January 2017

Designing Coastal Community Infrastructure for Climate Change

City of Chelsea, Massachusetts

Financial assistance provided by the Executive Office of Energy & Environmental Affairs (EEA), through the Massachusetts Office of Coastal Zone Management (CZM), under the FY16 Coastal Community Resilience Grant Program. This program provides financial and technical resources to advance new and innovative local efforts to increase awareness of climate impacts, identify vulnerabilities, and implement measures to increase community resilience.

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Massachusetts Office of Coastal Zone Management

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Coastal Community
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Change

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EXECUTIVE SUMMARY

The City of Chelsea is taking steps to pro-actively address its vulnerability to coastal flooding and build resiliency for changing climate conditions. City staff are actively engaged in the Metro Mayors Climate Preparedness Task Force and planning studies are being performed by the Metropolitan Area Planning Council, UMass Boston, and the American Geophysical Union.

In support of these efforts, the City, in collaboration with the Massachusetts Office of Coastal Zone Management (CZM), commissioned this climate change vulnerability assessment to:

- Identify vulnerable areas of the City at risk of coastal flooding (under present day and projected future climate change conditions).
- Assess flood risk and depth.
- Prioritize infrastructure at risk.
- Recommend adaptation measures of varying scale and complexity.

The City and its partners are already advancing elements of the recommended adaptation measures and thinking creatively about how to integrate resilient approaches into future planning efforts. Each next step will help protect economic activities for the region, and critical public infrastructure and the built environment that support daily life.

Figure S.1 Areas of Chelsea Vulnerable to Coastal Flooding

Coastal Flooding Vulnerability

With approximately 60% of its municipal boundary bordering tidally influenced waterways, Chelsea is especially vulnerable to coastal flooding. Once a network of waterways and tidelands, the low-lying areas of the City are, on average, less than 10 feet above sea level. Disruption of these natural systems by urban development has made these areas even more susceptible to coastal flooding under present day and future climate change conditions.

The assessment team used the Boston Harbor Flood Risk Model (BH-FRM) to determine which areas of the City are most vulnerable to coastal flooding. The BH-FRM is a probabilistic, dynamic model, meaning that it includes the physical processes associated with storm events (e.g., waves, winds, tides, storm surge, etc.) and not just static increases in water levels (Bosma et al., 2016). BH-FRM also assesses future flood risk based on sea level rise projections and a range of potential storm events. This is the same model being used by other metro-Boston area municipalities, Massachusetts Department of Transportation (MassDOT), Massachusetts Port Authority, and other agencies.

The model determines key flood pathways where coastal flood waters are predicted to enter the City. The five primary vulnerability zones within Chelsea are shown on Figure S.1. Collectively, these zones place approximately 36% of the City within a flood risk area under present day, 42% in 2030 and 49% in 2070.

Table S.1 Prioritized Public Infrastructure

Rank	Asset / Facility	Sector	Vulnerability Zone	Owner
1	MWRA Chelsea Creek Headworks and Screen House	Wastewater	Lower Chelsea Creek	MWRA
2	Chelsea Street Bridge over Chelsea Creek	Transportation – Roadway, Maritime	Lower Chelsea Creek	MassDOT
3	MWRA Chelsea Facility	Water and Wastewater	Upper Chelsea Creek	MWRA
4	Railroad Bridge over Mill Creek	Transportation - Rail	Mill Creek	MassDOT/ MBTA
5	Substation #488 at Willoughby Street	Energy	Upper Chelsea Creek	Eversource
6	Carter Street Pump Station	Stormwater	Island End River	City
7	Williams Middle School	Buildings	Island End River	City
8	City Yard	Buildings	Island End River	City
9	Burke School Complex	Buildings	Upper Chelsea Creek	City
10	Chelsea High School	Buildings	Island End River	City
11	Meridian Street Bridge over Chelsea Creek	Transportation – Roadway, Maritime	Lower Chelsea Creek	MassDOT
12	Broadway Bridge over Mill Creek	Transportation - Roadway	Mill Creek	MassDOT

Critical Public Infrastructure

This assessment focuses on the critical public infrastructure in each of these vulnerability zones. Critical public infrastructure included City-, State-, and private utility-owned assets that provide critical public services. The decision to focus on public infrastructure was driven by the desire to provide Chelsea with some adaptation measures that can be implemented by the City in the near term, (for example, the results of this assessment are already being used to design improvements at the Carter Street pump station and at the Island End River site, as the City owns these properties). The decision was also based on the recognition that the assessment findings would support complementary resilience planning efforts by other public service providers including the Massachusetts Water Resource Authority, Massachusetts Bay Transportation Authority, MassDOT, and Eversource. Although the focus was on critical public infrastructure, the potential adaptation measures identified herein provide benefits to private property as well.

A total of 12 critical public infrastructure assets were identified in the vulnerability zones based on the City's Hazard Mitigation Plan (MAPC, 2014) and input by City staff. The assets were prioritized based on a total risk score that considered asset criticality (consequence) and likelihood of flooding (probability) now and in the future. Simply put, the higher the score, the higher the priority to implement adaptation measures to protect this asset.

The findings show:

- All 12 assets are distributed relatively evenly among four zones, with none occurring in the Mystic River Vulnerability Zone.
- Five of the 12 assets are owned by the City, and four of these are located in the Island End River Vulnerability Zone.
- The public infrastructure assets that are most critical to the region are also most at risk of coastal flooding under present day and future years.

Flexible Adaptation Strategies

Another interesting result of the modeling is that the locations where coastal flooding enters the City are anticipated to generally remain the same over time. However, the depth of anticipated flooding and resultant impacts will increase. This finding emphasized the need for shoreline and site-specific adaptation strategies that could be implemented in the near term, and are flexible enough to work over a range of future climate change conditions. The recommended adaptation strategy height is, on average, 2 feet in year 2030 and 5 feet in year 2070.

Flexible adaptation strategies considered include ecological approaches that grow with sea level rise, and natural berms and hard structures that can be adjusted vertically in height or lengthened over time. Shoreline strategies account for the need to support Chelsea's working waterfront within the Mystic River and Chelsea Creek Designated Port Areas. Depending on the specific site, adaptable flood walls (deployable and/or permanent) may need to be set back from the waterfront to preserve waterfront access (Figure S.2). At other locations, unique hybrid installations (green and gray infrastructure) are suggested (Figure S.3) .

The City is also interested in exploring policy and planning based approaches to encourage more resilient building and site design. A collection of paired measures – site specific, shoreline and policy/planning – can offer the highest level of protection.

Next Steps

With the impacts of climate change being experienced both locally and across the globe, the City of Chelsea is planning for sea level rise and severe weather events. Inherent in the City's vision is creating a forum within which public and private partners can see opportunities to act together for their mutual benefit. Such an approach will create opportunities for public/private partnerships and cost sharing. The key is to promote measures at all scales, in a coordinated manner, to address coastal flooding risks in the short term and long term. The City of Chelsea is devoted to incorporating a variety of adaptation and mitigation strategies to create a cohesive and united response to climate change.

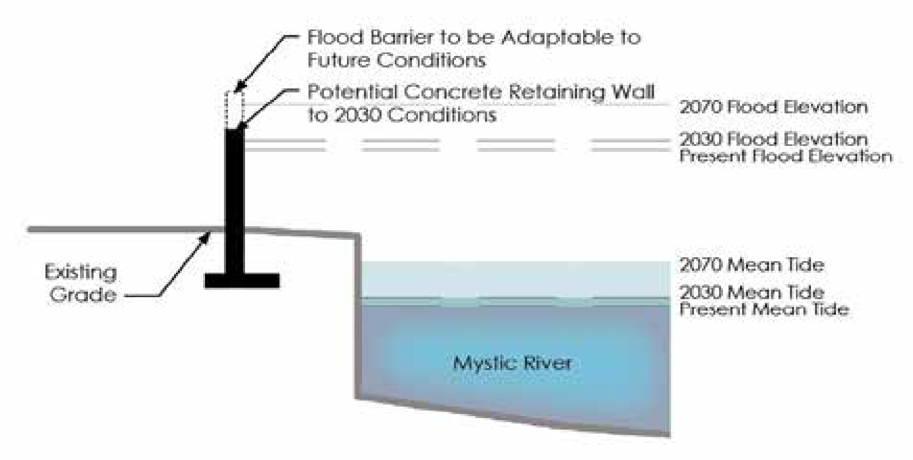

Figure S.2 Potential Shoreline Adaptation within a Designated Port Area (DPA), where Gray Infrastructure may require setbacks to preserve waterfront access

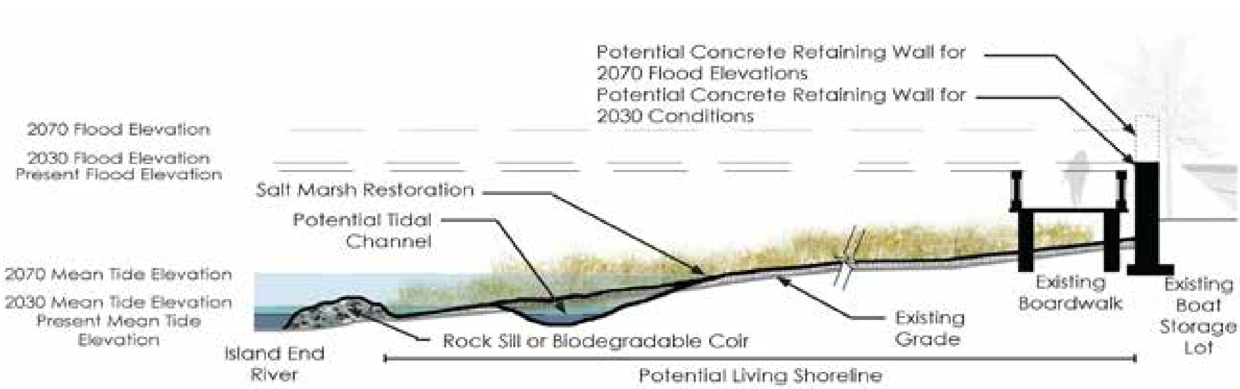

Figure S.3 Potential Shoreline Adaptation at Island End River Illustrates a "Hybrid" installation of Green Infrastructure (living shoreline) and Gray Infrastructure (retaining wall).

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1 INTRODUCTION

> ***Climate Change:***
> **"any significant change in the measures of climate lasting for an extended period of time, including major changes in temperature, precipitation, or wind patterns."**
> *- US EPA (2014)*

We have all learned about climate change over the past decades: our use of fossil fuels is releasing levels of carbon into the atmosphere that cause higher air and sea surface temperatures. These higher temperatures are causing sea levels to rise and increasing the odds of natural hazards, including flooding, fire, earthquakes, landslides, and extreme storm events. The immediate concern is the implication climate change has on the natural and built environments around us.

In 2012, Hurricane Sandy's impact on New York and New Jersey revealed the severe damage that can come from an extreme weather event. Here in Massachusetts, we are already seeing a rise in sea levels and greater intensity and frequency of storms causing flooding. Coincidently, as this study began, world leaders met to negotiate and sign the world's latest accord on climate change, the "Paris Agreement," which set forth a new global action plan to deal with greenhouse gas emissions mitigation, adaptation, and finance starting in the year 2020.

Urban Resilience:

"The capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience."

- 100 Resilient Cities pioneered by the Rockefeller Foundation

With the implications of climate change and related impacts of severe weather events accepted globally and the impacts of severe weather being felt locally, the City of Chelsea understands the importance of planning for future conditions. Based on a regional climate change model, approximately 20% of the City's 1.8 square miles of land area is mapped within the potential coastal flooding area under present day, 35% in 2030, and 45% in 2070. This footprint poses a major threat to public safety and the quality of life for people living and working in the Chelsea. It also has the potential for widespread regional impacts to the food distribution and petroleum enterprises.

In light of these projections, the City of Chelsea is committed to making strategic infrastructure investments, rooted in broadly acknowledged climate science, methods, and policy, while engaging public and private partners in community-level resiliency planning discussions and future implementation phases.

2

ASSESSMENT PROCESS

The goal of this study is to assess the vulnerability of critical public infrastructure in Chelsea, Massachusetts to coastal flooding and recommend adaptation measures to improve infrastructure resilience over a range of future conditions.

Public infrastructure includes City owned assets as well as state infrastructure and private utility assets that provide critical public services.

The 3-step process followed for this study is outlined on the following page.

Vulnerability:

"Structures, systems, populations, or other community assets as defined by the community, that are susceptible to damage and loss from hazard events."

- FEMA Local Mitigation Plan Review Guide (2011)

Public Infrastructure:

Includes City-owned assets as well as state infrastructure and private utility assets that provide critical public services.

1.IDENTIFY

What areas of the City are at risk of coastal flooding? What public infrastructure is located in these areas?

The study begins by explaining the lay of the land in Chelsea and the areas of the City most likely to experience coastal flooding based on sea level rise projections and a wider range of potential storm events. It focuses our attention on the existing public infrastructure located within five vulnerable areas of the City. (Chapters 3 – 5)

2.PRIORITIZE

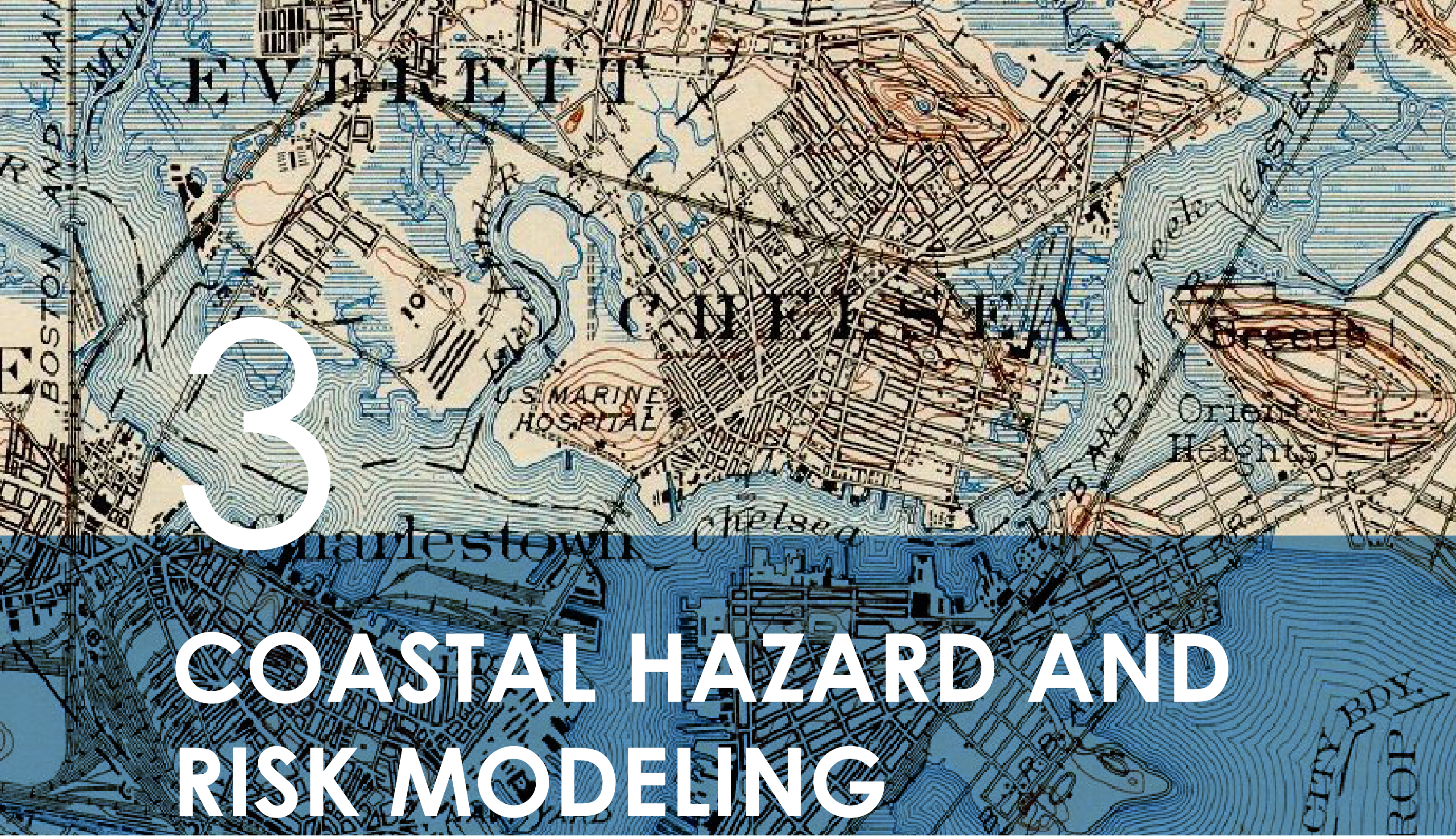
How critical is this infrastructure and what is the likelihood that it will be impacted?

The next step included ranking twelve public infrastructure assets based on criticality and the probability of flooding in present day, 2030, and 2070. The end result is a score that can be used as the basis for prioritizing infrastructure investments. (Chapter 6)

3.STRATEGIZE

What adaptation measures could help protect this infrastructure?

The last part of the study recommends site specific, shoreline, and policy or regulatory measures to improve the resilience of critical public infrastructure. It also lays the foundation for follow up study efforts and future implementation phases. (Chapters 7 – 9)



3 COASTAL HAZARD AND RISK MODELING

Approximately 60% of the City's 7.8 mile municipal boundary borders tidally influenced waterways. Each of these bordering waterways -- Mystic River, Island End River, Chelsea Creek, and Mill Creek -- is part of the Mystic River Watershed which drains into Boston Harbor.

Topographic mapping (Figure 3.3 on page 3-3) illustrates a ridgeline, aligned north to southeast, dividing the City roughly in half. From this ridgeline, water flows in the western direction to the Island End and Mystic Rivers, and in the eastern direction to the Mill and Chelsea Creeks. Inland from the stream's edge, a network of waterways and tidelands once flowed through what are now Chelsea's projected flood zones. Disruption of these natural systems, by unregulated urban development, has made these areas vulnerable to coastal flooding.

The Mystic River Watershed includes 76 square miles of land area and 21 other communities.
(MyRWA, n.d.)

Coastal flooding occurs when the wind and tides overtop the shoreline and inundate low-lying areas. With an average elevation of less than ten feet above sea level, it is not surprising that approximately 20% of the City is mapped within a potential coastal flooding area in present day. Add on sea level rise projections of 0.6 feet in 2030 and 3.2 feet in 2070, and anticipated more frequent and intense storm events, this percentage increases to 35% in 2030 and 45% in 2070.

Figure 3.1 1903 Map of Chelsea
(top of the page) Image courtesy of the University of New Hampshire Library Digital Collections

Flood Insurance Rate Maps

Chelsea's floodplain boundaries have been mapped by the Federal Emergency Management Agency (FEMA) for insurance purposes for over 40 years. Flood Insurance Rate Maps (FIRMs) are developed and updated based on historic information regarding river flow, storm tides, and rainfall. Additional sources include hydrologic and hydraulic analyses, topographic surveys, and anecdotal community information.

Fema mapping

is limited in that the maps only estimate the flood risk based on historical climate information and does no consider future problems caused by climate change.

The FIRMs issued in 1974, 1982, and 2009 for Chelsea show minimal coverage of and change to the flood hazard areas. These maps illustrate the floodplain hugging the shorelines of the Mystic and Island End Rivers and include some low-lying areas adjacent to Chelsea and Mill Creeks. FEMA issued new FIRMs for Suffolk County, effective March 16, 2016. The FEMA FIRMs are included as Appendix C.

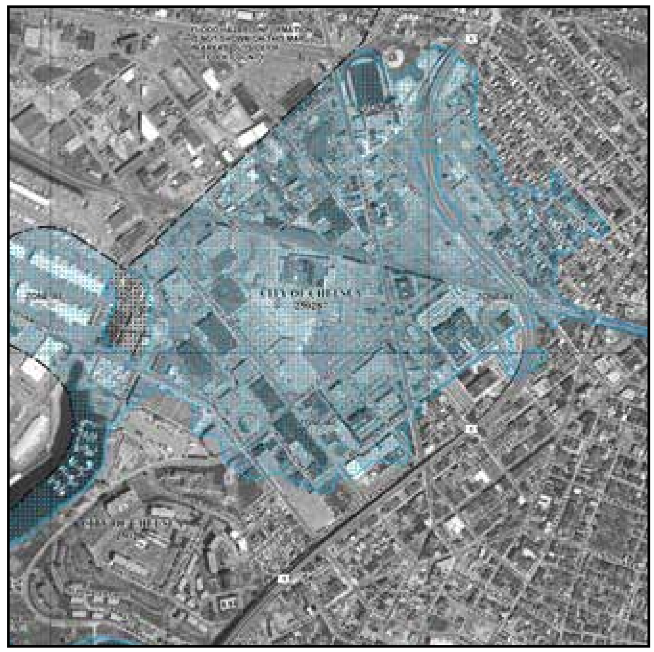


Figure 3.2 Island End River, 2016 FEMA Map

Chelsea's updated mapping shows a much larger flood risk area within the City, extending through the areas of the historic waterways shown on the 1903 mapping. Additionally, as part of the revised FEMA flood mapping process, the City of Chelsea intends to modify its Floodplain Overlay District to include the extents of the 2016 FIRM.

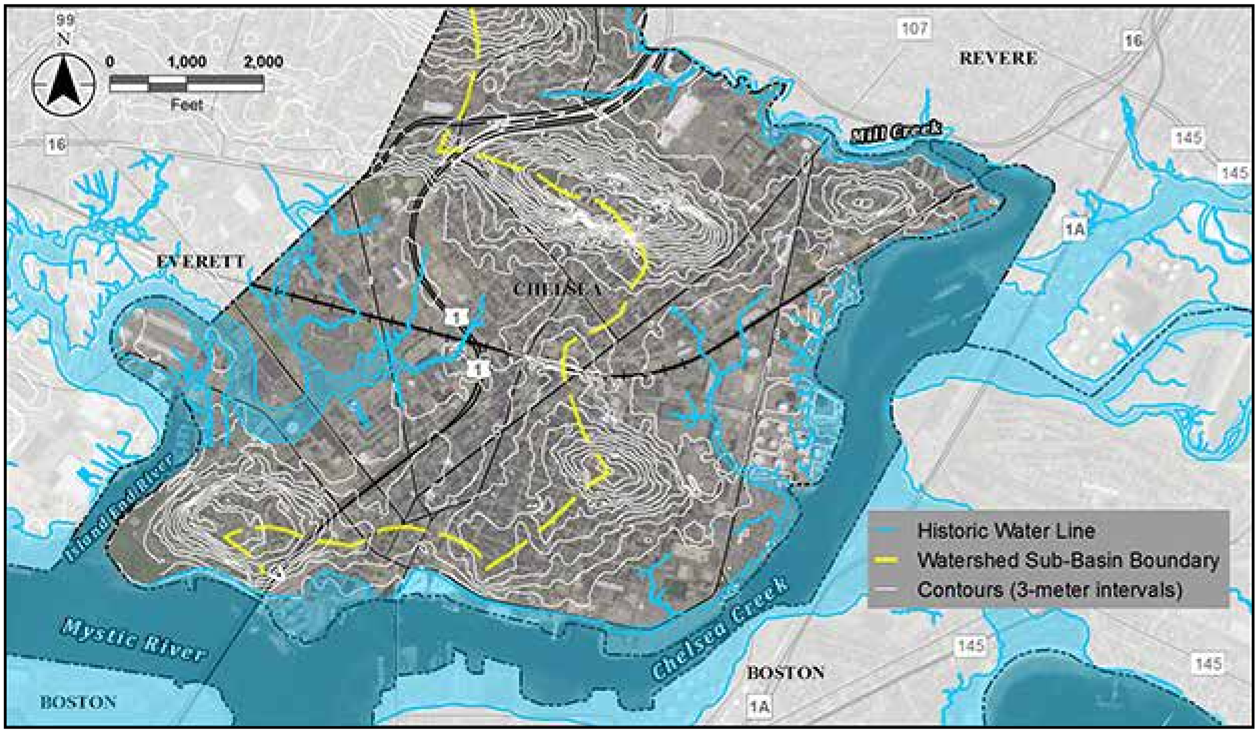


Figure 3.3 Topographic Map and Historic Water Lines in Chelsea (MassGIS)

Boston Harbor Flood Risk Model

Recognizing the limitations of FEMA mapping, communities and businesses in the Metro-Boston area are now using the Boston Harbor Flood Risk Model (BH-FRM), to evaluate which of their assets are vulnerable to coastal flooding. The BH-FRM is a dynamic model, meaning that it assesses future flood risk based on sea level rise projections and a range of potential storm events.

The BH-FRM was developed by the Woods Hole Group as part of a Massachusetts Department of Transportation (MassDOT) and Federal Highway Administration (FHWA) Pilot Project to assess the effects of climate change on the Central Artery Tunnel System. The Pilot Project report explains that the "hydrodynamic modeling is based on mathematical representations of the processes that affect coastal water levels such as riverine flows, tides, waves, winds, storm surge, sea level rise, and wave set-up, at a fine enough resolution to identify site specific locations that may require adaptation alternatives (Bosma, et. al., 2015)."

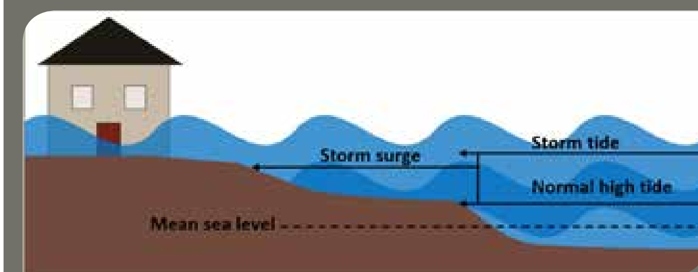
The BH-FRM models the topography, infrastructure, and other relevant local landscape information. Industry leading hydrodynamic and wave models[1] were coupled to depict probable future sea level elevations and simulate tides, waves, winds, velocities, and riverine flows from a variety of storm types. A more in depth discussion of the "Probabilistic Modeling of Sea Level Rise, Storm Surge, and Waves" is provided in Appendix D.

Maps were created for Chelsea for present day and future years 2030 and 2070. For this project, WHG has produced two types of maps for these time periods, displaying either the probability or depth of flooding . For the depth of flooding maps, one map depicts flooding depths associated with a 1% probability level (or 100-year flood level), and another map for a 0.1% chance flood (or 1,000-year flood level – a less frequent, more intense occurrence).

There is not much variation in the City's probable flood footprint between 2030 and 2070. This is not surprising for two reasons. First, the flood areas are topographically constrained to the low lying areas of the City. Second, coastal flooding in Chelsea is primarily due to still water impacts and not significant wave action. So while the flood footprint doesn't change, the likelihood and anticipated depths of flooding do increase over time.

What is Storm Surge ?

An abnormal rise of water generated by a storm, over and above the normal tide range. (Adapted from NOAA)



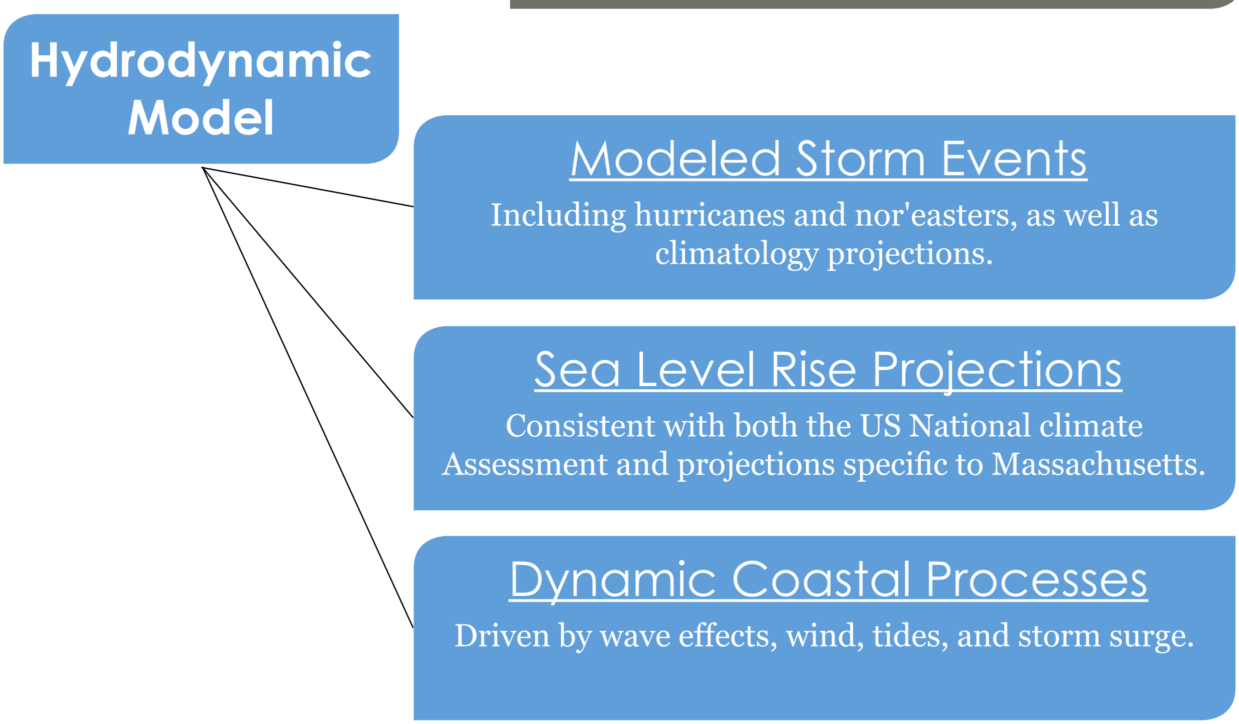


Figure 3.4 Mapping Coastal Flooding
The mapping on pages 3-6 and 3-7 illustrate current (2013) and future (2030 & 2070) probability of coastal inundation in Chelsea, Massachusetts. Results are based on a hydrodynamic model developed for the Massachusetts Department of Transportation (Famely et al. 2016). Note: This data does not take into account inland freshwater flooding.

Natural Resource Modeling

It is also environmentally responsible for the City to consider the impact of sea level rise on natural resources, not just built infrastructure.

Salt Marsh
(credit: Matt Poole/USFWS, Flickr)

The Sea Level Affecting Marshes Model (SLAMM) was first developed with Environmental Protection Agency (EPA) funding in the 1980s. As part of the Statewide Modeling the Effects of Sea Level Rise on Coastal Wetlands Project for the Massachusetts Office of Coastal Zone Management, Woods Hole Group evaluated the impact of sea level rise on wetlands and shorelines throughout the Commonwealth.

In Chelsea, the shorelines consist of tidal flats, rocky intertidal shoreline, coastal beach, coastal bank, salt marsh, shallow marsh meadow or fen, and salt marsh (see Table 3.1 below).

Table 3.1 Wetland Resources Along Chelsea's Streams

Wetland Resource	Island End River	Mystic River	Chelsea Creek	Mill Creek
coastal beach	•	•	•	
coastal bank bluff or sea cliff	•		•	
rocky intertidal shore		•	•	
salt marsh			•	•
shallow marsh meadow or fen				•
tidal flats	•	•	•	•

The model shows areas of likely coastal wetland loss due to higher water tables and more frequent flooding. These impacts may be mitigated by constructing living shorelines as an alternative to, or in addition to, hardened waterfront structures such as sea walls or bulkheads. Living shorelines use plants, sand, coir fiber logs, and stone to provide shoreline protection and maintain valuable habitat (www.habitat.noaa.gov). Further information on the SLAMM process and its results for Chelsea is provided in Appendix E.

[1]Advanced Circulation (ADCIRC) models surface elevations of sea level rise and tidal effects of storm surges. SWAN (Simulating Waves Nearshore) shows the effects of waves generated by the modeled storms.

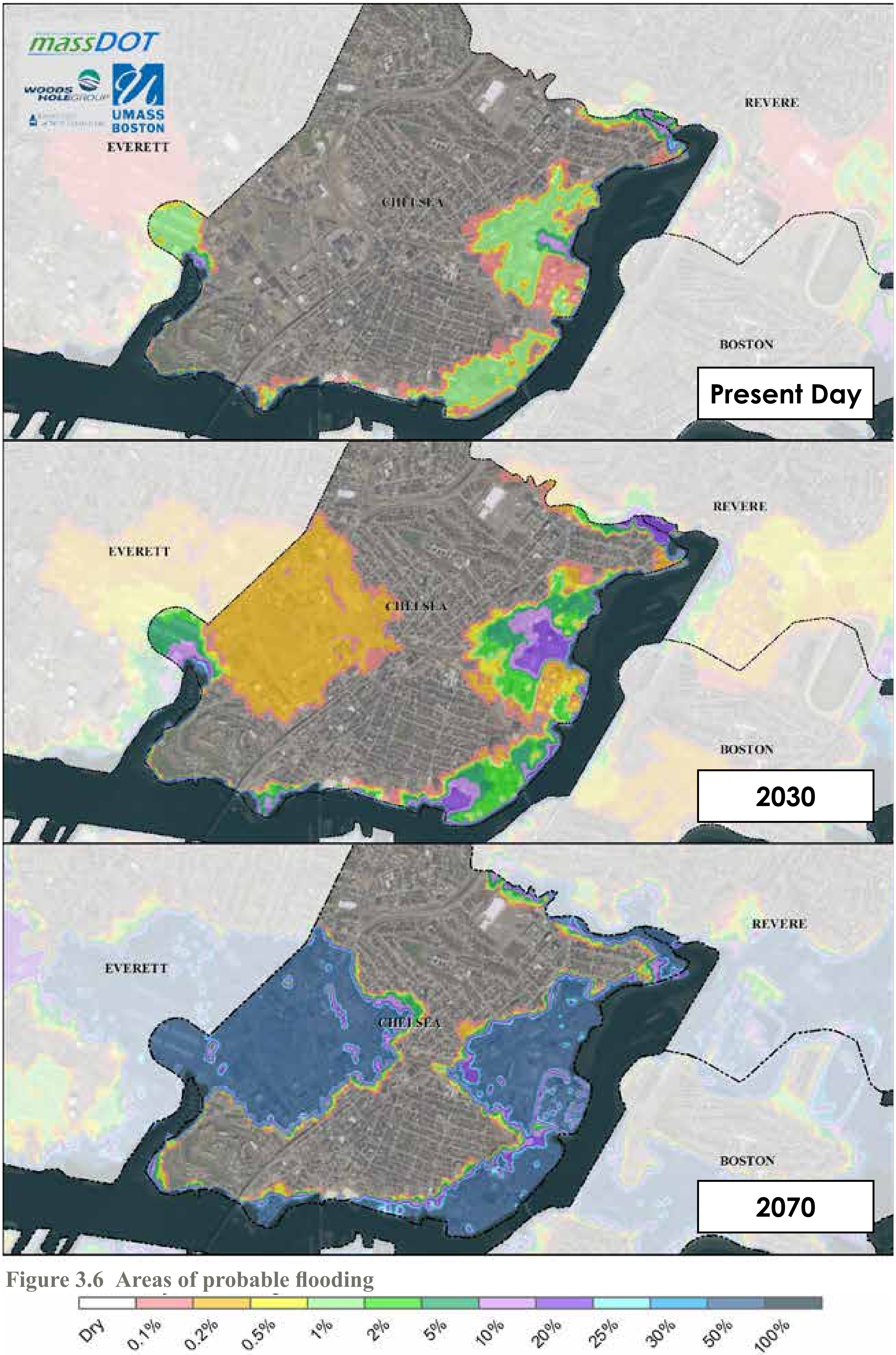


Figure 3.6 Areas of probable flooding

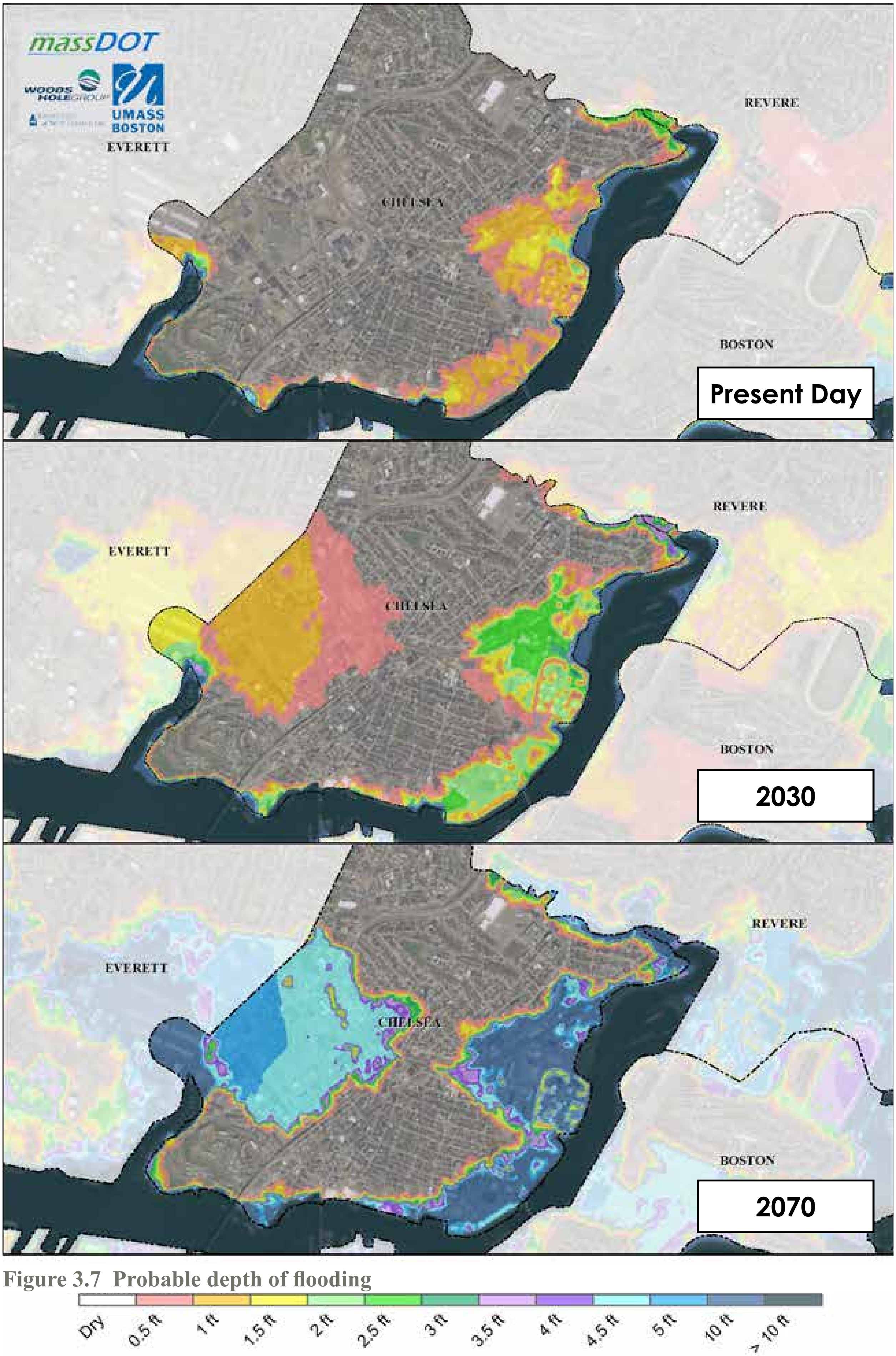


Figure 3.7 Probable depth of flooding

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4

COASTAL FLOODING IN CHELSEA

There are key pathways where coastal flood waters are predicted to enter the low-lying areas of the City. These pathways are identifiable by the areas with a high probability of flooding on the 2030 BH-FRM mapping (10-20%, shown on Figure 4.1 on page 4-2, in color purple). Interestingly, these flood pathways mimic the historic network of waterways and tidelands that existed prior to the urban development that occurred in the mid- to late-nineteenth century.

Each of the identified flood pathways puts critical public infrastructure at risk. The pathways also have the potential to impact private commercial, industrial, and residential areas throughout Chelsea. From west to east, five zones vulnerable to flooding were identified:

- **Island End River**
- **Mystic River**
- **Lower Chelsea Creek**
- **Upper Chelsea Creek**
- **Mill Creek**

In total, these vulnerability zones comprise approximately 20% of the City's land area under present day, 35% in 2030, and 45% in 2070. This footprint poses a major threat to public safety and the quality of life for people living and working in the City. It also has the potential for widespread regional impacts to food distribution and petroleum enterprises. The following pages look at each of the five identified vulnerability zones in closer detail.

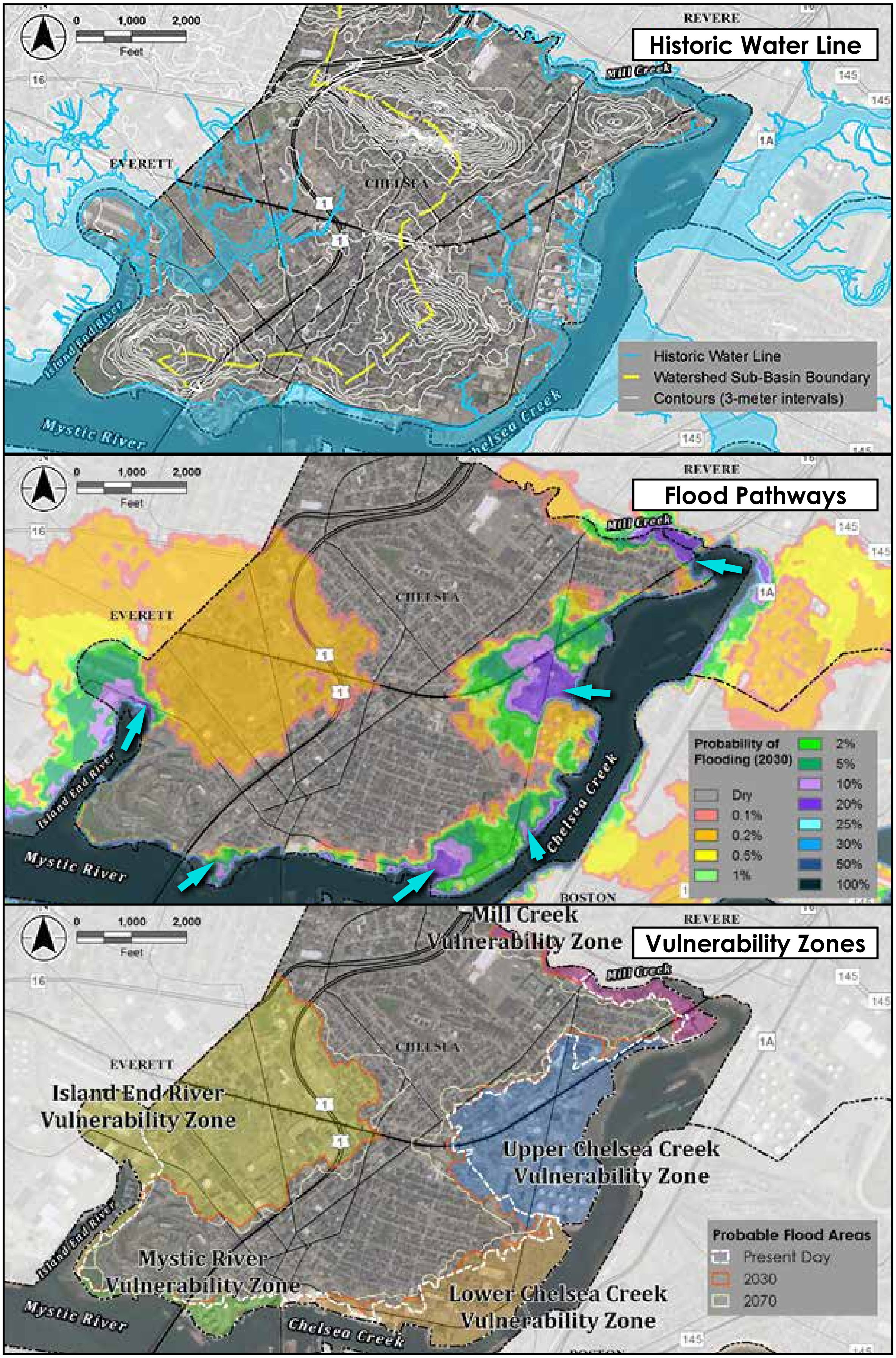


Figure 4.1 Flood Pathways and Vulnerability Zones

Island End River Vulnerability Zone

General Description

290+ ACRES IN 2030

The Island End River is a tributary to the Mystic River. The western bank is in Everett, and the eastern bank is in Chelsea. This vulnerability zone generally extends from the Island End River at Beacham/Williams Street (a major freight corridor), north to Route 16, and east beyond Route 1 to the MBTA Commuter Rail Station. This area is a significant local and regional commercial, industrial, and food distribution center.

The historic path of the river once extended through the New England Produce Center into Everett, and north through the existing commercial area to Revere Beach Parkway and Route 1. These low-lying areas were once extensive tidal flats and salt marsh, but the tidelands were dammed and filled to support development in the late 19th century. The Island River has been the subject of many years of hazardous substance remediation and natural resource restoration efforts.

Today, the edge of the Island End River in Chelsea is characterized by tidal flats, coastal banks and beaches. The shoreline also includes armored slopes at Admiral's Hill Marina, and salt marsh. The Market Street culvert discharges stormwater runoff from a 119-acre catchment area in Chelsea and Everett to the River. The Carter Street pump station is currently being redesigned to redirect flows from the catchment area to nearby underground systems rather than the culvert. Stormwater flows from other portions of Everett will continue to discharge at the culvert.

Figure 4.2 Island End River
shown at King Tide, October 2016 (top); high tide, May 2016 (middle); and low tide, April 2016 (bottom)

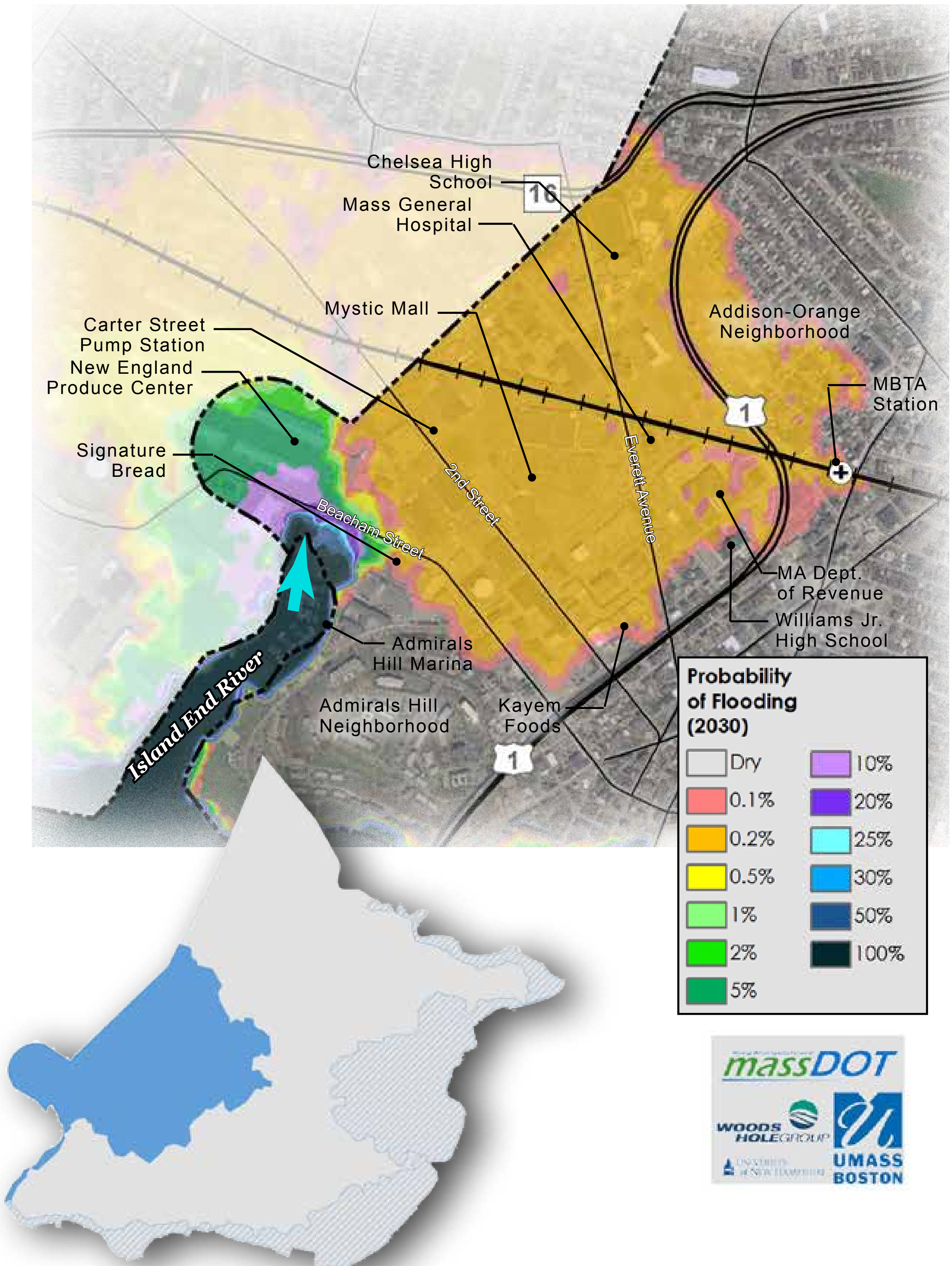
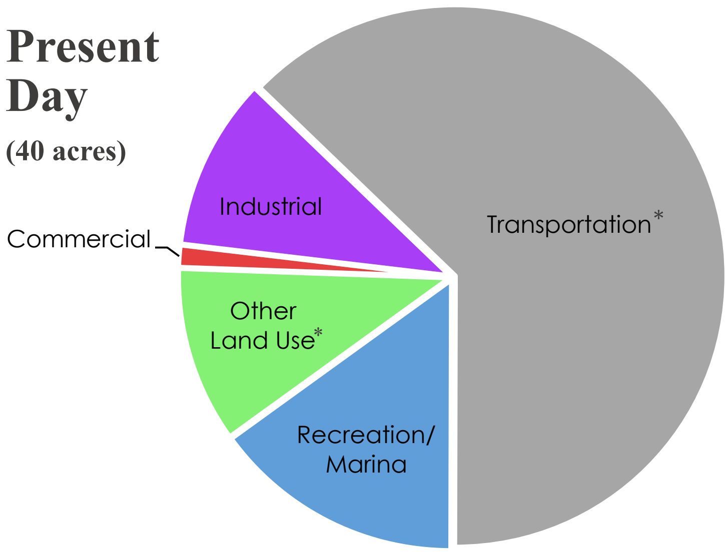
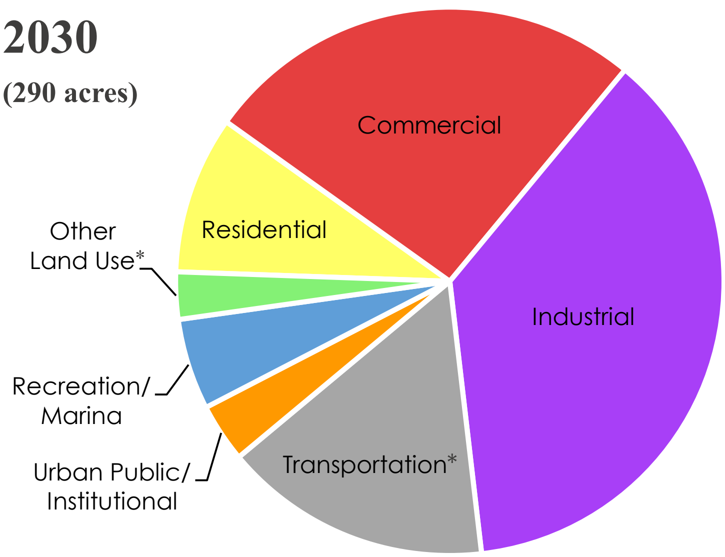


Figure 4.3 Island End River Vulnerability Zone: Flood Pathway and Locus

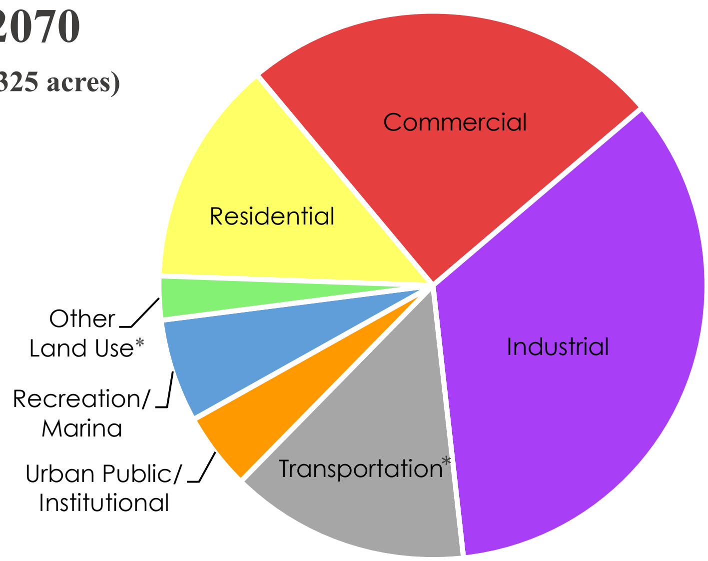
Present Day
(40 acres)



2030
(290 acres)



2070
(325 acres)



*"Other Land Use" includes wetlands, waterways, forest, beach, open land, cemetery. "Transportation" includes roads, parking areas, and fuel terminals

Land Use within the Island End Vulnerability Zone:

The majority of this zone is comprised of industrial and commercial land uses. Industrial uses include food distribution and processing facilities and manufacturing. Commercial uses include a combination of small and large scale retail shopping, restaurants, hotels, hospitals, and office space. There are also city, state and federally-owned buildings.

Residential land use is located in the Addison-Orange Neighborhood along the northeast perimeter of the zone. This neighborhood is an Environmental Justice Population (2010 Census), where more than 25 percent of its residents identify as minorities and/or speak languages other than English.

The City and State have invested significant resources in the Everett Avenue Urban Renewal District, located on the north side of the railroad corridor. Over $20 million dollars of public funding has been spent on roadway and utility infrastructure improvements to support continued mixed use development in this area.

Recreation land directly abutting the River is dedicated waterfront recreation including the DCR-owned Mary O'Malley Park, privately-owned Admiral's Hill Marina, and the city-owned Island End Park built in 2010.

Critical Infrastructure:

Critical infrastructure within the Island End River Vulnerability Zone includes:

	Type	Asset/Facility
	Transportation	Key connector roadways Commuter Rail and Station Freight Rail Silver Line Bus Rapid Transit Corridor and Station Maritime commerce
	Water and Wastewater	Underground system
	Stormwater	Carter Street Pump Station Market Street Culvert
	Buildings	High School and Williams Middle School City Yard US Post Office Hospital New England Produce Center Commercial business district Industrial Massachusetts Information Technology Center FBI Headquarters Residential
	Energy	Electric transmission and distribution system Natural gas distribution system and pressure regulating station
	Telecommunications	Underground conduits and aboveground lines
	Recreational	Island End Park (City of Chelsea) Mary O'Malley Park (DCR) Admiral's Hill Marina (private)

Mystic River Vulnerability Zone

General Description

23+ ACRES IN 2030

The Mystic River is the main waterway draining the 76 square mile Mystic River Watershed to Boston Harbor. The edge of the Mystic River in Chelsea is generally characterized by stone seawalls or sheet pile walls. The seawall and floodplain along the base of Mary O'Malley Park helps reduce the probability of flooding at lower elevations of the Admiral Hill neighborhood.

The identified vulnerable area generally extends from the Tobin Bridge, east to the Meridian Street Bridge, and north to Medford Street. Here, heating oil transport/distribution operations and other industrial/light industrial uses are particularly at risk of flooding. The Chelsea Yacht Club Marina, Lower Broadway Neighborhood, and access to the Admirals Hill neighborhood are also identified on the flood model.

Figure 4.4 Floodplain at Mary O'Malley Park

Figure 4.5 Mystic River
Looking East, up Chelsea Creek

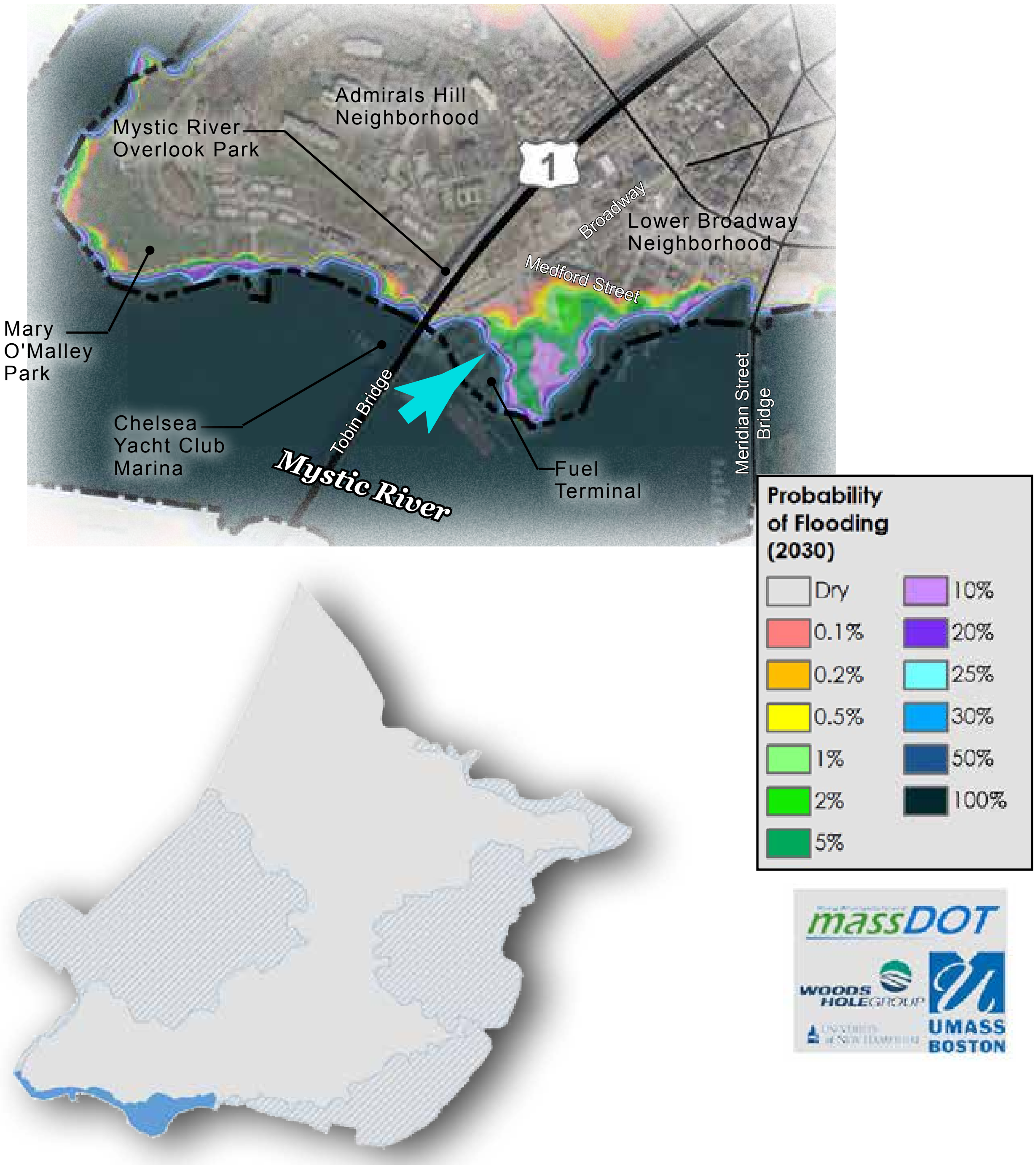
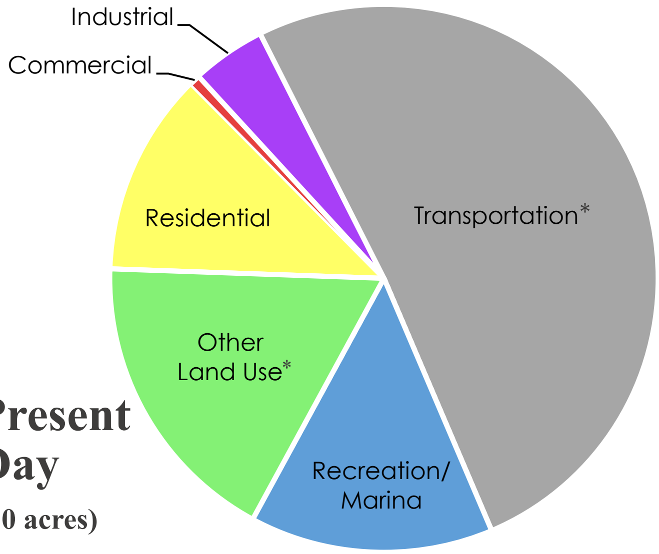
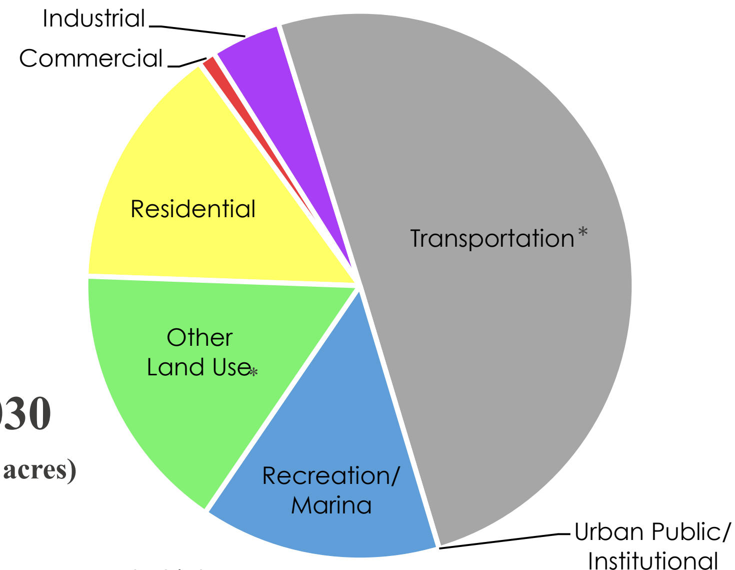


Figure 4.6 Mystic River Vulnerability Zone: Flood Pathway and Locus



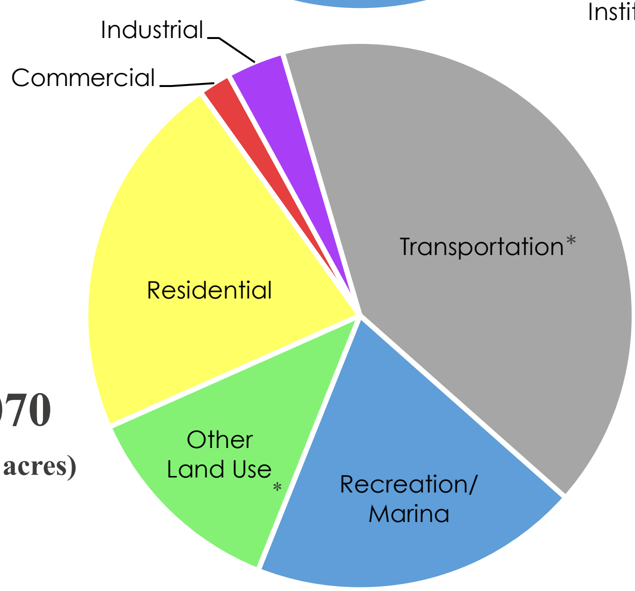
Present Day

(20 acres)



2030

(25 acres)



2070

(30 acres)

*"Other Land Use" includes wetlands, waterways, forest, beach, open land, cemetery. "Transportation" includes roads, parking areas, and fuel terminals

Land Use within the Mystic River Vulnerability Zone:

Much of this zone includes an oil terminal transportation and distribuition facility. Residential buildings are vulnerable in the Lower Broadway Neighborhood. This neighborhood is an Environmental Justice Population (2010 Census), where more than 25 percent of its residents identify as minority. The area also encompasses access to the Admirals Hill Neighborhood.

Critical Infrastructure:

Critical infrastructure within the Mystic River Vulnerability Zone includes:

	Type	Asset/Facility
	Transportation	Maritime commerce
	Water and Wastewater	Underground system
	Stormwater	Underground system Outfall at the end of Broadway Infrastructure supporting the Tobin Bridge/Expressway
	Buildings	Commercial Industrial Residential
	Energy	Electric transmission and distribution system Natural gas distribution system Petroleum
	Telecommunications	Underground conduits and aboveground lines
	Recreational	Polonia Playground Chelsea Yacht Club Two planned parks at the end of Broadway

Lower Chelsea Creek Vulnerability Zone

General Description

100+ ACRES IN 2030

This area generally extends from the Meridian Street Bridge over Chelsea Creek, northeast along the shoreline to Bass Creek, and inland generally following Marginal Street and Eastern Avenue. It is included in the Massachusetts Office of Coastal Zone Management's (CZM's) Chelsea Creek Designated Port Area (DPA). Vulnerable properties include those owned by Eastern Mineral, Massport, MWRA, as well as other small businesses.

Chelsea shares this section of industrial waterway with East Boston. The waters' edge in this area consists of a rocky shoreline or coastal banks and beaches. There are some tidal flats at the inlet to former Bass Creek, just south of the oil terminal. The shoreline also includes concrete and steel sheet bulkheads, riprap slopes, multiple berths, concrete and timber-decked piers, off-shore wharf and dolphins (CZM, 2015).

Designated Port Area (DPA)
boundaries are designated and regulated by CZM, under the Code of Massachusetts Regulations (301 CMR 25.00), for the promotion and protection of water-

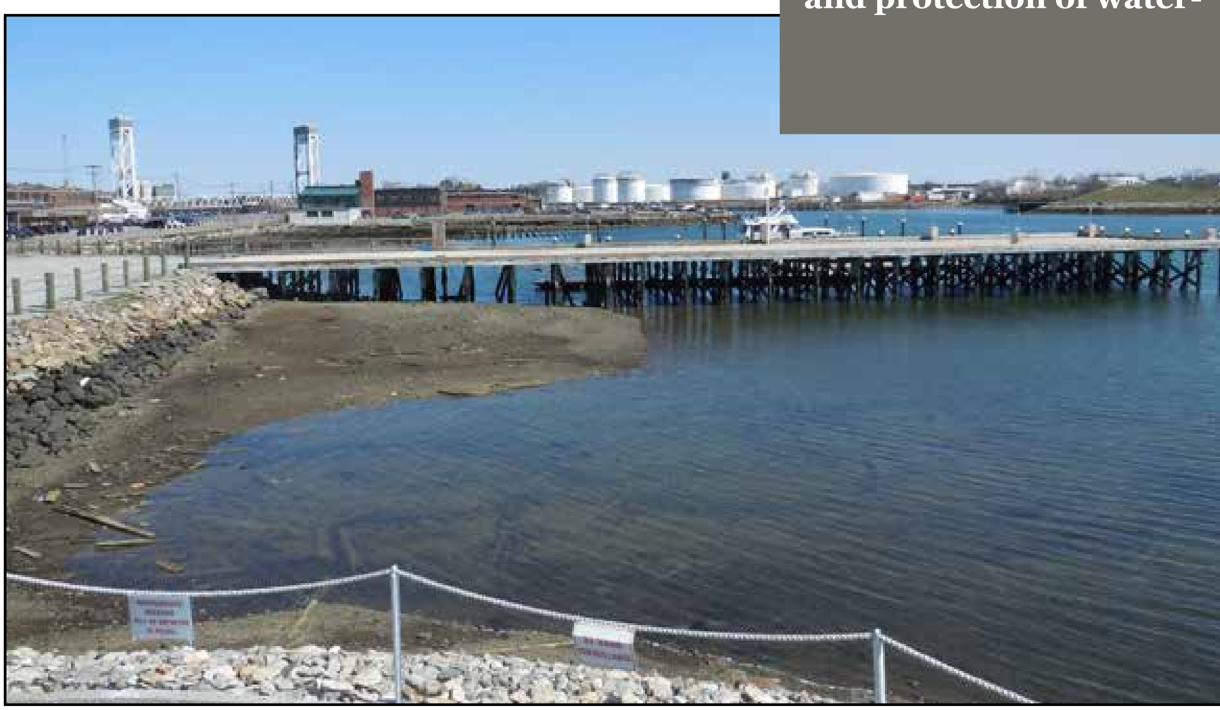


Figure 4.7 Lower Chelsea Creek
looking upstream from PORT Park

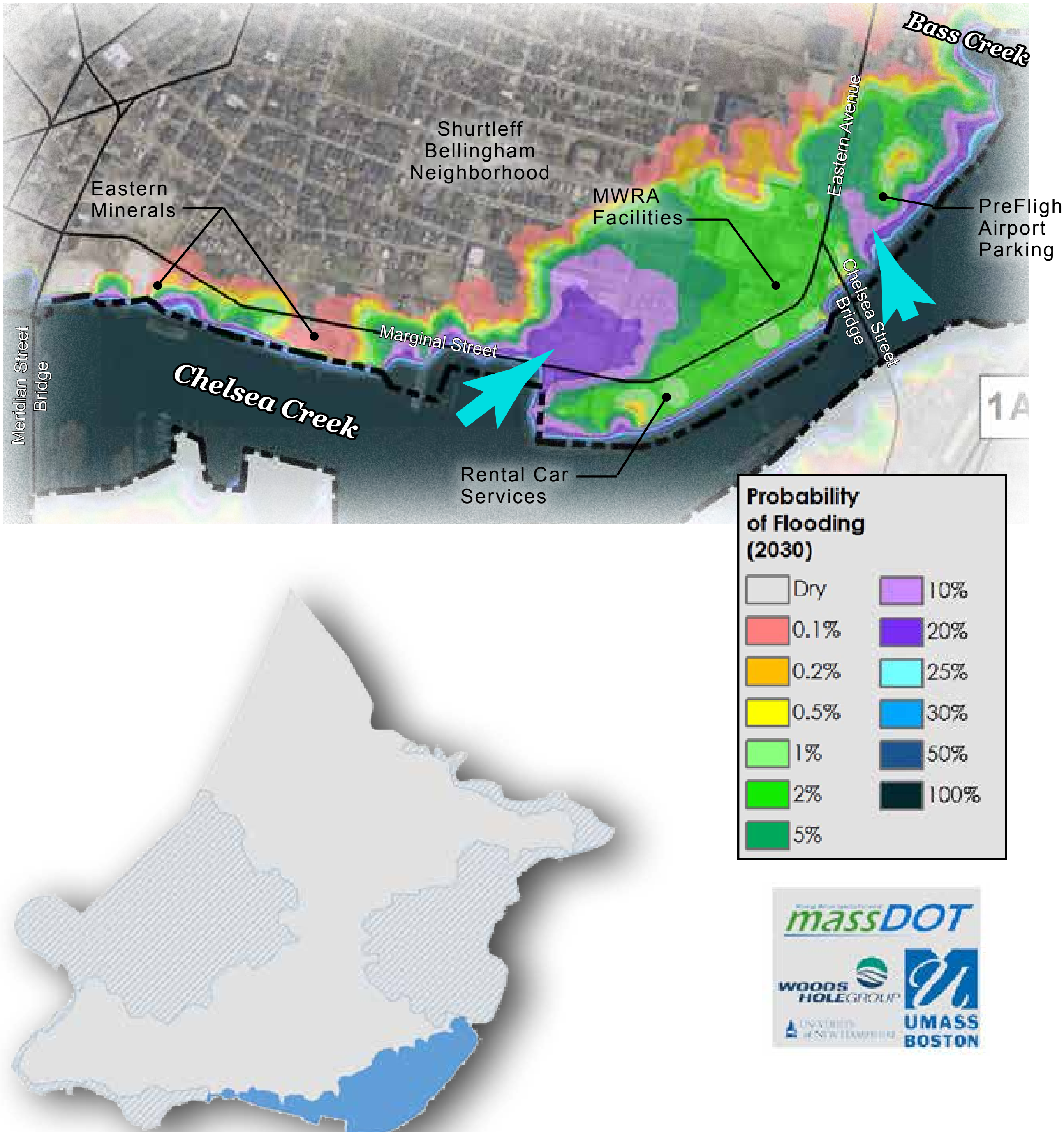
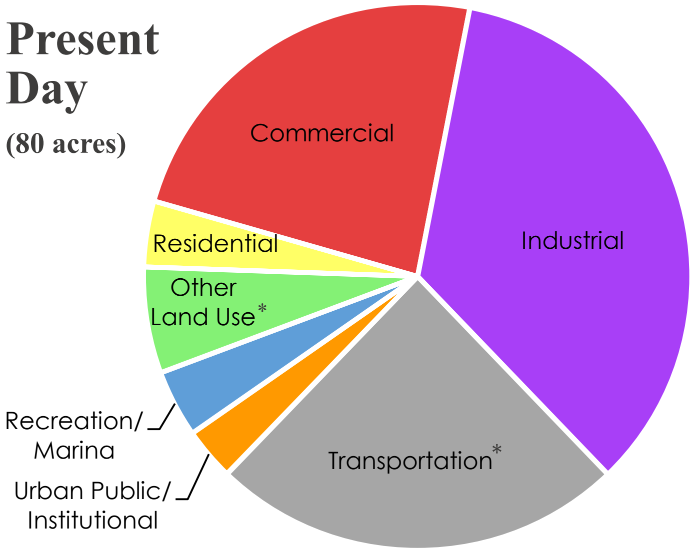


Figure 4.8 Lower Chelsea Creek Vulnerability Zone: Flood Pathway and Locus

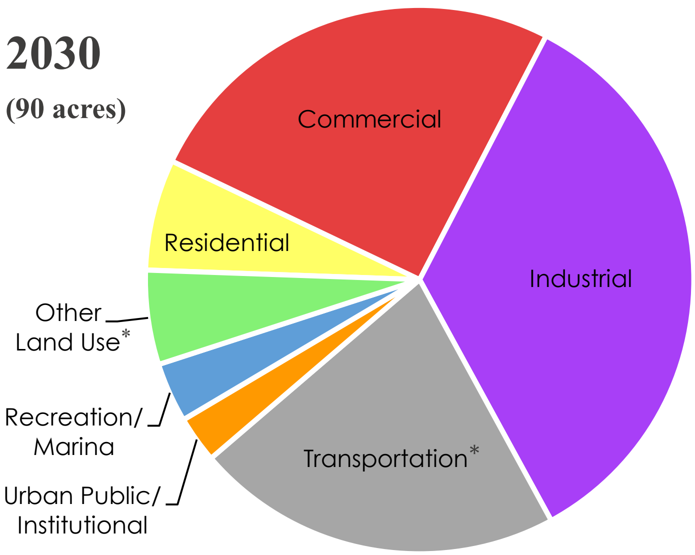
Present Day

(80 acres)



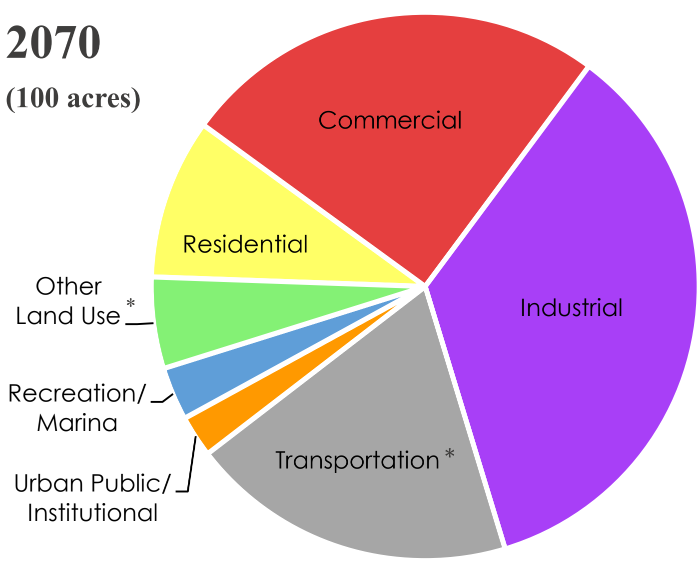
2030

(90 acres)



2070

(100 acres)



*"Other Land Use" includes wetlands, waterways, forest, beach, open land, cemetery. "Transportation" includes roads, parking areas, and fuel terminals

Land Use within the Lower Chelsea Creek Vulnerability Zone

The majority of this zone is comprised of industrial and commercial land uses that abut both sides of Marginal Street and Eastern Avenue. These uses include Eastern Salt importation and distribuition facility, and Massport's leased parking, shipping & logistics facilities. Other uses include the MWRA Screen House wastewater facility and a hotel. The perimeter of the Lower Chelsea Creek Vulnerability Zone includes residential buildings within the Shurtleff Bellingham Neighborhood. This neighborhood is an Environmental Justice Population (2010 Census), where more than 25 percent of its residents identify as being minority, having low-income, and/or primarily speaking foreign languages.

Critical Infrastructure:

Critical infrastructure within the Lower Chelsea Creek Vulnerability Zone includes:

	Type	Asset/Facility
	Transportation	Key connector roadways Silver Line Bus Rapid Transit Corridor and Stations Maritime commerce
	Water and Wastewater	Underground system Screen House and Headworks
	Stormwater	Underground System
	Buildings	Commercial and industrial Hotel Residential
	Energy	Electric transmission and distribution system Natural gas distribution system
	Telecommunications	Underground conduits and aboveground lines
	Recreational	PORT Park at Rock Chapel Marine Highland Park Chelsea Shared-Use Trail Proposed waterfront parks at Chelsea Street

Upper Chelsea Creek Vulnerability Zone

General Description

150+ ACRES IN 2030

This area generally extends from Bass Creek to Mill Creek, and inland to Broadway. Businesses along Eastern Avenue (a major freight route), include numerous transport/logistic/air forwarding facilities, and function as a major employment anchor. The MWRA owns a facility on Griffin Way, and residential neighborhoods (Shurtleff Bellingham and Mill Hill) are on the frindge of the area.

Chelsea Creek is a Designated Port Area (DPA), regulated by the Massachusetts Office of Coastal Zone Management (MCZM). Within DPA boundaries, properties are generally restricted to water-dependent industrial uses. Chelsea shares this section of industrial waterway with East Boston and Revere. The shoreline consists of coastal beach, riprap slopes, bulkheads and dolphins (CZM, 2015). This section of River also contains tidal flats and salt marsh.

Figure 4.9 Arial Photograph of Upper Chelsea Creek
View from East Boston at Chelsea Creek Bridge, looking upstream

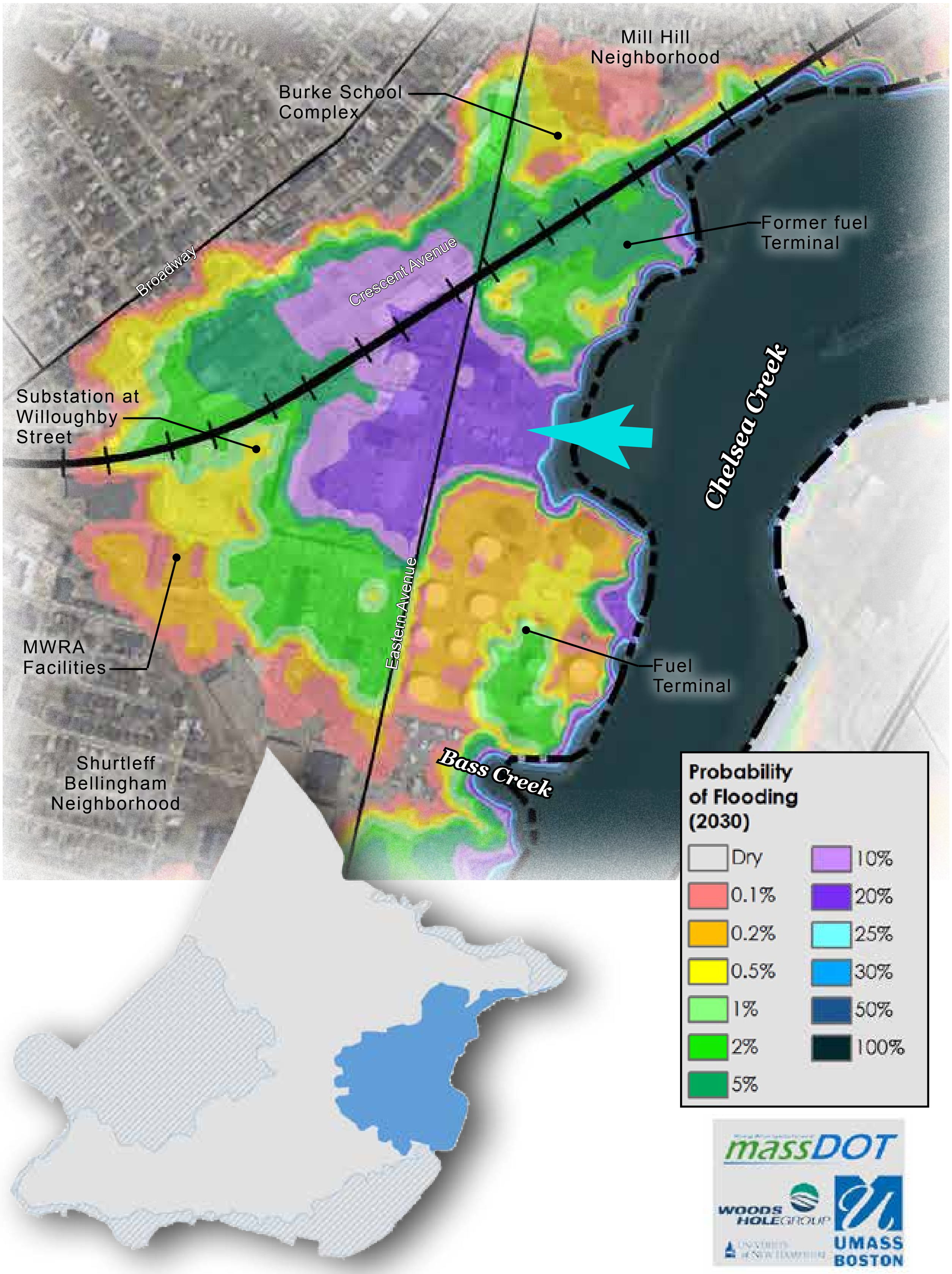
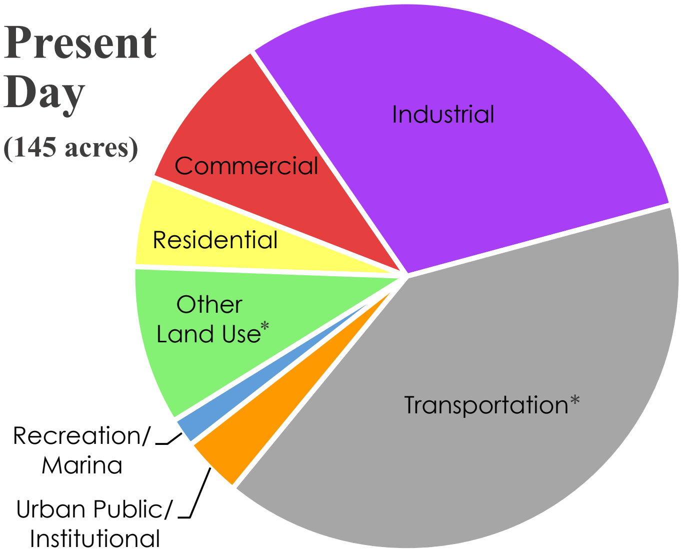


Figure 4.10 Upper Chelsea Creek Vulnerability Zone: Flood Pathway and Locus

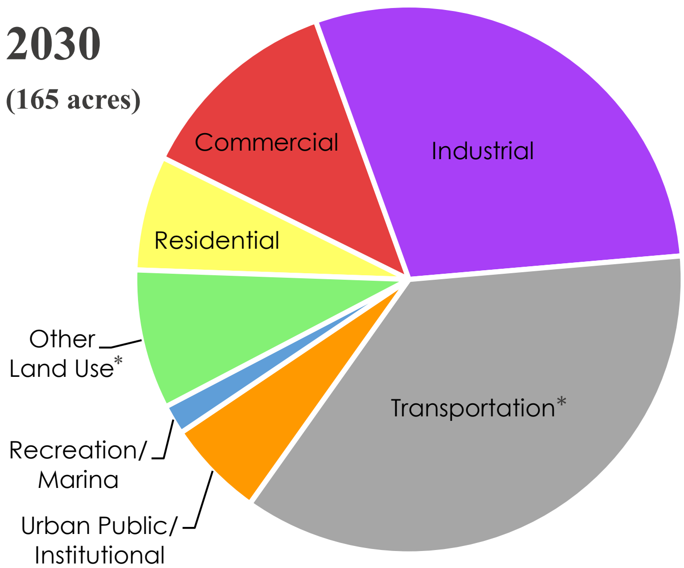
Present Day

(145 acres)



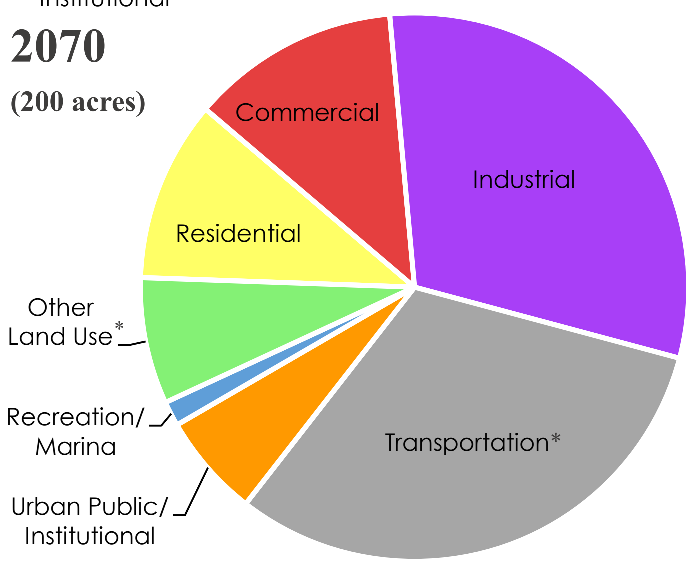
2030

(165 acres)



2070

(200 acres)



*"Other Land Use" includes wetlands, waterways, forest, beach, open land, cemetery. "Transportation" includes roads, parking areas, and fuel terminals

Land Use within the Upper Chelsea Creek Vulnerability Zone

As a major freight route, Eastern Avenue houses a number of commercial and industrial uses, including existing and former fuel terminals and numerous other facilites specializing in transport, logistics, and air forwarding services.

The Burke Complex, which houses the City's three elementary schools, is in this zone.

Residential use within the risk area includes the Shertleff-Bellingham Neighborhood located west of the Silver Line Bus Rapid Transit (BRT) corridor and the Mill Hill Neighborhood located north of the active MBTA railroad corridor the northwest perimeter. These neighborhoods are Environmental Justice Populations (2010 Census), where more than 25 percent of the residents identify as being minority and/or having low-income.

Critical Infrastructure:

Critical infrastructure within the Upper Chelsea Creek Vulnerability Zone includes:

	Type	Asset/Facility
	Transportation	Key connector roadways Silver Line Bus Rapid Transit Corridor Commuter and freight rail
	Water and Wastewater	Underground system MWRA Facility
	Stormwater	Underground System
	Buildings	Burke Elementary School Complex Commercial and industrial Residential
	Energy	Electric transmission and distribution system Substation #488 Natural gas distribution system Petroleum
	Telecommunications	Underground conduits and aboveground lines
	Recreational	Playground and fields at Burke Complex

Mill Creek Vulnerability Zone

General Description

20+
ACRES IN 2030

Mill Creek is a tributary to Chelsea Creek, bordered on the north by Revere. This creek has the most natural edge of Chelsea's waterways, lined with salt marsh and tidal flats. More than two acres of salt marsh have been restored along Mill Creek by the Chelsea Collaborative, a community organization focusing on environmental, social, and economic justice in the city (Chelsea Collaborative, n.d.).

In Chelsea, the vulnerable area associated with this flood pathway extends along Mill Creek, from its confluence with Chelsea Creek, west to Route 1, and inland to Clinton Street. The Mill Hill neighborhood abuts much of the creek, while a concentration of commercial and institutional properties exists north of Broadway. Six bridges cross Mill Creek, from its origin in Revere to Chelsea Creek, including Broadway and the MBTA Commuter Rail. Portions of Revere could also be affected by this flood pathway, including the Revere Beach Parkway (Route 16).

Figure 4.11 Mill Creek
View looking upstream at Broadway Bridge

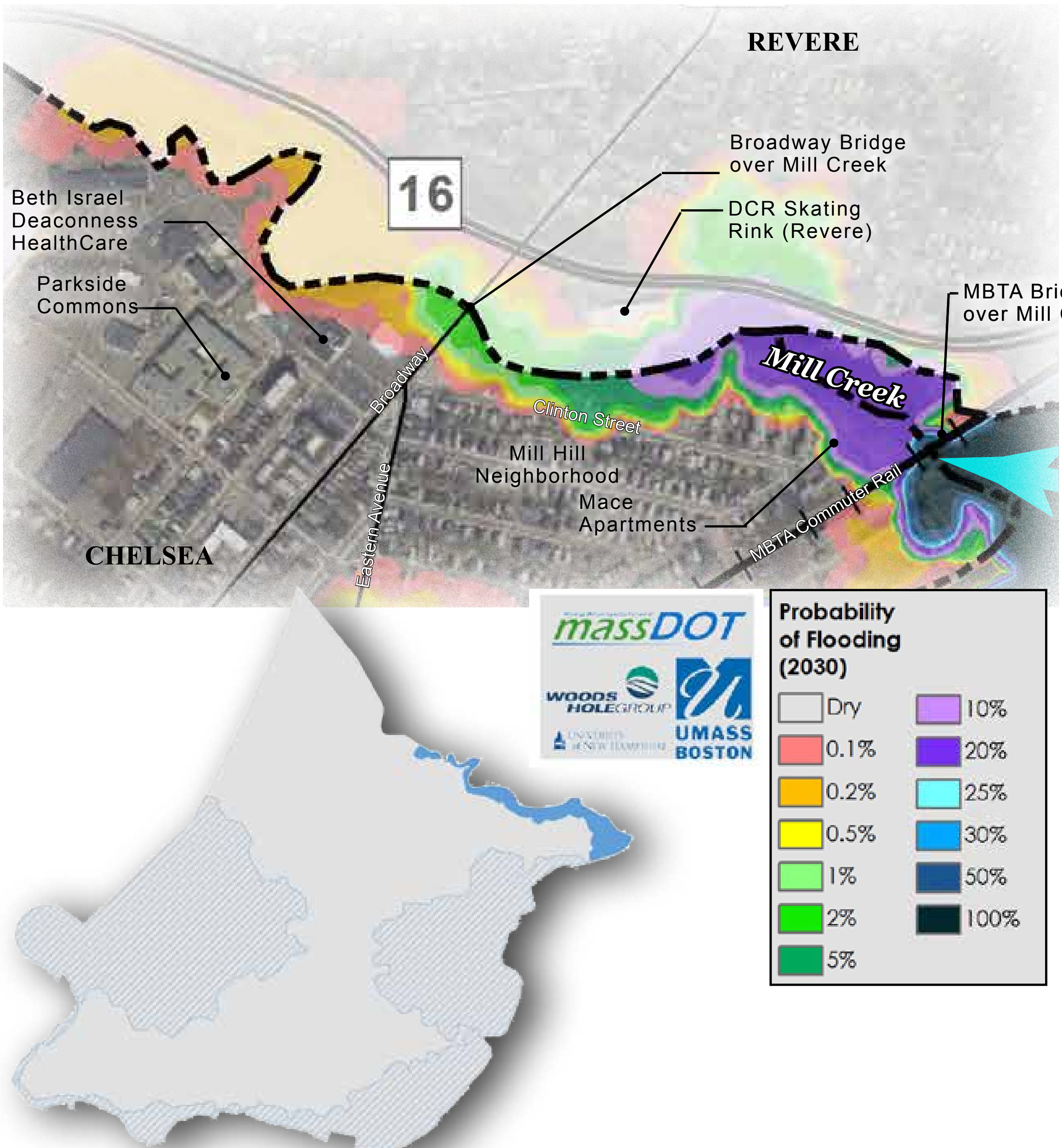
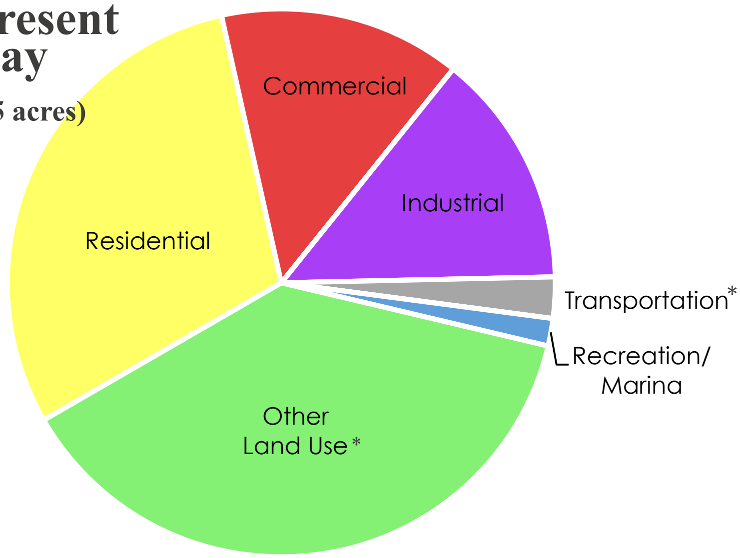


Figure 4.12 Mill Creek Vulnerability Zone: Flood Pathway and Locus

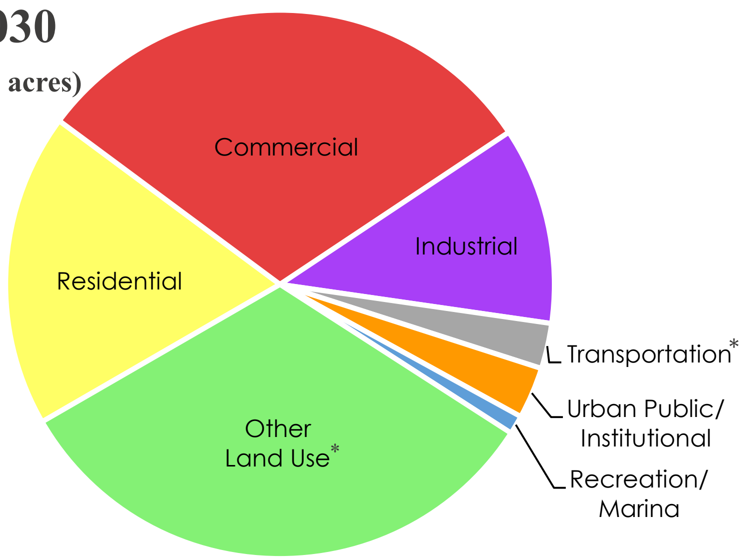
Present Day

(15 acres)



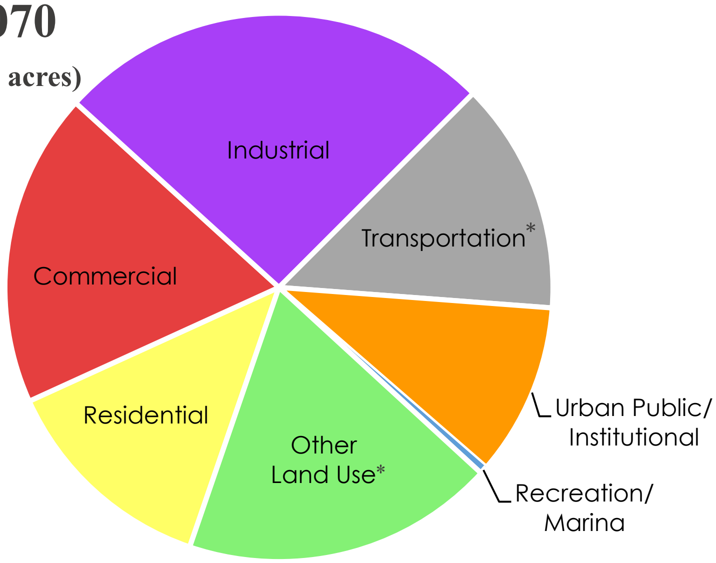
2030

(20 acres)



2070

(40 acres)



*"Other Land Use" includes wetlands, waterways, forest, beach, open land, cemetery. "Transportation" includes roads, parking areas, and fuel terminals

Land Use within the Mill Creek Vulnerability Zone

The primary land uses along the creek include commercial, institutional, and residential properties. The Beth Israel Deaconess HealthCare Center is located north of Broadway and the Mace Apartments public housing complex is located on Mill Court just north of the railroad tracks and former Forbes Industrial Park. Additional residential use within the risk area includes the Mill Hill and Chelsea Commons neighborhoods located along the south side of the Creek. These neighborhoods are Environmental Justice Populations (2010 Census), where more than 25% of the community identifies as minority and/ or having low-income.

Critical Infrastructure:

Critical infrastructure within the Mill Creek Vulnerability Zone includes:

	Type	Asset/Facility
	Transportation	Key connector roadways Commuter and freight rail
	Water and Wastewater	Underground system
	Stormwater	Underground System
	Buildings	Commercial and industrial Public housing Residential
	Energy	Electric transmission and distribution system Substation #445, reserved for future need Natural gas distribution system
	Telecommunications	Underground conduits and aboveground lines
	Recreational	Creekside Commons Dever Park

5 VULNERABLE INFRASTRUCTURE

As outlined in the prior chapters, the combination of future sea level rise and storm events has the potential to damage key infrastructure within five vulnerability zones in the City. Due to climate change, this infrastructure is in danger of becoming subject to conditions for which it was not designed. Without proper planning, damage could become more frequent, take longer to repair, and entail more costly repairs and socioeconomic disruption (EEA, 2011).

The following sections describe why this infrastructure is important to the City and the region, and what elements are susceptible to damage from the combination of coastal flooding and higher groundwater elevations due to sea level rise.

> **"A society cannot function without well-maintained infrastructure that provides critical services for its citizens. These services include providing habitable residential and workspace, transportation, energy sources, telecommunications, clean water, health, and safety, as well as systems to control such infrastructure threats as flooding, and improper release or disposal of wastewater, solid waste, and hazardous materials."**
>
> *- Executive Office of Energy and Environmental Affairs, Massachusetts Climate Change Adaptation Report*

Transportation

Chelsea's transportation infrastructure includes a multi-modal network of roads, rail, and maritime facilities that are critical for the regional movement of people, equipment, and goods. Damage to these networks due to coastal flooding would have significant economic, social, and emergency response impacts.

Roadways

The road network in Chelsea includes a combination of limited access highway (US Route 1), multi-lane highway (Route 16), major local collectors (e.g. Broadway or Eastern Avenue), and minor local arterials (e.g. Cottage Street or Clinton Street). The City is responsible for maintaining over 44 miles of roads. This network provides significant commuter and truck access to and from Boston and the surrounding cities and towns. The Tobin Bridge, connecting Route 1 over the Mystic River between Chelsea and Charlestown, transports approximately 79,000 vehicles across the bridge daily (MassDOT, 2016). MassDOT traffic counts show about 43,000 vehicles crossing Chelsea Creek each day[1] – 47% via the Meridian Street Bridge and 53% using the Chelsea Street bridge.

Residents also rely upon public bus service provided by the Massachusetts Bay Transportation Authority (MBTA). There are over 100 stops serving five bus routes throughout Chelsea. In addition, the Silver Line Gateway Bus Rapid Transit corridor is under construction from Eastern Avenue northwest to the Mystic Mall, including 4 new bus stations.

These State- and City-owned road systems are also essential to providing safe passage for residents and workers evacuating flooding areas prior to storm events. Roads also play an important role in disaster recovery efforts by providing access to damaged areas for emergency responders and construction equipment.

Why are roadways vulnerable?

Flood waters can destroy roadway pavement and lead to washouts. Sea level rise will result in higher groundwater elevations, which could damage the roadbed and also lead to road collapse. Bridges and culverts are also vulnerable to flood damage. As the depth and strength of flood waters increase, the streambed surrounding these structures can erode or washout, causing damage or collapse.

[1]Traffic volumes were grown from 2004 MassDOT Transportation Management System Traffic Count Database System data to 2016, using the region wide average annual traffic growth rate of 0.5% as determined by the state-wide travel demand model.

Rail

Rail lines in Chelsea are used for both transit and freight. CSX and Pan Am Railways provide freight service along the same corridor as the MBTA commuter rail. The tracks through Chelsea are generally located at ground-level. Approximately 80% of the active rail corridor in Chelsea is located within the 2030 mapped risk area.

> ### *Why are rail lines vulnerable?*
>
> **Flood waters would restrict transit and freight rail service to and through the City. Similar to roadways, the railbed, stone ballast, and structures are vulnerable to erosion and washout.**

The MBTA's Newburyport/Rockport commuter rail lines connect 15 northeastern coastal communities to North Station in Boston. About 17,000 boarders commute through Chelsea on an average weekday (MBTA, 2014). The current MBTA commuter rail station is located at the intersection of Arlington and Sixth Streets, however there are plans to move the station to the Mystic Mall at Everett Avenue.

The CSX corridor reaches north to Montreal, west to Chicago, Kansas City and Memphis, and south to New Orleans and Miami. CSX engines haul coal and merchandise including agricultural, food and consumer, chemical, automotive, metal, and forest products, as well as phosphates, fertilizers, minerals, waste and equipment. Locally, CSX serves the New England Produce Center on Beacham Street.

The Pan Am Railways corridor reaches from New Brunswick, Canada to New Haven, Connecticut and Upstate New York. The local branch has rights to the MBTA line serves industries in Lynn, Salem and Peabody, and a terminal interchange in Boston. Grain, coal, sand and gravel, food products, lumber, paper and pulp, chemicals and plastics, petroleum, processed minerals, metals, scrap metal, finished automobiles and intermodal trailers and containers are all handled by Pan Am trains.

Figure 5.1 MBTA Railroad Bridge over Mill Creek
Here, the existing high water level appears just below the beams of the bridge.

[2]Rounded average of 2012 and 2013 data for typical day boardings, by route (MBTA, 2014).

Maritime

Federal maritime navigation channels extend along Chelsea Creek, Mystic River, and Island End River. Each of these waterways is used for barge transport. Chelsea Creek has been identified by state and federal officials as a critical energy pathway, crucial to providing petroleum products (gasoline, diesel fuel, heating oil, jet fuel) to the region. The U.S. Army Corps of Engineers maintains the federal shipping channel in these waterways.

At the state level, the Designated Port Area (DPA) regulations at 301 CMR 25.00 protect and promote water-dependent industrial uses such as commercial fishing, shipping, and other vessel-related activities associated with water-borne commerce and to manufacturing, processing, and production activities reliant upon marine transportation or the withdrawal or discharge of large volumes of water. State policy seeks to preserve and enhance the capacity of the DPAs to accommodate water-dependent industrial uses and prevent significant impairment by non-industrial or nonwater-dependent types of development, which have a far greater range of siting options. (CZM, 2016). The DPA boundaries in Chelsea include Chelsea Creek and Mystic River, which also includes the Everett side of the Island End River.

In addition, with this report and various other recent planning efforts, Chelsea is exploring ideas for the future of the Chelsea Creek waterfront. These current projects aim to help inform the preparation of a future City of Chelsea Municipal Harbor Plan.

Oil Tanker Traveling up Chelsea Creek

Why is maritime infrastructure vulnerable?

The shoreline edge along these waterways is a combination of stone revetment protection and earth retaining structures such as granite or concrete seawalls. Other structures include steel sheet pile or concrete shutter panel bulkheads. These structures appear at locations where deeper berths are required to accommodate deep draft vessels. A significant storm event could overtop these structures and the increased frequency of storms could compromise the structural integrity over time. Flooding could also result in inland debris entering the channel which would impair maritime transportation.

Water and Wastewater

The City is part of the regional Massachusetts Water Resources Authority (MWRA) system. The MWRA is a Massachusetts public authority that provides wholesale water and sewer services to 2.5 million people and more than 5,500 large industrial users in 61 metropolitan Boston communities. The MWRA has over 5 miles each of water and sewer lines within Chelsea. In addition to this piping network, MWRA's Chelsea Facility and Chelsea Creek Screen House and Headworks are located within the City limits.

The City operates and maintains its own water and sewer systems. The City purchases all of its water directly from the MWRA. The water is delivered through five MWRA revenue meters into the city's distribution system. The system delivers water for drinking and other uses, and is used for fire protection. Chelsea's water distribution system is comprised of approximately 60 miles of water mains. 70% of which is over 50 years old. The City also has approximately 60 miles of sewer mains.

The MWRA's Chelsea Facility is located on Griffin Way and consists of two buildings – one administration building and one maintenance building. Over 500 employees work out of this facility. There are nearly three acres for outside material and equipment storage, employee parking, and other support infrastructure. The administration building also houses the

MWRA Screen House

Why is the water and wastewater system vulnerable?

Erosion and transportation infrastructure washout could have secondary impacts on the piping system. Rising sea levels and the consequent rising groundwater elevations could also cause soils to shift, particularly at boundaries between different soil types. Movement and loss of soil strength places stress on pipes and joints, and can cause significant damage. Flooding at the MWRA's Chelsea Facility and Chelsea Creek Screen House and Headworks could compromise the structural integrity of the building and put internal operation and control systems at risk. Service interruptions at these facilities would significantly impair regional MWRA operations.

MWRA’s central operations and control center, which can be remotely monitored and run via a supervisory control and data acquisition (SCADA) system.

The MWRA's Chelsea Creek Screen House and Headworks is located on Marginal Street near the Chelsea Street Bridge. This facility screens and removes grit and controls flows to the four-mile North Metropolitan Relief Tunnel which leads to the Deer Island Wastewater Treatment Plant. The tributary area to this facility includes 18 communities and 46% of the north system flow to Deer Island (and 30% of total system flow). A SCADA system at this facility also allows for remote operations.

Stormwater

The stormwater system in Chelsea generally consists of a closed drainage system that collects stormwater at street level, and discharges to bordering waterways via existing outfall structures.

The Carter Street pump station also serves to pump storm and ground water collected within a 119 acre catchment area, approximately 80% of which is in Chelsea and the remaining portion is in Everett. Improvements are currently proposed to the station to redirect Chelsea’s portion of the stormwater to a new force main that will discharge to the existing 72-inch gravity drain on Spruce Street.

The City has reduced inflow and infiltration into the sanitary sewer collection system over the last five years and separated stormwater drainage from its sewer system. This has helped to reduce flooding during high water runoff periods, particularly in low- lying areas in the western section of the City.

Mace Apartments Green Infrastructure Installation

Why is the stormwater system vulnerable?

When a heavy storm or tidal event occurs, the City’s drainage systems can fill up and fail, causing flooding at street level. Future sea level rise and storm surge events will worsen flooding conditions by increasing the volume of water to be handled by the system and blocking the outfall locations. In addition, the Carter Street pump station itself is at risk of flooding.

Additionally, the City has partnered with the EPA since 2011 to implement green infrastructure projects. These projects help reduce flooding impacts by decreasing the impervious footprint and encouraging stormwater to be absorbed (infiltrated) into the ground where it lands.

Buildings

Chelsea's building infrastructure encompasses a wide range of commercial, residential, industrial, institutional, and governmental buildings within its 1.8 square mile land area.

Public buildings include:

- Emergency response facilities (Police, Fire, Emergency Management)
- Schools, which are also used as emergency shelters
- Public works facilities
- Public housing
- Government administration facilities (MA Information Technology Center, FBI, U.S. Post Office)

Fortunately, in Chelsea, none of the City's Police, Fire or Emergency Management buildings were found to be at risk of coastal flooding under the 2030 and 2070 planning horizons.

Why are buildings vulnerable?

Some of these buildings are within current Federal Emergency Management Agency (FEMA) flood hazard areas and the City's Floodplain Zoning Overlay District, but others are not. As a result, existing flood-proofing may be inadequate making the buildings particularly susceptible to water damage or collapse under future conditions. In addition, sea level rise will result in higher groundwater elevations, which could compromise building foundations that are not supported on piles.

Businesses along Beacham Street (top) and Crescent Avenue (bottom) are located within present day flood zones.

Private buildings include:

- Single and multi-family residences
- Hospitals (Chelsea MGH, Beth Israel Deaconess)
- Food processing and distribution facilities (New England Produce Center, Kayem Foods)
- Commercial business districts (Mystic Mall)
- Industrial operations (Gulf Oil, Global Petroleum, Eastern Minerals)

Energy

Energy infrastructure in Chelsea includes facilities for energy production, transmission, storage, and distribution including substations and electric lines, natural gas systems, and petroleum products (e.g., gasoline, ethanol, diesel, kerosene, and fuel oil).

Energy infrastructure in Chelsea includes facilities for energy production, transmission, storage, and distribution including substations and electric lines, natural gas systems, and petroleum products (e.g., gasoline, ethanol, diesel, kerosene, and fuel oil).

Electric power is supplied by Eversource (formerly NStar). Eversource maintains a combination of above ground and underground systems. The company is improving the transmission system in response to growing energy demands as part of their Mystic-East Eagle-Chelsea Reliability Project. This project includes new underground transmission lines in a combination of existing and new duct bank systems. Electric transmission lines are located in sealed pipes within concrete ductbanks which defends against flooding and groundwater intrusion. Minor improvements are proposed to the existing Chelsea Substation #488 on Willoughby Street (off Eastern Avenue) in Chelsea. Substation #445 on Crescent Avenue will remain out of service, though the land is being reserved for future needs. In addition to serving residential and commercial customers, Eversource provides power for City and regional operations including traffic and railroad signals.

Natural gas service is supplied by National Grid. There are two pressure regulating stations within the mapped coastal flooding probability areas.

Why is energy infrastructure vulnerable?

Electric and gas lines are vulnerable to roadway erosion/ washout which can cause service interruptions or considerable damage to equipment. The same concerns apply to the substation properties. Increased flooding and groundwater levels also have the potential to threaten tank farm and related infrastructure, which in turn, pose public health and environmental hazards to the adjacent neighborhoods and Chelsea Creek.

There are two large tank farms in Chelsea – Gulf Oil upriver of the Chelsea Street Bridge and Global Petroleum, adjacent to the Tobin Bridge. These facilities provide petroleum products to greater Boston and MetroWest areas, as well as southern New Hampshire. The products are shipped by tanker or barge. Earthern berms and/or walls surround the sites, likely for spill containment.

Telecommunications

Telecommunications infrastructure systems in Chelsea include a combination of above ground and underground systems.

Providers include Comcast, Verizon, and Crown Castle International. These providers serve residential, commercial, and institutional customers, including City Hall. The best way to defend against failure scenarios is to build greater capacity and redundancy into systems. However, this is hard to do in a highly competitive commercial market, where efficiency and profit are the key drivers.

Why is telecommunication vulnerable?

Telecommunication systems are susceptible to failure or destruction due to increased flooding and groundwater levels. These conditions can weaken foundations that support overhead poles and expose underground conduits to increased water and salinity levels. Prolonged inundation could compromise short term and long term system integrity and function, and reduce the overall lifespan of system components (e.g. sheathing and cabling).

Recreational

Recreational assets in Chelsea include a combination of waterfront and neighborhood parks.

Mary O'Malley Waterfront Park, owned and maintained by the Massachusetts Department of Conservation and Recreation, resides along the Mystic River, from the Island End River to the Tobin Bridge. Other existing parks within the mapped risk areas include Island End Park, Polonia Playground, PORT Park, Highland Park, and Chelsea Greenway Shared Use Trail. Also included are playgrounds and fields at the City's schools.

The City also envisions creating a waterfront park at the end of the Chelsea Street Bridge (near the terminus of the Chelsea Shared-Use Path, being constructed along the BRT Silver Line). Public parks are particularly important to the quality of life for residents given the scarcity of open space and density of development.

There are also two private marinas – the Admiral's Hill Marina on the Island End River and Chelsea Yacht Club beneath the Tobin Bridge at the end of Broadway.

PORT Park, Marginal Street

How are parks vulnerable?

Coastal flooding and higher groundwater elevations has the potential to permanently damage hard and natural surfaces at these parks. Likewise, the marinas are at risk of temporary inundation during storms and permanent inundation under future sea level rise projections.

6 CRITICAL PUBLIC INFRASTRUCTURE

The next step in the assessment process ranks public infrastructure assets within the five vulnerability zones based on criticality and the probability of flooding in present day, 2030, and 2070. This process also considered state infrastructure and private utilities that provide critical public services.

> ***Public infrastructure***
> **is owned by the public or is for public use.**

Starting with the list of Critical Infrastructure in Hazard Areas identified by the City's Hazard Mitigation Plan (MAPC, 2014), the study team consulted with the City to identify critical public service infrastructure within the 2030 and 2070 BH-FRM probable flood areas. A total of 12 public infrastructure assets are identified as being at risk.

- Carter Street Pump Station
- City Yard
- Chelsea High School
- Williams Middle School Complex
- Burke School Complex
- Meridian Street Bridge over Chelsea Creek
- Broadway bridge over Mill Creek
- Chelsea Street bridge over Chelsea Creek
- Railroad bridge over Mill Creek
- MWRA Chelsea Creek Headworks and Screen House
- Electric Substation #488
- MWRA Chelsea Facility

Calculating Risk

There are many different mathematical models that can be used to calculate a risk score to prioritize infrastructure assets/facilities. For this study, the goal was to use a system that was simple to follow and easily communicated.

A simple five-tier qualitative rating system (Table 6.1) was developed for determining a consequence score. This score was then multiplied by the probability (likelihood) of flooding under present day, 2030, and 2070 scenarios using the BH-FRM. Because the BH-FRM provides estimated areas of probable flooding, a weighting factor was also applied to the calculation. Assets/facilities within present day flood areas were given higher priority than those at risk in future years. The weighting factor assigns a 60% weight to infrastructure within the present day flood area, 30% to 2030, and 10% to 2070.

The assets/facilities can then be ranked from highest to lowest, in order of priority, based on the total score. In other words, the higher the score, the higher the priority to investigate adaptation measures for the infrastructure.

Consequence

Table 6.1 Consequence Rating

Rating	Area of Service Loss	How critical is the asset?		
		Public Safety & Emergency Services	Economic Activities	Public Health & Environment
5	Regional	Severe	Severe	Severe
4	City Wide	High	High	High
3	Multiple Areas / Neighborhoods	Moderate	Moderate	Moderate
2	Single Area / Neighborhood	Low	Low	Low
1	Single Property	None	None	None

A consequence of failure score was calculated for each asset/facility. This score was based on adding the individual ratings (1 through 5) for each of the following four criticality criteria:

Area of Service Loss: Who is impacted by the loss of or damage to the core functions of the asset?

Public Safety & Emergency Services: How important is the asset to community evacuation and disaster response operations?

Social & Economic Activities: How important is the asset to providing people with access or service to their homes and jobs?

Public Health & Environment: How important is the asset to controlling human exposure to pollutants and secondary impacts to the natural environment?

In addition to the above criteria, the **Service Loss Duration** was also considered. However, the City regards an asset that is out of service for more than one day as Severe and therefore this item was not given a consequence rating score as it would have been the same for all 12 assets. Table 6.2 below provides an example of how a facility may be rated and scored.

Table 6.2 Example Criticality Rating: Carter Street Pump Station

Rating	Criteria	Justification
5	Area of Service Loss	119-acre catchment area in Chelsea and Everett
5	Public Safety & Emergency Service	Impacts major evacuation routes
4	Social & Economic Activities	Loss of access to local commercial areas
4	Public Health & Environment	Controls human exposure to surface contaminants
18	Total Consequence of Failure Score	

It is recognized that there is a certain level of interpretation or subjectivity applied when assigning consequence ratings. Appendix F includes the scoring guidance used for this study.

Probability

The likelihood of flooding under present day, 2030, and 2070 scenarios is based on data developed using the BH-FRM. A geographic data point for each public infrastructure asset was located in the BH-FRM. Based on a critical elevation at each location, an estimated depth of flooding was determined where the flood event has the probability to equal or exceed this depth in any given year (a 0.1 to 100% chance). In some cases, any depth of water would put a location at risk, whereas other locations can sustain core functions even with a few inches of water. The possibility that the water depth starts to impair an asset's core functions is calculated into the score. A detailed table of this data for each asset is included in Appendix G (Probability of Exceedance Curve Data).

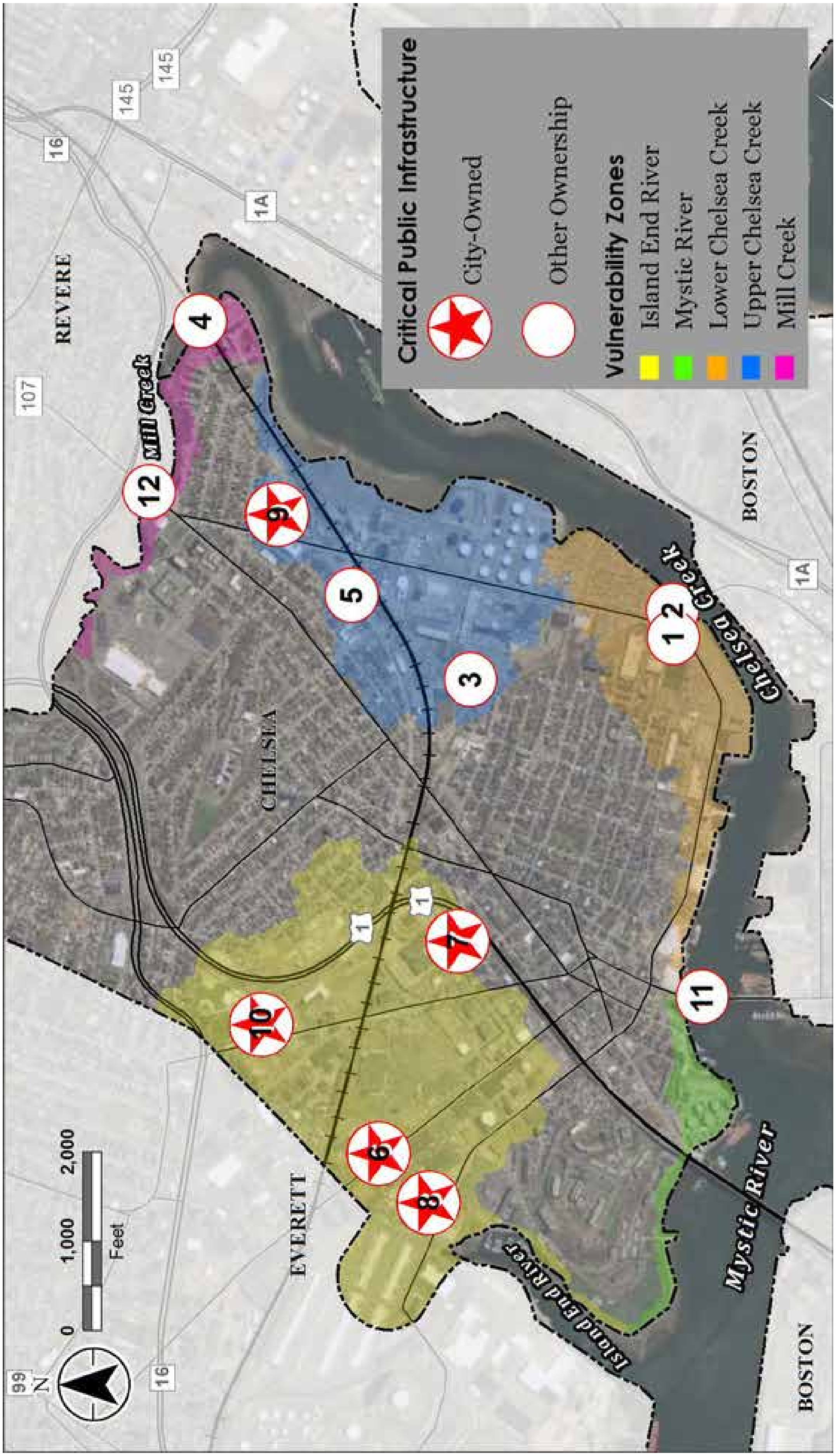


Figure 6.1 Prioritized Infrastructure located within Chelsea's Vulnerability Zones
Note: Labels represent rank of assets identified in Table 6.3

Critical Public Infrastructure Priorities

Based on the methodology described above and outlined in more detail in Appendix F, critical public infrastructure was prioritized as shown in Table 6.3.

Table 6.3 Prioritized Public Infrastructure

Rank	Asset / Facility	Sector	Vulnerability Zone	Owner
1	MWRA Chelsea Creek Headworks and Screen House	Wastewater	Lower Chelsea Creek	MWRA
2	Chelsea Street Bridge over Chelsea Creek	Transportation – Roadway, Maritime	Lower Chelsea Creek	MassDOT
3	MWRA Chelsea Facility	Water and Wastewater	Upper Chelsea Creek	MWRA
4	Railroad Bridge over Mill Creek	Transportation - Rail	Mill Creek	MassDOT/ MBTA
5	Substation #488 at Willoughby Street	Energy	Upper Chelsea Creek	Eversource
6	Carter Street Pump Station	Stormwater	Island End River	City
7	Williams Middle School	Buildings	Island End River	City
8	City Yard	Buildings	Island End River	City
9	Burke School Complex	Buildings	Upper Chelsea Creek	City
10	Chelsea High School	Buildings	Island End River	City
11	Meridian Street Bridge over Chelsea Creek	Transportation – Roadway, Maritime	Lower Chelsea Creek	MassDOT
12	Broadway Bridge over Mill Creek	Transportation - Roadway	Mill Creek	MassDOT

The prioritization process highlighted three major points:

1. **Ownership:** The majority of critical public infrastructure assets are not within the direct control of the City. In fact only, five of the twelve assets are owned by the City. This fact emphasizes the importance of engaging the other public service providers in the resiliency planning conversation.

2. **Vulnerability Zones:** The twelve critical public infrastructure assets are distributed relatively evenly among four vulnerability zones, with no assets in the Mystic River Zone. Four of the five City owned assets are within the Island End River Vulnerability Zone.

3. **Total Risk Score:** The public infrastructure assets that are most critical to the region are also most at risk of coastal flooding under the three planning horizons. As a result, these assets are ranked at the top of the priority list.

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7 ADAPTATION MEASURES

Identifying appropriate adaption measures to protect Chelsea from the effects of sea level rise and coastal storm surge could seem like an overwhelming task:

> *Where do we start? What probability of flooding are we willing to accept? To what elevation should we design? How much will this cost?*

The first step is to realize that these measures will need to be implemented over time with the help of public and private partners. The City does not need to do this alone, or all at once. The key is to advance measures at all scales, in a coordinated manner, to address coastal flooding risks in the short term and long term.

> ***Adapt:***
> **To adjust or modify something to a particular situation or circumstance**

The second step is to realize that no adaptation measure is a fail-safe solution as no amount of modeling or planning can fully predict the future. This is an important reality that focuses our attention on identifying measures that provide public benefits in the near term and are flexible enough to work over a range of future conditions. Public benefits can include improved public access to the waterfront, and protection and enhancement of ecosystems, for example. Flexible approaches include berms or walls that can be adjusted vertically in height, or ecological installations that grow with sea level rise. Clever adaptation measures that incorporate such elements are more likely to gain the community and financial support needed for implementation.

For the purposes of this assessment, three different scales of climate change adaptation measures were considered:

1. Site specific measures that protect a single property
2. Shoreline measures that protect multiple properties
3. Policy- or regulation-based measures to provide city-wide protection standards

Paired measures can offer the greatest level of protection. For example, a site-specific measure may function as a second line of defense to an area-wide focused shoreline measure. Policy or regulation-based measures are more far reaching and can guide or require coastal flooding adaptation elements as part of new construction or redevelopment projects.

Site Specific Measures

The decision to focus on public infrastructure is driven by the desire to provide the City with some adaptation measures that are within their own control and can be implemented in the near term. Therefore, the site specific measures below are focused on City-owned facilities identified through the prioritization process outlined in Chapter 6.

This focus on City-owned facilities does not discount the importance of understanding how other public service providers are modifying their facilities to coastal flooding. Seven of the twelve identified critical public infrastructure assets are not within the direct control of the City. These seven facilities are owned by the MWRA, MBTA (MassDOT Rail and Transit Division), MassDOT Highway Division, and Eversource. Each of these entities is at varying stages of assessing the vulnerability of their infrastructure to climate change.

The MWRA has flood preparedness plans in place and has already identified building envelope retrofits needed to protect their Chelsea facilities from coastal flooding. They also have remote and/or redundant operation and control capabilities for their facilities.

The MBTA has started implementing site specific adaptation measures at other facilities and will be further considering climate change impacts as part of their Focus40 planning effort, the agency's long range capital investment plan for the next 25 years. The MBTA is about to embark on a system-wide vulnerability assessment which will likely evaluate the MBTA railroad and bus corridors in Chelsea in more detail.

MassDOT Highway Division has extensively studied the vulnerability of the Central Artery system and is looking to expand these efforts statewide.

Eversource is in the process of assessing flood protection measures at their substation facilities. Any proposed flood-resilient improvements to the Chelsea facility would be done as part of a project separate from the Mystic - East Eagle - Chelsea Reliability Project.

All of these providers are thinking about climate change, which should open the door for follow-up discussions about community-level resilience planning and future implementation phasing.

The evaluation of site specific measures incorporates the research performed by Worcester Polytechnic Institute (WPI) students and faculty advisors in conjunction with the City and MIT Sea Grant program. The result of their work is a report entitled **Creation of Flood Risk Adaptation Measures for Critical Public Facilities in Chelsea, Massachusetts**, October 2015. The student's research has proven to be a valuable resource for this study.

Design Parameters for Adaptation Measures

For the purposes of this assessment, the proposed adaptation elevation above sea level is assumed to be 12 feet in 2030 and 15 feet in 2070. This translates to three to five foot tall installations. The elevations are based on the 0.1% exceedance probability shown in Appendix G, plus an approximate one foot of freeboard above the projected flood elevation in the Boston Harbor Flood Risk Model (BH-FRM).

In order to determine the elevation of adaptation measures considered for this assessment, the following baseline data was utilized:

1. Existing ground elevations were estimated from MassGIS LiDAR data (from 2013-2014).
2. Elevations were estimated for present and future tide[1], and flooding[2] (see Table 7.1).

Although not the focus of this assessment, consideration will also need to be given to how increased groundwater levels as a result of sea level rise could compromise the stability of building foundations, paved areas, and surrounding lands. In certain circumstances, high water tables may negatively impact a facility before coastal flooding, as a result of storm surge, is projected to occur.

Table 7.1 Estimated Water Elevations (in feet, vertical datum NAVD 88)

	Present (2013)	2030	2070
Mean Low Tide Elevation	-5.31	(+7") -4.73	(+38.6") -2.09
Mean Tide Elevation	0.53	(+7") 1.11	(+38.6") 3.75
Mean High Tide Elevation	4.24	(+7") 4.82	(+38.6") 7.46
Flood Elevation (0.1% risk)	9.8	10.8	14.1
Proposed Adaptation Elevation (installation height)	-	12 (2 feet)	15 (5 feet)

[1] Based on design water elevations presented on MassDOT's 2008 Plans for Chelsea Street Over Chelsea River

[2] Based on Woods Hole Group BH-FRM data

Carter Street Pump Station

The Carter Street Pump Station is located at the corner of Carter Street and Second Street adjacent to the Mystic Mall. The small structure houses three pumps approximately 25-feet underground that transmit storm and groundwater out of a 119 acre catchment area of Chelsea and Everett. Of this 119 acre catchment area, approximately 80% is in Chelsea. The pump station operates daily transmitting flows from this catchment area via a 30-inch force main to the Market Street culvert at the Island End River. The pump station is currently being redesigned to redirect flows from the catchment area to a new force main that will discharge to an existing 72-inch gravity drain on Spruce Street. The Market Street culvert will continue to receive flows from other portions of Everett.

The approximate ground elevation at the pump station building is 5.5 feet above sea level (MassGIS LiDAR data from 2013-2014) and the pump station top slab elevation is 7.43 feet(Weston & Sampson). The 7.43 foot elevation represents the critical elevation at which floodwaters could begin to impact pump station operations. As shown in the probability of exceedance tables in Appendix H, there is a 0.1 to 2% probability, or likelihood, that coastal flood waters will overtop this slab in 2030, and 30% probability in 2070. To protect and maintain the functionality of the station under these future conditions, a number of adaptation measures are recommended inside and outside of the existing pump station building envelope.

Carter Street Pump Station (photo by Stantec, April 13, 2016)

The City has indicated their preference to construct a permanent wall around the pump station as the primary means of protecting the facility from coastal flooding. A permanent wall would enable City personnel to focus their storm preparation efforts on other critical tasks rather than spending valuable time erecting a temporary barrier. The wall will need to allow for scalable access by City personnel, such as through removable entranceways or ladder/stairs, and be designed to withstand the hydrostatic pressures of the floodwaters. The wall should have a top line elevation of 12 feet NAVD88 with design provisions to allow the wall to be heightened an additional 3 feet if future conditions warrant. A top of wall elevation of 12 feet NAVD88 correlates to a 6.5-foot wall from ground level (or a 4.5-foot wall above slab elevation).

Example of a permanent perimeter wall (Stantec, Santa Barbara, CA - top) and flood logs (Flood Control International - bottom)

Other building envelope and equipment retrofits and/or relocations would provide secondary means of protection for the station. Recommendations include:

- Install flood logs at doorways
- Raise electrical and HVAC equipment
- Raise or protect generator and fuel oil storage tank
- Repoint/waterproof exterior masonry
- Install watertight access hatches
- Install a Supervisory Control and Data Acquisition System (SCADA) to provide remote control operation of major systems

The cost of the perimeter wall and recommended building envelope and equipment retrofits and/or relocations is estimated to be in the range of $500,000, up to $750,000 for programming purposes. A structural evaluation of the pump station building is also required to determine if additional structural reinforcement is required to withstand the hydrostatic pressures of the floodwaters.

Schools

There are three public schools within the mapped flood risk probability area: Chelsea High School, Williams Middle School Complex, and Burke Elementary School Complex. In addition to serving the student community, each of these schools is used as an emergency shelter. The City expects the buildings will exceed a 50 year life span in the absence of a significant hazard event.

- **Chelsea High School:** This school is located at 299 Everett Avenue, adjacent to Route 16, and serves the Grade 9-12 student community. The main building opened in September 1996 and a 500 student addition was built in 2002.
- **Williams Middle School Complex:** This complex is located at 180 Walnut Street, just north of Route 1. This school complex includes 2 middle schools for Grades 5-8. These schools include the Joseph A. Browne School and the Wright Science and Technology Academy. This complex also opened in 1996.
- **Burke Elementary School Complex:** This complex is located at 300 Crescent Street adjacent to Eastern Avenue and the MBTA railroad corridor. This school complex includes four elementary schools for Grades 1-4. These schools include the William A. Berkowitz, Edgar F. Hooks, George F. Kelly, and Frank M. Sokolowski Elementary Schools. The Burke Complex opened in September 1996.

Chelsea High School & Burke Elementary School Complex (Google StreetView)

The structural elements comprising the buildings' foundations are assumed to be piles, grade beams and slabs based on available record plans. Typically, in a system of this kind, the grade beams are positively connected to the piles and the slabs are structural, spanning between and positively connected to the grade beams. The approximate ground elevation at the schools range from 6 to 10 feet above sea level (MassGIS LiDAR data from 2002-2014). And it is assumed that the critical elevation is within 6 inches (1 step) of the elevation. As shown in the Probability of Exceedance Tables in Appendix H, there is a 0.1 to 2% chance that coastal flood waters could overtop this slab in 2030, and 30% chance in 2070.

In order to protect the schools from flood damage during their anticipated life span, exterior retrofits could include:

- Modify window openings and reducing size
- Install flood logs at the exterior doors and adjacent storefront glazing
- Repoint/waterproof exterior masonry

Unlike the pump station, the schools will not need to be operational during a coastal flood event unless they are intended to still function as emergency shelters. As an emergency shelter, not only would these buildings need to be flood resistant, but also allow people, goods and services in and out during the flood event. Accordingly, under coastal flood conditions, the building would require the addition of doors above the 3 foot line with portable ramps on the inside of the building. The assumption is, with the site under water, people, goods and services would come and go by boat. A better solution would seem to be to discontinue use of these buildings as emergency shelters. Instead, the City could make arrangments with neighboring towns having higher elevations, such as Everett, and one or more of their buildings could be designated to be Chelsea's emergency shelters in the event of a flood. This would eliminate the need for difficult and costly modifications.

City Yard

The Department of Public Works (DPW) City Yard is located at 280 Beacham Street. The facility includes a larger hanger-style space where public maintenance vehicles and equipment are stored and serviced. There are also on-site offices for DPW and the water and sewer maintenance and operation staff. Road salt, excavated materials and street sweeper deposits are stored along the exterior perimeter of the property.

Given the age and condition of the City Yard building and the City's desire to eventually relocate DPW operations to a new location, no permanent measures are proposed at this location. Consideration could be given to two temporary adaptation solutions:

1. Temporarily relocating equipment prior to and during flood events to enable emergency response and cleanup operations.
2. Purchasing a deployable (portable) flood mitigation system.

Deployable perimeter installations include paneling systems such as Aquafence or water inflated flood barriers such as Tiger Dams. Massport has purchased the Aquafence system for use at their critical facilities at Logan Airport such as the State Police Building. The cost for a 4 foot high installation is approximately $350 per linear foot based on the Massport example. The systems break down into roughly 5-foot by 5-foot crates. These installations need to be used in conjunction with a sump pump and stairs system to keep the interior dry during storm events and maintain access. The concern with these systems, especially in an urban setting, is the need to store the materials when not in use and routinely test the setups to verify they are still operational.

Aquafence Installation in Mount Vernon, WA

City Yard Storage Facility

Shoreline Measures

Recalling the discussion on flood pathways in Chapter 4, the Boston Harbor Flood Risk Model presents low-elevation locations where water is anticipated to enter the City (Figure 4.1). In response to this information, this section presents adaptation measures focused at the shoreline that could reduce the probability of coastal flooding.

These shoreline adaptation measures will require significantly more time and effort to finance, design, permit, and construct than the site-specific measures presented above. The measures can range from 1,500 to 3,200 linear feet of shoreline and involve a combination of public and private properties. To make installations like this possible, it is crucial to open communication between the City, property owners, community, and regulatory agencies early in the planning process to gain support, develop partnerships, secure funding, and set realistic project timelines.

What types of installations are recommended?


Living Shoreline

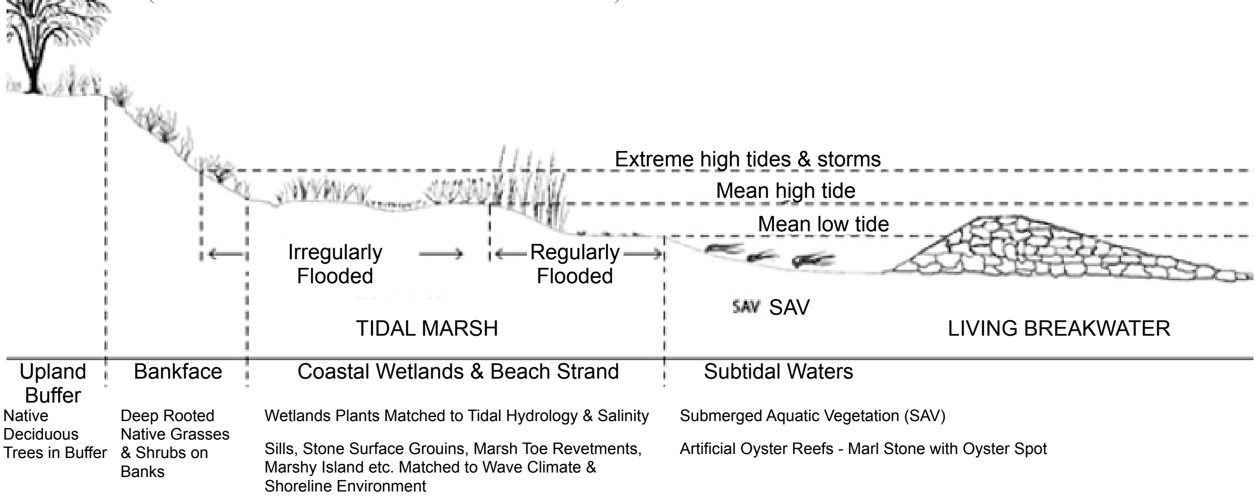
Where feasible, natural systems and processes should be employed to help protect the City from coastal flooding and provide ecological benefits. The potential for “green infrastructure” installations exist where large areas of tidal flats or salt marsh line the shore. However, in many locations, industrial development and state regulations limit this type of installation and therefore engineered barriers should be utilized. Here, more traditional "gray infrastructure" is appropriate.

Some locations may benefit from a hybrid of green and gray infrastructure to provide protection for a wider range of potential flood depths. Coastal wetland plantings and berms can be designed to manage low to medium tidal flooding, where engineered walls could be provided for additional storm surge protection (NOAA, 2015).

In any case, some shoreline installations can also provide an opportunity to benefit the surrounding community, including improved public access to the waterfront and enriching an area's visual character.

Future design of these installations must keep in mind that the Mystic River and majority of Chelsea Creek are within a Designated Port Area (DPA). The water-dependent industrial properties in the DPA are regulated by the Massachusetts Office of Coastal Zone Management (CZM) and must maintain access to maritime transportation (among other specific regulatory requirements). This means that adaptation measure installations must not preclude future water dependent development opportunities. Depending on the site, this could mean that any vertical walls may need to be set back from the waterfront. In many locations, a deployable barrier (as discussed under Site Specific Measures) may be appropriate.

Figure 2 Coastal Shoreline Continuum & Typical "Living Shorelines Treatments" (NOAA & Burke Environmental Associates)



Green Infrastructure

Existing and constructed "living shorelines" have proven ecological benefits to coastal communities.

More specific to Chelsea, a living shoreline may involve planting salt marsh and fringe marsh behind a biodegradable coir or rock sill, and creating tidal channels to enhance restoration and drainage. Some ecological benefits associated with this type of green infrastructure include:

- Absorption of wave energy.
- Erosion protection.
- Water quality improvement.
- Shallow water habitat for wildlife and plant species.
- Visual character enhancement along the shoreline.

In addition, some of these systems maintain themselves after storms and flood events, and adapt to changes in sea level rise (NOAA, 2015).

Green Infrastructure:

Ecological systems and processes harnessed by humans to combat climate change, create healthy built environments, and improve quality of life. These high-performing systems provide real economic, ecological, and social benefits at multiple scales. Some examples of green infrastructure include:

- **Constructed Wetlands**
- **Urban Forests**
- **Green Roofs**
- **Green Streets**
- **Rain Gardens**

- American Society of Landscape Architects (ASLA)

Gray Infrastructure

Throughout Chelsea's industrial waterfront areas, there is less opportunity to create the green infrastructure systems needed to reduce the impacts of future sea level rise and storm surges. Here, engineered barriers such as bulkheads and sea walls could help reduce the probability of coastal flooding.

Bulkhead with railing, Charleston, SC

One benefit to constructing these steel and/or concrete structures is that they can be vertically extended over time. This would allow wall height to be increased in phases as data regarding future impacts from sea level rise and storm surges is refined.

In some situations, a concrete cap or wall may benefit from aesthetic details, to soften the visual impact. Concrete form liners can be designed with patterns to create an artistic statement and/or announce a particular place or neighborhood. Another way to break up a large wall could be to let community artists or schools paint murals, or designate an approved graffiti location to provide a creative platform for the city's youth.

Sea Wall, UK (photo by Nick Rice, ***FGW 'Double act'*** https://www.flickr.com/photos/capuchinoking/)

What can be built at each location?

Based on existing shoreline features, potential adaptation measures have been identified for each Vulnerability Zone described in Chapter 4. Table 7.2 provides an overview of where opportunities for green, gray, and hybrid infrastructure are explored.

Additional Considerations

These adaptation measures must be permitted under public laws protecting natural, cultural and recreational resources along the shoreline. This includes requirements set by the:

- Massachusetts Environmental Policy Act (MEPA), M.G.L. c. 30, §61-62H
- Massachusetts Wetlands Protection Act (WPA), M.G.L. c.131, §40
- Federal Water Pollution Control Act, 33 U.S.C. 1341 *et seq.*, §401 / Massachusetts Clean Water Act, M.G.L. c. 21, §26-53
- Public Waterfront Act, M.G.L. c. 91
- National Environmental Policy Act (NEPA),
- Federal Coastal Zone Management Act, 16 U.S.C. §1451 *et seq.*/ Massachusetts Coastal Zone Management Act, M.G.L. c. 21A, §2, 4
- Federal Clean Water Act, 33 U.S.C. c. 1344 §404 *et seq.* / Rivers and Harbors Act, 33 U.S.C. c.403 §10

A more in depth discussion of the local, state and federal permits/approvals associated with the above laws can be reviewed in Appendix I. It should be noted that although living shorelines have been constructed in the in states south of New England, there are not many in Massachusetts. The WPA Regulations were recently revised to include special provisions for ecological restoration projects, however there is not yet a specific option regarding the creation of living shorelines.

Table 7.2 List of Potential Adaptation Measures by Vulnerability Zone[1]

Vulnerability Zone	Adaptation Description	Potential Co-Benefits			Cost Comparison	Study Page
		Public Access	Ecological	Aesthetic		
Island End River	Living shoreline with earthen berm / flood wall	Y	Y	Y	$$	7-14
Mystic River	Flood Wall	-	-	-	$$$	7-14
Lower Chelsea Creek, Marginal Street	Flood Wall	Y	-	Y	$$$	7-24
Lower Chelsea Creek, Eastern Avenue	Flood Wall	-	-	-	$$	7-14
Upper Chelsea Creek	Living shoreline with earthen berm / flood wall	Y	Y	Y	$$$$	7-28
Mill Creek	Further hydraulic study needed					7-32

Key to Construction Costs: $ < $1million; $$ = $1 to $5 million; $$$ = $5 million to $10 million; $$$$ > $10 million. Please note, these estimates do not include general site civil work, floodplain restoration/phytoremediation, or right-of-way acquisition. Time and labor to install deployable flood walls is also excluded.

Island End River Vulnerability Zone

Area Review

The Island End River once meandered through low-lying marshes in Chelsea. The 2030 flood map shows approximately 25% of Chelsea's land at risk of flooding, just in this zone. Additionally, about 15% of Everett is also vulnerable to coastal flooding from the Island End River.

Table 7.3 Island End River Vulnerability Zone Quick Facts

Probable Size of Flood Zone	• 40 acres (present) • 290 acres (2030) • 320 acres (2070)
Critical Public Infrastructure	• Carter Street Pump Station • Chelsea High School • Williams Middle School • City Yard
Additional Properties At-Risk	• Produce distribution facilities • Everett Avenue commercial and urban renewal areas • Portions of Addison-Orange Neighborhood • Portion of the City of Everett
Flood Pathways Identified	• The end of Island End River, from Island End Park to Market Street in Everett

View up Island End River - Everett DPA Property at left, Admiral's Hill Marina at center, and residences on right.

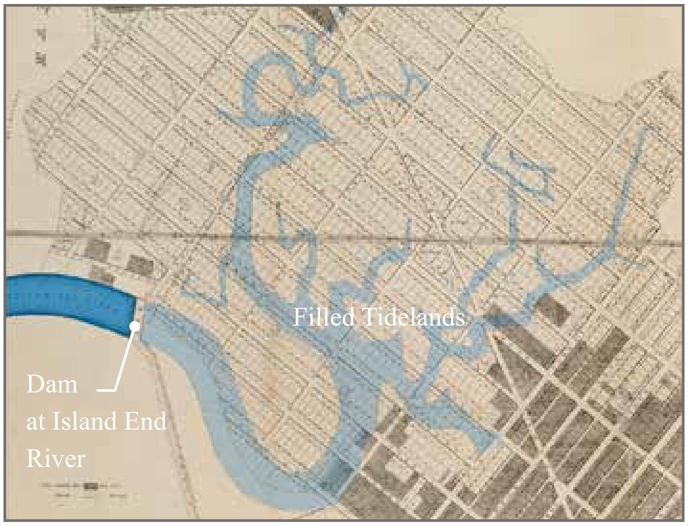


Figure 4.3 Island End River, ***Plan of the Lands of the Winnisimmet Co. and Others in Chelsea & Malden***, 1846.

A stand of Phragmites encroaches on tidal flats at the head of the Island End River. Everett industrial properties shown in the background.

Shoreline Adaptation Opportunities

Here, there is an opportunity to employ natural systems and processes, in conjunction with engineered barriers, to reduce the flood risks anticipated from future storm surges and sea level rise. Constructed salt marsh and vertical barrier installations could benefit this Vulnerability Zone (see "Potential Shoreline Adaptation" on page 7-14).

Other Considerations

Existing stormwater runoff from the properties along Beacham Street currently flows into the eastern end of the river. The silt and warmer waters from this runoff have degraded the salt marsh in the area and allowed for an overgrowth of invasive Phragmites. A bio-swale could be installed on the adjacent property to help capture and infiltrate the stormwater, before it reaches the river. A stormwater retention area could also be constructed near the Market Street culvert outfall to treat the runoff from other surrounding impervious properties.

The shoreline of this zone is publicly owned within the City of Chelsea. In Everett, the property is privately owned and within the Mystic River Designated Port Area (DPA). Successful implementation of shoreline measures will need to include outreach to, and input from, property owners abutting Island End Park, the Everett property owner, the Massachusetts Office of Coastal Zone Management (CZM) and other regulatory agencies.

Environmental permits/approvals to construct a living shoreline and perimeter walls may include:

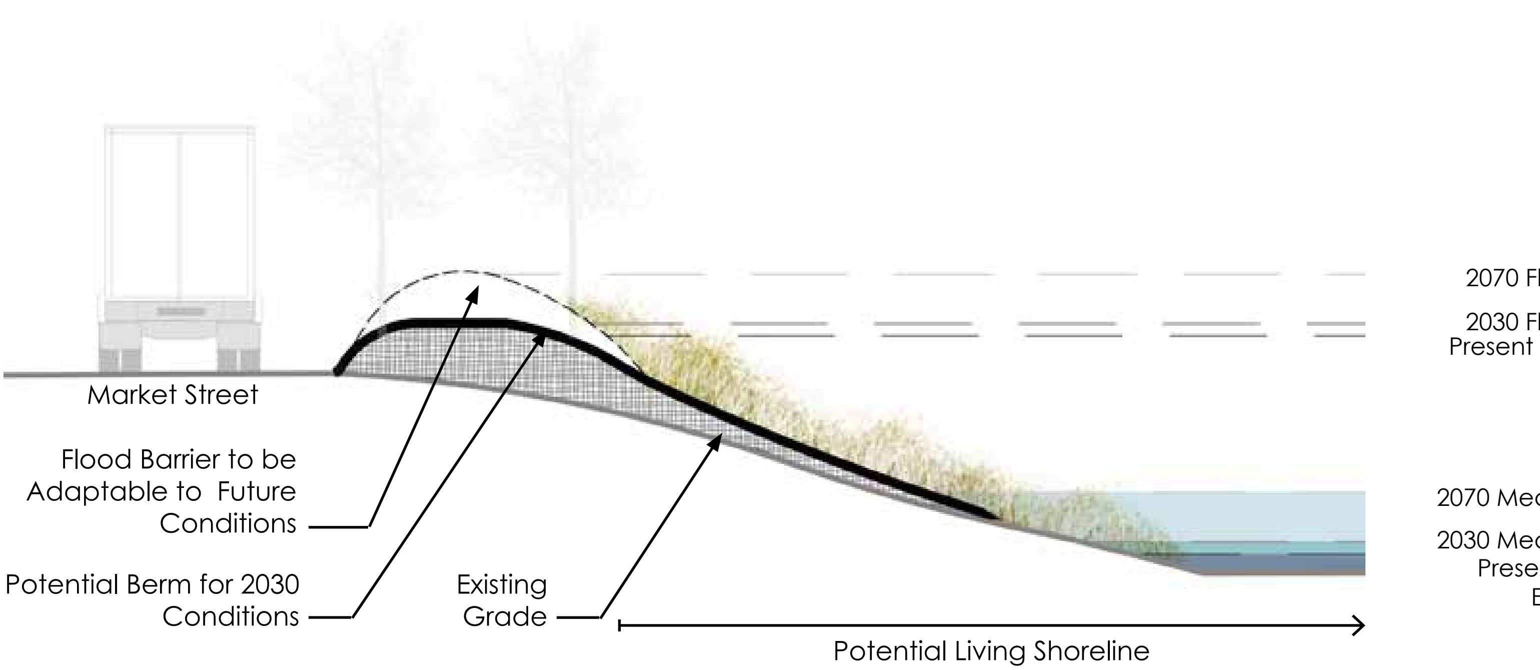
- Massachusetts Environmental Policy Act (MEPA)
- National Environmental Policy Act (NEPA)
- Chelsea Conservation Commission
- Everett Conservation Commission
- Massachusetts Department of Environmental Protection (DEP)
- United States Army Corps of Engineers (USACE)
- Massachusetts Office of Coastal Zone Management (CZM)

Island End River Vulnerability Zone

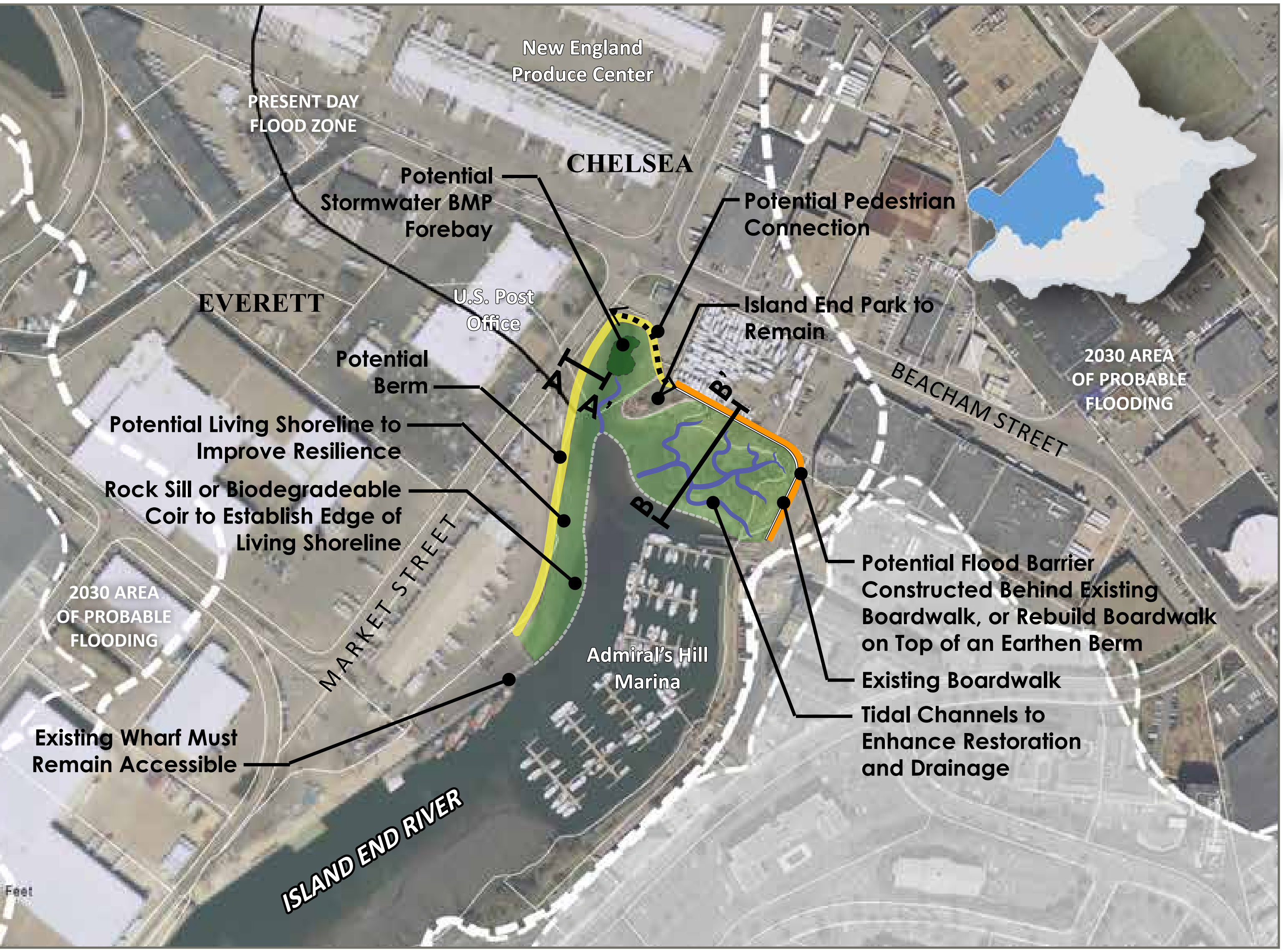
Potential Shoreline Adaptation

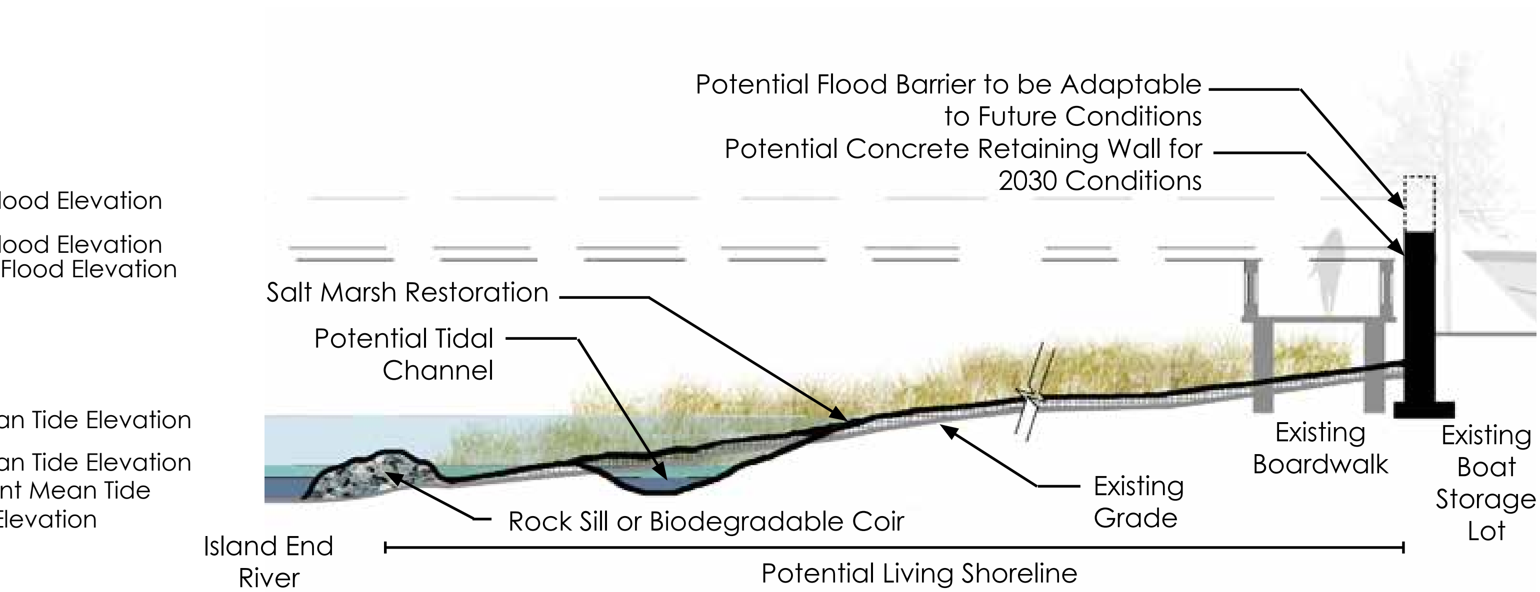
This area of Chelsea, Massachusetts supports important local and regional industrial and commercial uses, and contains critical public infrastructure (including the Carter Street Pump Station). In 2030, this vulnerability zone is projected to include nearly 300-acres of the city's land area and a portion of Everett. The adaptation measures shown here include new salt marsh and tidal channels in the existing tidal flats. A concrete retaining wall and/or an earthen berm is located at the edge of Market Street and at the Island End Park boardwalk. This unique hybrid adaptation is geared towards using natural processes to provide energy dissipation and other ecological benefits, while using vertical barriers for a second line of coastal flood protection. It should be noted that the Everett side of the Island End River is part of the Mystic River Designated Port Area (DPA), and any installation must maintain access to maritime activities.


Tidal Wetland Restoration



SECTION A-A'


New England Produce Center
PRESENT DAY FLOOD ZONE
CHELSEA
Potential Stormwater BMP Forebay
Potential Pedestrian Connection
EVERETT
U.S. Post Office
Island End Park to Remain
Potential Berm
A
A'
B'
B
BEACHAM STREET
2030 AREA OF PROBABLE FLOODING
Potential Living Shoreline to Improve Resilience
Rock Sill or Biodegradeable Coir to Establish Edge of Living Shoreline
MARKET STREET
Potential Flood Barrier Constructed Behind Existing Boardwalk, or Rebuild Boardwalk on Top of an Earthen Berm
2030 AREA OF PROBABLE FLOODING
Admiral's Hill Marina
Existing Boardwalk
Tidal Channels to Enhance Restoration and Drainage
Existing Wharf Must Remain Accessible
ISLAND END RIVER
Feet


Potential Flood Barrier to be Adaptable to Future Conditions
Potential Concrete Retaining Wall for 2030 Conditions
lood Elevation
lood Elevation
Flood Elevation
Salt Marsh Restoration
Potential Tidal Channel
an Tide Elevation
an Tide Elevation
nt Mean Tide
Elevation
Existing Boardwalk
Existing Boat Storage Lot
Existing Grade
Rock Sill or Biodegradable Coir
Island End River
Potential Living Shoreline

SECTION B-B'

Mystic River Vulnerability Zone

Area Review

Much of this zone includes a wharf on former tidelands. This part of the Mystic River was likely filled in the late 19th Century to expand the industrial port between Winnisimmet Landing and Tobin Bridge (Figure 7.3). No critical public infrastructure sites were identified in this zone. However, this still leaves nearly 25 acres of Chelsea's land area, including residential and industrial properties, at risk of coastal flooding.

Table 7.4 Mystic River Vulnerability Zone Quick Facts

Probable Size of Flood Zone	• 20 acres (present) • 25 acres (2030) • 30 acres (2070)
Critical Public Infrastructure	• None
Additional Properties At-Risk	• Petroleum and manufacturing facilities • Lower Broadway Neighborhood • Polonia Playground
Flood Pathways Identified	• Low points between the Tobin and McArdle Bridges

View of wharf area at the end of Broadway (view from East Boston)

Shoreline Adaptation Opportunities

The properties identified in the Mystic River Vulnerability Zone may benefit from deployable and/or permanent wall installations to reduce the probability of flooding (see "Potential Shoreline Adaptation" on page 7-18).

Other Considerations

The shoreline here is privately owned and within the Mystic River Designated Port Area (DPA). Successful implementation of shoreline measures will require outreach to, and input from, these property owners, abutters to these properties, the Massachusetts Office of Coastal Zone Management (CZM) and other regulatory agencies.

Environmental permits/approvals to construct perimeter walls may include:

- Massachusetts Environmental Policy Act (MEPA)
- National Environmental Policy Act (NEPA)
- Chelsea Conservation Commission
- Massachusetts Department of Environmental Protection (DEP)
- Massachusetts Office of Coastal Zone Management (CZM)

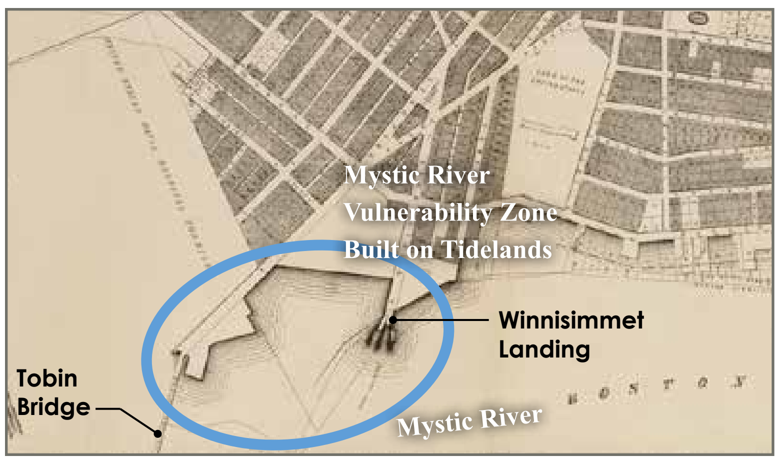


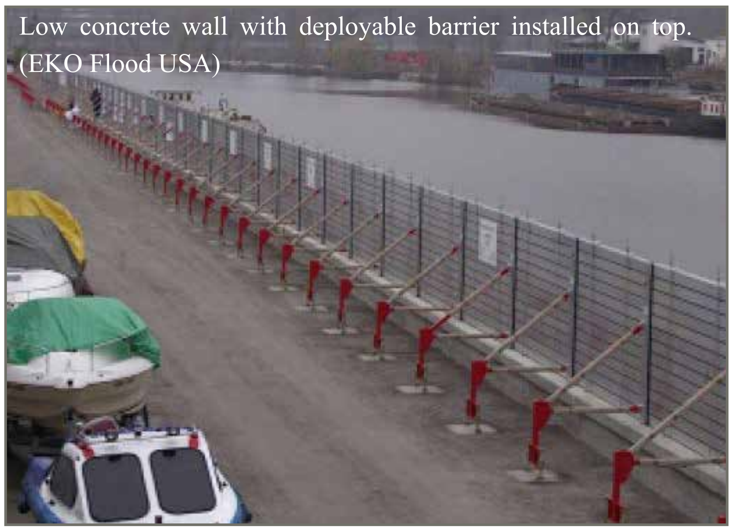
Figure 4.4 Mystic River, ***Plan of the Lands of the Winnisimmet Co. and Others in Chelsea & Malden***, 1846.

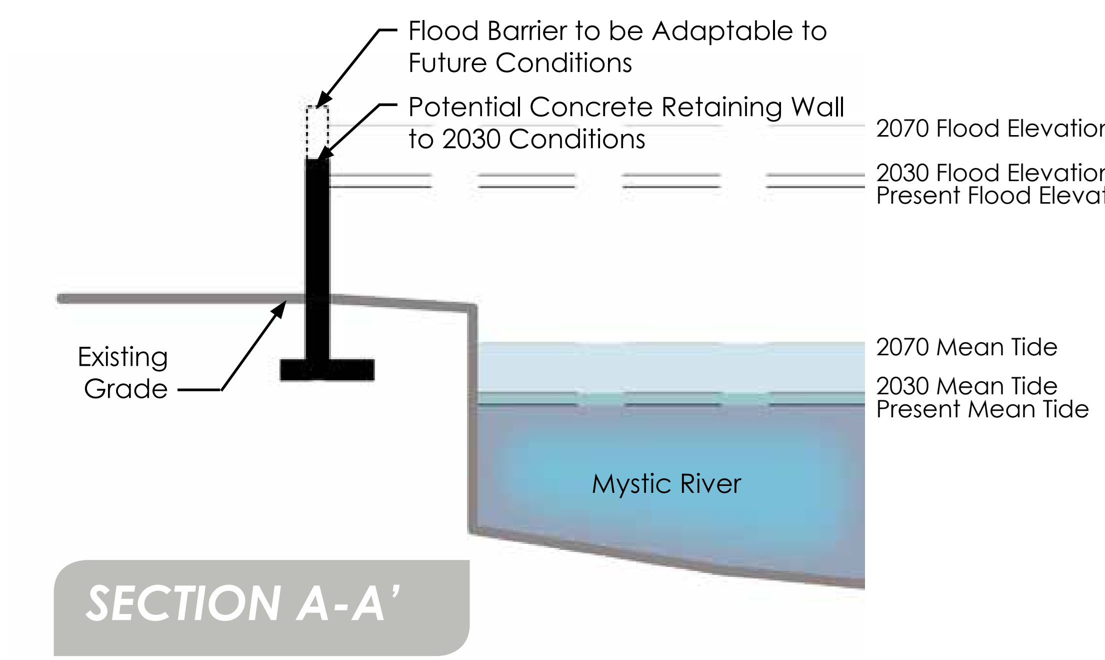
Looking toward the Tobin Bridge from O'Malley Park

Mystic River Vulnerability Zone

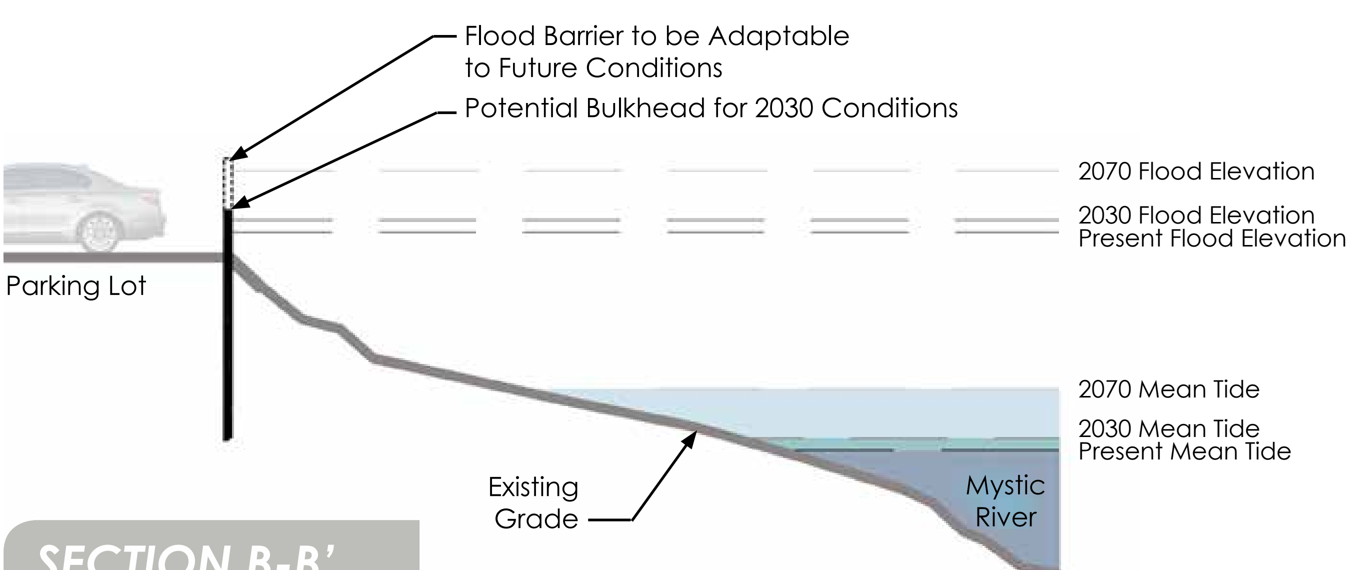
Potential Shoreline Adaptation

South of Broadway and east of the Tobin Bridge, approximately 20 acres of land in Chelsea, Massachusetts are currently at risk of inundation during a severe storm event. The area susceptible to coastal flooding is likely to increase by an additional five acres due to sea level rise and climate change in 2030. Petroleum and manufacturing facilities front this zone's shoreline, with the Lower Broadway Neighborhood immediately behind. Installation of concrete retaining walls, bulkheads and/or deployable barriers could help reduce the probability of inundation.


Low concrete wall with deployable barrier installed on top. (EKO Flood USA)



OUTSIDE OF FLOOD AREA
2070 AREA OF PROBABLE FLOODING
BROADWAY
MEDFORD STREET
TREMONT STREET
WINNISIMMET ST
2030 AREA OF PROBABLE FLOODING
PRESENT DAY FLOOD ZONE
Existing Docks Must Remain Accessible
A
A'
B
B'
Adaptation Measures May Need to be Located Behind Designated Port Area (DPA) Properties.
Potential Location for Adaptable Walls, Deployable or Permanent
MYSTIC RIVER
Existing Docks Must Remain Accessible



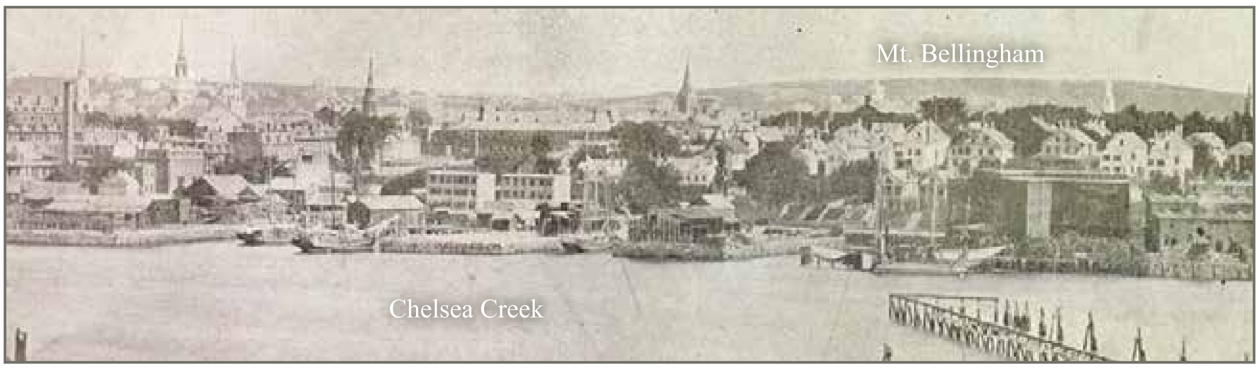
Flood Barrier to be Adaptable to Future Conditions
Potential Bulkhead for 2030 Conditions
2070 Flood Elevation
2030 Flood Elevation
Present Flood Elevation
Parking Lot
2070 Mean Tide
2030 Mean Tide
Present Mean Tide
Existing Grade
Mystic River

SECTION B-B'

Lower Chelsea Creek Vulnerability Zone

Area Review

Low elevations along Marginal Street and the existing Eastern Avenue parking lots pose a risk of flooding to this area during a 1% chance storm. This portion of Chelsea, Massachusetts includes a regional wastewater facility and a significant transportation connection to Boston.



Lower Chelsea Creek Waterfront from East Boston c.1868 (Chelsea Historical Society)

Table 7.5 Lower Chelsea Creek Vulnerability Zone Quick Facts

Probable Size of Flood Zone	• 80 acres (present) • 90 acres (2030) • 105 acres (2070)
Critical Public Infrastructure	• MWRA Chelsea Creek Headworks and Screen House • Chelsea Street Bridge over Chelsea Creek
Additional Properties At-Risk	• Industrial facilities • Shurtleff-Bellingham Neighborhood • Port Park, Highland Park • Car rental and parking facilities • Hotel facilities • Social/cultural group facilities
Flood Pathways Identified	• Marginal Street, between Highland and Willow Streets • North of the Chelsea Street Bridge, along the existing parking lot.

Shoreline Adaptation Opportunities

Adaptable flood walls, deployable and/or permanent, could reduce the probability of flooding at the businesses and residences within this zone. Walls could be high in some locations, offering the potential to become a community art canvas - with paint, veneer wall panels, colored concrete, form liners, stamping, or other adornment (see "Potential Shoreline Adaptation" on page 7-22 and 7-24).

Other Considerations

The shoreline of this zone is within the Chelsea Creek Designated Port Area (DPA). The land is privately-owned, with the exception of the Marginal Street right-of-way. The Chelsea Street Bridge is owned and maintained by the Massachusetts Department of Transportation. Outreach to, and input from, these property owners and the adjacent community will be critical to install a successful adaptation.

Environmental permits/approvals to construct walls in or adjacent to wetlands and water-dependent waterfronts may include:

- Massachusetts Environmental Policy Act (MEPA)
- National Environmental Policy Act (NEPA)
- Chelsea Conservation Commission
- Massachusetts Department of Environmental Protection (DEP)
- Massachusetts Office of Coastal Zone Management (CZM)

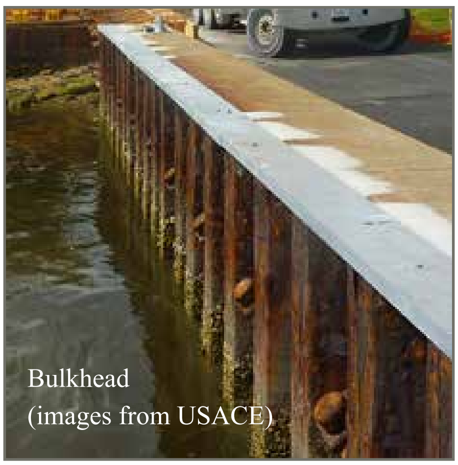
Example of a combination permanent and deployable wall along the waterfront (image from EKO Flood USA)

Marginal Street Shoreline

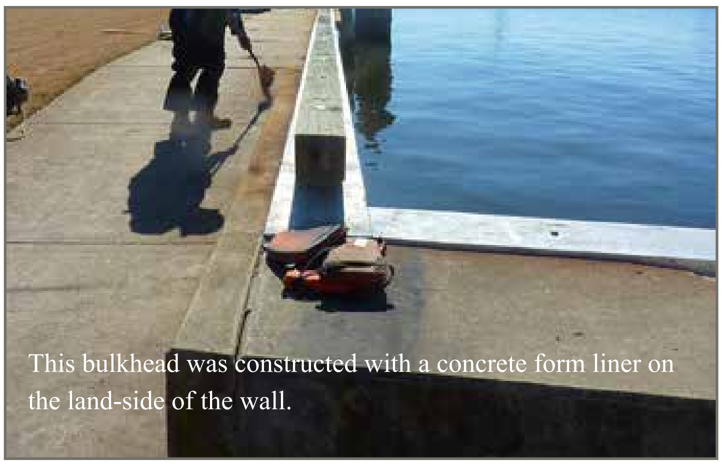
Lower Chelsea Creek Vulnerability Zone

Potential Shoreline Adaptation

Locating vertical barriers at main flood pathways may help minimize this 90 acre (in 2030) zone in Chelsea, Massachusetts. Deployable barrier sections, set on the ground or on low walls, could be installed to maintain Designated Port Area (DPA) maritime water access. Permanent walls, such as concrete retaining walls or bulkheads, would reduce the time and labor needed to prepare for a storm. A new sidewalk along Marginal Street could be elevated to maintain pedestrian water views.

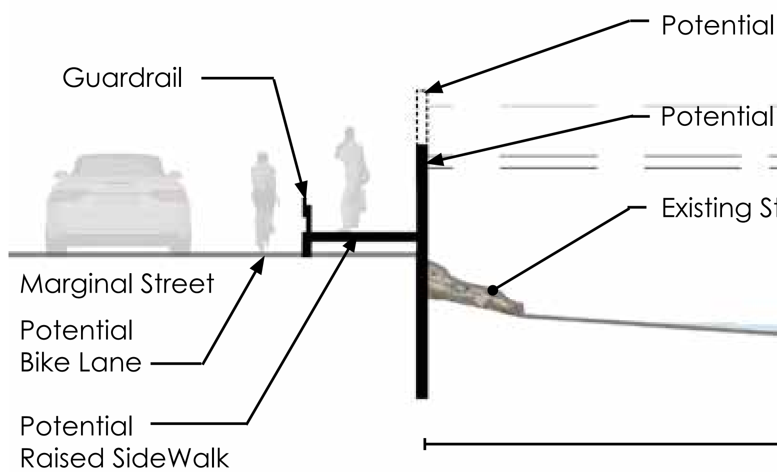


Bulkhead
(images from USACE)

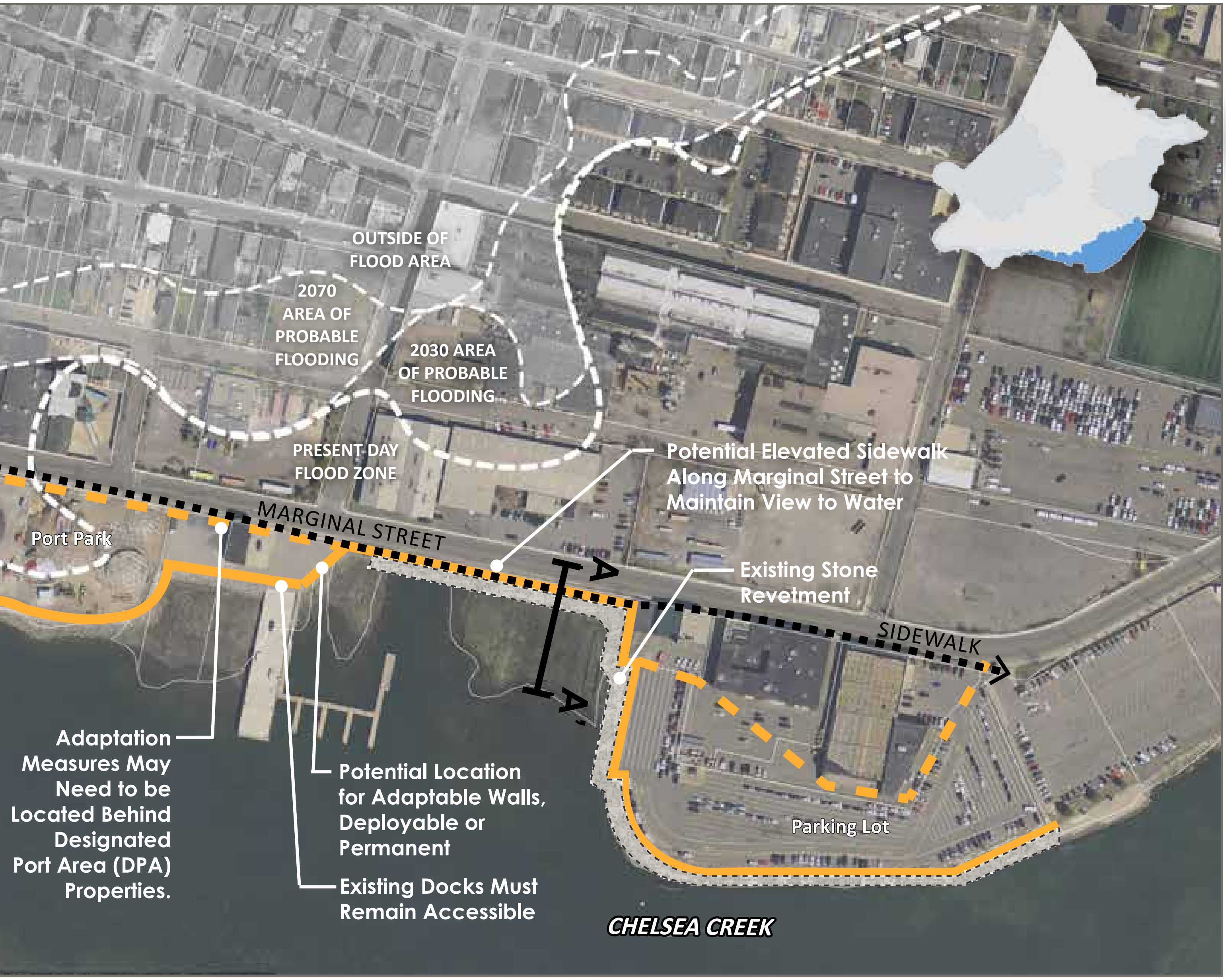


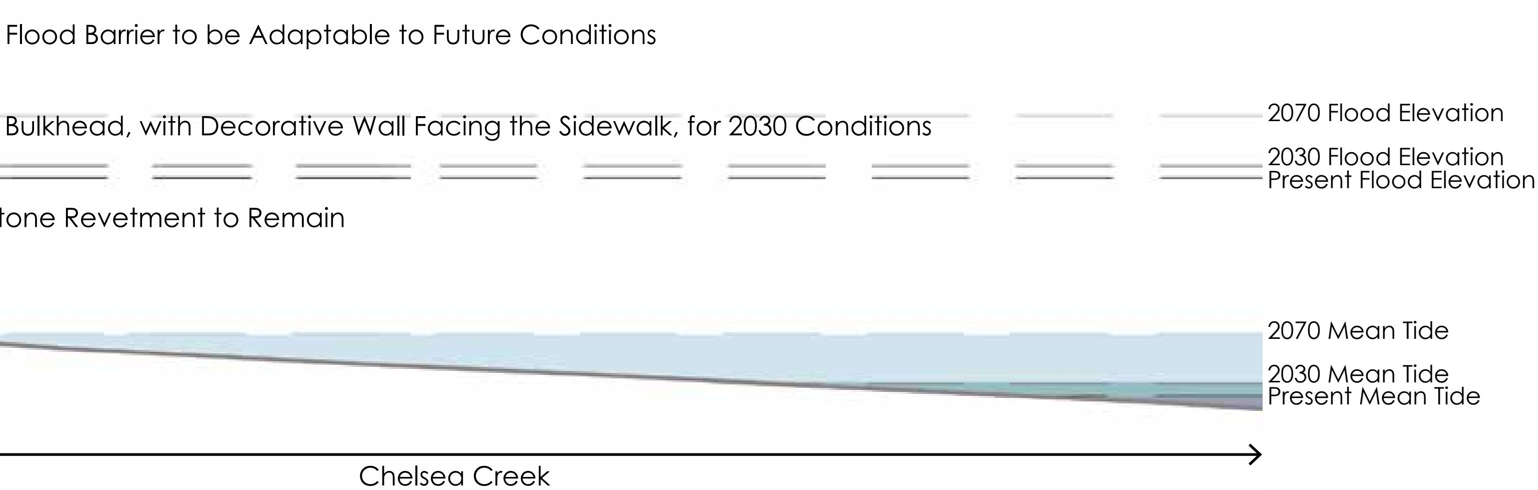
This bulkhead was constructed with a concrete form liner on the land-side of the wall.

Concrete walls can be decorative, using form liners, colored concrete, or veneer (photo from Google Street View, October 2014)



SECTION A-A'


OUTSIDE OF FLOOD AREA
2070 AREA OF PROBABLE FLOODING
2030 AREA OF PROBABLE FLOODING
PRESENT DAY FLOOD ZONE
Potential Elevated Sidewalk Along Marginal Street to Maintain View to Water
MARGINAL STREET
Port Park
Existing Stone Revetment
SIDEWALK
A
A'
Adaptation Measures May Need to be Located Behind Designated Port Area (DPA) Properties.
Potential Location for Adaptable Walls, Deployable or Permanent
Existing Docks Must Remain Accessible
Parking Lot
CHELSEA CREEK

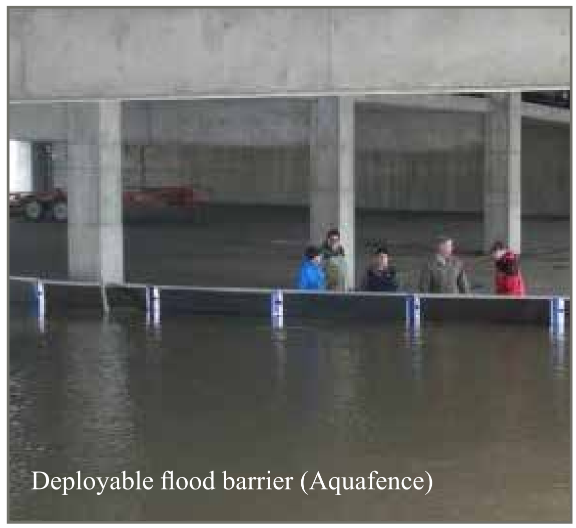

Flood Barrier to be Adaptable to Future Conditions
Bulkhead, with Decorative Wall Facing the Sidewalk, for 2030 Conditions
tone Revetment to Remain
2070 Flood Elevation
2030 Flood Elevation
Present Flood Elevation
2070 Mean Tide
2030 Mean Tide
Present Mean Tide
Chelsea Creek

Lower Chelsea Creek Vulnerability Zone

Potential Shoreline Adaptation

Constructing vertical barriers in front or behind the existing parking lots could deter coastal flooding in this 90 acre (2030) zone in Chelsea, Massachusetts. Deployable barrier sections, set on the ground or on low walls, could be installed to maintain Designated Port Area (DPA) maritime water access. Permanent walls, such as concrete retaining walls or bulkheads would reduce the time and labor needed to prepare for a storm.

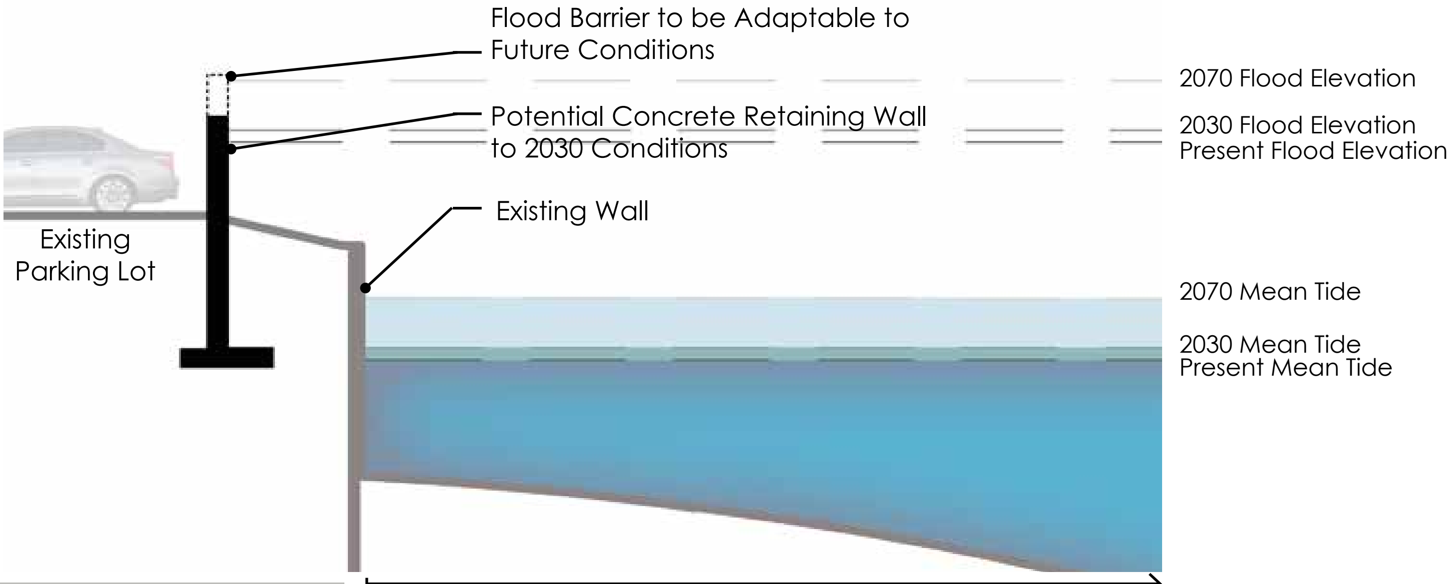
Example of a deployable flood wall. Metal panels could be a good option for future adaptation (EKO Flood USA).



Deployable flood barrier (Aquafence)

Existing Shoreline East of Chelsea Street Bridge

OUTSIDE OF FLOOD AREA
2070 AREA OF PROBABLE FLOODING
PRESENT DAY FLOOD ZONE
Parking Garage
CENTRAL AVE
EASTERN AVENUE
CHELSEA STREET
Highland Park
MWRA Screen House
Adaptation Measures May Need to be Located Behind Designated Port Area (DPA) Properties.
Existing Parking Lot (DPA Property)
Existing Sea Wall
CHELSEA CREEK
Existing Docks Must Remain Accessible
Potential Location for Adaptable Walls, Deployable or Permanent
A
A'



Flood Barrier to be Adaptable to Future Conditions
Potential Concrete Retaining Wall to 2030 Conditions
Existing Wall
Existing Parking Lot
2070 Flood Elevation
2030 Flood Elevation
Present Flood Elevation
2070 Mean Tide
2030 Mean Tide
Present Mean Tide
Chelsea Creek

SECTION A-A'

Upper Chelsea Creek Vulnerability Zone

Area Review

Historically, the tidelands of Bass Creek flowed through this area, from its confluence with Chelsea Creek up to Crescent Avenue and Broadway (Figure 7.4). Today, Bass Creek is encased by a culvert about 500 feet upstream from Chelsea Creek, and the former tidelands are home to a busy industrial area. Low elevations along the shoreline still provide potential flood pathways into this vulnerable zone, threatening approximately 10% of Chelsea's land area. This includes the MWRA Chelsea Facility and Elementary School Complex on Eastern Avenue.

Table 7.6 Upper Chelsea Creek Vulnerability Zone Quick Facts

Probable Size of Flood Zone	• 145 acres (present) • 165 acres (2030) • 200 acres (2070)
Critical Public Infrastructure	• MWRA Chelsea Facility • Substation #488 at WilloughbyStreet • Burke Elementary School Complex
Additional Properties At-Risk	• Existing and former oil terminals (Gulf Oil, Northeastern Fuel) • Portions of the Shertleff-Bellingham and Mill Hill Neighborhoods • MBTA railroad corridor, from Cary Ave to the former Forbes Industrial Park
Flood Pathways Identified	• Low points at 283 Eastern Avenue

Shoreline Adaptation Opportunities

A living shoreline could be constructed in this area to provide energy dissipation and other ecological benefits along the Chelsea Creek. A system of vertical barriers behind this natural system would provide further flood protection for this vulnerable area (see "Potential Shoreline Adaptation" on page 7-28).

Other Considerations

The open space where a former fuel tank farm once resided could be investigated as a floodplain restoration area. There is an Activity and Use Limitation (AUL) associated with this property, which prevents certain uses from occurring on site due to hazardous soil conditions. However, this $2 million property could be redeveloped with a proper soil maintenance plan. The redevelopment could include incentives to establish phytoremediation plantings to continue site clean-up and allow for a future path for public access to the waterfront.

In general, an *AUL* is used to limit activities on sites where remaining concentrations of contaminants in soil are acceptable for the current land use, but are above acceptable concentrations for other uses.

The shoreline of this zone is privately held. The City should reach out to property owners within the zone and coordinate efforts to install a successful adaptation. Including public agencies and community groups early in the conversation may also foster environmental restoration and recreational collaboration when shoreline measures are installed.

Environmental permits/approvals to construct a living shoreline and perimeter walls may include:

- Massachusetts Environmental Policy Act (MEPA)
- National Environmental Policy Act (NEPA)
- Chelsea Conservation Commission
- Everett Conservation Commission
- Massachusetts Department of Environmental Protection (DEP)
- United States Army Corps of Engineers (USACE)
- Massachusetts Office of Coastal Zone Management (CZM)

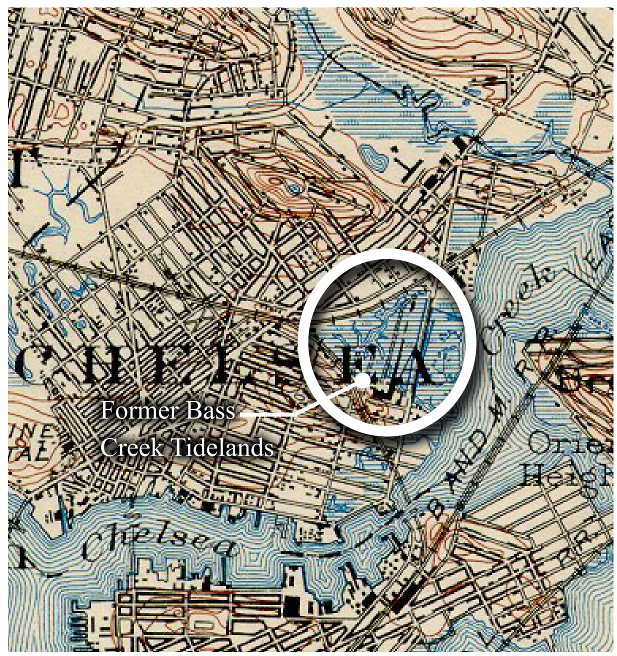


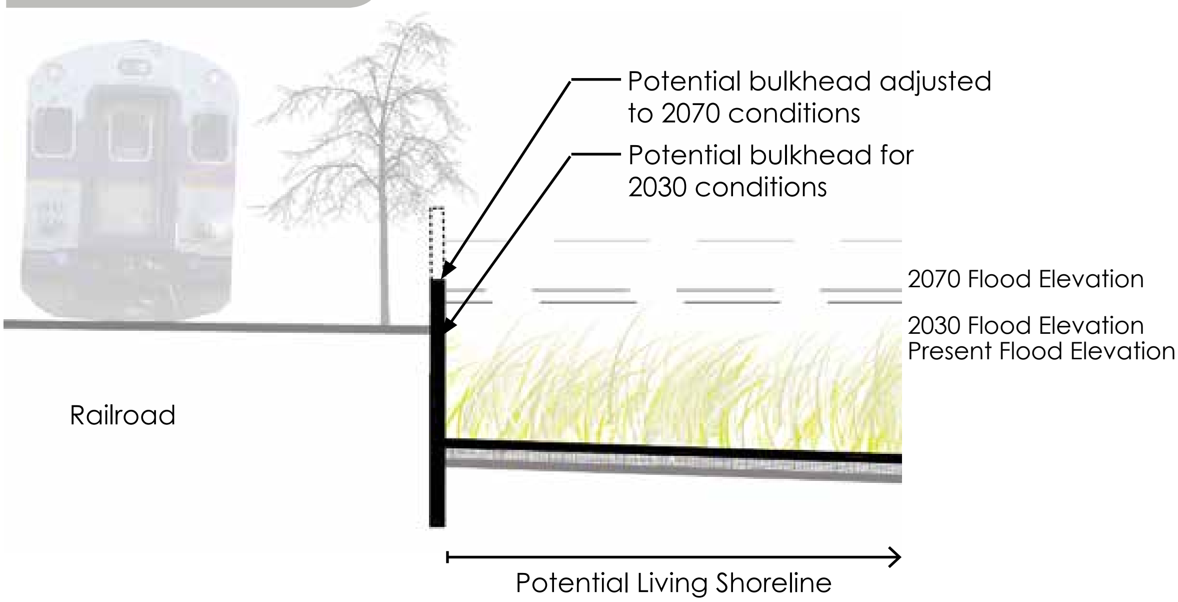
Figure 4.5 1903 USGS Topographic Map


Photos of Upper Chelsea Creek Vulnerability Zone, from East Boston, 10/17/2016.

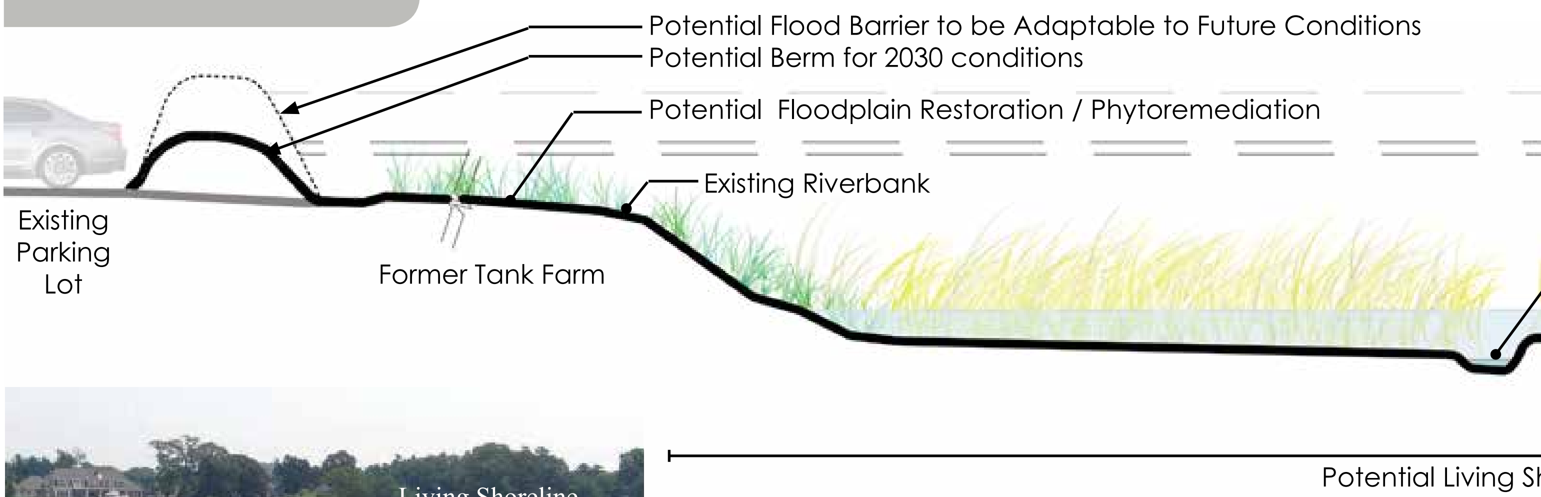
Upper Chelsea Creek Vulnerability Zone

Potential Shoreline Adaptation

SECTION A-A'

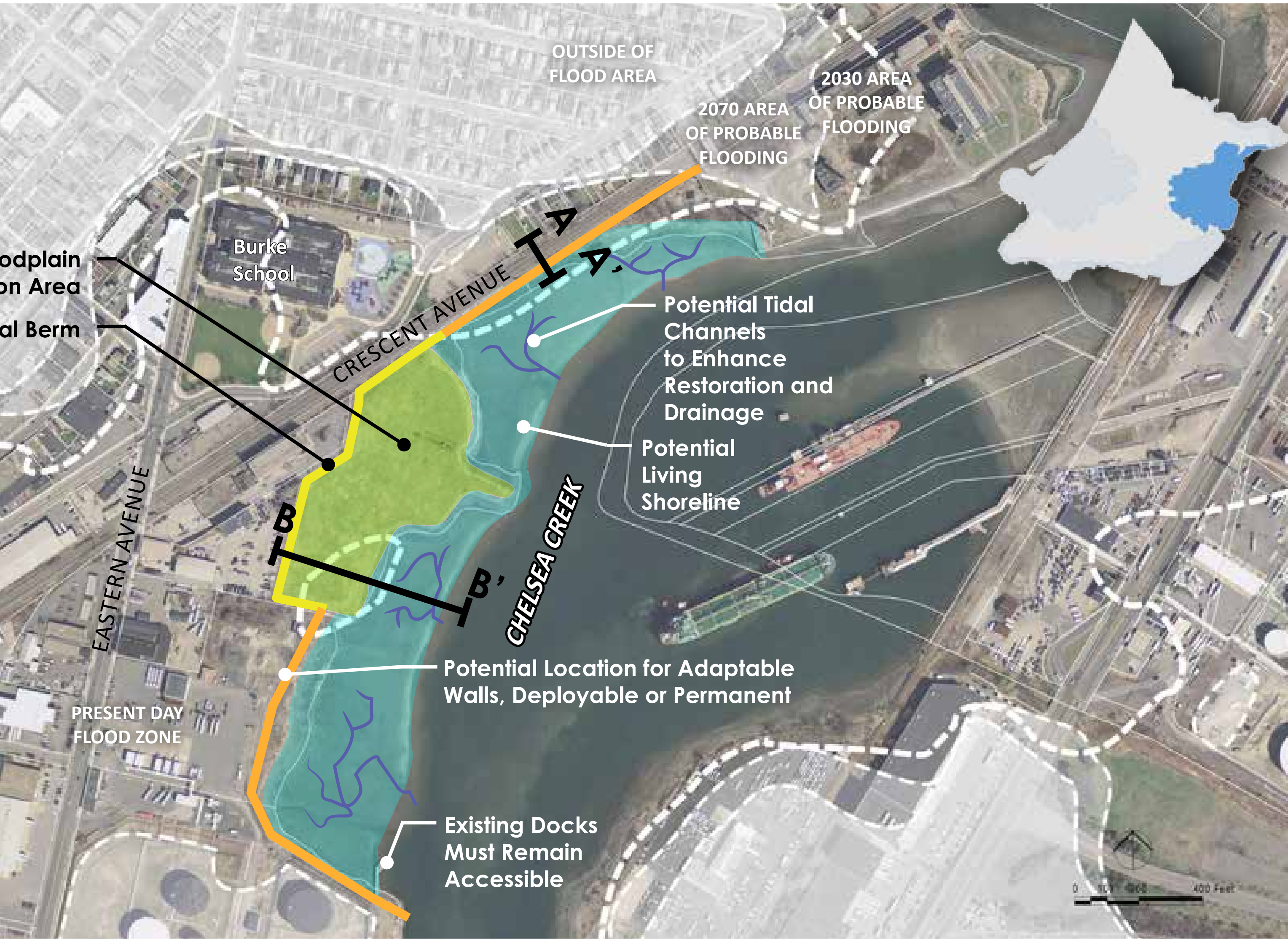


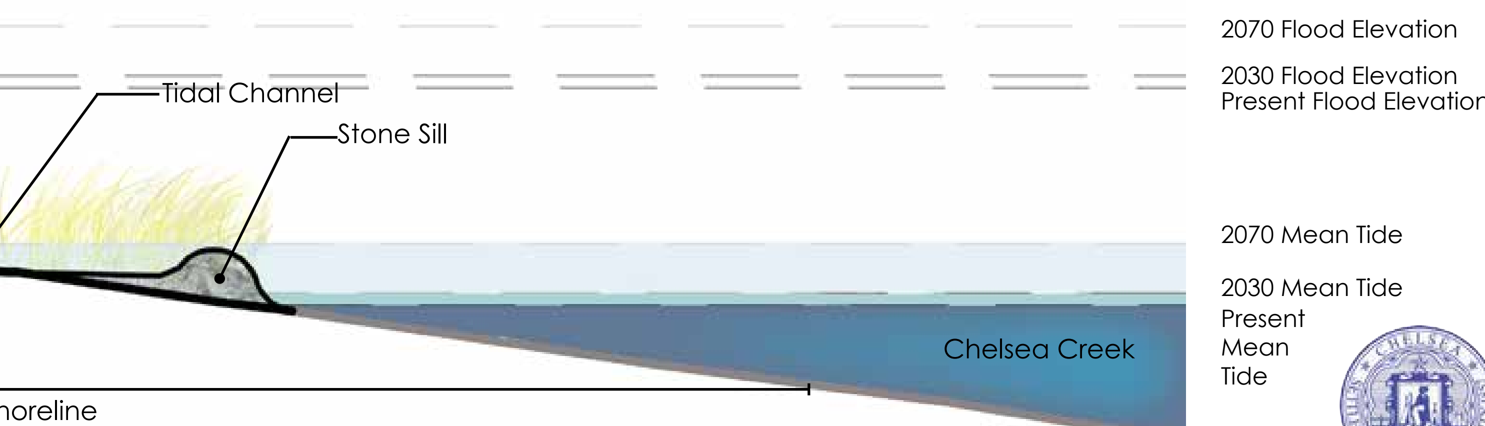
SECTION B-B'




Living Shoreline (Chesapeake Bay Foundation)

Low elevations along this stretch of Chelsea Creek leave critical p
flooding. A portion of the existing shoreline presents an opportunity t
A vertical barrier behind these natural systems would further provide f
within the Chelsea Creek Designated Port Area (DPA). A study of th
contaminated soils, and public access, as also create a masterplan for





ublic infrastructure and several industrial and commercial properties susceptible to coastal o use natural processes to provide energy dissipation and other ecological benefits to this zone. flood protection for this vulnerable area. Deployable flood walls may be required on properties e former fuel tank site could weigh the benefits of floodplain restoration, site remediation for future development.

Mill Creek Vulnerability Zone

Area Review

Mill Creek has the most natural shoreline of Chelsea's four waterways, edged with tidal flats and salt marsh. Much of these wetlands end abruptly, however, with steep lawns, retaining walls, or stone revetment separating adjacent development. The decks of the Broadway Bridge and MBTA Railroad Bridge over Mill Creek sit just above the projected 2030 flood elevation. Furthermore, the bridge openings could make draining the floodwaters of a coastal superstorm difficult.

There are currently no known plans to repair or replace the existing railroad bridge and the Broadway bridge was reconstructed in the 1990s.

Table 7.7 Mill Creek Vulnerability Zone Quick Facts

Probable Size of Flood Zone	• 15 acres (present) • 20 acres (2030) • 35 acres (2070)
Critical Public Infrastructure	• MBTA Railroad Bridge over Mill Creek • Broadway Bridge over Mill Creek
Additional Properties At-Risk	• Mace Apartments • Portions of the Mill Hill Neighborhood • Beth Israel Deaconess HealthCare Center • Chelsea Commons
Flood Pathways Identified	• Chelsea Creek

Shoreline Adaptation Opportunities

The next steps for the Mill Creek Vulnerability Zone include further hydrodynamic modeling. The model will study the forces at play along the creek, related to predicted storm surge, sea level rise, and stormwater runoff from the surrounding watershed. Study results should more accurately identify the probability of the bridges being overtopped. Once this information is obtained, adaptation measures can be identified for this zone.

Many of the Properties Along Clinton Street Drop Steeply to Mill Creek. Photo at left taken during low tide, April 2016. Photo at right taken during king tide, October 2016.

Tidal Flats and Salt Marsh along Mill Creek (April 2016)

Mill Creek Vulnerability Zone

Potential Shoreline Adaptation

A more detailed hydrodynamic model along Mill Creek, particularly in relation to the bridges crossing over the waterway, is recommended to determine the best way to prepare for future flooding in this vulnerability zone. This will better inform adaptation opportunities - initial ideas include raising the bridges and a passive control structure at, or just downstream of, the MBTA bridge.


REVERE
2030 AREA
OF PROBABLE
FLOODING
BROADWAY
Beth Israel
Health-Care
Center
DCR Ice Rink
REVERE PARKWAY
MILL CREEK
CLINTON STREET
OUTSIDE OF
FLOOD AREA
Mace
Apartments
EXISTING MBTA
BRIDGE
CRESCENT AVENUE
MBTA COMMUTER LINE
Former Forbes
Industrial Site
CHELSEA
CREEK


Mean High Water Line

Policy or Regulation Based Measures

Any overall planning strategy will need to consider first whether it is appropriate to adopt a policy of managed retreat, adaptation, or defense. The decision as to which approach should be applied, and what role the City should play, is one that can only be taken at the policy level, and with the input of City board, commissions, and residents.

The City's Floodplain Overlay District encapsulates a portion of the flood pathways identified in this study, adhering to the boundaries of the 2016 FEMA Flood Insurance Rate Maps. Areas outside of the FEMA FIRM catchment area are not subject to the Flood Plain Overlay District. The City should explore embarking on a zoning study to assess regulatory modifications that facilitate retrofits of existing buildings and ensure new development proceeds safely and is constructed consciously in potential flood pathways. Such a study should approach the topic holistically while addressing building and site design vulnerabilities.

Land use regulation is promulgated by M.G.L. Chapter 40 and overseen by the City's Zoning Board of Appeals (ZBA) and Planning Board. These entities are tasked with reviewing development proposals for zoning conformance in the event that an applicant requires dimensional relief or accommodation for use. The determination of a development or renovation proposal's compliance with M.G.L. Ch. 131 Section 40, the Wetlands Protection Act, is made by the City's Conservation Commission.

It is recommended that the City craft a resiliency review check-list for each of the boards and commissions. Addressing the probability of flooding, rising temperatures, and more volatile storm events, this checklist should encourage proper site, building, and landscape design. It should aim to effectuate the adoption of more in-depth resiliency measures by property owners/developers while pragmatically contemplating the economic variables involved in the real estate market. Particularly, how to urge the adoption of measures by smaller property owners should be assessed, as many may not be able to absorb the net cost. Additionally, the ability of buildings and land to withstand, endure, and recover from severe weather events and flooding should also be explored in the crafting of a check-list. Existing examples of materials for boards & commissions are available from the Boston Conservation Commission, Urban Land Institute, the American Planning Association, and other entities.

Structural resilience can be undermined if the appropriate building codes are not followed, which stipulate the bare minimum for safe, inhabitable, and functional buildings. Chelsea City Council adopted the Stretch Energy Building Code in 2016; a part-time Energy Coordinator staff position was also filled to advance the City's energy agenda and initiatives. Aimed at designing for energy conservation and reducing emissions, the Stretch Energy Code is an effective policy tool. Beyond the "floor" provided by the building code, the City is recommended to investigate and adopt a series of best policy practices for fostering sound design, construction, retrofits, and maintenance of structures situated in flood-risk areas. Moreover, site and landscape design should also be included. This can be done collaboratively through the City's Department of Planning and Development, the City's Energy Planner, the MAPC, and related organizations active in sustainable design and construction.

Through policy and planning, the City can encourage the creation of scalable site-specific adaptation plans for regionally significant facilities. Publicly, resilience plans should be considered for the City's schools. Recreation area design should also respond to the risks characterized in this study. Moreover, with the City embarking on an update of its Open Space and Recreation Plan in 2017, climate adaptation and mitigation measures should be analyzed for use in varying types of parks and open space.

For private industry and commerce, tailored site solutions could be pursued, in conjunction with the property's owners, tenants, and stakeholders. For example, a study of the New England Produce Terminal's vulnerability to climate change was conducted concurrent to this effort. Undertaken by the MAPC, American Geophysical Union, UMass Boston, and City of Chelsea, this constellation of organizations reflect the collaborative make-up that the City could choose to employ. Similar studies could be conducted for other industrial clusters vital to the regional economic, or posing a hazard to the City in a severe weather event. Overall, conceptualization and resulting activities should materialize as public-private partnerships and vanquish any cultural or educational barriers that may be present.

In 2017, the City will embark on a Municipal Harbor Plan with the Massachusetts Office of Coastal Zone Management. Encompassing the Designated Port Area, this plan will chart the maritime future of Chelsea's waterfront, accounting for projected economic, demographic, and climactic factors. Resilience should be an the underlying element present throughout this study. Specifically, design propositions in this study, which would need to comprehensively accommodate M.G.L. Ch. 91 regulations and access, could be incorporated into discussions about port infrastructure.

8 NEXT STEPS

This assessment identified vulnerable areas of the City at risk of coastal flooding, prioritized public infrastructure in these areas, and recommended site, shoreline, and policy based adaptation measures. Following this assessment, additional efforts are needed to:

Assess valued socioeconomic components in the five vulnerability zones

The assessment should be broadened to include consideration of where residents live and work and their continued ability to maintain a high quality of life when these social and economic components of the built environment are at risk of coastal flooding under present day, 2030 and 2070 conditions. Valued socio-economic components include, but are not limited to:

- Environmental Justice (EJ) neighborhoods
- Number of residential units
- Major employers, health care providers, and supermarkets

In order to accomplish this goal, the population of these zones need to understand the topic of vulnerability and adaptation planning, and what it means to their daily life.

Communicate the topic of vulnerability and adaptation to a wider audience

A more robust public outreach and education process is needed to educate the public about climate change related vulnerability in their neighborhoods, the places they work, and the city in general. Creating this level of informed involvement will require peer to peer engagement at the neighborhood level, adaptation training for City staff/boards/commissions, and the formation of working groups focused around each vulnerability zone. Working group membership could include City Council members, non-profits, neighborhood groups, major employers/property owners, and public agencies with a vested interest in the specific vulnerability zone. With wider public understanding of these issues, the expectation is that residents, agencies, businesses, and property owners will become invested in the resiliency planning effort.

Conduct supplemental modeling of key flood pathways

Two supplemental hydrodynamic modeling efforts are recommended to better assess the probability of coastal flooding and support the public outreach and education process. First, street level analysis of the flood pathways in each of the vulnerability zones will allow for a better understanding of where coastal flooding will be concentrated and illustrate the value of action (or inaction). The street level analysis will also allow for further refinement of the adaptation measures developed to date. Second, a hydraulic study along Mill Creek, particularly in relation to the bridges crossing over the creek, is needed to assess future flooding and determine appropriate adaptation measures.

Form public/private partnerships

These next steps will highlight opportunities for the public, private, and non-profit entities in the City and neighboring municipalities to act together to improve community resilience for their mutual benefit. It is also hoped that these discussions will lead to the formation of public/private partnerships and cost sharing around agreed upon adaptation strategies and heighten the need to modify City ordinances and other policies to limit the vulnerability of future development. Again, no one single entity can do this alone, or all at once.

Seek potential funding

Funding is needed to design, permit, and construct the site specific and shoreline adaptation measures discussed in Chapter 7. In addition, some of the shoreline measures require land acquisition which will add to the overall project cost. The site specific measures can likely be funded through the City's Capital Improvements Program and/or maintenance budgets. However, each of the shoreline measures requires a significant level of investment which cannot be independently borne by the City. In these locations, the City should seek to leverage City and private funds (corporations, foundations, non-profits) with a combination of state and federal funding grant funding from sources such as the Federal Emergency Management Agency (FEMA), Environmental Protection Agency (EPA), and Massachusetts Executive Office of Energy and Environmental Affairs (EOEAA). Consideration should also be given to phasing each project to spread out the overall project costs and allow for adequate time to secure the required environmental approvals. Creative funding and implementation strategies are needed to successfully advance the concept designs towards implementation.

These additional efforts should be advanced in parallel in the near term recognizing that year 2030 is just over a decade away. Again, the City does not need to do this alone. The formation of strategic partnerships and engagement of local champions is critical to advancing the City's resiliency agenda and address coastal flooding risks in the short term and long term.

Appendix A

Glossary of Terms and Abbreviations

Terms

Adaptation	Adjustment or modification to a particular situation or circumstance
Critical Energy Pathway	Crucial path that provides petroleum products (gasoline, diesel fuel, heating oil, jet fuel) to a region
Deployable (portable) perimeter installations	Paneling systems such as Aquafence or water inflated flood barriers
Environmental Justice	Fair treatment and meaningful involvement of all people regardless or race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations and policies
Green Infrastructure	Ecological systems and processes harnessed by humans to combat climate change, create healthy built environments, and to improve quality of life. Ecamples include constructed wetlands, urban forests, green roofs, green streets and rain gardens
Grey Infrastructure	Infrastructure projects that occur when industrial development and state regulations limit green infrastructure installations, therefore resulting in engineered barriers
Hydrodynamic Modeling	Modeling based on mathematical representations of the processes that affect coastal water levels such as riverine flows, tides, waves, winds, storm surge, sea level rise, and wave set-up, at a fine enough resolution to identify site specific locations that may require adaptation alternatives
Inundation	The flooding of low-lying coastal land caused by severe weather
Risk	(Consequence of Failure x Probability of Flooding) - Score to prioritize infrastructure assets/facilities. Rated through a five-tier qualitative rating system (Severe to None)
Storm Surge	An abnormal rise of water generated by a storm, over and above the normal tide ranges
Urban Resilience	The capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt and grow no matter what kinds of chronic stresses and actue shocks they experience

Vulnerability	Structures, systems, populations or other community assets as defined by the community that are susceptible to damage and loss from hazard events

Abbreviations

301 CMR	Code of Massachusetts Regulation: Energy and Environmental Affairs
ADCIRC	Advanced Circulation
BH-FRM	Boston Harbor-Flood Risk Model
CIP	Captial Improvement Program
DCR	Department of Conservation and Recreation
DPA	Designated Port Area
DPW	Department of Public Works
EOEEA	Executive Office of Energy and Environ-mental Affairs
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIRMs	Flood Insurance Rate Maps
LiDAR	Light Detection and Ranging
MA CZM	Massachusetts Office of Coastal Zone Man-agement
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transportation Authority
MEPA	Massachusetts Environmental Policy Act
MWRA	Massachusetts Water Resources Authority
MyWRA	Mystic River Watershed Association
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Admin-istration
SCADA	Supervisory control and data acquisition
SLAMM	Sea Level Affecting Marshes Model
SWAN	Stimulating Waves Nearshore
USACE	U.S. Army Corps of Engineers
WHG	Woods Hole Group

Appendix B

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Massachusetts Water Resources Authority website. http://www.mwra.com/

National Oceanic and Atmospheric Administration, Fisheries Office of Habitat Conservation, n.d. "Living Shorelines." NOAA Restoration Center. www.habitat.noaa.gov/

Appendix C

FEMA FIRMs

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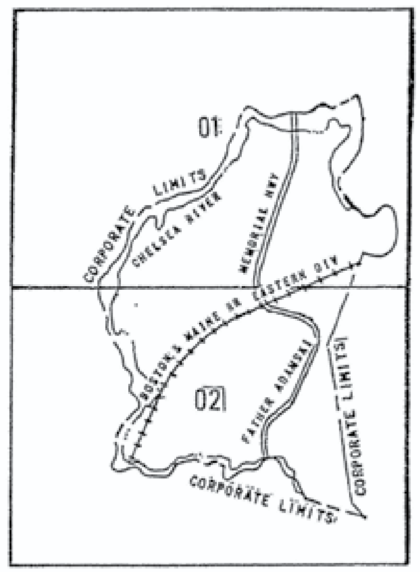
These maps may not include all Special Flood Hazard Areas in the community. After a more detailed study, the Special Flood Hazard Areas shown on these maps may be modified, and other areas added.

Consult NFIA Servicing Company or local insurance agent or broker to determine if properties in this community are eligible for flood insurance.

Community No. 25C287 A



MAPS REVISED DECEMBER 27, 1974 TO IDENTIFY:
1. ADDITIONS OF SPECIAL FLOOD HAZARD AREA
2. DELETIONS OF SPECIAL FLOOD HAZARD AREA

SPECIAL FLOOD HAZARD AREA

IDENTIFICATION DATE
ZONE A JUNE 7, 1974
ZONE A-1 DECEMBER 27, 1974

LEGEND

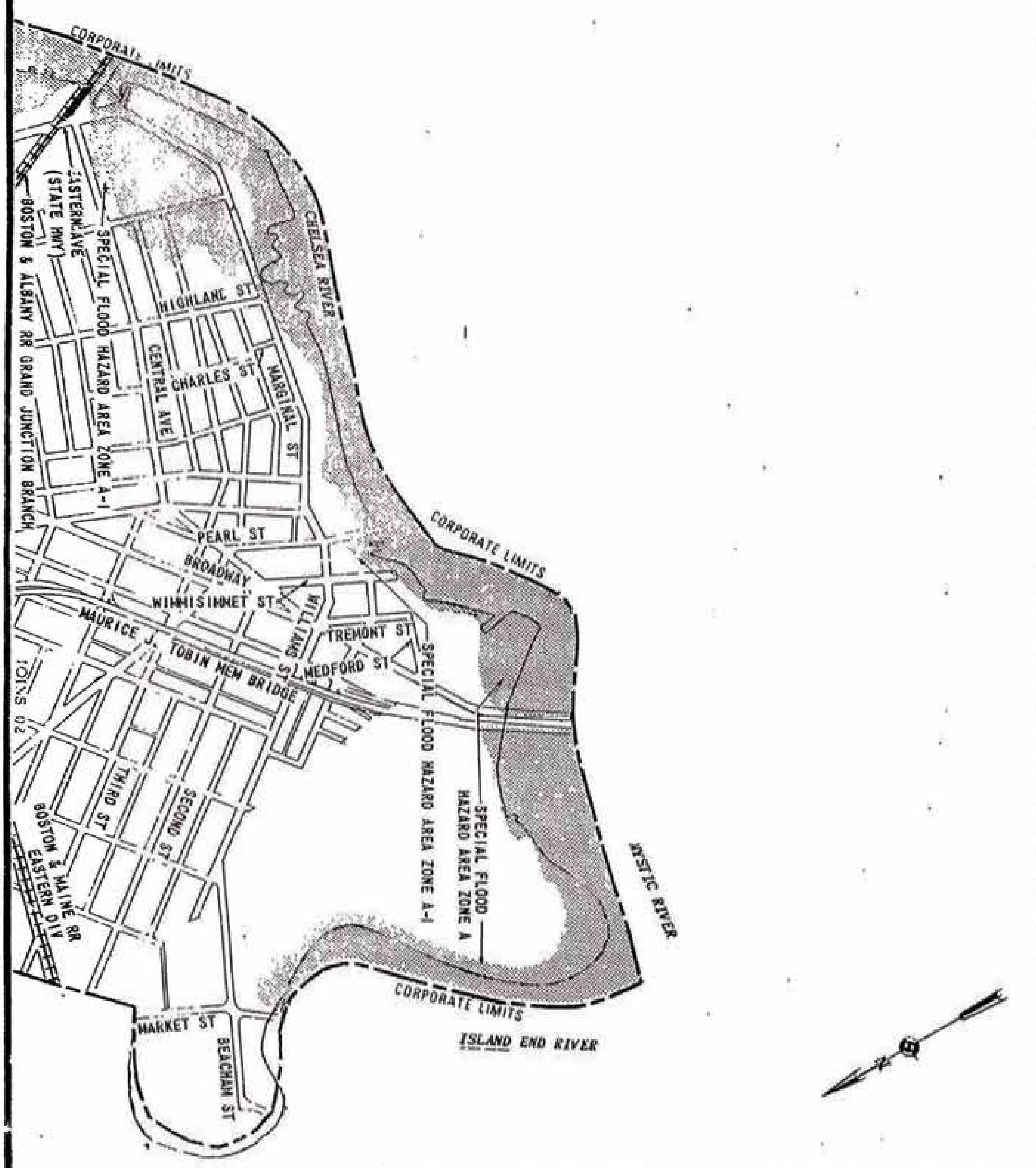
Levee

Sea Wall

SPECIAL FLOOD HAZARD AREA — ZONE A

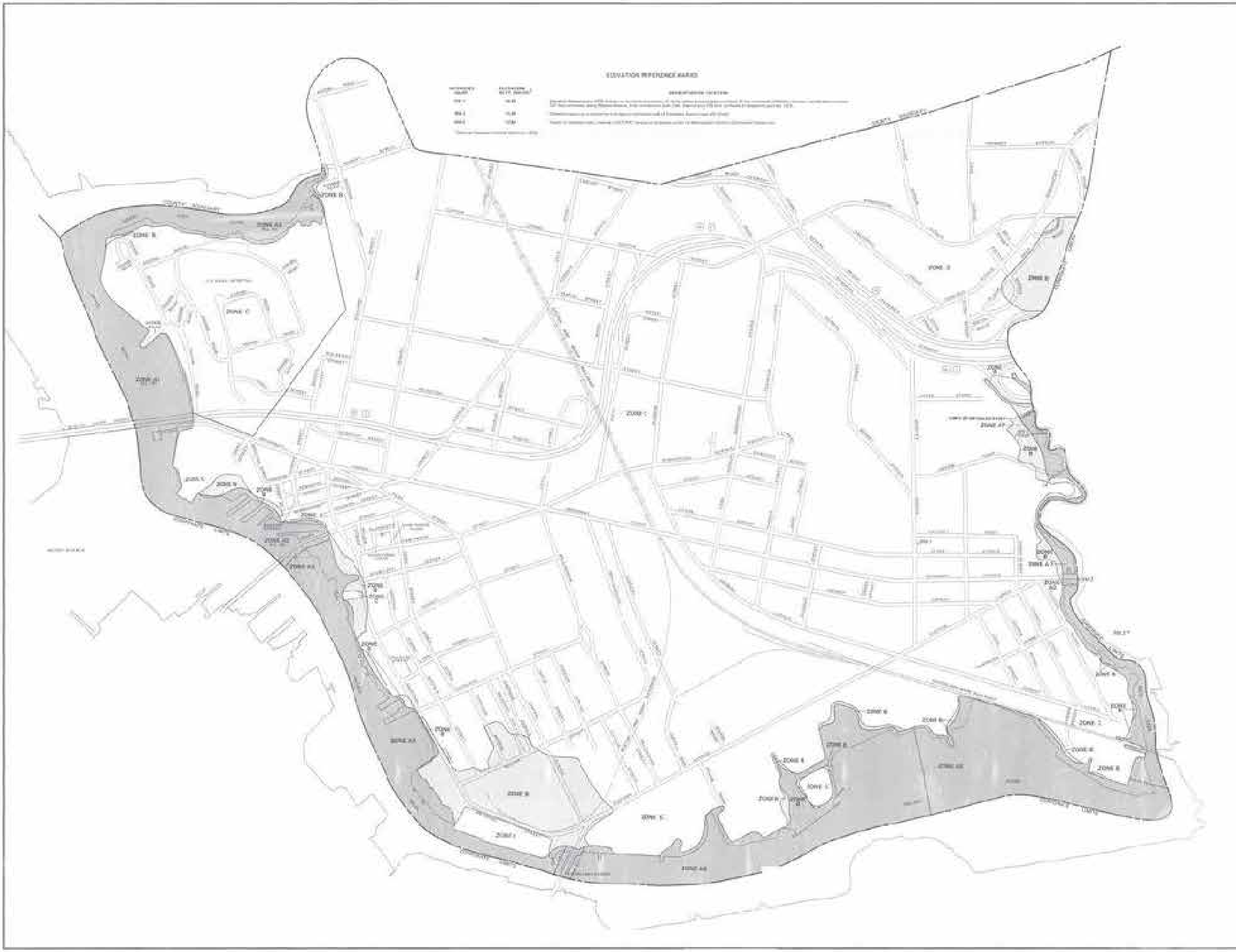
DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
Federal Insurance Administration
CITY OF CHELSEA, MA
(SUFFOLK CO.)

MAP INDEX
FIA FLOOD HAZARD BOUNDARY MAPS
No H 01-02



01	DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT Federal Insurance Administration CITY OF CHELSEA, MA (SUFFOLK CO.)	APPROXIMATE SCALE 500 0 1000 2000 3000	
		FIA FLOOD HAZARD BOUNDARY MAP No H 01	Effective Date: DECEMBER 27, 1974

02	DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT Federal Insurance Administration CITY OF CHELSEA, MA (SUFFOLK CO.)	APPROXIMATE SCALE 500 0 1000 2000 3000
		FIA FLOOD HAZARD BOUNDARY MAP No H 02
		Effective Date: DECEMBER 27, 1974



NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

CITY OF CHELSEA, MASSACHUSETTS SUFFOLK COUNTY

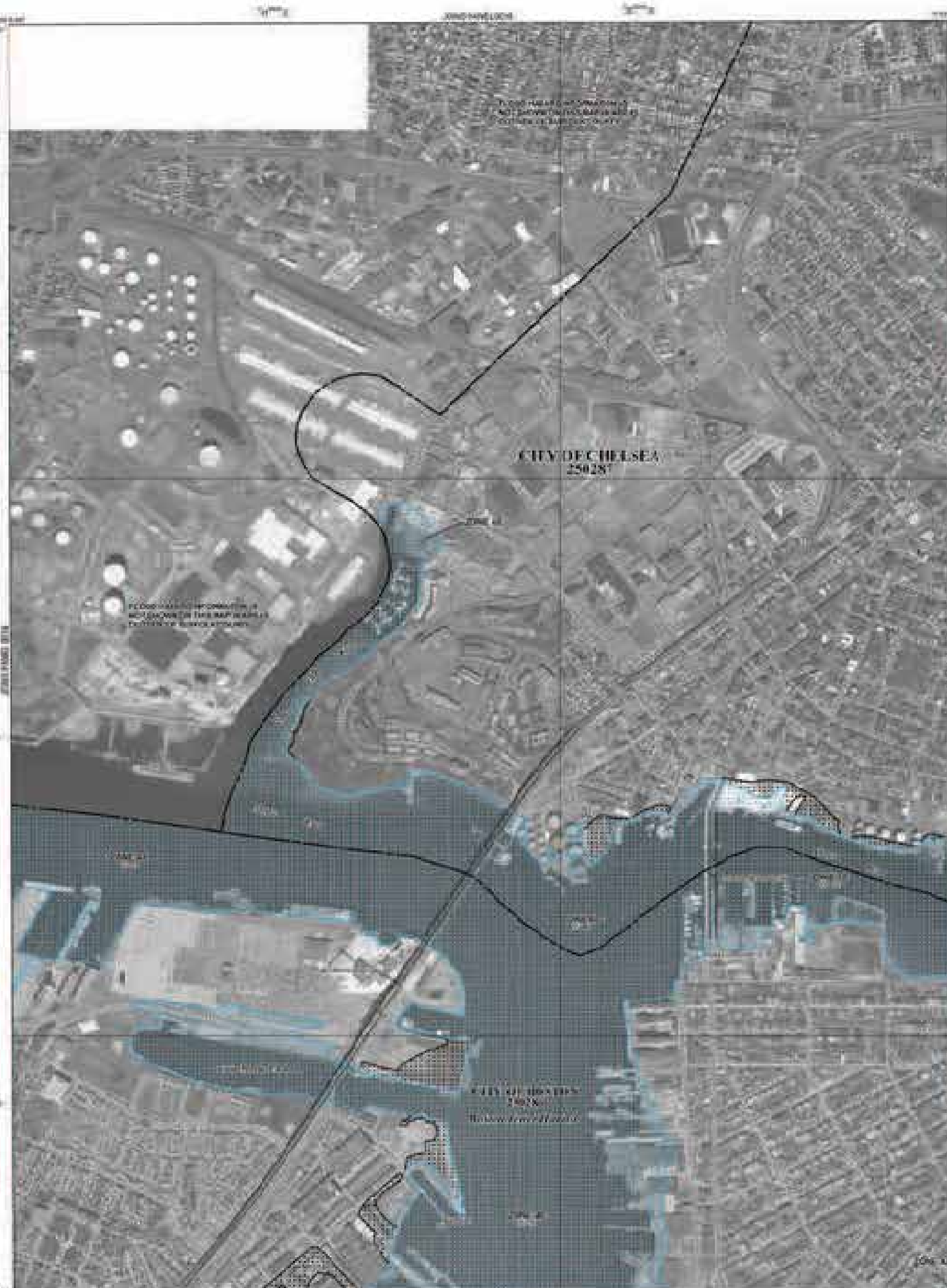
ONLY PANEL PRINTED

COMMUNITY-PANEL NUMBER 250287 0001 B

EFFECTIVE DATE: AUGUST 2, 1982

Federal Emergency Management Agency

NOTES TO USERS



LEGEND

NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

SUFFOLK COUNTY,
MASSACHUSETTS
(ALL JURISDICTIONS)

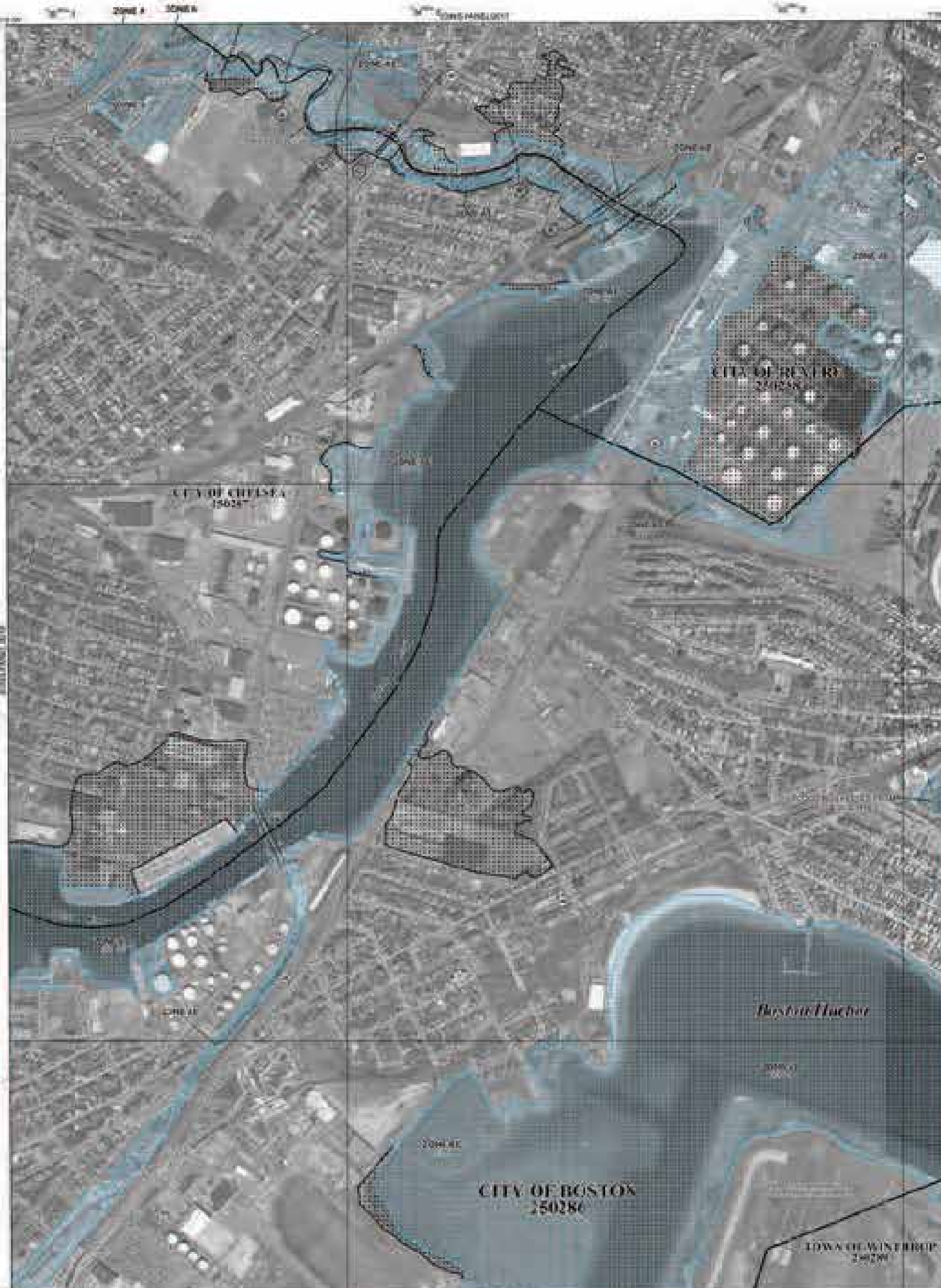
MAP NUMBER

EFFECTIVE DATE

Federal Emergency Management Agency

NOTES TO USERS

LEGEND



NATIONAL FLOOD INSURANCE PROGRAM

NFIP

FIRM

FLOOD INSURANCE RATE MAP

SUFFOLK COUNTY, MASSACHUSETTS

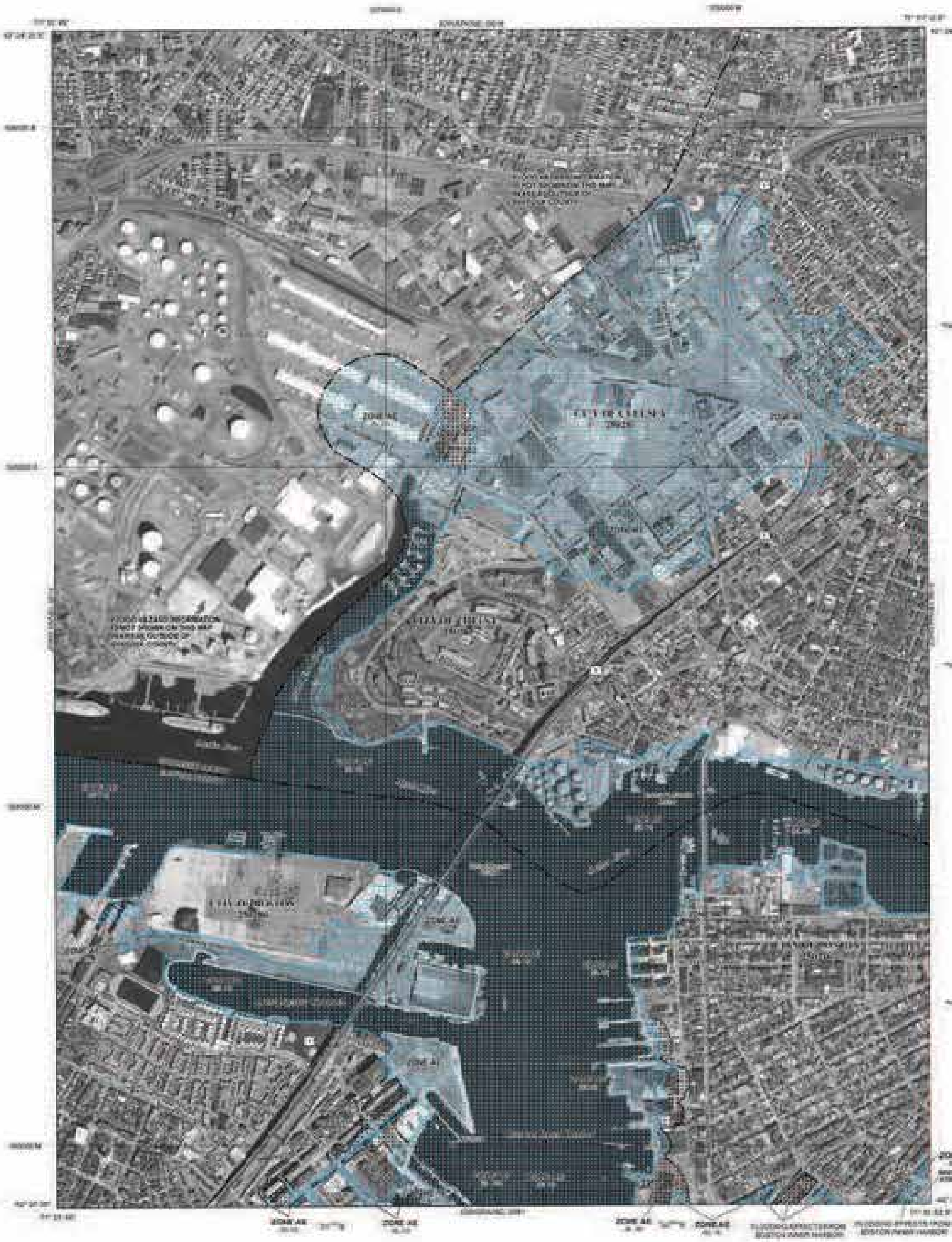
(ALL JURISDICTIONS)

MAP NUMBER

EFFECTIVE DATE

Federal Emergency Management Agency

NOTES TO USERS



LEGEND

OTHER FLOOD AREAS

OTHER AREAS

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

MAP SCALE 1" = 500'

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0018J

FIRM

FLOOD INSURANCE RATE MAP

SUFFOLK COUNTY, MASSACHUSETTS (ALL JURISDICTIONS)

PANEL 18 OF 171

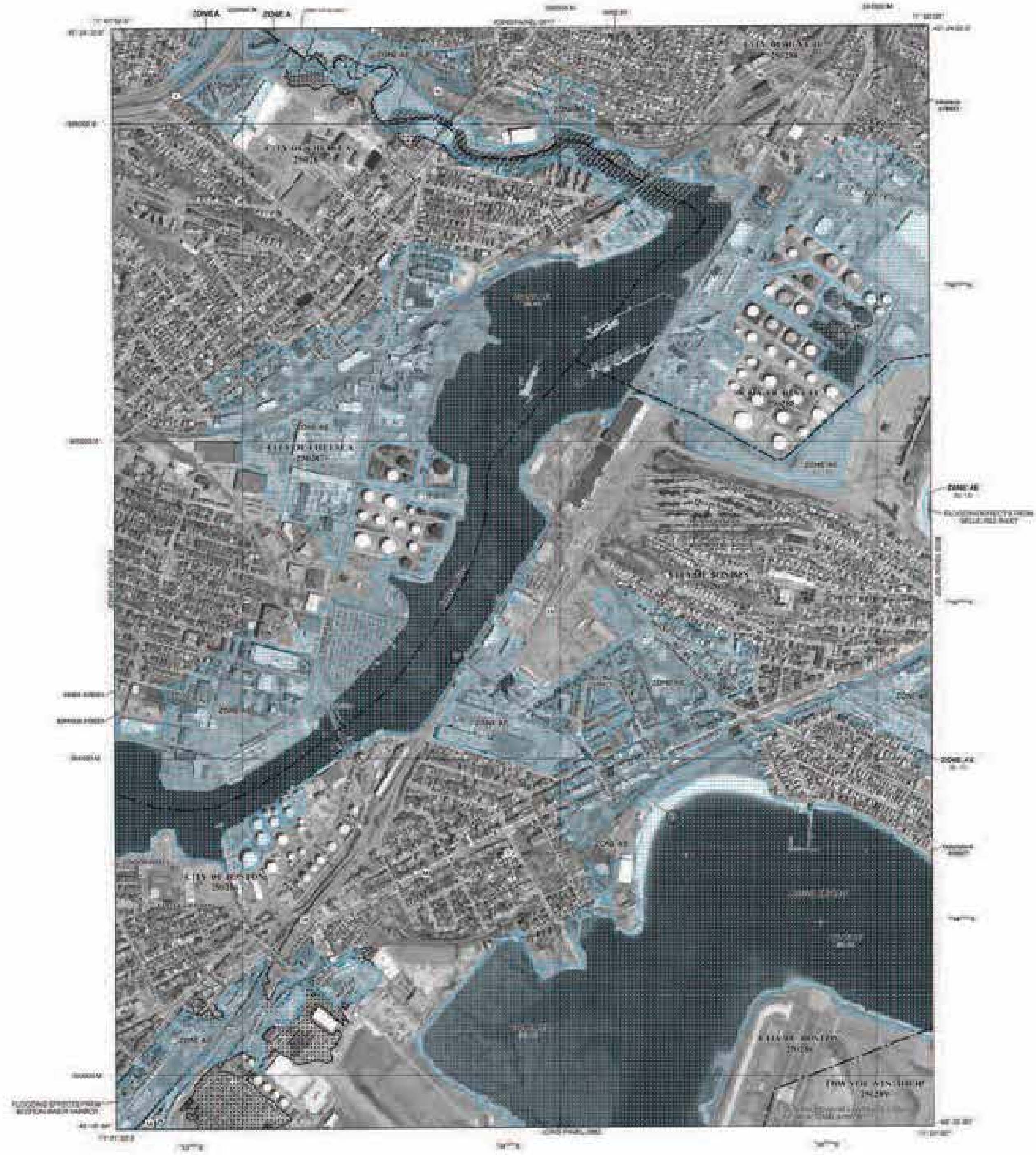
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

MAP NUMBER 25025C0018J

MAP REVISED MARCH 16, 2016

Federal Emergency Management Agency

NOTES TO USERS



LEGEND

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0019J

FIRM

FLOOD INSURANCE RATE MAP

SUFFOLK COUNTY, MASSACHUSETTS (ALL JURISDICTIONS)

PANEL 19 OF 175

MAP NUMBER 25025C0019J

MAP REVISED MARCH 16, 2016

Federal Emergency Management Agency

Appendix D

Probabilistic Modeling of Sea Level Rise, Storm Surge, and Waves

Probabilistic Modeling of Sea Level Rise, Storm Surge, and Waves

A key component of any climate change vulnerability study for a coastal community is the accurate assessment of the effects of storm surges, rising sea levels, and increased discharges from overland flooding. One of the impacts of climate change is that coastal flooding risks are also likely to increase. Although there are various options for modeling sea level rise and storm surge, the most accurate approach for assessing combined storm surge risk and sea level rise conditions is through the implementation of hydrodynamic models that include the physical processes that are associated with storm climatology and propagation. The probabilistic model approach developed by Woods Hole Group is a comprehensive flood risk model that can accurately assess flooding risk under present day and future climate change conditions. The probabilistic modeling system is comprised of the Advanced CIRCulation model (ADCIRC), a two-dimensional, depth-integrated, long wave, hydrodynamic model for coastal areas, inlets, rivers and floodplains that in this application is used to predict storm surge flooding, and the unstructured grid version of Simulating Waves Nearshore model (UNSWAN), a wave generation and transformation model. The ADCIRC model is tightly coupled with UNSWAN, dynamically exchanging physical processes information during each time step, to provide an complete and accurate representation of water surface elevations, winds, waves, and flooding along the coastline and upland areas. For example, the probabilistic model includes important physical processes such as wave setup, wind stresses, and wave-current interaction such that these processes are included in the flooding dynamics of the coastline. This model has been successfully applied and used in Boston, MA and the Boston Harbor Area for assessing potential vulnerabilities in the Central Artery tunnel system. The model, called the Boston Harbor Flood Risk Model (BH-FRM) is the model that is being used to provide the results for the City of Chelsea. Full details on the model can be obtained from the report (https://www.massdot.state.ma.us/highway/Departments/EnvironmentalServices/EMSSustainabilityUnit/Sustainability.aspx). The model is currently being extended to the entire coastline of Massachusetts. Numerous communities are applying the probabilistic model results to assess vulnerabilities and design adaptations. The model is also regularly being used to prioritize climate change adaptations and engineering designs such that communities can direct funding to the most critical areas of need first without being encumbered by financial constraints to fix everything at once. If applied, the model results can be used to assess the vulnerability and risk of coastal flooding for Chelsea infrastructure and natural resources, as well as provide design condition inputs and adaptation and resiliency options for the Town.

The probabilistic modeling approach simulates a statistically robust set of storms (both tropical and extra-tropical) for each climate change and/or Sea Level Rise (SLR) scenario through a Monte Carlo statistical approach (Figure 1). Results of the Monte Carlo simulations are used to generate Cumulative Probability Distribution Functions (CDFs) of the storm surge water levels at a high degree of spatial precision. In particular, an accurate and precise assessment of the exceedence probability of combined SLR and storm surge, provided at high spatial resolution help decision makers identify areas of existing vulnerability requiring immediate action, as well as, areas that benefit from present planning for future preparedness. Results of the Monte Carlo approach also produce a statistically robust, spatially variable map of risk for each given SLR scenario that can be used to determine the potential need for adaptation, and the timing for potential adaptation, at each facility and for each infrastructure asset. Specific adaptations can also be provided to the model (both gray and green designs) and the model can be re-simulated with these adaptations or solutions in place. As such, the model can be used to predict the effectiveness of various resiliency options and the influence the adaptations have on the nature, extent, and depth of flooding probabilities. The model results also can be, and have been, tied directly to economic models that assess the cost implications of future climate changes and associated adaptation options.

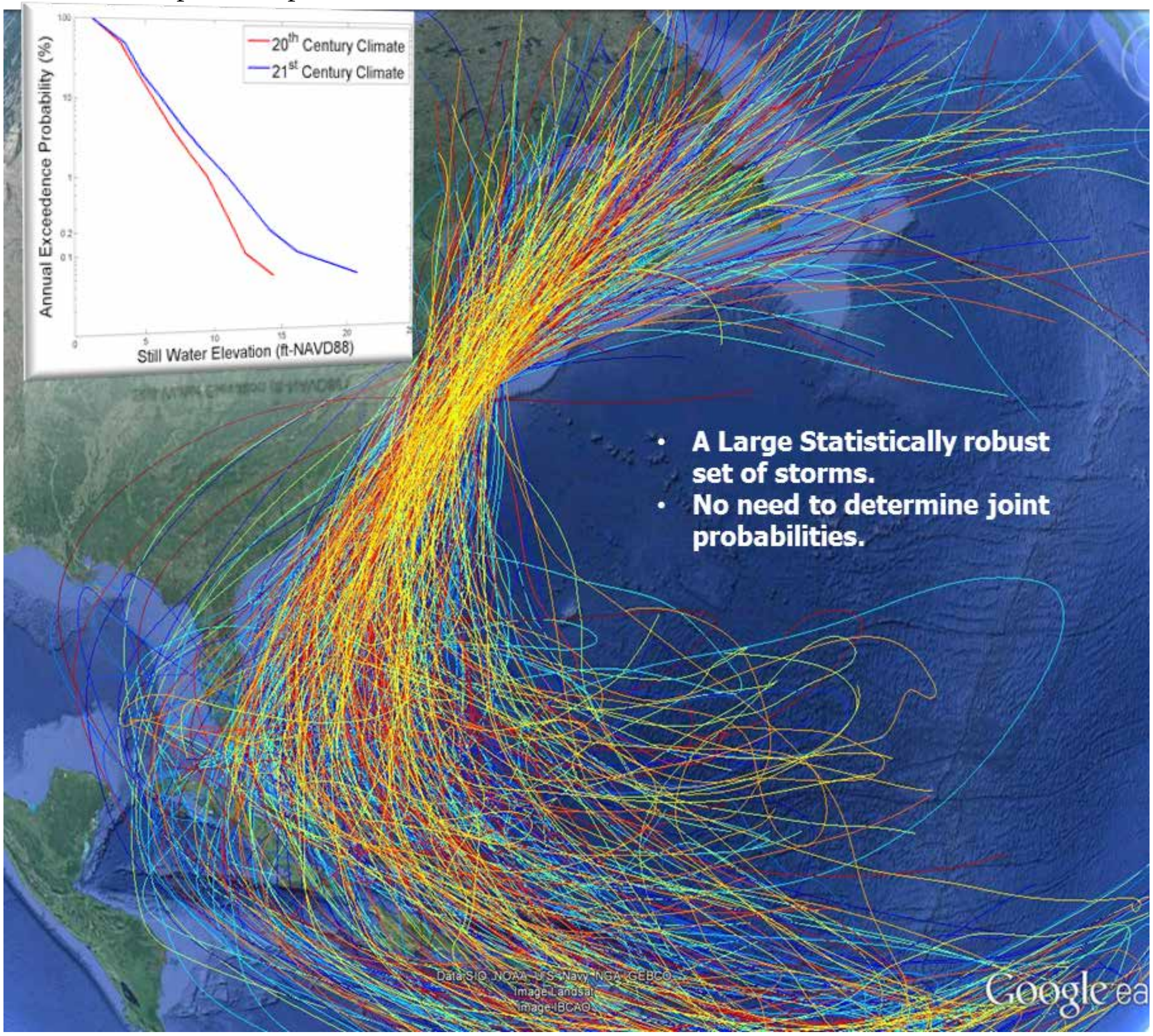


Figure 1. Tropical Storm tracks simulated through the probabilistic model.

Appendix E

Chelsea Natural Resource Evolution Summary

These results are part of the Statewide Modeling the Effects of Sea Level Rise on Coastal Wetlands for Massachusetts Coastal Zone Management. (ENV 14 CZM 08 in publication, 2016).

Background:

Climate change, with increased storm intensity, changes in precipitation patterns, and global sea-level rise will exacerbate already difficult coastal management issues related to both infrastructure and natural resources (Bosma et al., 2015). Recent studies have identified sea-level rise as one of the most certain and potentially destructive impacts of climate change (Meehl et al., 2007). Coastal wetlands are among the most susceptible ecosystems to climate change, especially accelerated sea-level rise. Nicholls et al. (2009) points out that coastal wetlands, including salt marshes and intertidal areas, could experience substantial area losses due to sea-level rise. Because coastal wetlands are extremely productive ecosystems, and provide a variety of ecosystem services, such as flood protection, waste assimilation, nursery areas for fisheries, and conservation and recreation benefits, such loss would have a high human cost.

Recognizing the threats posed by climate change and sea-level rise, the Massachusetts Office of Coastal Zone Management (CZM) desired to assess and analyze the effects of sea-level rise on coastal wetlands for the Commonwealth of Massachusetts (ENV 14 CZM 08 in publication, 2016). The project's intent was to simulate the effects of sea-level rise using an ecological model and implement the model at its highest level of complexity.

The model selected to evaluate the impact of sea level rise on coastal resources was the Sea Level Affecting Marshes Model (SLAMM), originally developed with EPA funding in the 1980s. The SLAMM model attempts to capture the major coastal processes, at least at a rudimentary level, involved in wetland conversions and shoreline modifications expected to occur over a long term.

The results of the marsh migration modeling are intended to be used for future coastal planning in a number of ways. For instance, model results from this project can be used to identify areas with barriers to landward migration of salt marshes. These results can therefore serve as a guide for development and implementation of adaptation strategies for coastal managers and policymakers to proactively address potential impacts from long-term sea-level rise. The results produced for the City of Chelsea have been extracted from the larger CZM Commonwealth of Massachusetts project for this particular study.

Input Data:

High resolution elevation data may be the most important Sea Level Affecting Marsh Migration (SLAMM) model data requirement, since the elevation data demarcate not only where salt penetration is expected, but also the frequency of inundation for wetlands and marshes when combined with tidal range data. Input elevation data also helps define the lower elevation range for beaches, wetlands and tidal flats, which dictates when they should be converted to a different land-cover type or open water due to an increased frequency of inundation.

For this project, LiDAR was acquired from MassGIS. The majority of the state was covered with the 2011 USGS LiDAR for the Northeast project, and this covers the Hull area. In order to reduce processing time within the SLAMM model, areas of higher elevation within each regional panel that are unlikely to be affected by coastal processes, such as sea level rise, were excluded prior to processing; all areas above an elevation of 60 feet (NAVD88) were clipped from the input files.

Wetland Classification Information:

The 2011 wetland layer developed by the National Wetlands Inventory (NWI) is used as the baseline source for the wetlands input file for marsh migration modeling.

Utilizing the NWI data had two key benefits over the 1990s MassDEP wetland layer. First, the NWI data not only provided a more recent dataset, but also more closely temporally matches that of the LiDAR datasets.

The second benefit to utilizing the NWI data is that it streamlined the conversion between source wetland categories and Sea Level Affecting Marsh Migration (SLAMM) model wetland codes. The documentation provided with the SLAMM software contains a key to convert each NWI classification to the wetland classification system used by SLAMM. A summary of this conversion key is present in Table 1.

Sea Level Rise Projections:

The Sea Level Rise (SLR) projections are consistent with those used in the BH-FRM modeling to produce the inundation proba maps. As such, there SLR used in the marsh migration modeling is consistent with the values used it the flood risk modeling for the City of Chelsea.

Additional Data Input:

Additional model input includes, but is not limited to, accretion rates (marsh, beach, etc.), erosion rates, tidal range and attenuation, freshwater parameters, dikes and dams, and impervious surfaces. For complete details, see the Statewide Modeling: the Effects of Sea Level Rise on Coastal Wetlands for Massachusetts Coastal Zone Management. (ENV 14 CZM 08 in publication, 2016).

Table E-1. NWI Category to SLAMM code conversion table.

		NWI Code Characters					
SLAMM Code	SLAMM Name	System	Subsystem	Class	Subclass	Water Regime	Notes
1	Developed Dryland	U					Upland
2	Undeveloped Dryland	U					Upland
3	Nontidal Swamp	P	NA	FO, SS	1, 3 to 7, None	A,B,C,E,F,G,H,J,K, None or U	Palustrine Forested and Scrub-Shrub
4	Cypress Swamp	P	NA	FO, SS	2	A,B,C,E,F,G,H,J,K, None or U	Needle-leaved Deciduous Forest and Scrub-Shrub
5	Inland Fresh Marsh	P	NA	EM, f**	All, None	A,B,C,E,F,G,H,J,K, None or U	Palustrine Emergents; Lacustrine and Riverine Nonpersistent Emergents
		L	2	EM	2, None	E,F,G,H,K, None or U	
		R	2, 3	EM	2, None	E,F,G,H,K, None or U	
6	Tidal Fresh Marsh	R	1	EM	2, None	Fresh Tidal N, T	
		P	NA	EM	All, None	Fresh Tidal S, R, T	Riverine and Palustrine Freshwater Tidal Emergen
7	Transitional Marsh / Scrub Shrub	E	2	FO, SS	1, 2, 4 to 7, None	Tidal M, N, P, None or U	Estuarine Intertidal, Scrub-shrub and Forested (ALL except 3 subclass)
8	Regularly Flooded Marsh	E	2	EM	1, None	Tidal N, None or U	Only regularly flooded tidal marsh; No intermittently flooded "P" water regime
9	Mangrove	E	2	FO, SS	3	Tidal M, N, P, None or U	Estuarine Intertidal Forested and Scrub-shrub, Broad-leaved Evergreen
10	Estuarine Beach	E	2	US	1,2	Tidal N,P	Estuarine Intertidal Unconsolidated Shores
		E	2	US	None	Tidal N,P	Only when shores
11	Tidal Flat	E	2	US	3,4, None	Tidal M, N, None or U	Estuarine Intertidal Unconsolidated Shore (mud or organic) and Aquatic Bed; Marine Intertidal Aquatic Bed
		E	2	AB	All, Except 1	Tidal M, N, None or U	
		E	2	AB	1	P	Specifically for wind-driven tides on the south coast of TX
		M	2	AB	1, 3, None	Tidal M, N, None or U	
12	Ocean Beach	M	2	US	1, 2	Tidal N, P	Marine Intertidal Unconsolidated Shore, cobble-gravel, sand
		M	2	US	None	Tidal P	
13	Ocean Flat	M	2	US	3, 4, None	Tidal M, N, None or U	Marine Intertidal Unconsolidated Shore, mud or organic, (low energy coastline)
14	Rocky Intertidal	M	2	RS	All, None	Tidal M, N, P, None or U	Marine and Estuarine Intertidal Rocky Shore and Reef
		E	2	RS	All, None	Tidal M, N, P, None or U	
		E	2	RF	2, 3, None	Tidal M, N, P, None or U	
		E	2	AB	1	Tidal M, N, None or U	
15	Inland Open Water	R	2	UB, AB	All, None	All, None	Riverine, Lacustrine, and Palustrine Unconsolidated Bottom, and Aquatic Beds
		R	3	UB, AB, RB	All, None	All, None	
		L	1, 2	UB, AB, RB	All, None	All, None	
		P	NA	UB, AB, RB	All, None	All, None	
		R	5	UB	All	Only U	
16	Riverine Tidal Open Water	R	1	All, Except EM	All, None, Except 2	Fresh Tidal S, R, T, V	Riverine Tidal Open Water
17	Estuarine Open Water	E	1	All	All, None	Tidal L, M, N, P	Estuarine subtidal
18	Tidal Creek	E	2	SB	All, None	Tidal M, N, P; Fresh Tidal R, S	Estuarine intertidal streambed
19	Open Ocean	M	1	All	All	Tidal L, M, N, P	Marine Subtidal and Marine Intertidal Aquatic Bed and Reef
		M	2	RF	1, 3, None	Tidal M, N, P, None or U	
20	Irregularly Flooded Marsh	E	2	EM	1, 5, None	P	Irregularly Flooded Estuarine Intertidal Emergent marsh
		E	2	US	2, 3, 4, None	P	Only when these salt pans are associated with E2EMN or P
21	NotUsed						
22	Inland Shore	L	2	US, RS	All	All Nontidal	Shoreline not pre-processed using tidal range elevations
		P	NA	US	All, None	All Nontidal, None or U	
		R	2, 3	US, RS	All, None	All Nontidal, None or U	
		R	4	SB	All, None	All Nontidal, None or U	
23	Tidal Swamp	P	NA	FO, SS	All, None	Fresh Tidal R, S, T	Tidally influenced swamp

As part of the model setup, Massachusetts Coastal Zone Management made the decision to not incorporate impervious surface data directly into the SLAMM runs. Allowing the SLAMM model to utilize the impervious layer would "protect" developed upland areas (i.e. impervious areas would not be allowed to convert to other land cover types); however, this approach would have prohibited marshes and wetlands from expanding into currently "developed" areas. While in reality this may likely happen (marsh migration would halt at the impervious boundary), this approach to the modeling does not inform stakeholders where the marsh may desire to migrate given the elevation landscape if the impervious features were absent. Since one of the project goals was to determine how and where the marsh may want to migrate in response to sea-level rise, it was desired to determine what system were susceptible to ecological losses due to inability to adjust to the changing climate both independent of the impervious landscape and with it in place. As such, the SLAMM model simulations were run without the impervious layers (to show where natural resources would like to migrate in absence of anthropogenic influences) and subsequently the impervious layer was also overlain on the results to indicate where areas may likely not be subject to natural resource migration due to the built environment. In Chelsea, which is predominantly developed, the impervious overlay illustrates the limited areas that are available for natural resource migration.

Figures 1 through 3 show the wetland classification areas for 2011, 2030, and 2070 timeframes, respectively, for the City of Chelsea. Figures present maps with no impervious overlay (left hand panel in each figure) and with impervious overlay (right hand panel in each figure). Figure 1 presents the current conditions, as defined by the NWI. Subsequently, Figure 2 shows the change in wetland classification locations projected to 2030, impacted by SLR. Similarly, Figure 3 shows the change in wetland classification locations projected to 2070, impacted by SLR.

City Wide:

Although the SLAMM results project some minor wetland expansion and loss of upland area in 2030, and significantly more in 2070 (based on the left hand panels), a vast majority of these areas occur within developed and residential neighborhoods (based on the right hand panels). However, due to the high density of development and impervious surface in Chelsea is it unlikely that the majority of these areas will be allowed to transition to wetland. However, these developed areas will likely experience higher water tables, increased salt water intrusion, day to day nuisance flooding, and higher frequency of storm flooding. Therefore, these areas will likely need additional protection in the future under normal tidal conditions sea level rise conditions (no storms). For example, by 2070 (Figure 3), the SLAMM model projects that the industrial and residential areas near the Gulf Oil terminal east of Chelsea Creek will begin to transition to water levels that would support irregularly flooded marsh and transitional scrub-shrub wetland. Similarly, by 2070 (Figure 3), the model suggests that Willow St. and Highland Park area will experience more regular nuisance flooding creating a transitional scrub-shrub wetland (absent impervious area.

There are, however, a few undeveloped or less developed areas within Chelsea that will likely experience significant changes in land cover and wetland type and may offer opportunities for natural resource management and/or expansion due to the changing climate. These areas include:

- The Mill Creek corridor,
- The area around the Island End River
- The Chelsea Creek region just north of the Gulf Oil terminal and near Merritt Park

The Mill Creek Corridor:

- In the relative near term (between 2011 and 2030), there are minimal changes to the Mill Creek wetlands, which primarily consists of open water, irregularly flooded marsh, and fresh marsh resources. At the head of the creek, there are some minor changes by 2030 as salt laden water is able to further penetrate upstream in the system. Inland fresh wetlands begin to transition to irregularly flooded marsh areas and transitional scrub shrub areas. By 2070, a majority of the creek system has transitioned to regularly flooded marsh and estuarine open water.

- No immediate adaptations are required for this area in terms of natural resources as the Mill Creek corridor can be allowed to advance naturally for normal tidal conditions; however, in the long-term, and during storm events, more frequent overbank flooding can be expected to surrounding properties and the fringe marsh areas may be expected to expand. Smaller proactive restoration measures could be considered along the Mill Creek shorelines to protect infrastructure residing along the creek banks as well as to provide natural resource expansion and protection. Potential options could consider living shoreline applications and targeted thin layer deposition projects that would involve the placement of clean, compatible sediment in thin layers on the existing salt marsh to assist the elevations in keeping up with the rising tidal increases.

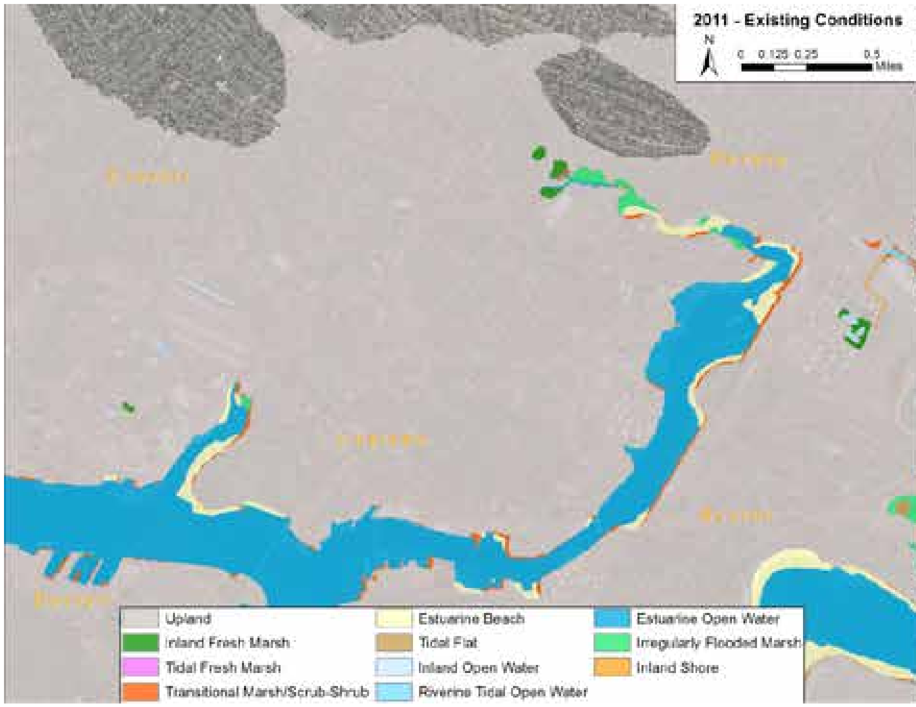
Island End River:

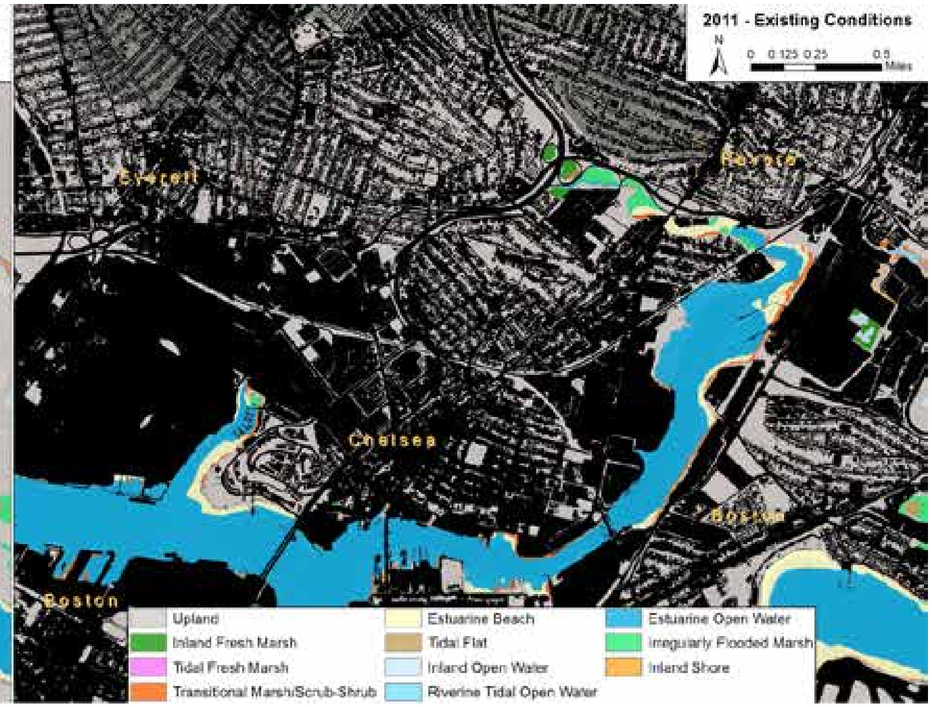
- The Island End River, which historically extended further to the north-northwest in Chelsea, is primarily open water with some limited salt marsh resources located at the head of the system. By 2030, minor expansion of the salt marsh areas is expected, including development of fringe marsh along the eastern bank of Island End River. By 2070, the salt marsh resources would migrate and expand to the north; however, much of this area is currently developed and would be faced with normal tidal nuisance flooding on a daily basis.
- Due to the overall vulnerability of this area to storm surge, the relatively focused pathway for flooding, and, in the long-term, daily flooding, adaptations should be considered that focus on protecting upland areas while also enhancing natural resources. Hybrid solutions consisting of green infrastructure that expands valuable and protective marsh resources via a living shoreline solution coupled with secondary defense components of natural berms is one potential option that serves to provide green resiliency. Efforts could also be made with expanding the public interaction with the water through integrated, elevated walkways and water access as part of a berm system. An outfall forebay to treat stormwater runoff, if the current outfall is left in place, could also be integrated into the overall hybrid design along the shoreline. This green resiliency option could extend and connect to the Mary O'Malley Waterfront Park to enhance both the wetland resources and the future recreational space.

The Chelsea Creek region north of the Gulf Oil terminal:

This area shows little change between 2011 and 2030. By 2070 there is normal tidal flooding that is expected throughout the Eastern Avenue area. While there isn't significant wetland resources in the area, due to the highly developed nature of this region (and the significant impervious area), there is an opportunity to expand wetland resources in this area, while also providing resilience and protection to upland infrastructure. The open space area off the Eastern Ave extension, as well as the shallow western edge of the Creek in this vicinity allow for potential green adaptations to create wetlands to serve a protective function.

- Potential green adaptations to enhance wetland resources in this area consist of deposition to create nearshore marsh resources, living shoreline applications along the western bank of Chelsea Creek, and hybrid solutions mixing gray and green resiliency approaches.





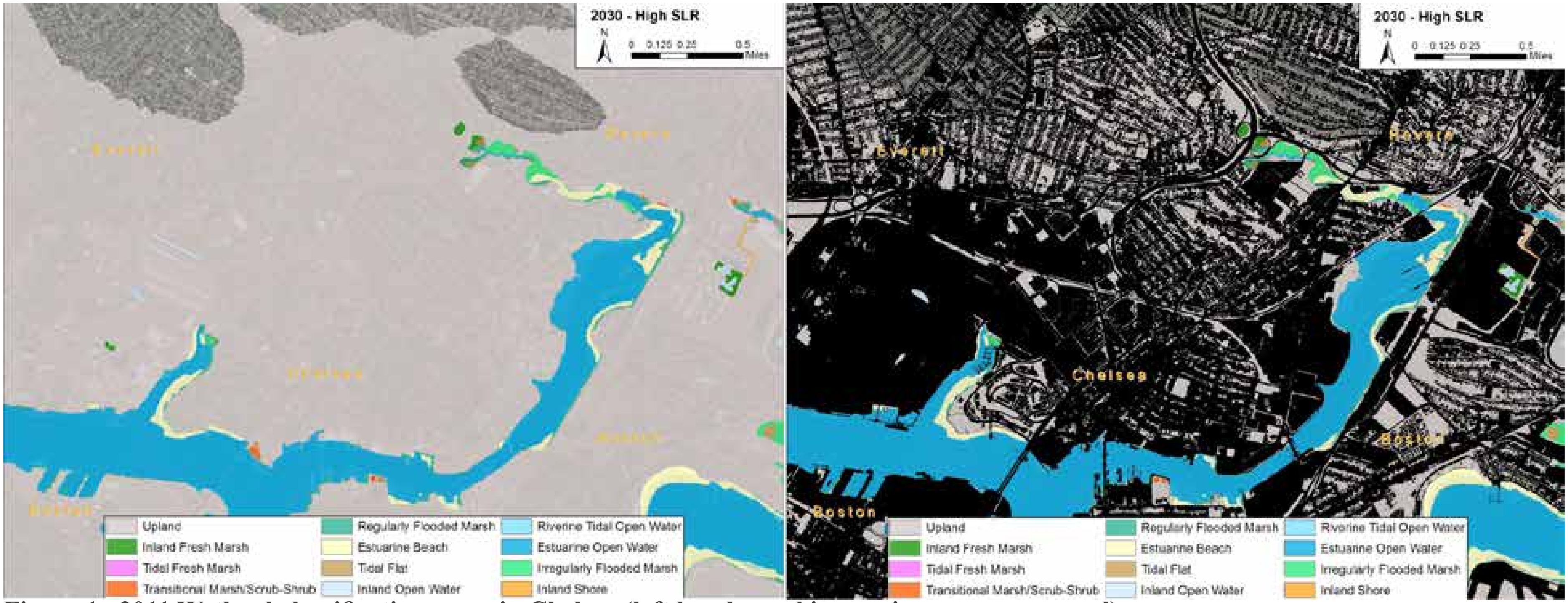


Figure 1. 2011 Wetland classification areas in Chelsea (left hand panel impervious areas removed).

Figure 2. 2030 Wetland classification areas in Chelsea (left hand panel impervious areas removed).

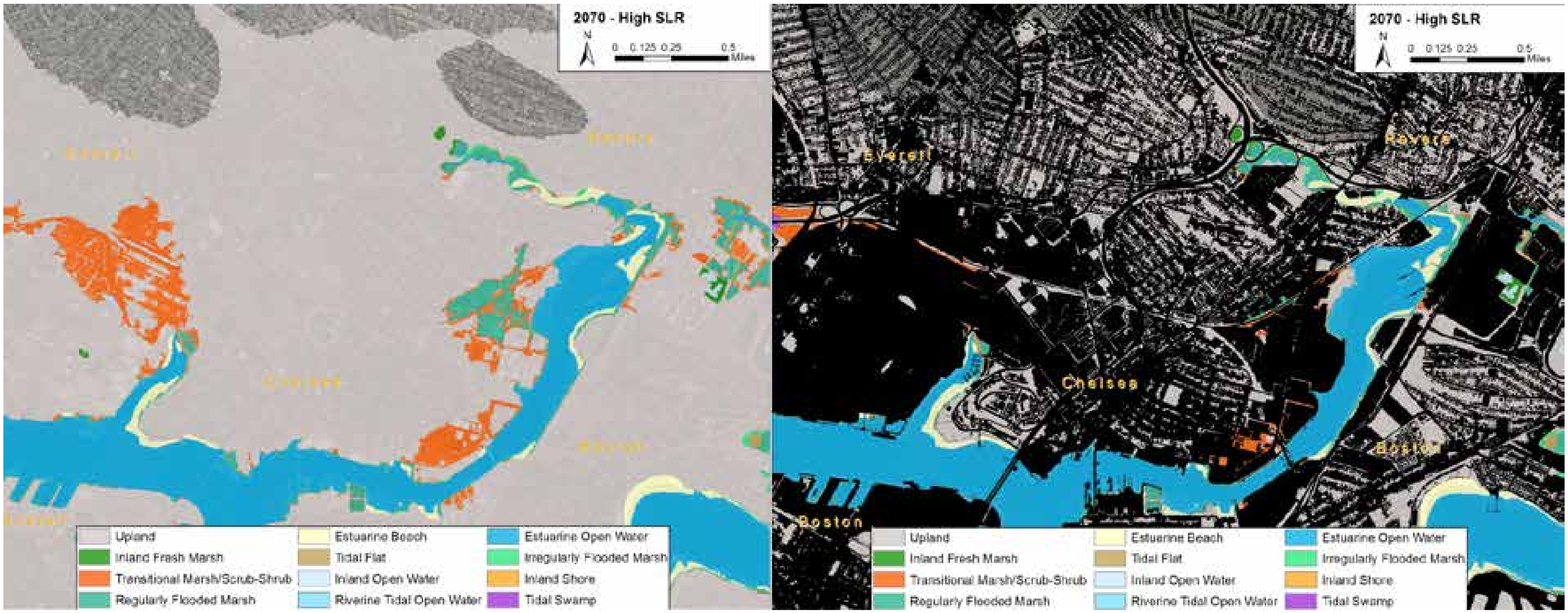


Figure 3. 2070 Wetland classification areas in Chelsea (left hand panel impervious areas removed).

Appendix F

Critical Public Infrastructure Scoring Guidance

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Scoring Guidance

Rating	Category	Area of Service Loss	Public Safety & Emergency Services	Social & Economic Activities	Public Health & Environment
			Critical infrastructure that is important for community evacuation and disaster response.	Critical infrastructure that is important for assuring people have access to their homes and jobs.	Critical infrastructure that controls human exposure to pollutants and secondary impacts to the natural environment.
5	Severe	Regional	Loss of major evacuation or response route. Loss of emergency operations centers (DPW, police, fire, ambulance). Loss of emergency communications. Loss of utility generation, distribution, or control facility.	Loss of transportation access or service for hundreds of residents and major commercial areas.	Significant pollution incident (damage to facilities that store hazardous materials). Permanent loss or major damage to a significant environmental resource.
4	High	City Wide	Loss of local evacuation or response route, no reasonable alternative available. Loss of medical centers, no reasonable alternative available in Chelsea Loss of emergency shelter, no reasonable alternative available in Chelsea. Utility service disruptions	Loss of transportation access or service to multiple neighborhoods, no major commercial impacts (single facility) Loss of school, no reasonable alternative available in Chelsea	Significant pollution event (failure of a major sewer force main, flooding of a pump station) Temporary damage to a significant environmental resource
3	Moderate	Multiple Areas or Neighborhoods	No loss of evacuation route, but major delays to emergency response times due to detours. Loss of medical centers, reasonable alternative available in Chelsea. Loss of emergency shelter, reasonable alternative available in Chelsea. Utility service disruptions.	Loss of transportation access or service to one neighborhood. Loss of school, reasonable alternative available in Chelsea.	Minor pollution incident (loss of sewer, minor force main, or manhole flooding). No permanent damage to significant environmental resources.
2	Low	Single Area or Neighborhood	No major impacts to emergency response, minor detours possible. Minor utility service disruption.	No complete loss of transportation access or service, but inconvenience – detour available.	Minor environmental impacts associated with erosion and/or loss of structures. No major pollution implications.
1	None	Single property	No impact	No impact	No impact

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Appendix G

Probability of Exceedance Curve Data

MWRA Headworks and Screen House

Approx. Critical Elevation 6.50

	Present		2030		2070	
Exceedance Probability	**Water Surface Elevation (ft-NAVD88)**	**Water Depth (ft)**	**Water Surface Elevation (ft-NAVD88)**	**Water Depth (ft)**	**Water Surface Elevation (ft-NAVD88)**	**Water Depth (ft)**
0.1	9.8	3.30	10.8	4.30	14.1	7.60
0.2	9.7	3.20	10.5	4.00	14.0	7.50
0.5	9.1	2.60	10.1	3.60	13.5	7.00
1	dry	dry	10	3.50	12.8	6.30
2	dry	dry	9.9	3.40	12.5	6.00
5	dry	dry	9.3	2.80	12.2	5.70
10	dry	dry	dry	dry	11.6	5.10
20	dry	dry	dry	dry	11.00	4.50
25	dry	dry	dry	dry	10.80	4.30
30	dry	dry	dry	dry	10.70	4.20
50	dry	dry	dry	dry	10.20	3.70
100	dry	dry	dry	dry	9.00	2.50

Chelsea Street Bridge over Chelsea Creek

Approx. Critical
Elevation 8.00

	Present		2030		2070	
Exceedance Probability	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	9.8	1.80	10.8	2.80	14.1	6.10
0.2	9.7	1.70	10.5	2.50	14.0	6.00
0.5	9.1	1.10	10.1	2.10	13.5	5.50
1	dry	dry	10	2.00	12.8	4.80
2	dry	dry	9.9	1.90	12.5	4.50
5	dry	dry	9.3	1.30	12.2	4.20
10	dry	dry	dry	dry	11.6	3.60
20	dry	dry	dry	dry	11.0	3.00
25	dry	dry	dry	dry	10.8	2.80
30	dry	dry	dry	dry	10.7	2.70
50	dry	dry	dry	dry	10.2	2.20
100	dry	dry	dry	dry	9	1.00

MWRA Chelsea Facility

Approx. Critical
Elevation 9.50

	Present		2030		2070	
Exceedance Probability	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	dry	dry	10.80	1.30	14.1	4.60
0.2	dry	dry	10.50	1.00	14.0	4.50
0.5	dry	dry	10.10	0.60	13.5	4.00
1	dry	dry	10.00	0.50	12.8	3.30
2	dry	dry	9.90	0.40	12.5	3.00
5	dry	dry	dry	dry	12.2	2.70
10	dry	dry	dry	dry	11.6	2.10
20	dry	dry	dry	dry	11.00	1.50
25	dry	dry	dry	dry	10.80	1.30
30	dry	dry	dry	dry	10.70	1.20
50	dry	dry	dry	dry	10.20	0.70
100	dry	dry	dry	dry	dry	dry

Railroad Bridge over Mill Creek

Approx. Critical
Elevation 11.20

	Present		2030		2070	
Exceedance Probability	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	9.8	-1.40	10.8	-0.40	14.1	2.90
0.2	9.7	-1.50	10.5	-0.70	14.0	2.80
0.5	dry	dry	10.1	-1.10	13.5	2.30
1	dry	dry	10.0	-1.20	12.8	1.60
2	dry	dry	9.9	-1.30	12.5	1.30
5	dry	dry	dry	dry	12.2	1.00
10	dry	dry	dry	dry	11.6	0.40
20	dry	dry	dry	dry	11.0	-0.20
25	dry	dry	dry	dry	10.8	-0.40
30	dry	dry	dry	dry	10.7	-0.50
50	dry	dry	dry	dry	10.2	-1.00
100	dry	dry	dry	dry	dry	dry

Substation #488 at Willoughby Street

Approx. Critical
Elevation 8.80

	Present		2030		2070	
Exceedance Probability	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	9.8	1.00	10.8	2.00	14.1	5.30
0.2	9.7	0.90	10.5	1.70	14.0	5.20
0.5	9.1	0.30	10.1	1.30	13.5	4.70
1	dry	dry	10.0	1.20	12.8	4.00
2	dry	dry	9.9	1.10	12.5	3.70
5	dry	dry	dry	dry	12.2	3.40
10	dry	dry	dry	dry	11.6	2.80
20	dry	dry	dry	dry	11.0	2.20
25	dry	dry	dry	dry	10.8	2.00
30	dry	dry	dry	dry	10.70	1.90
50	dry	dry	dry	dry	10.20	1.40
100	dry	dry	dry	dry	dry	dry

Carter Street Pump Station

Approx. Critical Elevation 7.43

Exceedance Probability	Present		2030		2070	
	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	dry	dry	10.80	3.37	14.1	6.67
0.2	dry	dry	10.50	3.07	14.0	6.57
0.5	dry	dry	10.10	2.67	13.5	6.07
1	dry	dry	10.00	2.57	12.7	5.27
2	dry	dry	9.90	2.47	12.4	4.97
5	dry	dry	dry	dry	12.0	4.57
10	dry	dry	dry	dry	11.2	3.77
20	dry	dry	dry	dry	11.10	3.67
25	dry	dry	dry	dry	11.00	3.57
30	dry	dry	dry	dry	10.90	3.47
50	dry	dry	dry	dry	dry	dry
100	dry	dry	dry	dry	dry	dry

Williams Middle School

Approx. Critical Elevation 9.50

Exceedance Probability	Present		2030		2070	
	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	dry	dry	10.80	1.30	14.1	4.60
0.2	dry	dry	10.50	1.00	14.0	4.50
0.5	dry	dry	10.10	0.60	13.5	4.00
1	dry	dry	10.00	0.50	12.7	3.20
2	dry	dry	9.90	0.40	12.4	2.90
5	dry	dry	dry	dry	12.0	2.50
10	dry	dry	dry	dry	11.2	1.70
20	dry	dry	dry	dry	11.1	1.60
25	dry	dry	dry	dry	11.0	1.50
30	dry	dry	dry	dry	10.9	1.40
50	dry	dry	dry	dry	dry	dry
100	dry	dry	dry	dry	dry	dry

City Yard

Approx. Critical
Elevation 9.80

Exceedance Probability	Present		2030		2070	
	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	dry	dry	10.8	1.00	14.1	4.30
0.2	dry	dry	10.5	0.70	14.0	4.20
0.5	dry	dry	10.1	0.30	13.5	3.70
1	dry	dry	dry	dry	12.7	2.90
2	dry	dry	dry	dry	12.4	2.60
5	dry	dry	dry	dry	12.0	2.20
10	dry	dry	dry	dry	11.5	1.70
20	dry	dry	dry	dry	11.0	1.20
25	dry	dry	dry	dry	10.8	1.00
30	dry	dry	dry	dry	10.7	0.90
50	dry	dry	dry	dry	dry	dry
100	dry	dry	dry	dry	dry	dry

Burke School Complex

Approx. Critical
Elevation 10.00

Exceedance Probability	Present		2030		2070	
	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	dry	dry	10.8	0.80	14.1	4.10
0.2	dry	dry	10.50	0.50	14.0	4.00
0.5	dry	dry	10.10	0.10	13.5	3.50
1	dry	dry	10.00	0.00	12.8	2.80
2	dry	dry	9.90	-0.10	12.5	2.50
5	dry	dry	dry	dry	12.2	2.20
10	dry	dry	dry	dry	11.6	1.60
20	dry	dry	dry	dry	11.0	1.00
25	dry	dry	dry	dry	10.8	0.80
30	dry	dry	dry	dry	10.70	0.70
50	dry	dry	dry	dry	dry	dry
100	dry	dry	dry	dry	dry	dry

Chelsea High School

Approx. Critical
Elevation 6.00

	Present		2030		2070	
Exceedance Proba-bility	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	dry	dry	10.8	4.80	14.1	8.10
0.2	dry	dry	10.5	4.50	14.0	8.00
0.5	dry	dry	10.1	4.10	13.5	7.50
1	dry	dry	10.0	4.00	12.7	6.70
2	dry	dry	9.9	3.90	12.4	6.40
5	dry	dry	dry	dry	12.0	6.00
10	dry	dry	dry	dry	11.2	5.20
20	dry	dry	dry	dry	11.1	5.10
25	dry	dry	dry	dry	11.0	5.00
30	dry	dry	dry	dry	10.9	4.90
50	dry	dry	dry	dry	dry	dry
100	dry	dry	dry	dry	dry	dry

Meridian Street Bridge over Chelsea Creek

Approx. Critical
Elevation 12.10

	Present		2030		2070	
Exceedance Proba-bility	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	dry	dry	dry	dry	14.1	2.00
0.2	dry	dry	dry	dry	14.0	1.90
0.5	dry	dry	dry	dry	13.5	1.40
1	dry	dry	dry	dry	12.8	0.70
2	dry	dry	dry	dry	12.5	0.40
5	dry	dry	dry	dry	12.2	0.10
10	dry	dry	dry	dry	11.6	dry
20	dry	dry	dry	dry	11.0	dry
25	dry	dry	dry	dry	dry	dry
30	dry	dry	dry	dry	dry	dry
50	dry	dry	dry	dry	dry	dry
100	dry	dry	dry	dry	dry	dry

Broadway Bridge over Mill Creek

Approx. Critical
Elevation 10.00

	Present		2030		2070	
Exceedance Probability	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)	Water Surface Elevation (ft-NAVD88)	Water Depth (ft)
0.1	dry	dry	dry	dry	14.0	4.00
0.2	dry	dry	dry	dry	14.0	4.00
0.5	dry	dry	dry	dry	13.5	3.50
1	dry	dry	dry	dry	12.8	2.80
2	dry	dry	dry	dry	12.5	2.50
5	dry	dry	dry	dry	12.2	2.20
10	dry	dry	dry	dry	dry	dry
20	dry	dry	dry	dry	dry	dry
25	dry	dry	dry	dry	dry	dry
30	dry	dry	dry	dry	dry	dry
50	dry	dry	dry	dry	dry	dry
100	dry	dry	dry	dry	dry	dry

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Appendix H

Prioritized Public Infrastructure

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NAME	Area of Service Loss	Public Safety & Emergency Services	Social & Economic Activities	Public Health & Environment	Consequence Score	Present	2030	2070	Risk Score
MWRA Headworks & Screen House	5	5	5	5	20	0.5	5.0	100.0	236
Chelsea Street Bridge over Chelsea Creek	4	4	4	2	14	0.5	5.0	100.0	165
MWRA Chelsea Facility	5	5	5	5	20	0.0	2.0	50.0	112
Railroad Bridge over Mill Creek	5	2	4	4	15	0.2	2.0	50.0	86
Substation #488 at Willoughby Street	4	4	4	2	14	0.5	2.0	50.0	83
Carter Street Pump Station	5	5	4	4	18	0.0	2.0	30.0	65
Williams Middle School	4	4	4	2	14	0.0	2.0	30.0	50
City Yard	4	4	4	4	16	0.0	0.5	30.0	50
Burke School Complex	3	4	3	3	13	0.0	2.0	30.0	47
Chelsea High School	4	4	2	2	12	0.0	2.0	30.0	43
Meridian Street Bridge over Chelsea Creek	5	4	4	4	17	0.0	0.0	20.0	34
Broadway Bridge over Mill Creek	5	4	4	3	16	0.0	0.0	5.0	8

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Appendix I

Permitting Discussion

When proposing work along the shoreline, there are a number of agencies with authority over what can be built in, on, and over environmental resources in the area. The descriptions of State and Federal Laws listed in Table 7.8 below, provide an overview of the potential permits, licenses, or approvals in place for the protection of wetlands and related natural (e.g. floodplain, wildlife habitat) and cultural resources (including historic sites and water-dependent uses).

Table 7.8 Overview of Potential Environmental Permits / Approvals for Construction in the Coastal Zone

Law	Regulation	Name	Permit / Approval	Discussion
M.G.L . c30 § § 61-62H	301 CMR 11.00	Massachusetts Environmental Policy Act (MEPA)	Secretary's Certificate MA Executive Office of Energy & Environmental Affairs (EOEA)	A MEPA Certificate is required when a project meets or exceeds review thresholds identified for impacts to resources such as wetlands, endangered species habitat, historical resources, among others.
42 U.S.C. § 4321	40 CFR 1500	National Environmental Policy Act (NEPA)	Categorical Exclusion Environmental Assessment/ Finding of No Significant Impact Environmental Impact Statements (EIS) / Record of Decision (ROD)	NEPA requires federal agencies to evaluate the environmental and related social and economic effects of their proposed actions.
M.G.L c.131 § 40	310 CMR 10.00	Massachusetts Wetlands Protection Act	Order of Conditions Local Conservation Commission	The Wetlands Protection Act prohibits the removal, dredging, filling, or altering of wetlands without a permit. General Performance Standards regulate any work in wetland resource areas to protect surface/ground water supplies and fisheries/ wildlife habitat, provide flood control, and prevent storm damage and pollution.
33 U.S.C. 1341 *et seq.* § 401 M.G.L. c.21 § §26-53	314 CMR 4.00	Section 401 of the Federal Clean Water Act Massachusetts Clean Water Act	Water Quality Certification (WQC) MA Dept. of Environmental Protection (DEP)	For construction projects requiring more than 100 cubic yards of dredged material, resulting in the loss of more than 5,000 square feet of wetlands, alteration of any salt marsh, or discharging dredged material or fill to an Outstanding Resource Water.

Law	Regulation	Name	Permit / Approval	Discussion
33 U.S.C 1251 § § 401	33 CFR 323	Section 10 of the Federal Clean Water Act	MA General Permits U.S. Army Corps of Engineers (USACE)	The discharge of dredged or fill material and discharges associated with excavation into waters of the U.S. The U.S. Army Corps of Engineers (USACE) regulates these activities under Section 404 of the federal Clean Water Act.
33 U.S.C. 1251 § 404	33 CFR 322	Section 404 of the Federal Clean Water Act	MA General Permits USACE	A Self Verification Notification Form (SVNF) is required to notify the USACE for up to 5,000 sf of impact to the waters of the U.S. A Preconstruction Notification Form (PCN) is required for 5,000 sf to 1 acre of impacts to waters of the U.S., and an Individual Permit is required for over 1 acre of disturbance. These applications must demonstrate that the proposed project is the Least Environmentally Damaging Practicable Alternative (LEDPA) to achieve the project's purpose.
M.G.L. c.91	301 CMR 9.00	Chapter 91 Public Waterfront Act	License or Permit MA DEP Waterways Program	A Chapter 91 license is required for placement or removal of any fill or structures in or over a waterway. A license must be signed by the governor and filed with the Registry of Deeds. A Chapter 91 permit is required for dredging in a waterway. The permit process is generally faster than the licensing process and does not require signature by the governor or filing with the Registry of Deeds. Chapter 91 is enforced to protect and promote public interest in filled and flowed tidelands of the Commonwealth. Walls and living shorelines should be considered water-dependent activities and is presumed to serve a proper public purpose. Chapter 91 also enforces uses in Designated Port Areas (DPA, 301 CMR 25.00) and Municipal Harbor Plans (MHP, 201 CMR 23.00).

Law	Regulation	Name	Permit / Approval	Discussion
16 U.S.C. 1451 *et seq.* M.G.L. c21A § § 2, 4	15 CFR 930 301 CMR 20.00 301 CMR 21.00	Coastal Zone Management Act Federal Consistency Review	Federal Consistency Determination MA Coastal Zone Management (CZM)	Any project that requires a federal permit or meets/exceeds thresholds for a MEPA certificate must be consistent with state coastal policies. CZM policies are designed to "preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations."
M.G.L. c.131A	321 CMR 8.00	Massachusetts Endangered Species Act (MESA)	MA Division of Fish & Wildlife / Natural Heritage & Endangered Species Program (NHESP)	MESA protects rare species and their habitats by prohibiting the "Take " of any plant or animal species listed as Endangered, Threatened, or Special Concern by the MA Division of Fisheries & Wildlife. Coordination with NHESP will determine what level of effort is required for each project/location.
M.G.L. c.9, § § 26-27D	950 CMR 71.00	State Historic Review	Project Notification Form (PNF) Massachusetts Historical Commission (MHC)	Any projects that require licenses or permits from federal or state agencies must be reviewed in compliance with Section 106 of the National Historic Preservation Act of 1966, and.
M.G.L. c. 40A	City of Chelsea Code of Ordinances Part II, Chapter 34	Massachusetts Zoning Act	Special Permit Zoning Board of Appeals	Zoning by-laws to regulate uses of land, buildings, and other structures for the purpose of protecting the health, safety, and general welfare of present and future inhabitants. Special Permits are required when a project is seeking relief from the requirements of the Zoning Ordinance.
780 CMR		State / Local Building Codes	Building Permit Municipal Building Inspector	State Building Code reviews projects to ensure buildings protect public safety.

City of Chelsea, Massachusetts