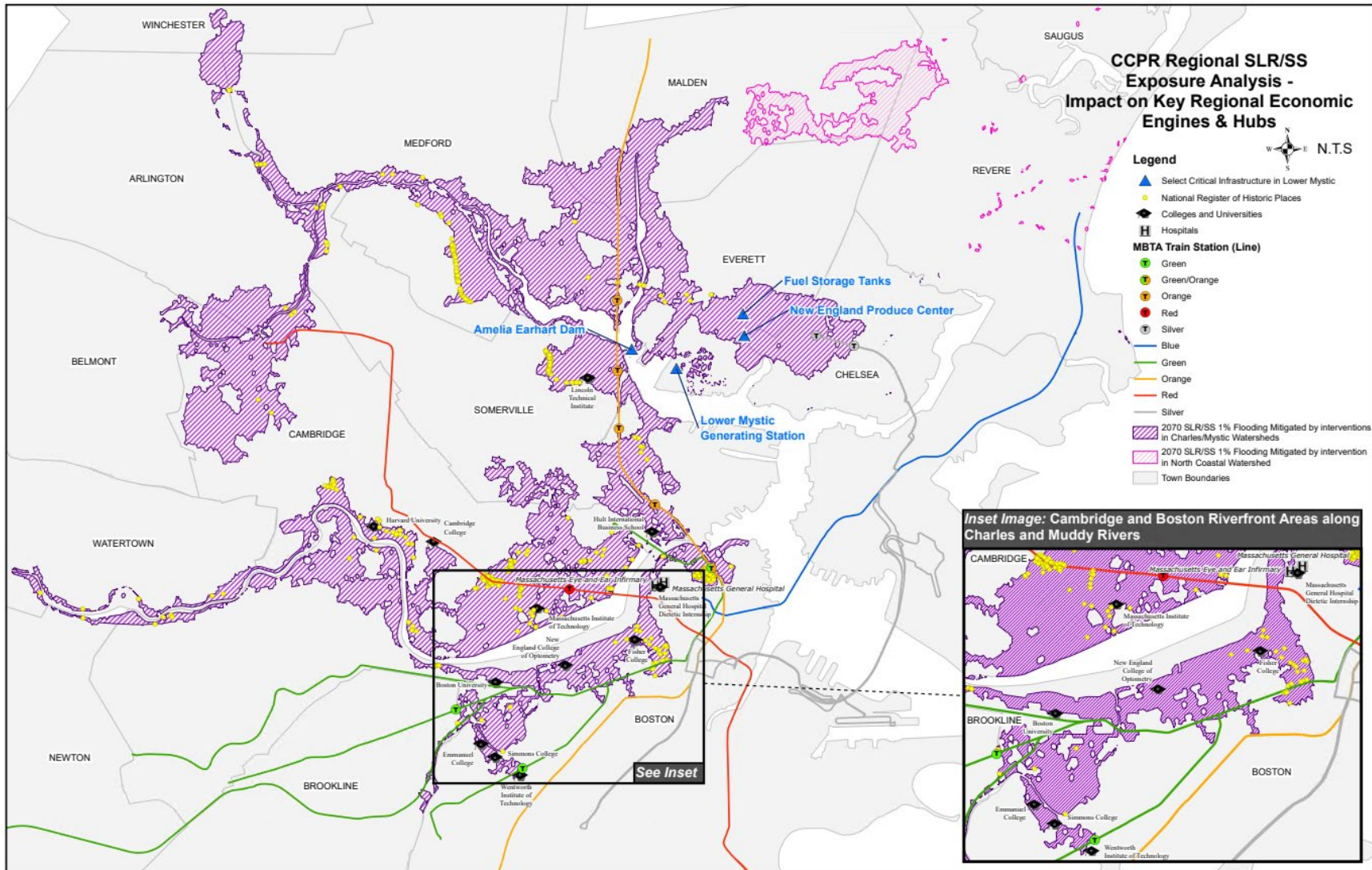


Figure 14 - 2070 SLR/SS 1% Event - Impact on Key Regional Economic Engines & Hubs

Figure 15 (below) shows – in geographic terms – the key commercial, industrial, and institutional hubs where there is a high-density of regionally-significant assets and economic production are clustered in areas that would be exposed to a 2070 SLR/SS 1% coastal flood event, absent interventions.

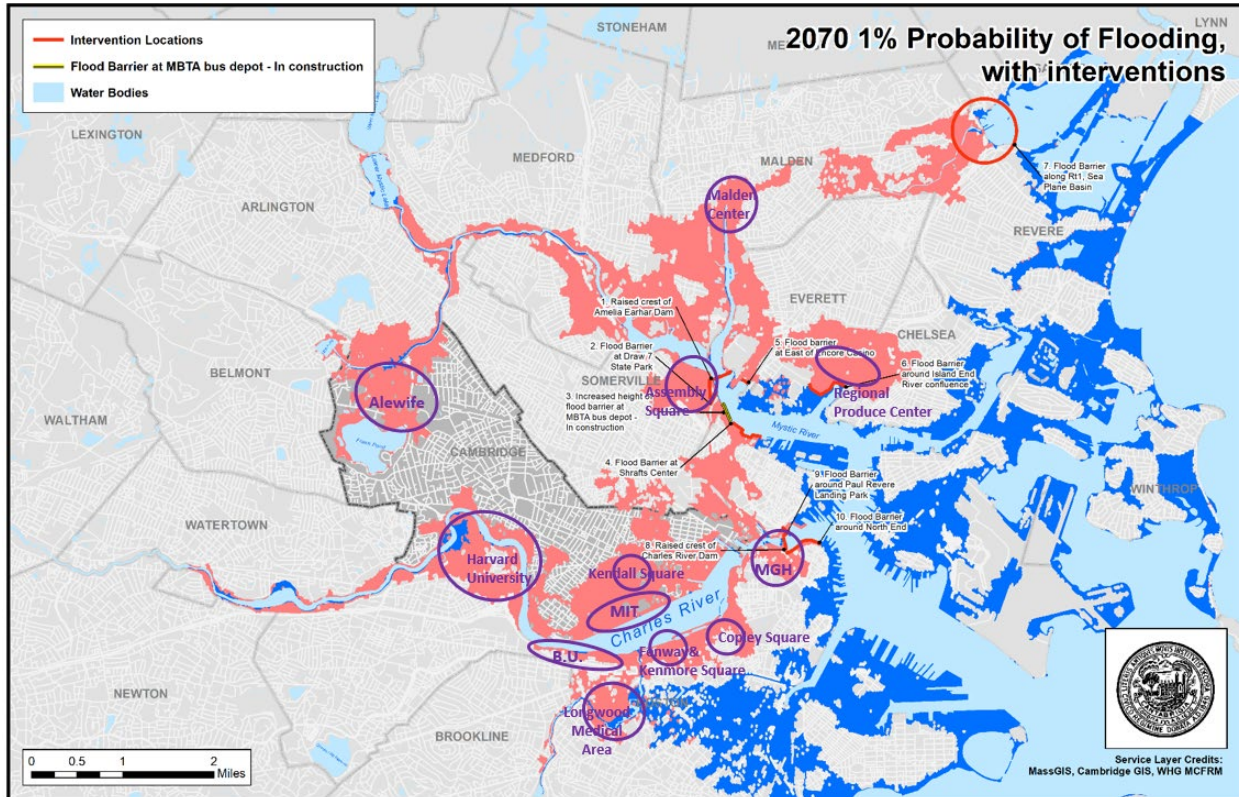


Figure 15 - Select Commercial and Institutional Hubs Protected by Regional Coastal Flood Interventions

4.2 Sample Hub Focus: Longwood Medical Area

One low-lying area of particular concern is the Longwood Medical Area (LMA), which the MC-FRM modeling highlights as experiencing significant flooding during a coastal surge event.

This area houses a unique concentration of 22 institutions that include three major Harvard affiliated teaching hospitals, three research or research treatment centers, three Harvard graduate schools, six historic colleges and universities, a private secondary school, an art museum, one public high school, a State mental health center, a children’s treatment center, a religious institution, and an international pharmaceutical research company.

The LMA hosts world-famous medical campuses such as: Brigham & Women’s Hospital, Children’s Hospital, Dana-Farber Cancer Institute, Harvard Medical School, Harvard School of Public Health, Harvard School of Dental Medicine, Merck, and other healthcare, research, and educational institutions. The LMA has more than 45,000 scientists, researchers, and staff and over 21,000 undergraduate and graduate students¹⁵. The LMA brings in over \$1 billion in

¹⁵ https://www.masco.org/system/files/downloads/thelma/lma_factsheet_10.30.18.pdf

National Institute of Health (NIH) funding annually, a total that grows to over \$2 billion when considering private, industry, and other research funding¹⁶.

Medical Academic and Scientific Community Organization (MASCO) members are: Beth Israel Deaconess Medical Center, Brigham and Women’s Hospital, Boston Children’s Hospital, Dana-Farber Cancer Institute, Emmanuel College, Isabella Stewart Gardner Museum, Harvard Medical School, Harvard School of Dental Medicine, Harvard T.H. Chan School of Public Health, Joslin Diabetes Center, Judge Baker Children’s Center, Massachusetts College of Art and Design, Massachusetts College of Pharmacy and Health Sciences University, Massachusetts Mental Health Center, Simmons University, Temple Israel, Wentworth Institute of Technology, Wheelock College (now B.U.), and The Winsor School. Mass. Eye and Ear, Merck Research Laboratories, the Boston University Wheelock College of Education and Human Development, and Fenway Health are Associate Members of MASCO.

Over 112,000 people commute to and visit the LMA daily including employees, students, volunteers, nonmember employees, patients and visitors². As shown in **Figure 16**, MA employees come from across the state and New England.

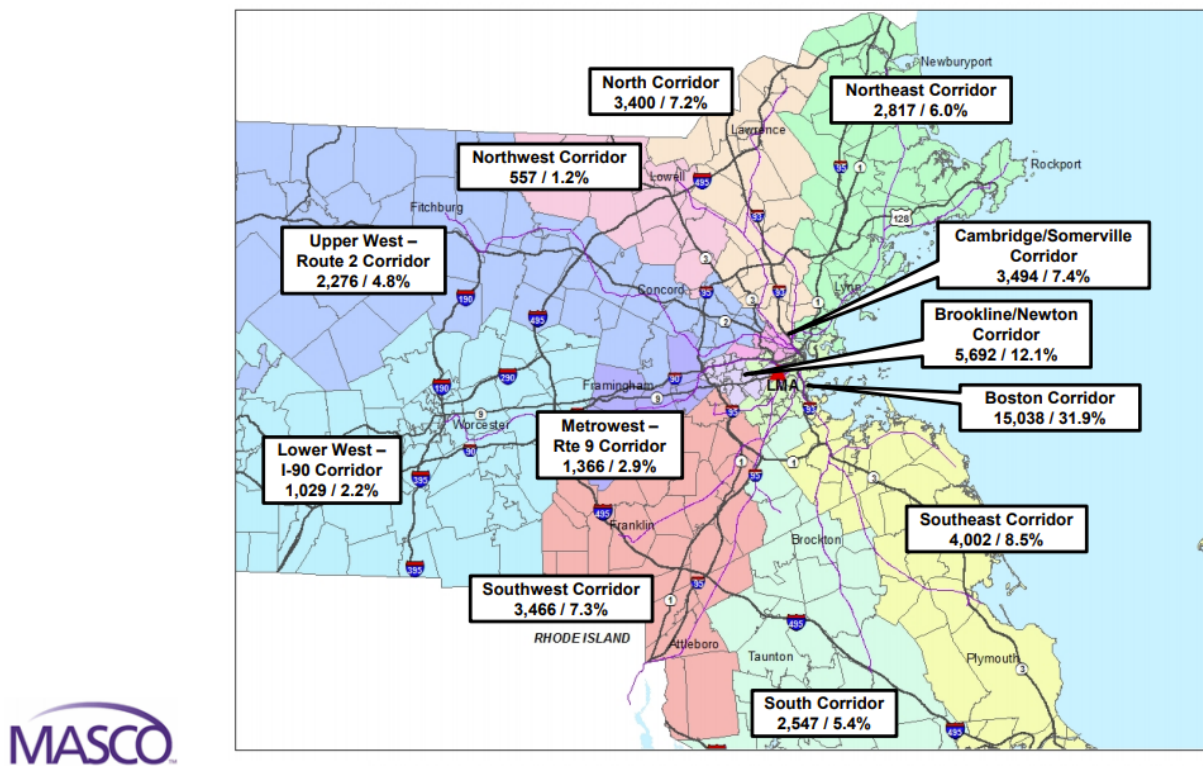


Figure 16 - Geographic Reach of Employee Base - Longwood Medical Area (MASCO, 2018)

¹⁶ https://www.masco.org/system/files/downloads/thelma/lma_factsheet_10.30.18.pdf

The presence and success of the institutions in the LMA provide significant financial support for the local public transportation system. As of 2018, LMA users generated nearly \$27 million in MBTA T-pass spending, and private funds supplemented MBTA service by \$10.6 million².

4.3 Sample focus area: Biotech and pharmaceutical clusters

Another geographic area protected by the regional coastal flood interventions is the high-density cluster of biotech, pharmaceutical, and R&D interests in the Kendall Square/MIT neighborhoods of Cambridge, highlighted in **Figure 17** and **Figure 18**.

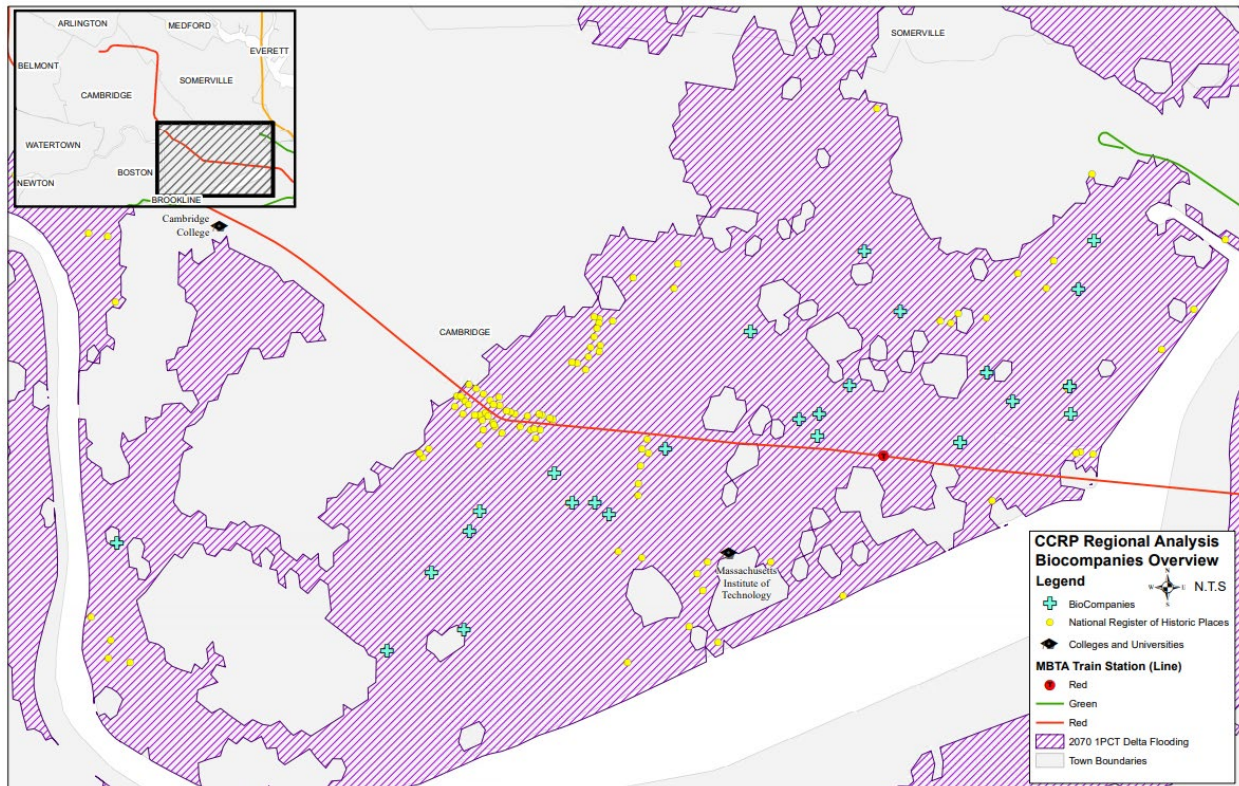


Figure 17 - Overview of BioCompanies and Historic Places Protected by Regional Coastal Flood Interventions in the Kendall Square/MIT Neighborhoods in Cambridge

In 2018, Massachusetts biopharma companies surpassed more than \$4.8 billion in venture capital investment, up from \$900 million in 2012¹⁷, according to Robert Coughlin, CEO of the Massachusetts Biotechnology Council (MassBio), an industry trade group with more than 1,200 members that span biotech and life sciences companies, research institutions and hospitals. Today, there are more than 110 laboratories, 113,000 biopharma and biotech research and development jobs and more than 30 million square feet of lab space throughout the state¹⁸.

¹⁷ <https://www.massbio.org/news/recent-news/massbios-2019-industry-snapshot-shows-highest-year-over-year-employment-growth-for-the-biopharma-industry-in-massachusetts-in-over-a-decade/>

¹⁸ <https://fivethirtyeight.com/sponsored/massachusetts-biotech/>



Figure 18 – Sample Biotech cluster in Cambridge (list of laboratories and companies is not comprehensive; Image source: MIT Sloan School of Management, 2021)

4.4 Sample focus area: Vulnerable public transit stations

Past SLR/SS flooding in the City of Boston have resulted in flooded MBTA subway stations that were not only significant in terms of direct damages, but also in terms of loss of service for extended periods of time during station repair and rehabilitation. As a result, increased travel times and offline stations deter visitors, tourists, patrons, and commuters who otherwise frequent local businesses near these transport hubs.

There are several instances of major flooding occurring in at Boston subway stations in the past few decades. For example, Aquarium Station on the Blue Line flooded with ocean water associated with the surge from a January 2018 storm experienced several million in damages to elevators, escalators and subsurface infrastructure and was retrofit with deployable flood barriers as part of a \$1.7 million project in the past year¹⁹. In 1996, flooding of the Kenmore Station on the Green Line incurred tens of millions of dollars of loss, and the station was closed for over 2 months²⁰. While the latter instance occurred as a result of extreme precipitation (not coastal flooding and storm surge), the scale of damages and service loss duration may be comparable or even greater if other MBTA stations were to flood in the future with ocean water. For instance, the New York City Metropolitan Transportation Authority’s (MTA) rehabilitation of subway infrastructure flooded by ocean waters during Hurricane Sandy (October, 2012) just wrapped up

¹⁹ <https://www.mbta.com/projects/aquarium-station-floodproofing>

²⁰ http://www.nafsm.org/sites/default/files/shared-files/Gershwin_MuddyRiver.pdf

work in March, 2021 after 8+ years of repair and resiliency projects, and over \$8 billion in federal funding support²¹.

There are at least ten (10) MBTA subways stations at risk of flooding from the 2070 1% SLR/SS event, without interventions along the Charles River and Mystic River. These include:

- Kendall/MIT (Red Line)
- North Station (Orange/Green Line)
- Wellington (Orange Line)
- Sullivan Square (Orange Line)
- Community College (Orange Line)
- Assembly (Orange Line)
- Museum of Fine Arts (Green Line)
- Saint Mary’s Street (Green Line)
- Bellingham Square (Silver Line)
- Chelsea (Silver Line)

As noted in Section 4.2, a significant amount of the workforce in the LMA commutes from outside the area. As shown in **Figure 19**, over 28% of the employees reach via North Station. Many others come through Orange and Green Line connections, which are exposed to flooding along routes to LMA.

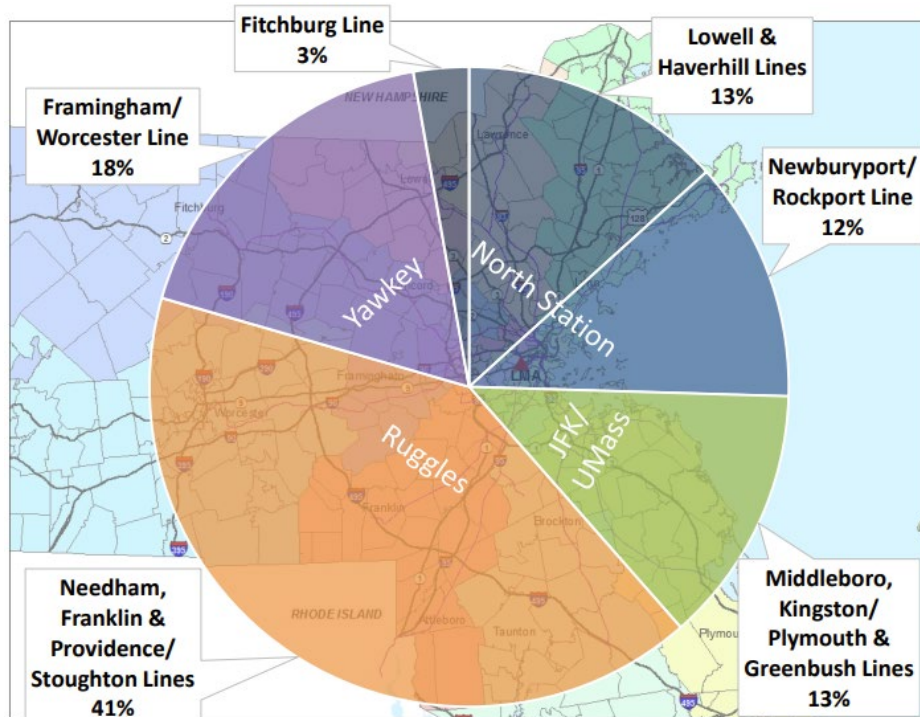


Figure 19 - Distribution of Commuter Rail Riders to Longwood Medical Area (MASCO, 2018)²²

²¹ <https://www.thecity.nyc/2021/4/6/22370970/mta-touts-tunnel-fixes-but-sandy-subway-and-rail-repairs-still-have-long-way-to-go>

²² https://www.masco.org/system/files/downloads/thelma/lma_facts_for_web_11-5-18.pdf

4.5 Key Limitations of Economic Analysis

This analysis is only a limited regional economic analysis of key economic engines and select commercial, industrial, and institutional clusters. It is not a comprehensive analysis and does not consider many of the indirect costs associated with flood damages and disruption (costs which usually exceed property damage). It does not estimate value of businesses, services, or infrastructure. The analysis also does not capture the value of disruption to infrastructure assets such as the MBTA transit system (e.g., tunnels flooded with saltwater), energy distribution systems, food distribution hubs, or other critical infrastructure. Further, it does not account for any cascading impacts on businesses and industries that could arise from a significant coastal flood event, which can be a significant economic stressor.

Note: The RMC and the City of Somerville are concurrently leading a separate project identifying interdependencies among critical infrastructure, indirect impacts, and cascading failures from failure of supporting critical infrastructure services (e.g., electricity, transportation, communications) during and after an extreme coastal storm in the Lower Mystic Watershed. The *Critical Regional Infrastructure and Social Vulnerability in the Lower Mystic Watershed* project is separate from this analysis and includes input from seven host municipalities, 15 infrastructure managers, as well as state and federal emergency response agencies. For more information, refer to the RMC's project website²³.

5 Conclusions & Next Steps

5.1 Conclusions

The preliminary estimates produced by this effort highlight the tremendous scale of real estate value (>\$60 billion in total value) and populations (>108,000 residents) that would benefit from this strategic portfolio of 10 regional coastal flood interventions under a coastal flood event (2070 SLR/SS 1% event). While this study serves only as a first pass and incorporates numerous simplifying assumptions, the values reported in this memorandum can help serve as base estimates underpinning future conversations. For example, there is value in understanding the order-of-magnitude benefits that these interventions can yield, as these can help frame initial Benefit-Cost analyses for these regional coastal flood interventions.

There is also value in understanding the proportional breakdown of exposed real estate by land use and ownership, as this may inform the composition and balance of landowners, jurisdictional entities, business- and other interest groups and other stakeholders within future working groups or project financing discussions. Whereas the City of Cambridge and City of Boston account for more than \$50 billion of the \$60+ billion in total real estate value protected from this portfolio of interventions, these regional coastal flood interventions still protect over \$10 billion (cumulatively) within 13 communities, including over \$1 billion (each) in Everett, Malden, Medford, and Somerville, and over \$500 million in Arlington, Chelsea, and Watertown.

The results of the population flood exposure and socially vulnerable populations analysis also show that there are significant numbers of vulnerable residents within these communities that would benefit from these interventions. As methods and data are refined and updated in follow-

²³ <https://resilient.mysticriver.org/lower-mystic-learn-more>

on analyses, the prioritization impacting capital investments (being made both now and in the future) should consider the specific population subgroups that benefit from these projects.

5.2 Next Steps

The initial findings from this preliminary regional analysis, which was developed concurrently with the Resilient Cambridge plan and other technical reports, have been presented to a variety of audiences and stakeholder groups outside of Cambridge, including the RMC. The findings of this study assist in demonstrating that there is a significant benefit to continuing this work that Cambridge has started, transitioning to a more regional effort with buy-in and engagement from the other state agencies, communities, and stakeholder groups. Next steps should include pursuing grant funding collectively and continued engagement of communities on regional SLR/SS vulnerabilities and awareness of potential coastal flood interventions.

The City of Cambridge, RMC, and other regional stakeholders have noted that further study and regional collaboration is needed on the coastal flood interventions highlighted in this preliminary analysis. Together, these regional partners are actively pursuing grant funding and other state/federal funding opportunities for follow-on analysis, which may include – but are not limited to - the next steps identified below:

- An immediate next step in the near-term is to investigate the efficacy of pairing/phasing sub-sets of these (or other) coastal flood interventions. It is important that the next step include not only Benefit-Cost analyses, but also investigate specific populations and socially vulnerable sub-groups that these coastal interventions would protect.
- In addition to advancing the dialogue between key stakeholders, there are number of additional analyses that may be worth future follow-up in the near term, as they could branch into separate studies, inform regional planning efforts more broadly, or be useful in identifying strategic capital projects. For example, this analysis did not include any detailed analysis to identify specific clusters of socially vulnerable residents (such as affordable housing, senior housing, or high occupancy rental properties, dormitories, etc.), where implementation of building-, neighborhood-, or district-scale solutions could be strategic opportunities to reduce flood risk and build social resiliency for a large number of these residents. An analysis of this type, similar to that described in the Resilient Cambridge Closer Neighborhoods Technical Report, could be performed at the regional scale to identify opportunities for community resilience projects.
- In addition to exploring different scenarios (i.e., combinations - or phasing – of the 10 regional coastal flood interventions in this analysis), the MC-FRM can also be used to explore the regional benefits/efficacy of other coastal interventions. For example, this analysis excluded Winthrop because the specific portfolio of regional coastal flood interventions considered did not eliminate flooding within Winthrop. Future modeling runs could consider alternative portfolios of interventions.

- The technical analyses in this memo also did not explore any additive flooding impacts from propagated flooding (i.e., the combined effects of precipitation-based flooding²⁴ and surcharged stormwater system capacity). The regional precipitation-based flood model outputs from recent MVP Action project in the Upper Mystic watershed could be integrated within future analyses to assess additive effects and vulnerabilities from stormwater flooding.
- There is also a need to better understand the relationship between flood depths and damages, as this analysis made simplifying assumptions with respect to the direct losses from flood-exposed properties. While it is widely acknowledged that indirect losses (e.g., business and travel disruption, displacement costs, cascading impacts on businesses and industries, long-term impacts on commercial and real estate value, etc.) can be much greater – comparatively - than direct losses, a more detailed study of specific sectors, businesses, and mobility could help better frame the discussions, further bolstering the case for one or more of these regional coastal flood interventions.

²⁴ <https://resilientma.org/changes/changes-in-precipitation>