CITY OF SOMERVILLE
Climate Change Vulnerability Assessment

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Commission on Energy Use and Climate Change

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Table of Contents

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Letter from the Mayor

The scientific evidence and consensus is clear: climate change is a reality that we cannot ignore.

Just as each of us as individuals must do our part to reduce the carbon emissions that cause climate change, cities too must take action. Cities and towns must not only work to reduce local emissions, we bear the responsibility to protect our communities from the changes that are already underway. All cities around the world will experience some impacts of the changing climate. Hotter weather, sea level rise, and more intense rain and winter storms are just a few of the challenges we will likely confront. With this Climate Change Vulnerability Assessment, we now have a better understanding of what threats Somerville may specifically face in the coming years, better positioning us to make smart decisions now.

This study shows that in Somerville we are fortunate to be less exposed to the threats of sea level rise than some of our neighbors, and we have pinpointed the specific places where we know we are more exposed and action must be taken. For one, stronger, more frequent rain presents a risk of flooding in areas where we work, live, and commute. We are already taking action to reduce this threat with ambitious infrastructure projects in Union Square.

We recognize that, with the information in this study, we have an opportunity to make decisions in the coming years that can reduce our risks both within Somerville and in the Boston region. Keeping Somerville a safe, prosperous, inclusive community is a complex challenge, and climate change is just one fact that will affect our success. But over time it may well prove to be the most significant factor.

In Somerville though, we have proven over and over again—from fighting for the Green Line Extension to continually improving the quality of our schools to clearing ten feet of snow—that we, as a community, are up for the difficult challenges. Determination is in ample supply here and it will serve us well as we problem solve around climate change.

Coupled with our Greenhouse Gas Inventory, which was released last year, this study will also serve us well. It provides the baseline for Somerville’s climate change planning so we know where to start and where we need to go. With this report in hand, I look forward to continue working with our community to develop the right strategies to address climate change locally and to advance our goals to make Somerville carbon neutral and resilient.

Joseph A. Curtatone
Mayor

Executive Summary

Somerville's Climate Action Efforts

The Somerville community has a long-standing and passionate interest in addressing climate change. In recent years, the City of Somerville has taken a leadership role in understanding the impacts of climate change, highlighted by Mayor Joseph A. Curtatone's commitment to achieving carbon neutrality by 2050 and the city's launch of the SustainaVille initiative to assist Somerville in the implementation of practical solutions to achieve carbon neutrality and resilience. Somerville is also a committed leader on a regional and global scale with its membership in the Global Covenant of Mayors for Climate & Energy[1], a global coalition of city leaders committed to combatting climate change and reducing greenhouse gas (GHG) emissions, and its involvement in the climate change preparedness efforts of the Metro Mayors Coalition[2], a coalition of 14 Boston-area municipalities working to develop regional solutions to advance climate action.

The Climate Change Vulnerability Assessment (CCVA) is the next step towards advancing the city's commitment to climate action and creating a comprehensive climate change plan for the City. The CCVA and Somerville's Greenhouse Gas Inventory establish the baseline understanding of Somerville's contribution to climate change and anticipated impacts from climate change. Together, these studies will serve as the baseline for developing the analysis and strategies that will comprise the City's Climate Change Plan

Climate Change Plan

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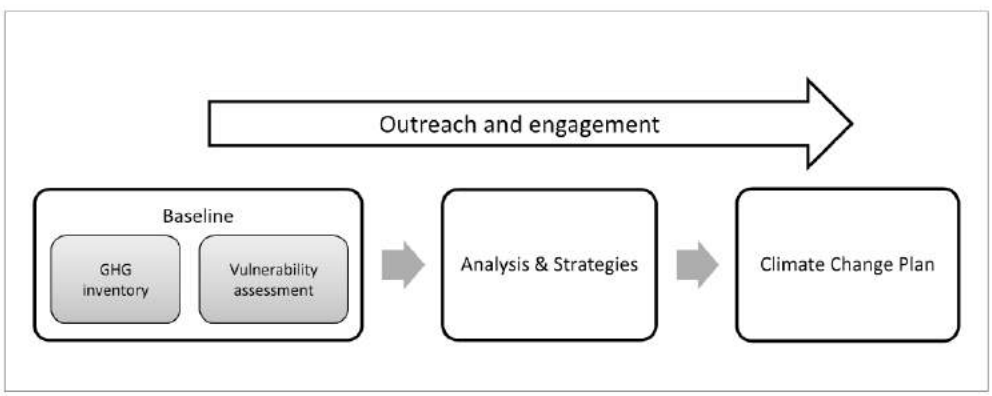

Figure 1: Somerville Climate Change Planning Process

CCVA Overview

The general trends in Somerville associated with the world's shifting climate include warmer temperatures, more extreme precipitation events, and sea level rise. In many ways climate change will intensify impacts that Somerville is already experiencing, such as precipitation-based flooding and heat waves. However, climate change will also present new impacts from sea level rise and storm surge along the Mystic River. Somerville is already working to reduce some of these known risks through planning

1 Global Covenant of Mayors for Climate & Energy, 2016. https://www.compactofmayors.org/globalcovenantofmayors/.

2 Metro Mayors Coalition: Climate Preparedness Commitment, 2015. http://www.mapc.org/climate-preparedness.

and infrastructure decisions. For example, the City is carrying out a $40 million project - with a $13 million grant from the Commonwealth of Massachusetts - to support sewer and water infrastructure upgrades in Union Square in order to alleviate strains on the existing and outdated stormwater infrastructure. In order to improve decision making as Somerville prepares for climate change, the analysis in this study identifies key priorities that Somerville will need to address in order to enhance resilience to intensified and new impacts caused by climate change.

Climate change will impact all cities and towns in some way. Eastern Massachusetts is particularly vulnerable to sea level rise and storm surge and New England will have to adapt to a hotter and wetter climate. In Somerville, sea level rise and storm surge, increased precipitation, and heat are all concerns. However, Somerville's flood risks are somewhat unique. Unlike some neighboring coastal communities, precipitation will affect larger portions of Somerville than coastal flooding. Coastal flooding will primarily occur through two known pathways located on Somerville's borders, as opposed to a widely exposed coastline. Somerville has the opportunity to drastically reduce coastal flood vulnerability by finding solutions to prevent flooding at these two pathways. Similar to most communities in the Greater Boston region, heat will significantly increase in the summers, intensifying existing public health issues associated with heat waves and causing new public health concerns due to shifts in vector borne diseases.

The priorities identified in this assessment will be carried through into the next phase of Somerville's climate change planning process. The Climate Change Plan will identify strategies and actions to address these priorities and to collaborate regionally with state actors and neighboring communities to collectively increase resilience to climate change.

High emissions (RCP 8.5): emissions continue to rise throughout the 21st century and expected temperatures increase between 4.7 and 8.6°F by 2100.

Low emissions (RCP 4.5): emissions peak around 2040 and then decline and expected temperatures increase between 2.0 and 4.7°F by 2100.

CCVA Methodology

This study assesses the City of Somerville's vulnerability to the following climate factors: sea level rise (SLR) and storm surge; precipitation; and, temperature. The scope of this assessment is limited to the direct impacts of these climate stressors within Somerville's borders and does not extend to secondary impacts from climate factors or more regional and global climate considerations, such as food insecurity and population migration as a result of climate change.

The vulnerability assessment was organized around a three step process, based on the widely-used methodology developed by ICLEI – Local Governments for Sustainability.[3]

Step 1: Establishing a climate baseline for the various types of climate exposures.

Step 2: Understanding the vulnerabilities and assessing the overall risks throughout the city, culminating in the identification of the most at-risk populations, assets and systems.

Step 3: The most at-risk assets will form the focus of future mitigation and adaptation actions – rolling up into the second phase of the City's climate planning process: analysis and strategies plan (not addressed in this report).

3 ICLEI: Local Governments for Sustainability. http://www.iclei.org/.

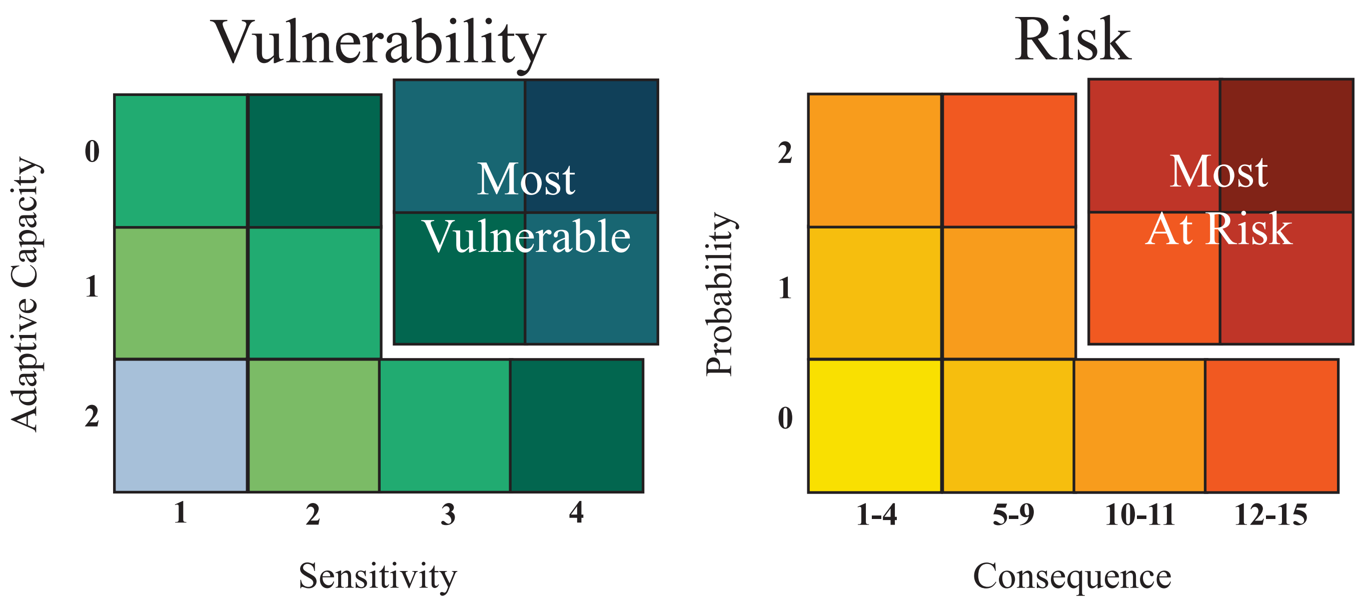

Figure 2: Vulnerability and Risk Matrices

Climate projections are not an exact science; the future climate depends greatly on universal global action to limit GHG emissions. Because of this uncertain future, the City decided to consider a high emissions scenario and a low emissions scenario in this assessment.

The high emissions scenario approximates a "business as usual" scenario and represents the extent of possible futures if there is not significant global action towards GHG emissions reduction and mitigation. The low emissions scenario approximates a "target goal". This scenario represents a future environment in which global GHG emissions are reduced in line with the goals of the Paris Agreement, a global agreement in which world leaders committed to GHG reductions that would limit global warming to 2° Celsius (3.6°F).

Climate Projections

This assessment utilized projections for future increases in sea level rise and storm surge, precipitation and heat in order to assess the potential impacts of climate change on Somerville's critical assets and systems over time. This study employed climate change projections that are consistent with analyses that have been conducted by the Cities of Cambridge and Boston. In the Boston metro region, sea level is projected to rise approximately 4-8" by 2030 and 15-36" by 2070.[4] Figure 4 maps the probability of coastal flooding in Somerville by 2070.

Similarly, Figure 5 maps the 2070 100-year, 24-hour design-storm against the landscape of the city. Additional detail is shown in Figure 3, which displays the anticipated increases in precipitation in 2030 and 2070 for the 10-year, 24-hour and 100-year, 24-hour design storm.

Design Storm	Present-day	2030	2070
10-year, 24-hour	4.9 in	5.6 in	6.4 in
100-year, 24-hour	8.9 in	10.2 in	11.7 in

Figure 3: Precipitation Projections[5]

4 Climate Ready Boston, 2016. https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf.

5 City of Cambridge Climate Change Vulnerability Assessment, Appendix B: Temperature and Precipitation Projections, 2015. http://www.cambridgema.gov/CDD/Projects/Climate/~/media/A9D382B8C49F4944BF64776F88B68D7A.ashx.

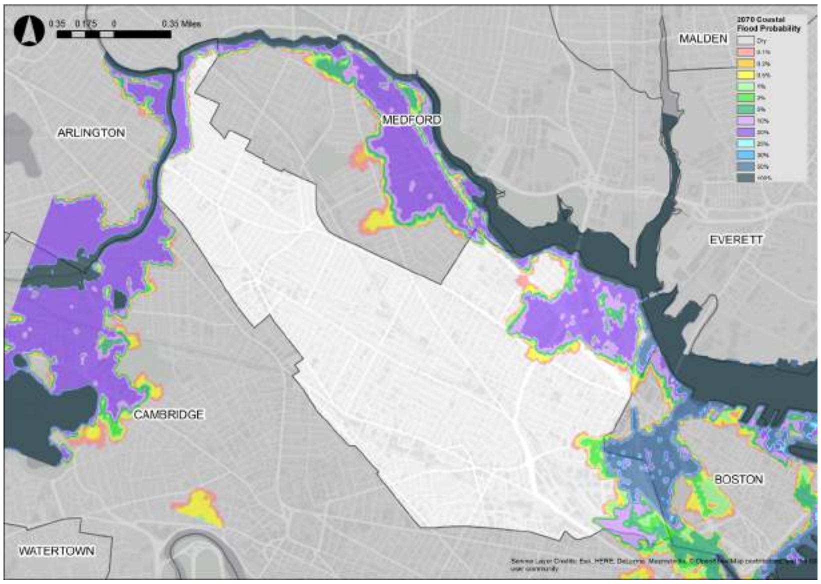

Figure 4: Probability of Coastal Flooding in 2070

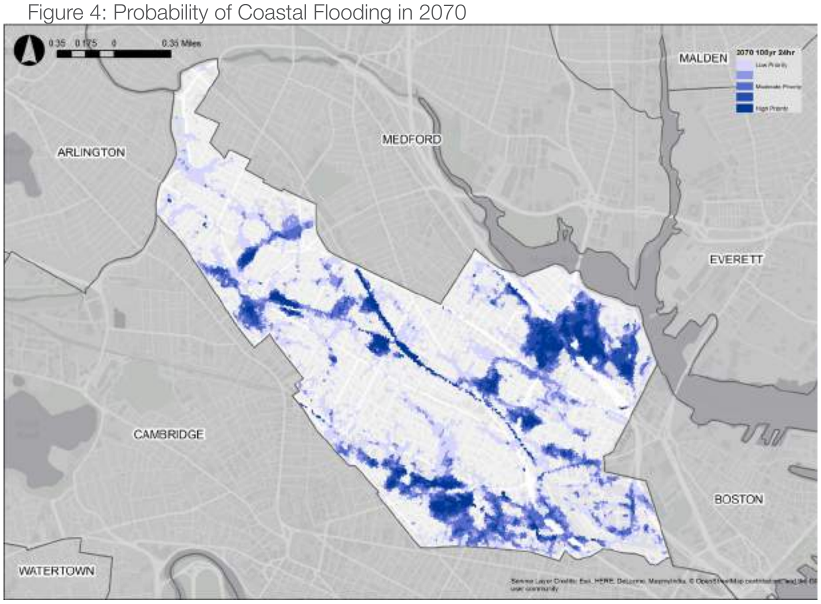

Figure 5: 2070 100-year, 24-hour Design Storm Priority Areas of Flood Concern

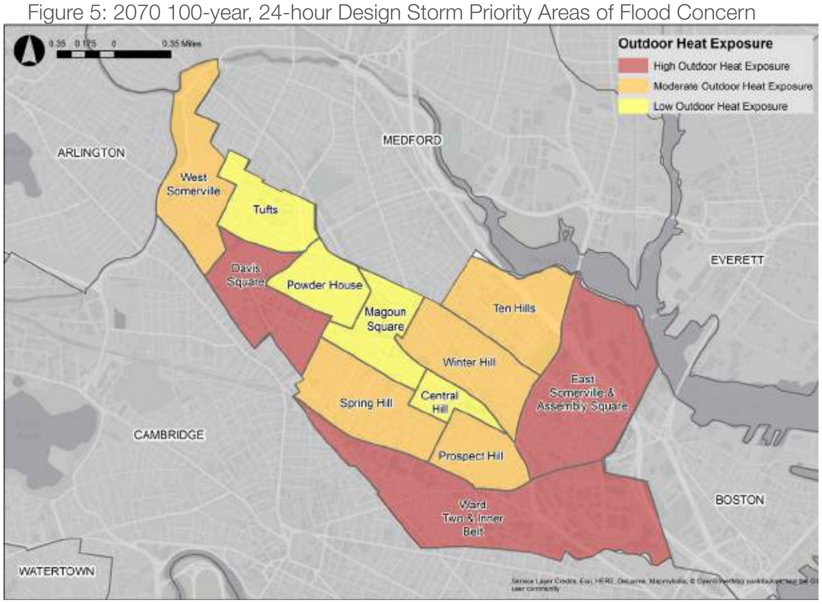

Figure 6: Relative Urban Heat Island Exposure by Neighborhood

Following standard practice, this study uses fixed years - 2030 and 2070 in this case - to indicate the projected future climate. However, **climate change is gradual, and individual climate impacts may come sooner or later depending on many factors, such as GHG emissions.** As such, 2030 and 2070 are best interpreted as markers for near and long-term predicted climates. **Starting today, climate impacts are projected to gradually trend toward the scenarios modeled for 2070.**

Lastly, Figure 6 maps the relative urban heat island exposure by neighborhood in Somerville and Figure 7 details the average annual and seasonal temperatures.

	1971-2000	2030		2070	
	Average	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Average Annual Temperature	50.0	53.0	53.5	55.8	58.7
Average Summer Temperature	70.6	74.5	74.8	77.4	80.6
Average Winter Temperature	29.8	32.2	33.0	34.6	38.0

Figure 7: Average Annual Temperature Projections[6]

Key Priorities

The vulnerability and risk assessment utilizes these climate projections to analyze key assets, systems, and populations in the City of Somerville, with a focus on the built, social and natural environments. A separate economic analysis was also completed.

This assessment largely highlights the major areas of vulnerability in the City of Somerville; however, it is important to note that there are several assets and types of climate exposure for which Somerville does not need to be concerned. In terms of key assets, energy infrastructure and healthcare facilities are largely insulated from the damaging impacts of climate events. While some of the energy infrastructure is vulnerable to climate events, there is sufficient redundancy within the system to withstand these impacts. An impact to one facility will not impact the regional power supply; however, a larger event that takes out multiple facilities may still have more serious impacts on the power grid. Moreover, although the healthcare network in Somerville may experience indirect impacts from climate change, such as an increased demand for services resulting from the public health impacts of climate change, the healthcare facilities within Somerville's borders are largely insulated from the direct impacts of precipitation-based and coastal flooding.

In addition, Somerville has minimal exposure to nighttime urban heat island hot spots. Nighttime hot spots are particularly important from a public health perspective, because higher nighttime temperatures often have a greater impact than daytime temperatures on the prevalence of heat-related illness.

From a vulnerability perspective, this assessment highlighted nine key priorities upon which the City of Somerville should focus its collective efforts and resources throughout the climate change planning process (see Figure 8). These priorities are detailed below.

PRIORITY 1: Precipitation-based flooding will impact much more of Somerville than coastal flooding. By nature of Somerville's location and topography, much more of the city is exposed to precipitation flooding than coastal flooding. Precipitation flooding exposure is worse in areas with higher concentrations of impervious surfaces, such as roads, parking lots, larger buildings that do not manage runoff onsite, and drainage systems that are overcapacity. Areas of highest exposure are concentrated in the Davis Square, Union Square, and Winter Hill neighborhoods. Flooding is likely to cause damage to homes in these neighborhoods, which can be costly for homeowners and may lead to public health concerns from contamination and mold. Precipitation flooding exposure also tends to follow key transportation corridors, including the MBTA

6 City of Cambridge Climate Change Vulnerability Assessment, Appendix B: Temperature and Precipitation Projections, 2015. http://www.cambridgema.gov/CDD/Projects/Climate/~/media/A9D382B8C49F4944BF64776F88B68D7A.ashx.

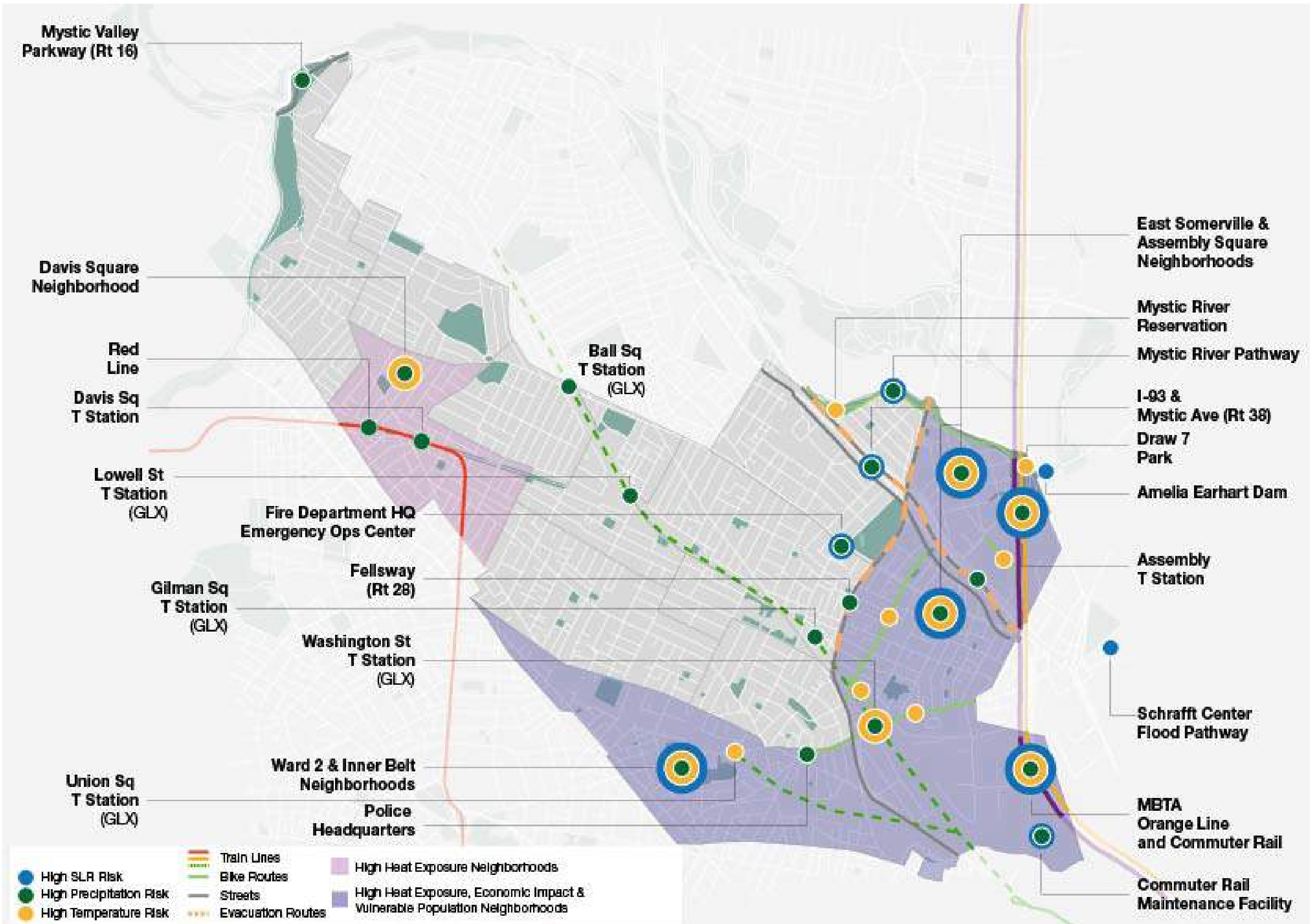

Figure 8: Key Priorities for the City of Somerville

commuter rail line to West Medford, portions of I-93/Mystic Ave and Washington Street, and the Somerville Community Path between Lowell Street and Davis Square. Historical occurrences of nuisance flooding have also been reported at the Route 28 underpass along Mystic Avenue, at underpasses on Washington Street, McGrath Highway and Medford Street, and at the Police Department Headquarters, where the police fleet was flooded out during the July 2010 storm event. While the identified areas are high priority concerns for risk of flooding from precipitation, it is important to note that the citywide modeling for precipitation did not account for the capacity of the stormwater drainage system to handle the projected increase in frequency and intensity of rainfall; the City should complete detailed modeling of the capacity of the drainage system to accommodate for the projected increase in rainfall as a result of climate change.

PRIORITY 2: Sea level rise and storm surge flooding associated with the flanking of the Amelia Earhart Dam may occur as early as 2035 if significant investment in infrastructure improvements is not made. Sea level rise and storm surge modeling for the area suggests that the Amelia Earhart Dam may be regularly flanked during 1% annual storm events as early as 2035 and may be overtopped during the 1% annual storm event as early as 2055. Flanking is expected to exacerbate shorefront (riverine) flooding in the Ten Hills and East Somerville & Assembly Square neighborhoods, resulting in 1 to 2 feet of flooding in those areas. While most of the flooding associated with the flanking of the Dam would be limited to the shorefront, the Ten Hills and East Somerville & Assembly Square neighborhoods will be significantly impacted by the

Flanking means that the water flows around the edges of the dam.

Overtopping refers to the flow of water over the top of the midsection of the dam.

failure of the dam, with flooding depths averaging several feet and as much as 10 feet in some areas during these events. Those volumes could be even greater if the coastal storms were accompanied by significant rainfall.

PRIORITY 3: The Schrafft Center flood pathway in Boston, north of Sullivan Square, is of immediate concern to Somerville. It has the potential to flood under a present-day extreme event. The Schrafft Center flood pathway in Boston, north of Sullivan Square, has the potential to flood under a present-day extreme event. While the entry point for this pathway is not under Somerville's jurisdiction, flooding in this area could have significant implications in the Ward Two & Inner Belt neighborhood. Under current conditions, there could be 0.5 to 1 foot of flooding along the western boundary of Ward Two & Inner Belt. By 2070, the extent and depth of that flooding would increase substantially and reach depths of up to 3 feet in some areas, as well as encroaching on the southeast section of the East Somerville & Assembly Square neighborhood. The City of Boston is currently developing design solutions to address this flood pathway; however, the City of Somerville should continue to advocate for flood protection solutions in this area to ensure that the solutions are ultimately implemented. In addition, there is an opportunity for future development in and around this area to be more resilient to flooding and be coupled with solutions to address flooding concerns.

PRIORITY 4: The Fire Department Headquarters and Emergency Operations Center and the Police Department Headquarters are both vulnerable to flooding, which presents significant challenges to both daily city operations and operations during an emergency event. The Fire Department Headquarters and Emergency Operations Center are both currently exposed to precipitation flood risk and are located in close proximity to the coastal flood extents expected during the 100-year storm in 2070. Although the facility may not be directly impacted by this coastal flooding, access to the facility could be significantly impacted, which would disrupt the facility's ability to operate effectively during a flood event. The surrounding coastal flooding coupled with the flood risk from a precipitation storm event could exacerbate these challenges. The Police Department Headquarters, located in Union Square is also exposed to present-day risk from precipitation events. Impacts to either of these facilities could significantly inhibit Somerville's ability to provide essential public safety services and to respond to climate events.

PRIORITY 5: The transportation system (including MBTA lines and stations, major roadways, evacuation routes, and bike paths) is highly vulnerable to all three climate hazards – coastal flooding, precipitation, and heat. The Orange Line, Commuter Rail, Green Line Extension, and Assembly Square Station along with I-93, the Fellsway and Route 28 are expected to experience impacts from sea level rise and storm surge. Precipitation impacts are expected for many of these same assets along with some additional transportation resources, including: the Red Line, Davis Square Station, the proposed Gilman Square, Washington Street, Lowell Street, and Ball Square Stations, streets surrounding the proposed Union Square Station, and local roads around Union Square and Assembly Square. There are opportunities for Somerville to couple stormwater infrastructure and flood protection improvements with transportation projects in order to reduce the vulnerability of the transportation system to flooding. MassDOT is already constructing stormwater conveyance and detention systems as part of the Green Line Extension project to ensure that storms will not fully inundate rail beds. Regional coordination will be essential in order to protect the overall transportation system because much of the MBTA and highway systems that Somerville relies on are vulnerable to flooding in surrounding communities.

Increased heat is also a concern for rails and roads because high temperatures can result in slow and steady damage to the system over time. In addition to rail and road corridors, more extreme heat may impact trains, buses and vehicles over time due to the need to run cooling systems longer during periods of high heat, which will lead to premature breakdown and shorter lifecycles for these vehicles. Bus stops and stations will also be exposed to heat impacts; however, the impacts here will be experienced by transit riders more so than the assets.

The transportation system is vital to daily life and without reliable transportation options, there will be cascading impacts in other areas, including workforce availability, freight resources, food access, job access and access to health care. Transportation access is particularly important to vulnerable populations, as they rely on these systems and are often stranded when public transportation is unavailable.

PRIORITY 6: Union Square, Assembly Square, and the Inner Belt, Somerville's transformative economic development districts, are highly vulnerable to flooding impacts. The ongoing development in these areas presents an opportunity to better prepare these neighborhoods for climate events and shape how they will experience and respond to future events by coupling infrastructure improvements with new development and construction. Assembly Square and areas of the Inner Belt are vulnerable to flooding from storm surge through the Amelia Earhart Dam pathway and the Schrafft Center pathway, respectively. These areas are not expected to experience impacts from sea level rise alone; therefore, addressing the origin of the flooding will protect these important development areas during storm events. New development in Assembly Square includes early resiliency measures such as mechanical equipment located above basement level and extensive solar distributed generation.

Precipitation events are also expected to impact Assembly Square and Union Square. Detailed drainage modeling of the Assembly Square area suggests that the drainage system has adequate capacity to handle the projected increase in the frequency and intensity of precipitation events. Union Square does not currently have the same level of adaptive capacity built into its drainage system; however, the City of Somerville is actively working to improve the water and sewer infrastructure in Union Square. The Somerville Avenue Sewer Separation and Streetscapes Restoration is an approximately $40 million project currently underway that will include a 0.8 million gallon storage box culvert and a complete streets restoration, with enhanced pedestrian, transit rider, and bike facilities with green infrastructure and landscaping features. Sewer and water utility improvements are also included. Nearby, the Nunziato Field Stormwater Storage Project will create a 1.2 million gallon stormwater tank that will hold stormwater before it reaches the heart of Union Square. In addition to improved infrastructure, new buildings that are part of the Union Square redevelopment are targeted to be LEED Gold, which can increase resilience.

PRIORITY 7: Temperature is a ubiquitous threat throughout the city and will be relatively more intense in some areas based on a combination of surface types, lack of vegetation and level of emissions. Average historic temperatures could increase by as much as 17% over present-day averages of approximately 50°F by 2070. In addition, by 2070, annual days greater than 90°F could increase by as much as nine times, over historical averages of 11 days per year, with a possible result of one continuous heat wave lasting the entire extent of the summer. That increase in temperature will be exacerbated by the presence of factors that contribute to urban heat island (UHI) effects, such as lack of tree canopy and open space, high percentages of impervious surface, and high levels of emissions from vehicles. These sustained periods of high heat provide serious public health concerns for the City of Somerville and will only be further exacerbated by the high density of people and buildings throughout the city. The use of lighter building materials, construction of green roofs, designation of additional open space within new development areas, and planting of trees can help combat the UHI effect.

PRIORITY 8: Climate change presents the potential for serious public health impacts to vulnerable populations. Vulnerable populations, including the elderly, young, disabled, residents with limited English proficiency, residents with limited educational attainment, and low-income residents, typically stand to suffer more frequently and severely from climate-related impacts. Vulnerable populations within Somerville are concentrated in West Somerville, Ward Two & Inner Belt, East Somerville & Assembly Square, Ten Hills, and Winter Hill. When high concentrations of vulnerable populations are coupled with high exposure to coastal and precipitation flooding and heat risk, the personal and community impacts can be devastating. Climate change presents public health risks, which are exacerbated in vulnerable populations that are less able to cope with climate impacts. Public health concerns include: heat-related illness and mortality, exposure to contaminated flood waters and mold resulting from flood impacts, greater exposure to impacts from poor air quality, and an increase in vector-borne diseases.

PRIORITY 9: Open space and trees are highly valuable commodities to Somerville and need to be protected and enhanced. Somerville's open spaces and parks are extremely important commodities; only 6% of the land use of the city is dedicated open space. However, many of these open spaces and natural assets are exposed to climate impacts. Coastal flooding is expected to impact Draw Seven Park, Foss Park, and Mystic River Reservation. Foss Park, Lincoln Park, Glen Park, Albion Playground, and Hodgkin's-Curtin Park may be impacted by precipitation-based flooding and heat impacts will be felt citywide, but parks, trees and plants in Davis Square, Ward Two & Inner Belt, and East Somerville & Assembly Square will have increased exposure based on UHI factors. Protecting these natural resources is vital to not only maintaining the quality of life of Somerville's residents, but also mitigating the impacts of climate change.

Somerville's Future Climate Action

Following the release of this Climate Change Vulnerability Assessment, Somerville has a unique opportunity to build on this vulnerability assessment and integrate that understanding into effective and actionable policies and solutions as part of a comprehensive climate action plan. The plan will incorporate both adaptation and mitigation solutions that will not only progress Somerville towards its goal of carbon-neutrality by 2050, but also develop actionable adaptation solutions that will better prepare Somerville for the inevitable impacts of the world's changing climate.

Section 1: Overview

Image Source: Eric Kilby. 2014. "PowderHouse Circle Into Somerville." Licensed under CC BY-SA 2.0. https://www.flickr.com/photos/ekilby/14431802234/in/photostream/

Overview

At the 2015 United Nations Climate Change Conference, a global agreement was reached to limit global warming to less than 2 degrees Celsius. While this is a significant step towards combatting climate change, mitigation cannot be the only climate solution because the climate is already changing and impacting our built, social, and natural environments. We will not be able to combat climate change by merely limiting GHG emissions; we must also prepare for and protect our communities from the unavoidable impacts of climate change.

The Somerville community has a long-standing and passionate interest in addressing climate change. In recent years, the City of Somerville has taken a leadership role in understanding the impacts of climate change, highlighted by Mayor Joseph A. Curtatone's commitment to achieving carbon neutrality by 2050 and the City's launch of the SustainaVille initiative to assist Somerville in the implementation of practical solutions to achieve carbon neutrality and resilience. Somerville is also a committed leader on a regional and global scale with its membership in the Global Covenant of Mayors for Climate & Energy[7], a global coalition of city leaders committed to combatting climate change and reducing GHG emissions, and its involvement in the climate change preparedness efforts of the Metro Mayors Coalition[8], a coalition of 14 Boston-area municipalities working to develop regional solutions to advance climate action. In conjunction with Somerville's revised GHG Inventory Report, which was released in early 2016, these forward-thinking initiatives provide a solid framework for Somerville to supplement its mitigation goals with a comprehensive vulnerability assessment. The vulnerability assessment is intended to identify opportunities for significant adaptation efforts throughout the City and is the second step in the City's overall climate change planning process.

Climate Change Plan

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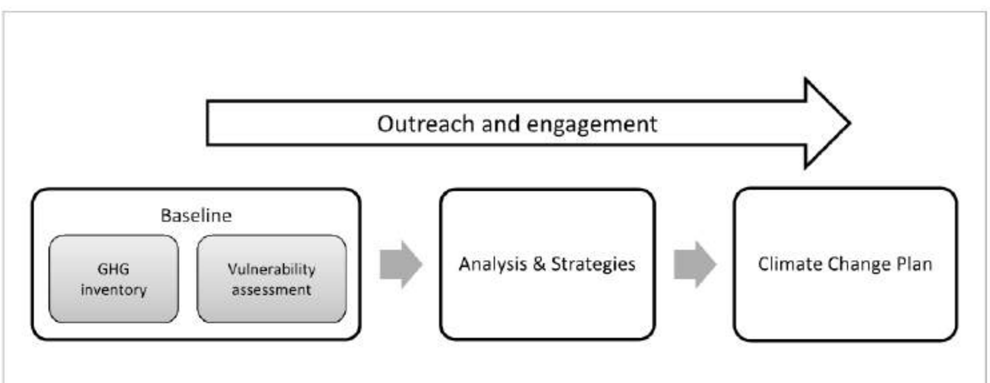


Figure 9: Somerville Climate Change Planning Process

The first step in the City of Somerville's climate change planning process is to develop a baseline of understanding of climate change that includes an inventory of the City's GHG emissions (completed in January 2016) and an assessment of the City's vulnerabilities to climate change impacts (detailed herein). With the completion of this

7 Global Covenant of Mayors for Climate & Energy, 2016. https://www.compactofmayors.org/globalcovenantofmayors/.
8 Metro Mayors Coalition: Climate Preparedness Commitment, 2015. http://www.mapc.org/climate-preparedness.

study, the next phase is to analyze the two baseline studies and develop adaptation and mitigation strategies that will feed into a comprehensive climate change plan for the City of Somerville.

Somerville has a unique opportunity to build on this vulnerability assessment and integrate that understanding into effective and implementable policies and actions, building on the existing climate baseline work completed by both public and private institutions in the Boston metropolitan region, which is a widely recognized national leader on climate action.

The City of Somerville's Climate Change Vulnerability Assessment (CCVA) is the next step towards creating a comprehensive climate change plan for the City. The general trends associated with the world's shifting climate include warmer temperatures, more extreme precipitation events, and global sea level rise. The impacts are widely recognized, but understanding the exact implications of these changes is more difficult to grasp. In order to translate those impacts into practical planning scenarios for Somerville, quantifiable projections were developed for the years 2030 and 2070. These planning horizons align with regional climate studies in order to facilitate coordinated regional climate assessments and solutions.

This assessment was conducted in collaboration with the Mayor's Office, the Office of Sustainability and Environment, the Health and Human Services Department, Engineering Department, Capital Projects Department, and the Office of Strategic Planning and Community Development. The Mayor's Commission on Energy Use and Climate Change (CEUCC) and the Vulnerability Assessment Advisory Committee also provided valuable expert advisory services, local knowledge and community feedback on the CCVA.

Section 2: Regional Coordination

Image Source: Eric Kilby. 2007. “Broadway + Central.” Licensed under CC BY-SA 2.0.
https://www.flickr.com/photos/ekilby/871114605/in/album-72157600351864087/

Regional Coordination

The Boston metropolitan region is considered a leader on climate action, both nationally and globally. In addition to the significant climate studies completed by the various cities and agencies in the region (see Figure 10), there has been a substantial regional effort to coordinate across jurisdictions.

Local Climate Change Plans
Mass DOT Boston Harbor Flood Risk Model
City of Cambridge Climate Change Vulnerability Assessment
Climate Ready Boston
Massport Disaster and Infrastructure Resiliency Plan and Capital Investment Resiliency Project
MassDOT Statewide Climate Assessment of the Transportation System
Partners HealthCare Facilities Resiliency and Operational Plan
Boston Water and Sewer Commission 10-year Capital Plan and Climate Study
East Boston Adaptation Planning
City of Boston FEMA Map Review and Revision
The Boston Harbor Association: Preparing for the Rising Tide
MWRA Climate Adaptation Study
City of Boston Climate Action Plan
MAPC Regional Climate Change Strategy
ICIC 2015 Report: Resilience Food Systems (Boston)

Figure 10: Local Climate Change Plans

Notably, the creation of the Metro Mayors Coalition Climate Preparedness Taskforce in 2015 provided a platform to ensure regional coordination and integration of existing and planned mitigation and resilience work across the fourteen member communities in Greater Boston. The City of Somerville has benefitted from the region's commitment to climate action and this study makes every effort to ensure consistency with other climate change efforts throughout the region, including building upon and further refining existing datasets and methodologies. An intention of this study is to further advance the significant body of work in the region.

While this assessment primarily focuses on vulnerabilities and risks within Somerville, there are also significant multi-jurisdictional vulnerabilities that cannot be solved by the City of Somerville, alone, but rather require regional coordination. There are two types of multi-jurisdictional vulnerabilities:

- Vulnerability of infrastructure located within Somerville that are connected to regional systems, such as T stations, rail lines, and highways; and,
- Vulnerability of infrastructure located outside of Somerville upon which the city relies, such as power generation facilities and hospitals.

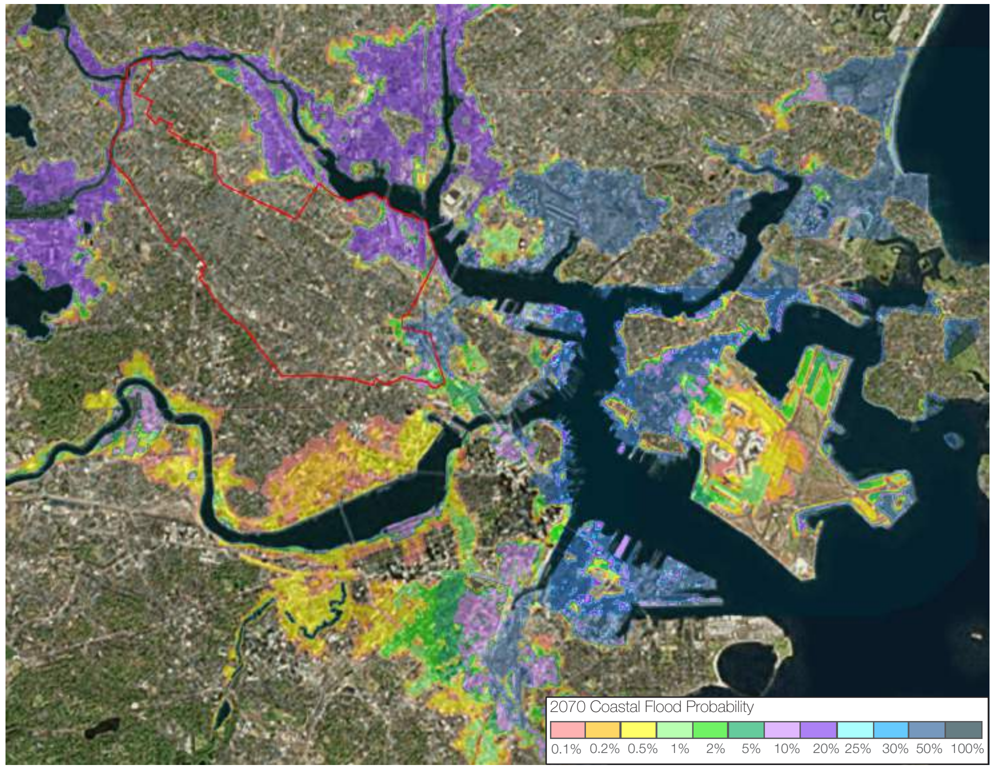


Figure 11: This map shows the annual chance of flooding from coastal storm events and sea level rise in 2070. A 100% chance of flooding means that area is very likely to flood that year, while a 50% chance means that there is an equal chance that it may or may not flood in a given year. A 1% chance of flooding correlates with a 1 in a 100 year event. A 0.1 % correlates with a 1 in 1000 year event.

It is important to distinguish between these two types of multi-jurisdictional vulnerabilities, because the extent to which Somerville can address vulnerability to these assets differs as well. While the City may be able to take direct action to address vulnerability of the area surrounding the Davis Square Station, the City might be limited to an advocacy or stakeholder role for addressing vulnerability of other assets, such as the Mystic Generating Station. Vulnerabilities of the latter type are not discussed in great detail in the following analysis, but efforts to minimize the risk to these regional systems are vital to ensuring regional resilience to climate change.

Some of the main regional concerns include the following:

• The Amelia Earhart Dam is expected to be flanked on a regular basis during a 100-year storm event by 2035; by 2070 it will be overtopped during those events, assuming no additional improvement to its current structure or operations.

• Major regional transportation corridors, such as I-93 and Route 28, as well as the Orange line, Red line, and the Green Line Extension, are likely to experience significant impacts from coastal flooding, cutting off portions of the regional transportation system. Commuters and residents could be stranded in Somerville or be cut off from the city.

• Increased average temperatures combined with longer and more intense heat waves may increase electricity demand for cooling and could result in regional brown outs.

• Both the New England Produce Center (in Chelsea) and the Boston Market Terminal (in Everett) are highly vulnerable to coastal flooding; impacts to these facilities in addition to impacts to the major food distribution route along I-93 pose serious threats to the availability of fresh food throughout the region.[9]

• The regional economy is intricately connected and impacts to Somerville's economy will have ripple effects throughout the region. Likewise, impacts outside of Somerville will affect Somerville's economy, particularly given that many Somerville residents work outside of the city.

While these vulnerabilities will not be adequately solved by any individual municipality's efforts to address climate change, understanding the implications of those climate change impacts will help to inform the broader discussions and coordinated action. Significant actions will be required by the State and Federal government, utilities, and other regional entities (such as ISO New England) to address certain infrastructure system vulnerabilities that are outside of Somerville's direct control. Somerville can work with other impacted municipalities to become a powerful advocate for appropriate policies and projects to reduce regional vulnerabilities that impact Somerville residents and businesses.

9 Resilient Food Systems, Resilient Cities: Recommendations for the City of Boston, 2015. http://icic.org/wp-content/uploads/2016/04/ICIC_Food_Systems_final_revised_post.pdf?x96880.

Section 3: Methodology

Image Source: Eric Kilby. 2012. “MBTA Bus 101.” Licensed under CC BY-SA 2.0. https://www.flickr.com/photos/ekilby/6935275928/

Methodology

This study assesses the City of Somerville's vulnerability to the following climate factors: sea level rise and storm surge; precipitation; and, temperature. The scope of this assessment is limited to the direct impacts of these climate stressors within Somerville's borders and does not extend to secondary impacts from climate factors or more regional and global climate considerations, such as food insecurity and population migration as a result of climate change. In some instances, systems or assets of regional concern in the Boston metropolitan area are highlighted for further assessment, but the regional considerations were not a specific focus of this study. Nonetheless, it is important to recognize that climate change is a challenge which will require regional coordination to adequately address; this study provides Somerville the necessary information to continue those discussions both internally and with a broader regional and national audience.

Mitigation addresses the root causes of climate change by reducing GHG emissions.

Adaptation refers to the policy and planning strategies geared at adapting to the effects of climate change that have already been set in motion.

Assessing and prioritizing climate risk is essential to understanding the City's overall vulnerability to a changing climate and prioritizing needs. Given that there will be limited resources to address all of the City's adaptation and mitigation needs, it is important to prioritize actions around the most immediate vulnerabilities, while also allowing for future flexibility. The vulnerability assessment was organized around a three step process, based on the widely-used methodology developed by ICLEI – Local Governments for Sustainability[10]:

ICLEI – Local Governments for Sustainability 3 Step Process

Step 1 - Establishing a climate baseline for the various types of climate exposures.

Step 2 - Understanding the vulnerabilities and assessing the overall risks throughout the city, culminating in the identification of the most at-risk populations, assets and systems.

Step 3 – Developing solutions for the most at-risk assets, which will form the focus of future mitigation and adaptation actions. This step will roll up into the second phase of the City's climate planning process: Analysis and Strategies and will not addressed in this report (see Figure 12).

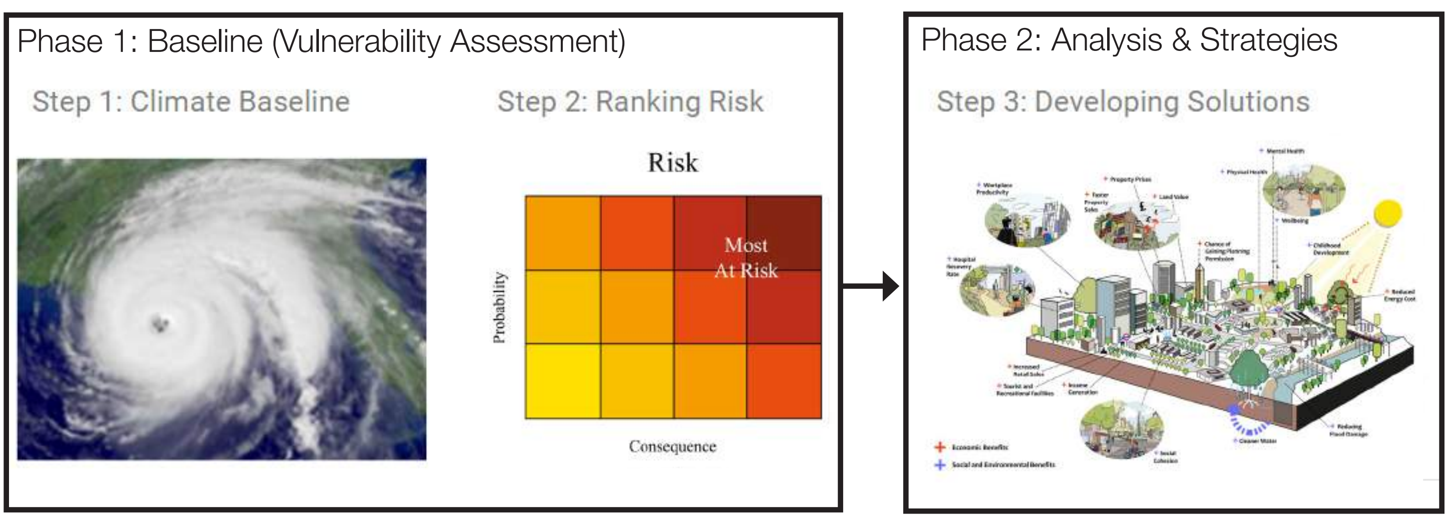


Figure 12: ICLEI Three-Step Process Aligned with the Phases of the Somerville Climate Change Planning Process

10 ICLEI: Local Governments for Sustainability. http://www.iclei.org/.

Step 1: Establishing a Climate Baseline

The climate baseline identifies the climate factors that are of highest concern to Somerville and lays the foundation for assessing vulnerability and risk within the City. The climate baseline is based on two factors: the future time period that we are planning for ("planning horizons") and the anticipated amount of GHG emissions in the atmosphere ("emissions scenarios"). These planning horizons and emissions scenarios are used to analyze anticipated changes in sea level rise and storm surge, precipitation, and temperature.

Planning Horizons

Because the climate is changing, today's climate will likely not serve as an adequate proxy for future climate conditions. The majority of future climatology studies within the Greater Boston area, including those conducted by the Cities of Boston and Cambridge, have adopted the time horizons of 2030 and 2070 to model possible futures. The approach allows for both a near-term and longer-term assessment of possible climate futures. The City of Somerville made the decision to adopt the same time horizons in order to facilitate greater regional collaboration on climate change and make the most efficient use of readily available data which has been independently vetted and verified through previous studies in the Boston metropolitan region.

Emissions Scenarios

High emissions (RCP 8.5): Emissions continue to rise throughout the 21st century and expected temperatures increase between 4.7 and 8.6°F by 2100.

Low emissions (RCP 4.5): Emissions peak around 2040 and then decline and expected temperatures increase between 2.0 and 4.7°F by 2100.

Climate projections are not an exact science and the future climate depends greatly on universal global action to limit GHG emissions. The City of Somerville is actively engaging in mitigation efforts, including the recent release of the GHG inventory in early 2016 and the City's commitment to attain carbon neutrality by 2050. However, reducing GHG emissions enough to significantly alter the course of climate change requires global action; it cannot be solved on a local level alone. Therefore, the City must plan for a range of possible climate futures depending on the effectiveness of global mitigation efforts in the coming years. Because of this uncertain future, the City decided to consider a high emissions scenario and a low emissions scenario in this assessment.

The high emissions scenario approximates a "business as usual" scenario and represents the extent of possible futures if there is not significant global action towards GHG emissions reduction and mitigation. This scenario represents a possible "worst case" given current emissions trends. The low emissions scenario approximates a "target goal", accounting for significant mitigation efforts and aligning with the recent Paris Agreement, a global agreement in which world leaders committed to GHG reductions that would limit global warming to a maximum of 2° Celsius (3.6° Fahrenheit). This scenario represents a future environment in which Somerville's GHG emissions goals have been met, but where the impacts of past emissions have already altered the global climate. It is important to note that while the Paris Agreement is now a legally binding agreement, nations have not yet submitted actual plans to accomplish the long term GHG reductions necessary to limit global warming to a maximum of 2° Celsius. Thus, it is currently a global commitment without a plan of action. For more information on emissions scenarios, please refer to Appendix B: Emissions Scenarios.

The narrative focuses on impacts associated with the high emissions scenario during the 2070 time horizon and adopts the precipitation and temperature values used by the Cities of Boston and Cambridge. However, impacts from both 2030 and 2070 are available as mapped GIS layers with the City and are captured through the detailed appendices on vulnerability and risk ranking. While 2070 was chosen as the longer-term planning horizon, it is likely that many of these impacts (particularly those associated with the Amelia Earhart Dam) will occur prior to that time. Therefore, the analysis presented here should be interpreted as possible futures that would likely occur before 2070 under the business as usual (high) emission scenario and could be somewhat delayed or less extensive under a lower emission scenario.

Step 2: Vulnerability and Risk Assessment

Building off the climate baseline, the vulnerability and risk assessment assess how the climate risks impact the built, natural, social, and economic landscape of the city to determine the most critical and pressing needs across the various existing assets, systems, and populations that comprise the city. In order to conduct the assessment, climate exposure to sea level rise and storm surge, precipitation, and heat were mapped to display which assets are currently exposed, acknowledging that both exposure and the existing facilities, systems and populations will likely change in the future.

Vulnerability Assessment

Vulnerability is a function of climate exposure, **sensitivity** and **adaptive capacity**.

Each asset was evaluated for its level of exposure to one or more of the identified climate stressors. In this report, asset is defined as the unit of analysis and is indicative of the systems and populations that comprise the city. If the asset is exposed to an identified climate change impact, it is then scored for its sensitivity and adaptive capacity related to that climate stressor and plotted on the vulnerability matrix (Figure 13) according to that combined sensitivity and adaptive capacity score. For more detail on the scoring of the individual assets, please refer to Appendix H: Vulnerability and Risk Assessment Tables. The most vulnerable assets, identified by the combination of the highest sensitivity (on a scale of 1-4) and the lowest adaptive capacity (on a scale of 0-2), were moved into the risk assessment.

Vulnerability = Sensitivity + Adaptive Capacity

Sensitivity is defined as the degree to which the functionality of a system is affected by a specific climate impact.

Adaptive capacity speaks to the ability of a system to respond and recover effectively in the face of climate change impacts.

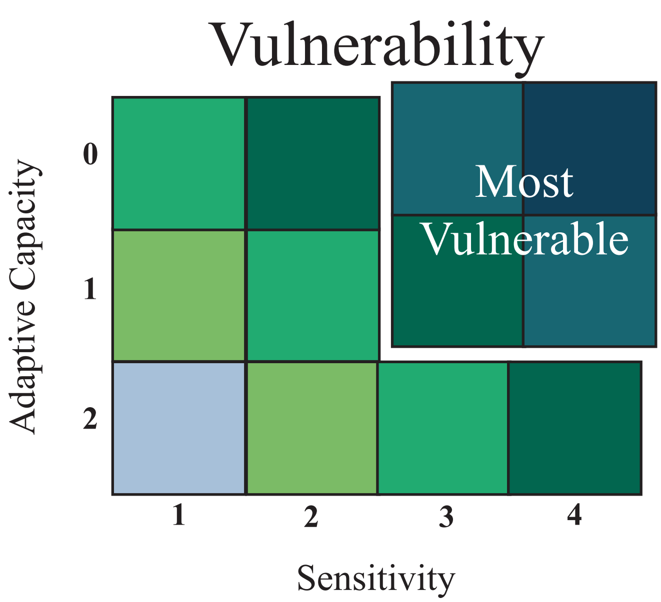


Figure 13: Vulnerability Matrix

Risk = Probability + Consequence

Probability is the likelihood that a system or asset will be impacted by the climate stressor to which it is exposed.

Consequence refers to the magnitude of the repercussions associated with system failure in the event of a climate impact.

Risk Assessment

Risk is defined as a function of probability and consequence. The most vulnerable assets identified during the vulnerability assessment were evaluated according to the probability and consequence associated with impacts to those assets. The most at-risk assets were identified by the highest combined probability (on a scale of 0-2) and consequence score (on a scale of 1-15). For more detail on the scoring of the individual assets, please refer to Appendix H: Vulnerability and Risk Assessment Tables.

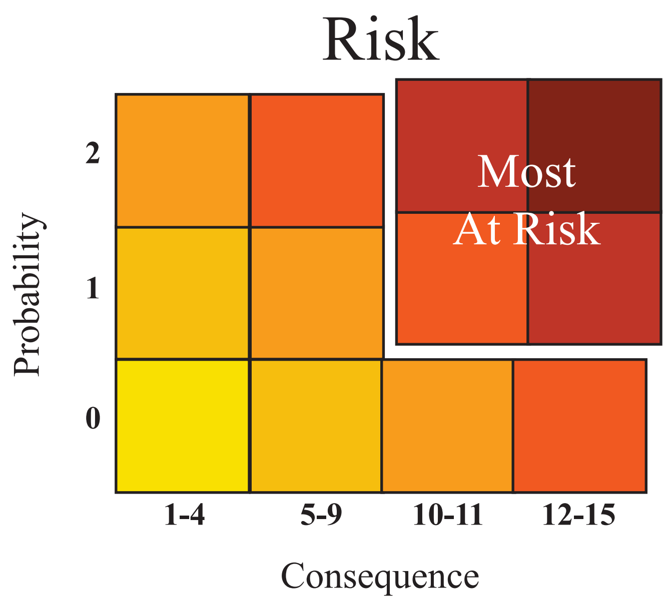


Figure 14: Risk Matrix

The assets or systems with the highest risk (i.e. highest combined probability and consequence) are the recommended areas of focus for adaptation and mitigation solutions (see Figure 14). Based on the vulnerability and risk assessment results, Somerville will identify strategies to mitigate the highest risks as part of the City's Climate Change Action Plan, which is the next phase of Somerville's climate planning process.

Economic Modeling

Economic modeling was conducted to provide a snapshot of the costs of climate-related damages in order to contextualize the risk and vulnerability analysis. The economic assessment analyzed the impacts of coastal flooding on the local and regional economy. The modeling utilized the sea level rise and storm surge projections to estimate monetary damages associated with flood impacts on both commercial and residential buildings. A smaller, focused study in the Union Square area highlighted potential impacts associated with precipitation-based flooding. A third analysis assessed the regional economic impacts associated with business interruption in Somerville. Due to limitations in data availability and lack of detailed modeling, the economic analysis does not include an assessment of how changes to temperature and precipitation could also impact the economy. For more information on the regional economic modeling analysis and the Union Square economic analysis, please refer to Appendix E: Regional Economic Analysis and Appendix I: Union Square Economic Analysis, respectively.

Section 4: Climate Exposure

Climate Exposure

Key Findings

- Climate exposure focused on sea level rise and storm surge, precipitation and temperature as the key stressors.
- Sea level rise and storm surge are already potential concerns for East Somerville & Assembly Square. Further exacerbating these concerns, the Amelia Earhart Dam could be regularly flanked by 2035 and could be overtopped during a 1% annual storm as early as 2055.
- The flood pathway which is of immediate concern to Somerville is located at the Schrafft Center in Boston, north of Sullivan Square. This has the potential to flood under a present-day extreme event.
- As part of a wet region, Somerville is projected to experience more than a 30% increase in rainfall during a 100-year 24-hour event by 2070.
- Much more of Somerville will be exposed to precipitation flooding than coastal flooding. Assembly Square, Winter Hill, Union Square, and Davis Square exhibit characteristics which increase exposure to precipitation flooding.
- By 2030, a third of the summer could be marked by temperatures over 90°F, by 2070, it is projected that the entire summer consists of days with temperatures greater than 90°F under the high emissions scenario.

Overall, the City of Somerville can expect to see increased flooding from coastal storms, increasing temperatures, and more extreme precipitation events as a result of climate change.

Sea Level Rise and Storm Surge

Sea level rise (SLR) is a global phenomenon caused by two main factors:

- Thermal expansion resulting from increasing ocean temperatures; and,
- Increasing volumes of water in the ocean as a result of melting ice sheets and glaciers.

As global temperatures increase, land-based ice melts and the temperature of the ocean rises. Melting ice results in additional volumes of water being added to the oceans. This is compounded by the fact that water expands as the temperature of the water gets warmer. Since 1900, it is estimated that global sea levels have been rising at a rate of 0.6 inches per decade. Since 1992, that rate has doubled to an estimated 1.2 inches of sea level rise per decade.[11]

While an annual probability of flooding for a particular asset might be 1%, the probability that asset will flood at least once in 30 years is 26%, and the probability of flooding at least once in 50 years is 39%.

Locally, these factors are further compounded by a slow geological sinking of the eastern seaboard (subsidence) and the slowing of currents in the Atlantic Ocean, which leads to a flattening of the dome of water set up by those currents, causing higher elevations at the shoreline. In fact, sea level rise is happening three times faster along the East Coast of the US than the global average.[12]

Storm surge is the increase in water level generated by a storm event and is primarily caused by strong winds. Storm surge refers to the amount of water above and beyond the normal tide level. As sea levels continue to rise, the effects of storm surge are likely to increase because the baseline water level is higher.

SLR and storm surge pose significant risks to both the health and well-being of populations living in coastal regions and the infrastructure situated along the coast. Since 1991, the Boston metropolitan region has experienced 21 federally- or state-declared

11 NOAA: Is Sea Level Rising?, 2016. http://oceanservice.noaa.gov/facts/sealevel.html.

12 Hotspot of Accelerated Sea-Level Rise on the Atlantic Coast of North America, 2012. http://www.nature.com/nclimate/journal/v2/n12/abs/nclimate1597.html.

100-year event: an event that statistically has a 1% chance of occurring in any given year.

1000-year event: an event that statistically has a 0.1% chance of occurring in any given year.

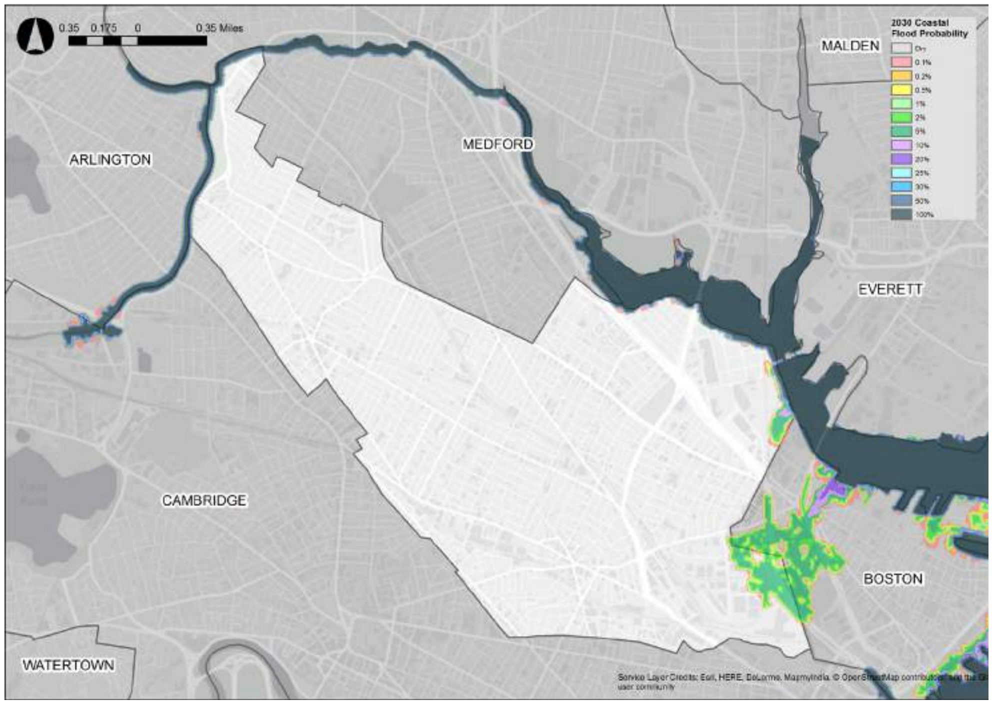


Figure 15: **2030 Coastal Flooding** - The annual chance of flooding in this geography from coastal storm events and sea level rise in 2030. A 100% chance of flooding means that area is very likely to flood that year, while a 50% chance means that there is an equal chance that it may or may not flood in a given year. A 1% chance of flooding correlates with a 100-year event. A 0.1% correlates with a 1000-year event.

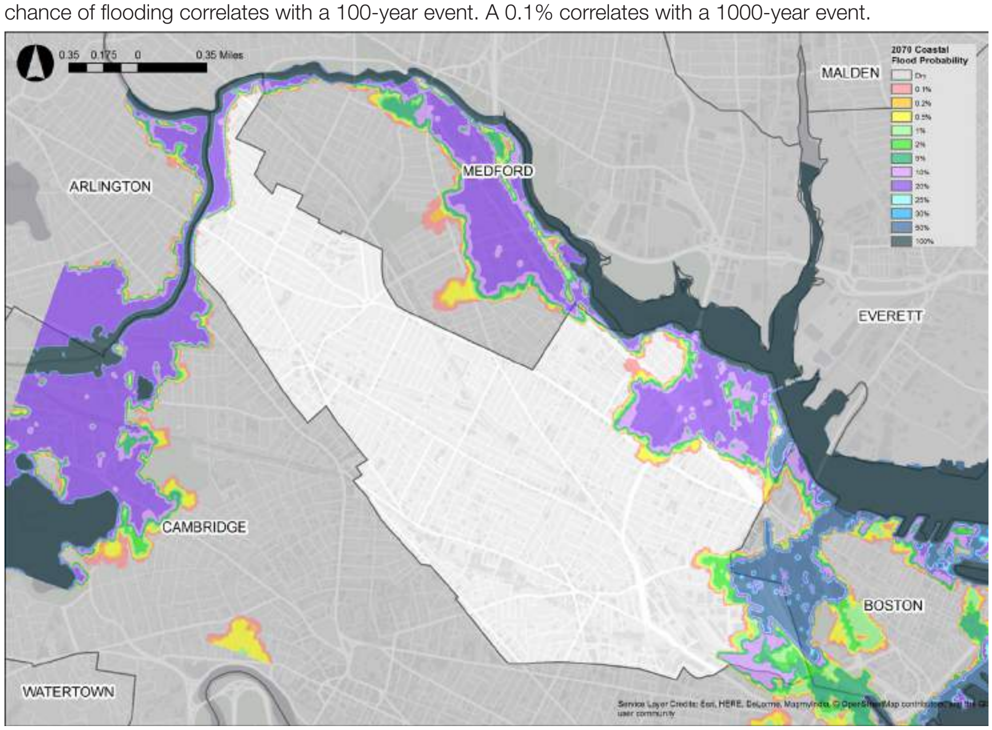


Figure 16: **2070 Coastal Flooding** - The annual chance of flooding in this geography from coastal storm events and sea level rise in 2070. A 100% chance of flooding means that area is very likely to flood that year, while a 50% chance means that there is an equal chance that it may or may not flood in a given year. A 1% chance of flooding correlates with a 100-year event. A 0.1% correlates with a 1000-year event.

disaster events.[13] Recent research now predicts that storms, similar to Superstorm Sandy, are much more likely to have a return period closer to 20 years, instead of a 100- or 1000-year event.[14]

Impact to Somerville

Within recent history, there has been no significant coastal flooding within Somerville; however future increases in sea level and the likelihood of storm events suggest greater risk. These impacts include both a change in the daily frequency of flooding as sea levels rise, which will impact the inland flooding associated with tides, and a change in the annual frequency of coastal storms. The tidal aspects of flooding will be most prevalent downstream of the Amelia Earhart Dam and will largely affect the East Somerville & Assembly Square neighborhood. The flood pathway which is of immediate concern to Somerville is located at the Schrafft Center in Boston, north of Sullivan Square (see Figure 15). This has the potential to flood under a present-day extreme event. Following 2035, there is a significant potential that the Amelia Earhart Dam will be regularly flanked. In fact, it is likely that the extent of flooding depicted in 2070 could occur earlier – especially in the area of the dam. By 2070, the depth of flooding associated with the 100-year event would significantly impact West Somerville along Alewife Brook and could be as high as 10 feet in some areas along the borders of Arlington and Medford (see Figure 16).

The Boston Harbon Flood Risk Model uses the following values of sea level rise:

2030: 0.68 feet (~8 inches)

2070: 3.4 feet (~40.8 inches)

Methodology

This assessment uses the Boston Harbor Flood Risk Model developed by Woods Hole Group in collaboration with UMass Boston and MassDOT.[15] It is a probability-based flooding model used to assess the yearly chance of flooding ("probability") as well as the depth of flooding associated with various events in the Boston metro region. This model underpins all of the coastal vulnerability work in this region. In this case, we are looking at the 100-year and 1000-year events (or 1% and 0.1% annual events, respectively) for the years 2030 and 2070. For more information on the flood modeling, please refer to Appendix A: Climate Baseline.

Precipitation

Precipitation-based flooding is projected to increase in Somerville and is currently more of an immediate and widespread threat than SLR and storm surge. As average temperatures increase, more water vapor is trapped in the air, resulting in increased precipitation. In fact, it is this very phenomenon that accounted for the significant snow storm that Somerville experienced in 2015. In general, climate change is causing a strengthening of existing precipitation patterns in two main ways:

- Intensification in frequency and intensity of rainfall in wet regions; and,
- Increasing drought conditions in dry regions.

Although Massachusetts experienced a severe drought in 2016, the Northeast is typically a wet region and is not anticipated to experience a change in the likelihood of drought conditions. Projections show that Somerville is more likely to experience an increase in average rainfall. The intensification of both the frequency and intensity

13 Climate Ready Boston, 2016. https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf.

14 Hurricane Sandy's flood frequency increasing from year 1800 to 2100, 2016. http://www.pnas.org/content/113/43/12071.abstract.

15 MasssDOT-FHWA Pilot Project Report: CLimate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery, 2015. https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_Report_MassDOT_FHWA.pdf

of rainfall events is likely to cause increased risk of flooding during rain events. These flood events often place additional stress on ageing infrastructure and can result in a degradation of water quality due to stormwater runoff. The decrease in water quality has implications for both human health and ecosystem health.

Impact to Somerville

Much more of Somerville will be exposed to precipitation-based flooding than coastal flooding. With climate change, precipitation events will become more intense—meaning that a greater volume of rain will fall in a shorter period of time. This can lead to flooding in areas where the drainage system does not have sufficient capacity. It will be further exacerbated by the presence of impervious surfaces, such as roads and parking lots, where the water cannot be absorbed into the ground, but rather is funneled into storm drains, nearby water bodies or other low-lying areas. Areas which exhibit these characteristics are concentrated around Assembly Square, Winter Hill, Union Square, and Davis Square (see Figure 17).

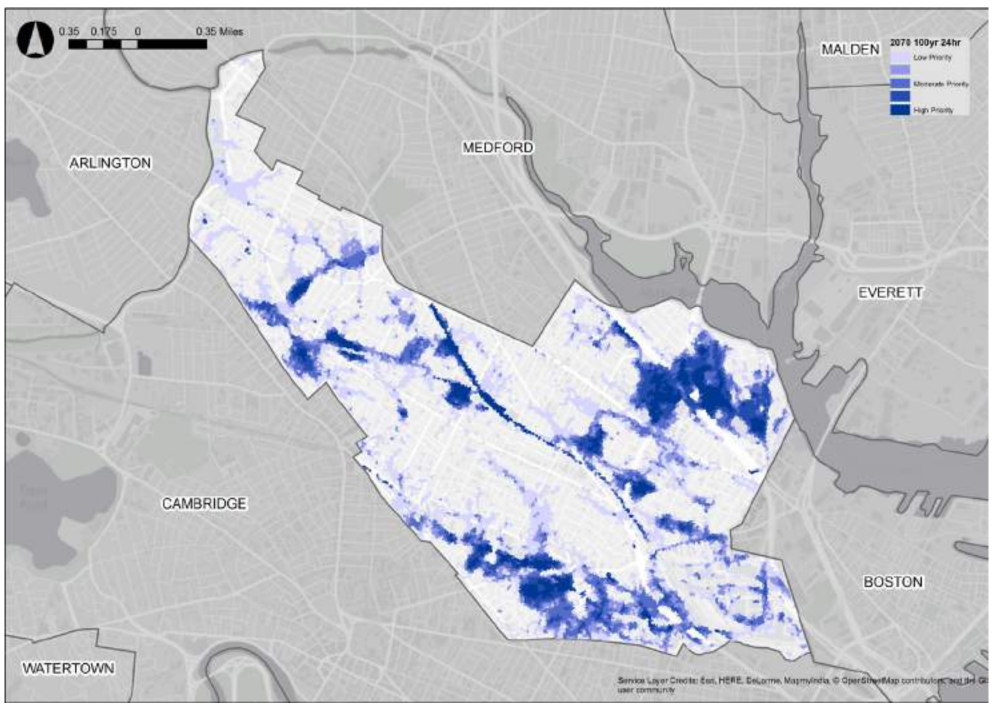


Figure 17: 2070 100-year, 24-hour Design Storm Priority Areas of Flood Concern

Historically, Somerville has experienced flooding from intense precipitation events in a few key areas, including:

- Repeated flooding of the Route 28 underpass along Mystic Avenue, near Foss Park;
- Repeated flooding of underpasses along Washington Street, McGrath Highway, and Medford Street (near the Cambridge city line); and
- Flash flooding during the July 2010 rainstorm, including flooding of the police fleet.

Methodology

This assessment utilized the precipitation scenarios developed for the City of Cambridge[16] as a baseline for predicting the intensity of future rainfall events. The two scenarios project rainfall for the 10-year, 24-hour rainfall event and the 100-year, 24-hour event. Those projections were translated into mapped flooding impacts based on existing land topography. It is important to note that these maps do not take into account citywide stormwater management drainage and infrastructure; therefore, they are intended to represent priority areas of flood concern, but are not intended to display actual flood depths as it is unclear without further modeling if the current infrastructure would be able to accommodate the anticipated increase in water volumes. For more detailed information on the precipitation projections and the modeling of those projections, please refer to Appendix A: Climate Baseline and Appendix D: Precipitation Modeling Methodology, respectively.

Design Storm	Present-day	2030	2070
10-year, 24-hour	4.9 in	5.6 in	6.4 in
100-year, 24-hour	8.9 in	10.2 in	11.7 in

Figure 18: Precipitation Projections

Temperature

Global temperatures are rising, largely as a result of increasing GHG emissions. Greenhouse gases trap heat in the earth's atmosphere, which results in an overall warming of the planet. Over the past 50 years, the earth has recorded the fastest rate of increase in average global temperatures in human history. Fifteen of the last 16 years have been the warmest years on record.[17] Global temperatures are expected to continue to increase, even with mitigation efforts. This is due to the fact that there are already significant volumes of carbon in the atmosphere that will not dissipate for many decades or even centuries. Without mitigation, the volume of carbon and associated impacts will continue to increase.

Increasing average temperatures can have wide-ranging impacts on human life, the built environment and natural ecosystems. Rising average temperatures as well as more intense heat waves present significant public health concerns; vulnerable populations are particularly susceptible to heat-induced illness and mortality. Even small changes in average temperatures can significantly impact the natural environment: plant and animal species have adapted to specific natural environments and if those environments change more quickly than those species are able to adapt, there will be significant species extinction.

While heat is expected to have some impacts to the built environment (e.g., extreme heat can cause localized failures in pavement, warping of rails, and can limit the supply of electricity from water-cooled power plants, limit the transmission capacity of electrical wires, and indirectly lead to brown-outs as demand during hot days outstrips the overall supply), the more immediate and concerning needs around heat relate to public health. Heat stress has significant implications for human health. Physiologically, humans

16 City of Cambridge Climate Change Vulnerability Assessment, Appendix B: Temperature and Precipitation Projections, 2015. http://www.cambridgema.gov/CDD/Projects/Climate/~/media/A9D382B8C49F4944BF64776F88B68D7A.ashx.

17 NOAA: Global Analysis – Annual 2015 State of the Climate, 2016. https://www.ncdc.noaa.gov/sotc/global/201513.

Heat wave: in the Northeast U.S., a heat wave is a typically defined as three or more consecutive days with maximum daytime temperatures of approximately 90°F or higher.

Morbidity rate: the frequency with which a disease appears in a population.

Mortality rate: a measure of the number of deaths in a particular population in a given timeframe.

can only endure brief periods of extreme heat. A two to three-day heat event can greatly impact human health and wellbeing as it often increases both the morbidity and mortality rates of a population – this is particularly true with children and the elderly, and in economically-challenged populations that do not have adequate access to cooling. In 1995, a 5-day heat wave in Chicago led to the death of more than 600 residents.[18] As a result, this study assesses heat from the perspective of the user experience. In particular, the assessment focuses on assets where people would be exposed to both shorter and longer-term heat impacts - these include bus stops, bike paths, and open space - as well as their overall access to assets and infrastructure that could minimize the impact of heat: air conditioning, building type, and vegetative coverage.

Impact to Somerville

In Somerville, annual average temperatures are projected to increase by 2-3°F by 2030 and could increase by as much as 7-8°F (under the high emissions scenario) by 2070. By the end of the century, average summer temperatures are expected to experience proportionally greater temperature increases than winter temperatures.[19] Winters will likely still be cold in Somerville, but summers could be much hotter than today.

	1971-2000 Average	2030 RCP4.5	2030 RCP8.5	2070 RCP4.5	2070 RCP8.5
Average Annual Temperature	50.0	53.0	53.5	55.8	58.7
Average Summer Temperature	70.6	74.5	74.8	77.4	80.6
Average Winter Temperature	29.8	32.2	33.0	34.6	38.0

Figure 19: Average Annual Temperature Projections

Extreme heat days are also projected to increase; by 2030, it is anticipated that the region could experience as many as 29-40 days over 90°F and, by 2070, that number could increase to 47-90 days over 90°F.[20]

While the numbers above focus on the number of days above 90 degrees, they do not directly call out heat waves. Heat waves have been defined in several ways but a commonly used definition for the Northeast is three or more consecutive days of daytime temperatures of 90°F or higher. Heat waves have significant implications for public health since the human physiology is not able to cope with long, extended periods of exposure to extreme heat. This vulnerability is exacerbated when there is insufficient cooling during the evening hours and/or people are unable to access adequate cooling during these events. Although this study did not specifically address the expected number and duration of heat waves moving forward or the heat index (which includes

18 Near-Fatal Heat Stroke during the 1995 Heat Wave in Chicago, 1998. https://www.ncbi.nlm.nih.gov/pubmed/9696724.

19 City of Cambridge Climate Change Vulnerability Assessment, Appendix B: Temperature and Precipitation Projections, 2015. http://www.cambridgema.gov/CDD/Projects/Climate/~/media/A9D382B8C49F4944BF64776F88B68D7A.ashx; Partners HealthCare Strategic Resiliency Plan, 2016. This Plan is not publicly available. However, permission was granted by Partners HealthCare to utilize data generated during that study to assist with the City of Somerville's Climate Change Vulnerability Assessment.

20 City of Cambridge Climate Change Vulnerability Assessment, Appendix B: Temperature and Precipitation Projections, 2015. http://www.cambridgema.gov/CDD/Projects/Climate/~/media/A9D382B8C49F4944BF64776F88B68D7A.ashx; Partners HealthCare Strategic Resiliency Plan, 2016. This Plan is not publicly available. However, permission was granted by Partners HealthCare to utilize data generated during that study to assist with the City of Somerville's Climate Change Vulnerability Assessment; Climate Ready Boston, 2016. https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf.

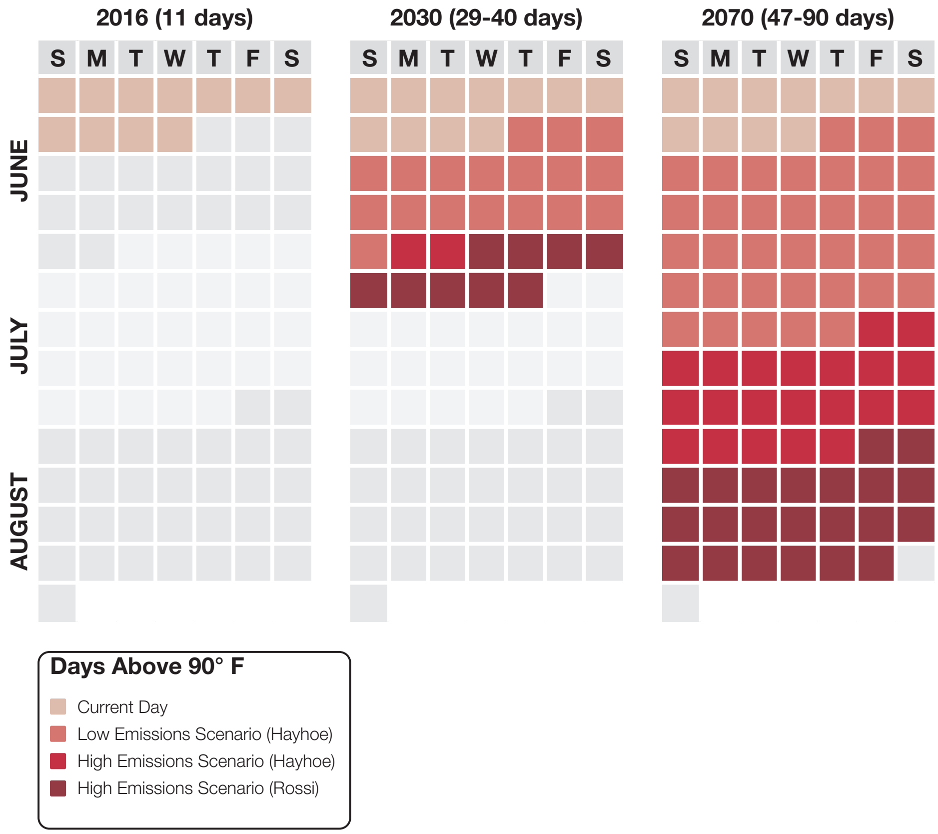


Figure 20: Comparison of Days above 90°F for Low and High Emissions Scenarios

the effects of humidity), Figures 19 and 20 provide a robust proxy of how those might increase moving forward. By 2070, it is possible that the entire summer will be marked by temperatures above 90°F.

On hot days and nights, variations in heat exposure throughout Somerville are largely dependent on the urban heat island effect. Nighttime hotspots are of particular concern from a public health perspective. Both people and building mechanical systems and infrastructure require cooler nighttime temperatures in order to effectively recover from extreme daytime heat. Thus, significant nighttime hot spots can impede the ability of people and systems to recover and therefore, result in increased heat illness. Heat illness may be further exacerbated by the fact that cooling systems cannot operate effectively in the daytime because they are overtaxed by the continual need to provide cooling services during the day and night. However, Somerville has relatively few nighttime hot spots, relative to the region as a whole, which has positive implications for public health impacts from increased temperatures throughout the city. UHIs are typically urban areas that are hotter than surrounding areas because of such factors as high emissions from roadways, high percentage of industrial uses, low percentage of trees and open space, and high density of buildings. In Somerville, the East Somerville & Assembly Square, Ward Two & Inner Belt, and Davis Square neighborhood all exhibit increased urban heat island exposure (see Figure 21).

As displayed in Figure 19, average historic temperatures are approximately 50°F; that average could increase by as much as 17% by 2070. In addition, annual days greater than 90°F have historically averaged around 11 days per year and days over 100°F have averaged approximately one day every seven years. The days over 90°F could increase by as much as nine times by 2070 with a possible result of one continuous heat wave lasting the entire extent of the summer (see Figure 20).

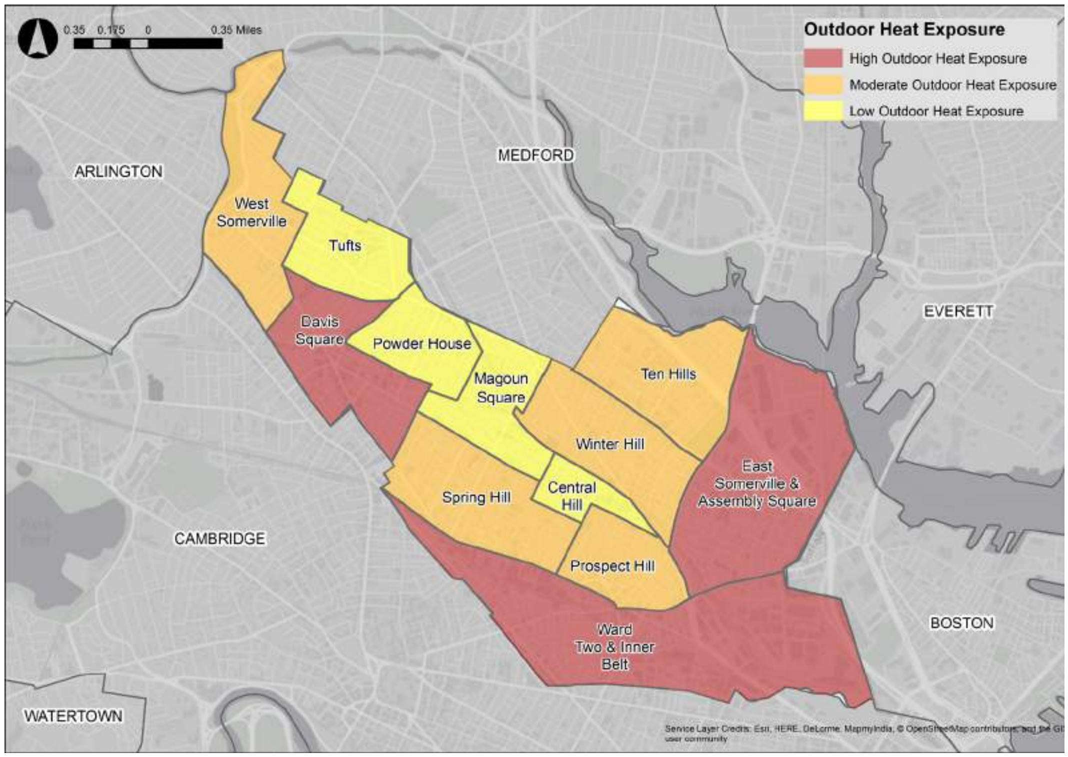


Figure 21: Relative Urban Heat Island Exposure by Neighborhood

Extreme heat days are days with temperatures greater than 90°F.

Thus, Somerville is expected to get a lot hotter, both on average and in extremes. Without significant changes to the physical environment, this increase in heat exposure, will have harmful public health implications for the residents of Somerville. Impacts, including mortality, heat stroke, and heat exhaustion will disproportionately affect the young, elderly, and those with pre-existing health conditions. Likewise, warming climates allow for the propagation of vector-borne diseases carried by insects that might otherwise not survive in colder environments. Examples include West Nile Virus, Eastern Equine Encephalitis (EEE), the Zika Virus, Lyme Disease and Dengue Fever. Air quality is another aspect that is often negatively impacted by extended periods of extreme heat. This results in increased respiratory and cardiac health concerns.

Figures 22 and 23 represent a typical neighborhood and a typical building typology in Somerville and provide more detail on the neighborhood-level and building-level attributes that contribute to urban heat island effects and may have negative impacts on public health implications for the city. This scale allows for modularity and the ability to scale up to the city level but still provide a sense of relativity for the smaller communities that make up the larger city.

At a neighborhood scale, some contributors to UHI effects, and therefore, opportunities for improvement, include: lack of street tree coverage in certain locations; large amounts of impervious surface; lack of bioswales and green infrastructure along streetscapes; and, lack of landscaping on vacant or underused parcels.

The most common housing structure in Somerville is the two-family home; thus, an analysis was also conducted for the typical two-family structure. Contributing UHI factors include dark-colored roofing and building materials; lack of landscaping or street trees on the parcel; paved driveways and additional impervious surfaces; and, direct exposure of windows to sunlight and uncoated windows that allow significant heat gain.

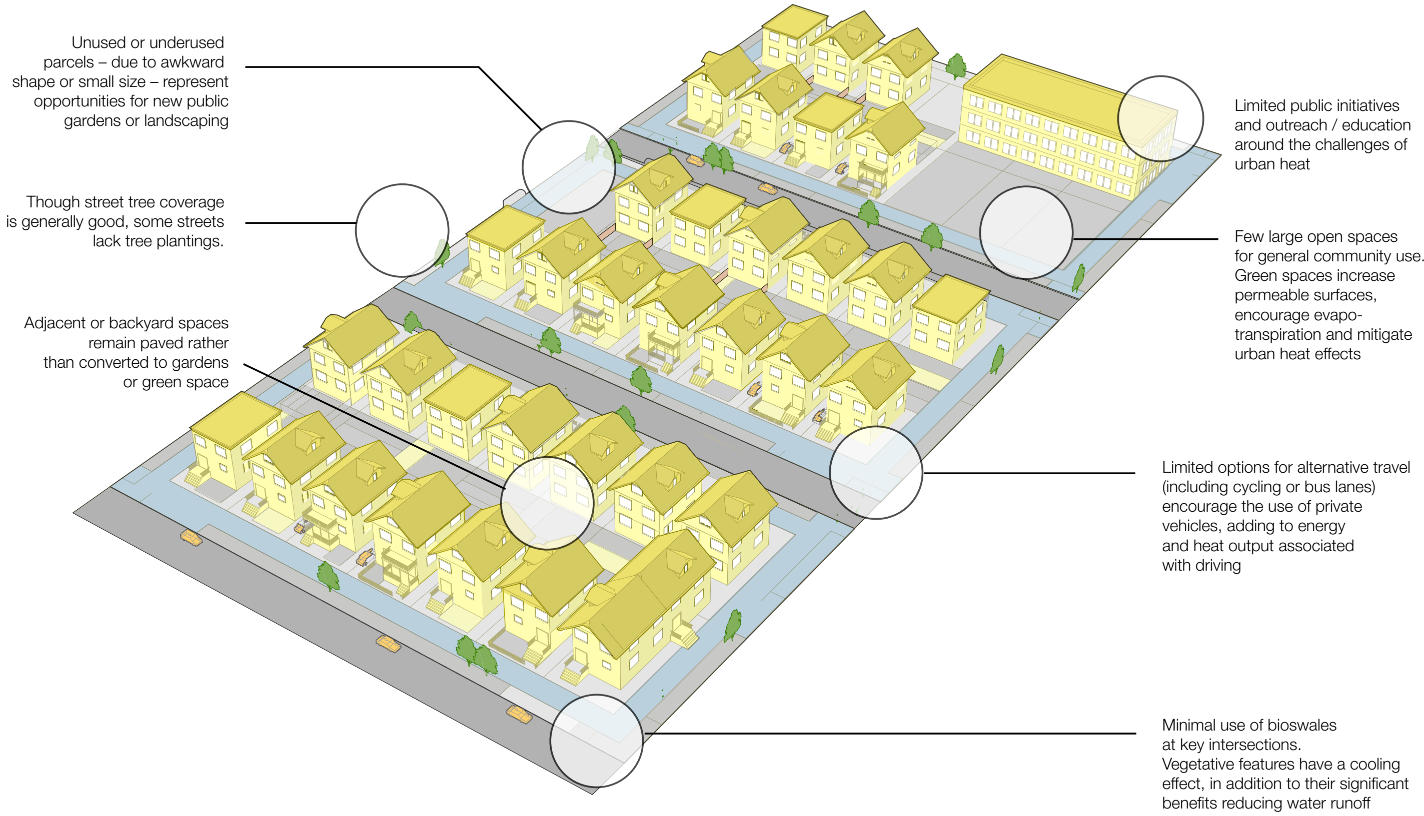


Figure 22: Potential Heat Concerns at a Neighborhood Level

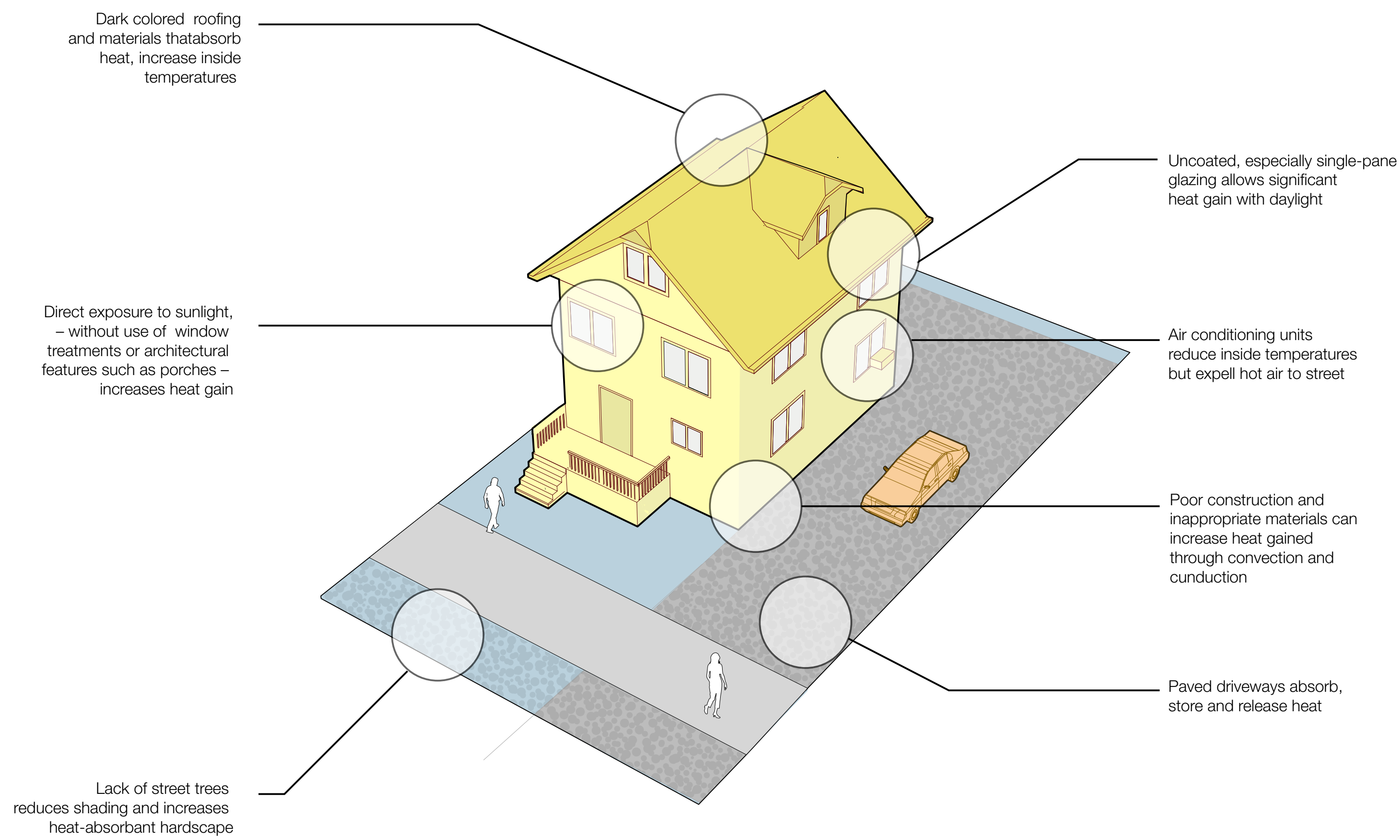


Figure 23: Potential Heat Concerns for a Typical Somerville Two-Family Structure

Methodology

Variations in heat exposure throughout Somerville were calculated using data from the Trust for Public Land with respect to surface temperatures and urban heat island.[21] That data was supplemented with additional variables that would contribute to the urban heat island effect in Somerville, including emissions (e.g., from heavily traveled roadways and industrial uses), percent of open space, and estimated tree coverage. For this analysis, we assessed heat according to the projected increase in average monthly temperatures and historic occurrences and projected occurrences of heat waves and extreme heat days. The downscaled heat projections developed for the City of Cambridge in addition to the recent results of Climate Ready Boston and the Partners HealthCare work were used as a baseline for understanding the general ratio of increase expected across the state as well as the increase in the number of extreme heat days.[22] Heat projections are regional in nature and, therefore, the work in Cambridge and Boston is an adequate proxy for the City of Somerville. For more information on the temperature projections and heat methodology, please refer to Appendix A: Climate Baseline and Appendix C: Heat Methodology, respectively.

21 The publicly-available data is currently limited to the City of Boston, but the Trust for Public Land is developing similar data for Somerville and the surrounding communities. TPL shared some of the data for Somerville to assist with the Urban Heat Island analysis for this project. Information on the methodology and the analysis for Boston can be found here: The Trust for Public Land: Climate-Smart Cities – Boston, 2016. https://www.tpl.org/climate-smart-cities%E2%80%93boston#sm.000000ov6i82syf5wrloin7b1vbzs.

22 City of Cambridge Climate Change Vulnerability Assessment, Appendix B: Temperature and Precipitation Projections, 2015. http://www.cambridgema.gov/CDD/Projects/Climate/~/media/A9D382B8C49F4944BF64776F88B68D7A.ashx.

Section 5: Vulnerability & Risk Assessment

Vulnerability Assessment

The projected exposure outlined in the climate baseline section can be overlain on the built, natural, social and economic landscape of Somerville to assess vulnerability. An inferred interim step here is the identification of critical assets, resources and vulnerable populations within the city that comprise this landscape. We created a list of assets by pulling data from Somerville's Hazard Mitigation Plan[23], City Departments, and the Vulnerability Assessment Advisory Committee. Technical experts vetted the data and added additional information to create and prioritize an asset list that covers critical built, natural, and social systems in Somerville.

Key Vulnerabilities

Vulnerability is defined based on the ICLEI methodology which considers exposure, sensitivity and adaptive capacity in the overall score. Exposure is the extent and overall intensity of the climate impact – for example, the depth of flooding or absolute temperature for a given time period. Sensitivity is defined as the asset's (or population's) ability to function or cope in the midst of a climate impact. For example, if temperatures exceed 100°F for three consecutive days, would people still be able/willing to use an unshaded bus stop? Would that bus stop continue operating at its full capacity or would ridership drop off?

Adaptive capacity speaks to the overall redundancy in the larger system. In this case, are there alternative bus stops? Is there adequate shading or other types of cooling that would provide relief to riders during heat events? It is the combination of these factors that yield the overall vulnerability score. Those assets with the highest vulnerability (plotting on the top right corner of the diagram shown in Figure 24) were then carried forward to the risk assessment for further prioritization. The detailed vulnerability assessment can be found in Appendix H: Vulnerability and Risk Assessment Tables. Below is the description of Somerville's most vulnerable assets and a high level summary of those vulnerabilities across the various systems.

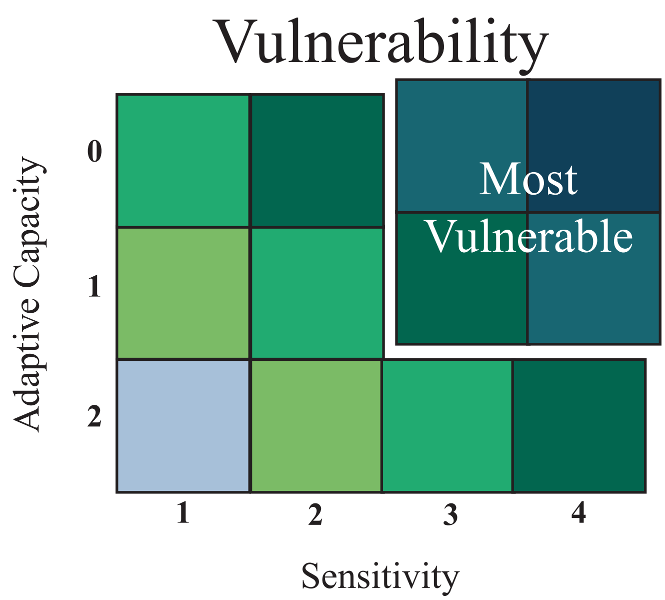


Figure 24: Vulnerability Matrix

23 Somerville Hazard Mitigation Plan, 2013. http://www.somervillema.gov/sites/default/files/hazard-mitigation-plan.pdf.

Most Vulnerable Assets

	Sea Level Rise	Precipitation	Temperature
Critical Assets			
Amelia Earhart Dam	■		
Somerville District Court	■	■	
Cooling Center (Ward Two)	■		
Cooling Center (West Somerville)	■		
Union Square Fire Station		■	
Police Headquarters		■	
Union Square Health Center		■	
Next Wave Junior High School		■	
Full Circle High School		■	
East Somerville Community School		■	
Capuano Early Childhood Center		■	
Albert F Argenziano School		■	
Energy			
Mystic Generating Station, Everett	■		
Amerigas Propane	■	■	
Mystic Substation	■	■	
Prospect Substation		■	
Bow Street Substation		■	
Washington Street Substation		■	
Linwood Street Substation		■	
Telecommunications			
Verizon Central Office Switching Station		■	
Water Infrastructure			
MWRA Sewer Pumping Station	■		
Outfalls	■	■	
Roadways			
I-93	■	■	
Fellsway (Rt. 28)	■	■	
McGrath Highway (Rt. 28)	■	■	
Mystic Valley Parkway (Rt. 16)	■	■	
Alewife Brook Parkway (Rt. 16)	■	■	
Mystic Valley / Alewife Brook Parkway Rotary	■		
Mystic Avenue (Rt. 38)	■	■	
Route 28 / Fellsway Bridge	■		
Boston Avenue Bridge	■		
Evacuation Routes	■	■	
Transit			
Fitchburg Commuter Rail	■	■	
Lowell Commuter Rail	■	■	
Newburyport / Rockport Commuter Rail	■		
Haverhill Commuter Rail	■	■	
Orange Line	■	■	
Assembly Row Station	■	■	
Sullivan Station	■	■	
Commuter Rail Maintenance Facility	■	■	
Orange Line / Haverhill Commuter Rail Bridge	■		
Newburyport / Rockport Commuter Rail Bridge	■		
Lowell Commuter Rail Bridge	■		
Davis Square Station		■	
Red Line		■	
Bus stops	■	■	■
Washington Street Station (Green Line Extension)			■
Union Square Station (Green Line Extension)			■

	Sea Level Rise	Precipitation	Temperature
Bike Paths			
Alewife Greenway Path	■	■	
Mystic River Pathway	■	■	
Assembly Square Drive	■	■	■
Powderhouse Boulevard	■	■	
Cross St		■	■
Tufts St		■	■
Elm St		■	■
Willow Ave		■	■
Highland Ave		■	■
Holland St		■	■
Community Path		■	■
College Ave		■	■
Cameron Ave		■	■
Broadway		■	■
Medford St		■	■
Joy St		■	■
Dane St		■	■
Beacon St		■	■
Park St		■	■
Somerville Ave		■	■
Cedar St		■	
Prospect St		■	■
Washington Street	■	■	■
Triple Avenue		■	
Open Space			
Foss Park	■	■	
Mystic River Reservation (& Draw 7 Park)	■		■
Alewife Brook Reservation	■		
Glen Street Park		■	■
Lincoln Park		■	■
Perry Park		■	■
Somerville Junction Park		■	
Community Path		■	■
Tufts University Fields		■	
Hodgkins-Curtin Park		■	■
15-25 Cross Street East			■
Perkins Park			■
Symphony Park			■
Florence Playground			■
Harris Playground			■
Palmacci			■
Durrell Playground and Community Garden			■
Conway Park			■
Allen Street Playground			■
Davis Square			■
Kenney Park			■
Minuteman Trail Extension			■

Figure 25: Most Vulnerable Assets

Built Environment

Key Findings

- The Amelia Earhart Dam could be regularly flanked by coastal storm events as early as 2035. This would result in significant coastal flood impacts to the Ten Hills and East Somerville & Assembly Square neighborhoods.
- The Somerville Fire Department Headquarters and Emergency Operations Center and the Police Department Headquarters are currently exposed to precipitation-based flooding impacts and are expected to experience increasing impacts from the 10-year and 100-year storms.
- While there are minimal projected impacts to the hospital and healthcare facilities in Somerville, climate impacts to healthcare facilities in the surrounding communities and increased need for medical care as a result of flooding and rising temperatures could result in increased demand on Somerville's healthcare resources.
- The District Court and District Attorney's Office play regional roles in the Boston metropolitan region and could experience significant impacts from both sea level rise and storm surge as well as precipitation-based flooding.
- Major commuter corridors and key transportation infrastructure, including Routes I-93 and 28, Assembly Square Station, the Commuter Rail, the Orange Line, and the Commuter Rail Maintenance facility in addition to several bike paths and bus stops may be at risk from coastal flooding as early as 2030 and may be significantly impacted by 2070.
- Routes I-93 and 28, Assembly Square Station, Davis Square Station and the proposed Green Line extension and associated stations could experience significant impacts from rainfall events.
- The Mystic Generating Station in Everett, which is critical to the region's electricity supply, along with other energy (5 substations) and fuel facilities, is likely to experience impacts from coastal flooding by 2070.
- Insufficient data exists to make meaningful assessments of the telecommunication system within Somerville or the metro-region as a whole.
- Somerville's combined sewer overflows (CSOs) are susceptible to increased inundation from coastal flood events. Inundation of CSO infrastructure can result in the discharge of raw sewage and present a serious public health risk from pollution of flood waters. There are 18 outfalls that are vulnerable to coastal flooding from sea level rise and storm surge, 4 of which are combined sewer overflows (CSOs), and an additional 5-6 that could be prone to precipitation events, 2 of which are CSOs.

Overview

The built environment analysis focuses on the key physical assets and systems that are important to the community and essential to the critical functionality and daily operations of the City of Somerville and the wider metropolitan region. These assets include municipal buildings and services, such as fire stations, police stations, schools, libraries, cooling centers and other municipally-owned buildings; courthouses; hospitals and other medical facilities; the Amelia Earhart Dam; energy and fuel distribution systems; telecommunications infrastructure; roadways and transit systems; and stormwater infrastructure.

Importance of the Built Environment

While the residents of Somerville are arguably the city's most valuable assets, the built environment is essential to providing public services, supporting the quality of life of Somerville's residents, and defining the character of the city. Municipal facilities allow the city to operate efficiently and effectively and provide needed services to the residents of the city, including public health, public safety, and education resources. Hospitals and medical facilities provide critical healthcare services; transportation systems, including public transit, roadways, and bike paths, provide vital means of mobility; and, telecommunications infrastructure forms the primary platform across which we exchange information and data for business, social, economic, and emergency communication. Together, all of these facilities and systems form the basic services that ensure residents of Somerville maintain a high quality of life. Climate change has the ability to negatively impact these assets and thus, diminish the city's ability to protect the public health, safety, and general welfare of its residents.

Exposure and Vulnerability

In general, the analysis of the built environment did not focus heavily on impacts from rising temperatures. By and large, there is sufficient resilience within major infrastructure (i.e., roadways, rails, energy, telecommunications, water and wastewater systems) to withstand the impacts of extreme heat events. As an example, ambient temperatures often have to exceed 120 degrees Fahrenheit for extended periods of time before asphalt will melt or deform. Buildings and other built infrastructure is usually not significantly impacted; rather, it is the experience of the user that is more negatively impacted by heat impacts, so that is where the focus has been for much of this analysis. However, it is important to note that rising temperatures are expected to increase demand on energy and cooling systems; a substantial increase in demand could cause power outages and blackouts which could have a ripple effect on the built environment, resulting in significant impacts to utility and mechanical systems that facilities rely on to operate.

Figure 26: Aerial View of the Amelia Earhart Dam, Somerville, MA

(Image Credit: MassDOT-FHWA Pilot Project Report)

Amelia Earhart Dam

In terms of flooding from both sea level rise and precipitation events, the Amelia Earhart Dam is of particular concern to the City of Somerville. **The Amelia Earhart Dam could be regularly flanked by coastal storm events as early as 2035. This would result in significant coastal flood impacts to the Ten Hills and East Somerville & Assembly Square neighborhoods.** The dam is located on the Mystic River and plays a critical role in controlling flooding in Somerville and the larger regional area. Before the Dam was constructed, there is evidence of coastal flooding as far back as 1933;[24] the flooding was significant, extending upstream into Malden and Medford.

There is no evidence that the dam has been overtopped or breached since its construction.[25] However, the modeling for this area suggests that the dam may be regularly flanked during 1% annual storm events (100-year storms) as early as 2035, and could be overtopped as early as 2055.[26] Flanking differs from overtopping since it focuses on the flow of water around the edges of the dam, rather than actually overtopping the midsection of the dam. This flanking is expected to exacerbate shorefront (riverine) flooding in the Ten Hills and East Somerville & Assembly Square neighborhoods, resulting in 1 to 2 feet of flooding in those areas. While most of this flooding would be limited to the shorefront, there is a smaller pathway in East Somerville that would extend inland several blocks.

24 Daily Boston Globe, 1933.
25 Personal communication, Kirk Bosma, 12/2016
26 MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery, 2015. https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_Report_MassDOT_FHWA.pdf

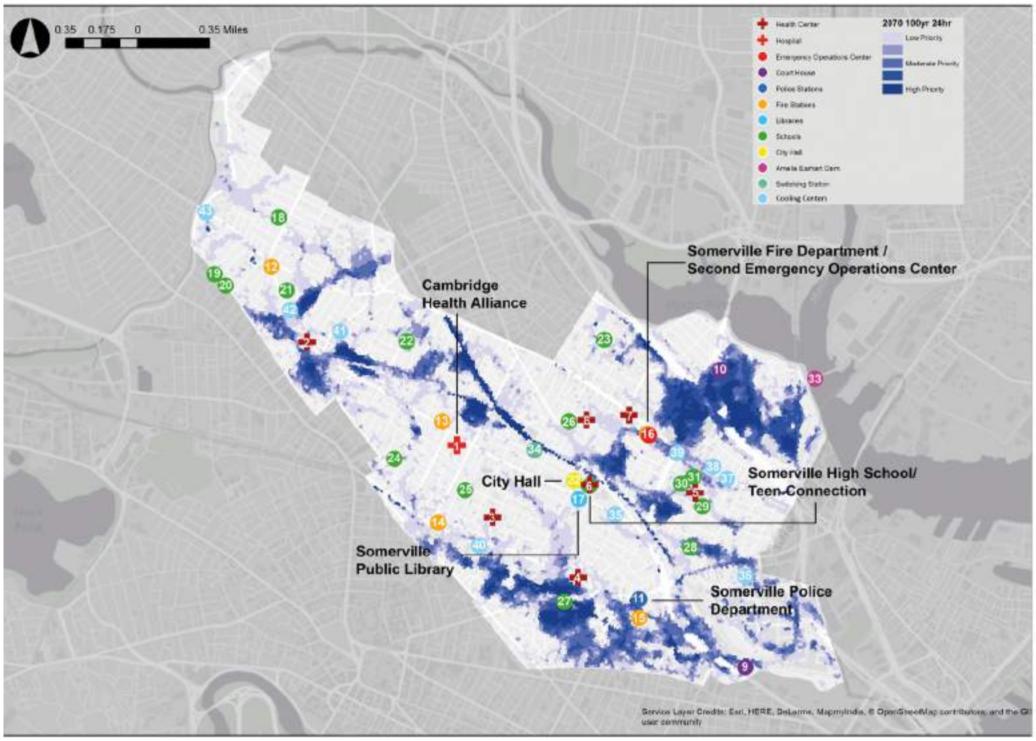


Figure 27: Exposure of Critical Assets to the 100-year 24-hour Precipitation Event in 2070

Hospital	1	Cambridge Health Alliance
Health Center	2	Harvard Vanguard Medical Associates
	3	Central Street Health Center
	4	Health Facility
	5	Health Facility
	6	Teen Connection
	7	Broadway Health Center
	8	Board of Health/Annex
Emergency Operations Center	16	Secondary Emergency Operations Center
Court House	9	District Attorney's Office
	10	Somerville District Court
Police Station	11	Somerville Police Department
Fire Station	12	Somerville Fire Department
	13	Somerville Fire Department
	14	Somerville Fire Department
	15	Somerville Fire Department
	16	Somerville Fire Department
Libraries	17	Somerville Public Library
Schools	6	Somerville High School
	18	West Somerville High School
	19	International School of Boston
	20	Matignon High School
	21	Holland Street Senior Center
	22	Benjamin G Brown School
	23	Arthur D Healey School
	24	John F Kennedy School
	25	St Catherine of Genoa School
	26	Winter Hill Community School
	27	Albert F Argenziano School at Lincoln Park
	28	Capuano Early Childhood Center
	29	East Somerville Community School
	30	Next Wave Junior High School
	31	Full Circle High School
City Hall	32	City Hall
Dam	33	Amelia Earhart Dam
Switching Station	34	Verizon Cental Office
Cooling Center	35-43	Cooling Centers

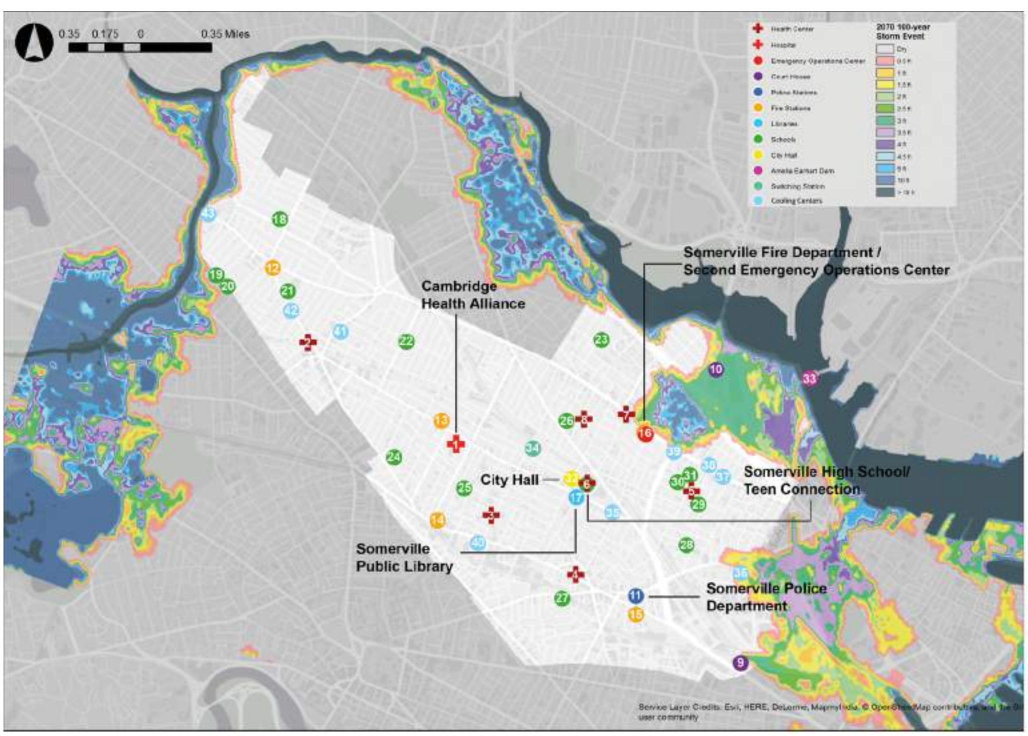


Figure 28: Exposure of Critical Assets to the 100-year Coastal Storm Event in 2070

Hospital	1	Cambridge Health Alliance
Health Center	2	Harvard Vanguard Medical Associates
	3	Central Street Health Center
	4	Health Facility
	5	Health Facility
	6	Teen Connection
	7	Broadway Health Center
	8	Board of Health/Annex
Emergency Operations Center	16	Secondary Emergency Operations Center
Court House	9	District Attorney's Office
	10	Somerville District Court
Police Station	11	Somerville Police Department
Fire Station	12	Somerville Fire Department
	13	Somerville Fire Department
	14	Somerville Fire Department
	15	Somerville Fire Department
	16	Somerville Fire Department
Libraries	17	Somerville Public Library
Schools	6	Somerville High School
	18	West Somerville High School
	19	International School of Boston
	20	Matignon High School
	21	Holland Street Senior Center
	22	Benjamin G Brown School
	23	Arthur D Healey School
	24	John F Kennedy School
	25	St Catherine of Genoa School
	26	Winter Hill Community School
	27	Albert F Argenziano School at Lincoln Park
	28	Capuano Early Childhood Center
	29	East Somerville Community School
	30	Next Wave Junior High School
	31	Full Circle High School
City Hall	32	City Hall
Dam	33	Amelia Earhart Dam
Switching Station	34	Verizon Cental Office
Cooling Center	35-43	Cooling Centers

By 2070 (and as early as 2055), the dam will be overtopped during the 1% annual storm event, resulting in extensive and widespread flooding throughout the area. This flooding will impede freshwater flows from the Mystic River and further exacerbate coastal flooding. Ten Hills and East Somerville & Assembly Square will be significantly impacted by failure of the dam, with flooding depths averaging several feet and as much as 10 feet in some areas during these events. Those volumes could be even greater if the coastal storms were accompanied by significant rainfall.

While the dam is of particular concern to Somerville, it does not fall within Somerville's jurisdiction (it is owned and operated by the Massachusetts Department of Conservation and Recreation (DCR)); however, it plays an important role in regional flood protection and, as a result, several recent climate assessments in the region have raised concerns related to the breach of the dam.

Emergency Services

One of the most important concerns for Somerville, resulting from precipitation flooding, is the inundation of the Somerville Fire Department Headquarters and Emergency Operations Center. In the present day, 10-year, 24-hour storms may impact the facility; exposure will increase for 100-year storms in the present-day and will continue to increase between now and 2070. The extent and frequency of these impacts will increase over time with the potential for precipitation-based flooding to become a nuisance issue, occurring with enough regularity to significantly impact access to the facility on a regular basis. While the facility is not directly impacted by coastal flooding according to modeling projections, flood waters are likely to impact Broadway on both sides of the facility during 100-year storm events in 2070, resulting in access and egress issues. **Similarly, the Police Department Headquarters is currently exposed to precipitation-related flooding impacts and is expected to experience increasing impacts from 10-year and 100-year storms.** The Police Department Headquarters is essential to daily city functions and vital during emergency events. Along with the Fire Department Headquarters and Emergency Operations Center, the Police Department Headquarters has a regional support role, so impacts to the functionality of both facilities would have ramifications beyond Somerville. Loss of police and fire services as well as emergency communication and transportation systems would result in an inability to respond to emergency events and life-threatening impacts from flooding.

Health and Human Services

Hospitals and healthcare facilities are also vital regional resources. **While there are minimal projected impacts to the hospital and healthcare facilities in Somerville, climate impacts to healthcare facilities in the surrounding communities may result in increased demand on Somerville's healthcare resources**. **Flooding impacts along with increasing temperatures and sustained periods of high heat could also place additional demand on Somerville's healthcare services from vulnerable populations in need of medical treatment and cooling services.** The healthcare system should have a plan for accommodating this increased demand. Further exacerbating the problem, **impacts to the transportation system, as a result of significant inundation from both precipitation and coastal flooding, will create challenges for both patients and staff trying to access healthcare services.**

The District Court also plays a regional role in the Boston metropolitan region and could experience significant impacts from both sea level rise and storm surge as well as precipitation flooding. The District Court could experience 2.5-3 feet of coastal flooding by 2070. The District Court is one of 11 district courts in Middlesex County;[27] the court system is already operating beyond capacity, thus, even minor delays caused by either nuisance or extreme flooding could greatly impact the functionality of the over-capacitated system. **Similar concerns exist for temporary interruption of services at the District Attorney's Office, which may be impacted by precipitation and coastal flooding.**

Transportation Systems

Major commuter corridors and key transportation infrastructure may be at risk from coastal flooding as early as 2030 and may be significantly impacted by 2070. Flooding along I-93 and Route 28 could significantly impact Somerville residents as well as commuters that rely on the I-93 and Route 28 corridors for their daily commute. Interstate 93 and Route 28 carry more than 150,000 and 30,000 vehicles per day, respectively.[28] Likewise, various aspects of the public transit system will also be impacted by coastal flooding, including the Orange Line, which services more than 200,000 weekday riders,[29] Assembly Square Station, the Commuter Rail, the Commuter Rail Maintenance Facility, which provides repair and storage services for the MBTA Commuter Rail lines, Sullivan Square Station in Boston, various bus stops, and portions of the city's bike paths. The Commuter Rail Maintenance Facility is a non-redundant asset within MBTA holdings;[30] therefore, if the facility is inundated and damaged, MBTA recovery functions and service could be severely disrupted. As a result of the projected flood impacts to the transportation system in Somerville, the City could be cut off from major transportation routes and essentially isolated for an indefinite amount of time during a major coastal storm event. From the larger regional models, we know that significant flooding south and east of Somerville would effectively block major travel routes into and out of Somerville. By 2070, Somerville could become a temporarily isolated community in the midst of a major coastal flooding event and the transportation system could be significantly impacted by precipitation events between the present-day and 2030.

In addition to coastal flood impacts, **Routes I-93 and 28 are located in high priority areas that could experience impacts from high intensity precipitation events.** While I-93 is an elevated highway, access to the highway occurs at ground level; therefore, vehicles would likely be unable to access the highway during a precipitation event and would have to rely on potentially flooded and likely over-congested local roads. A 100-year coastal flood in 2030 may also cut off access to and from the south, with up to 1 foot of flood waters near exits 28 and 29. By 2070, flooding increases to up to 3.5 feet in this area and access to and from the north could also be constrained by up to 10 feet of flood waters around exit 30. **Assembly Square Station, Davis Square Station, and the proposed Green Line Extension and associated stations could also experience impacts from rainfall events.** Many bus stops and portions of several bike paths are also located in potential priority precipitation inundation areas. Precipitation flooding may impact many of these facilities, particularly in the Assembly

27 Massachusetts Court System: Middlesex County. http://www.mass.gov/courts/court-info/courthouses/courts-middlesex-county-gen.html.

28 MassDOT Transportation Data Management System. https://www.massdot.state.ma.us/highway/TrafficVolumeCounts.aspx.

29 MBTA 2014 Ridership and Service Statistics. http://www.mbta.com/uploadedfiles/documents/2014%20BLUEBOOK%2014th%20Edition(1).pdf.

30 Personal communication, Marybeth Gilbert-Riley, 10/2016.

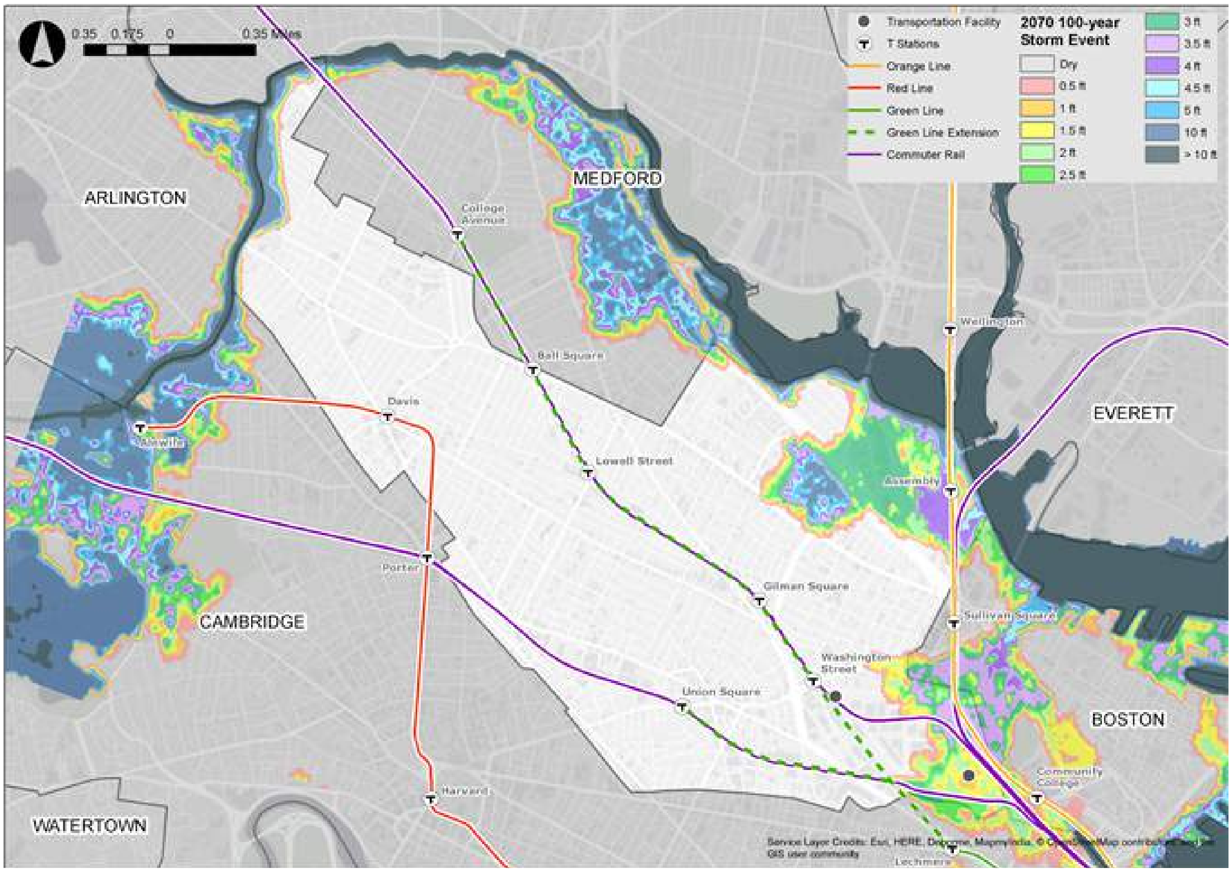


Figure 29: Exposure of the MBTA System to the 100-year Coastal Storm Event in 2070

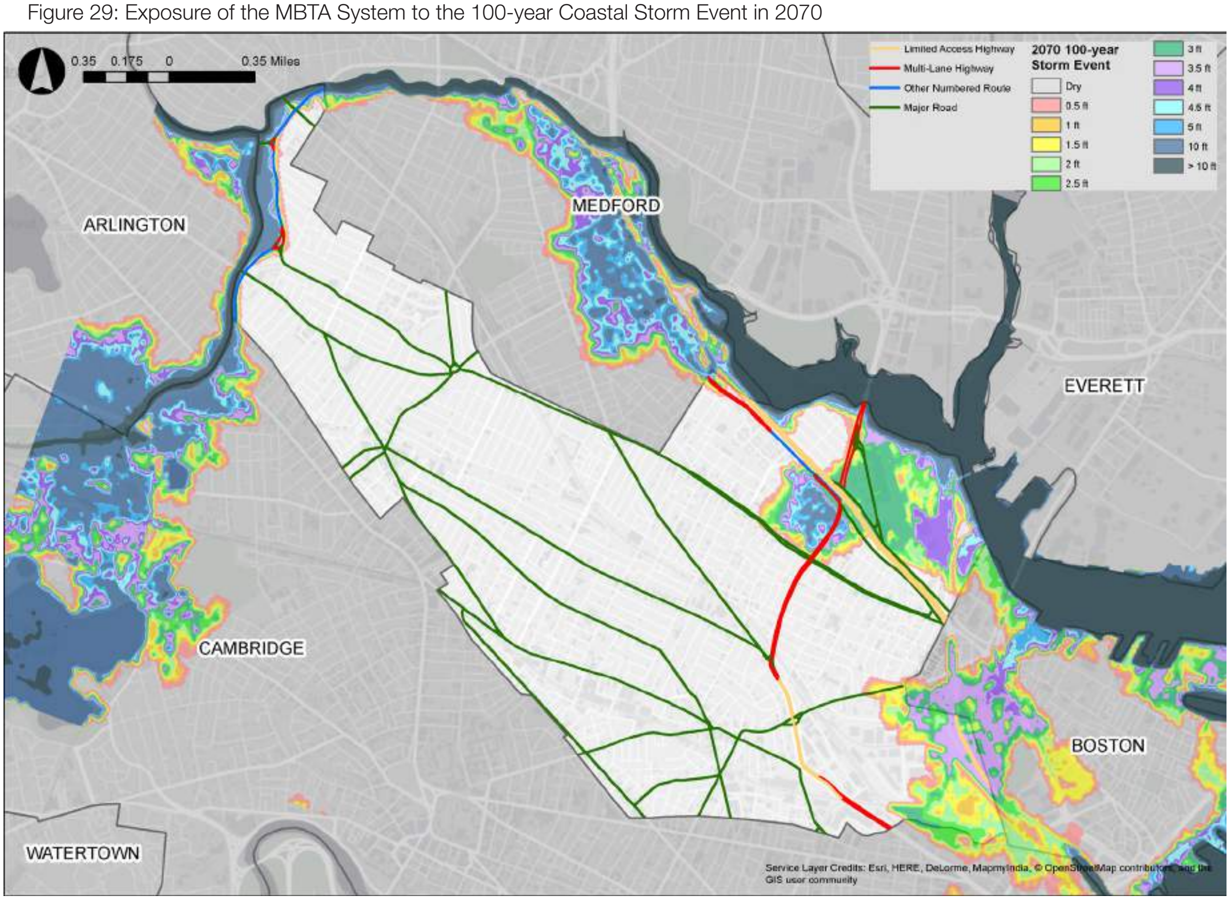


Figure 30: Exposure of Major Roadways to the 100-year Coastal Storm Event in 2070

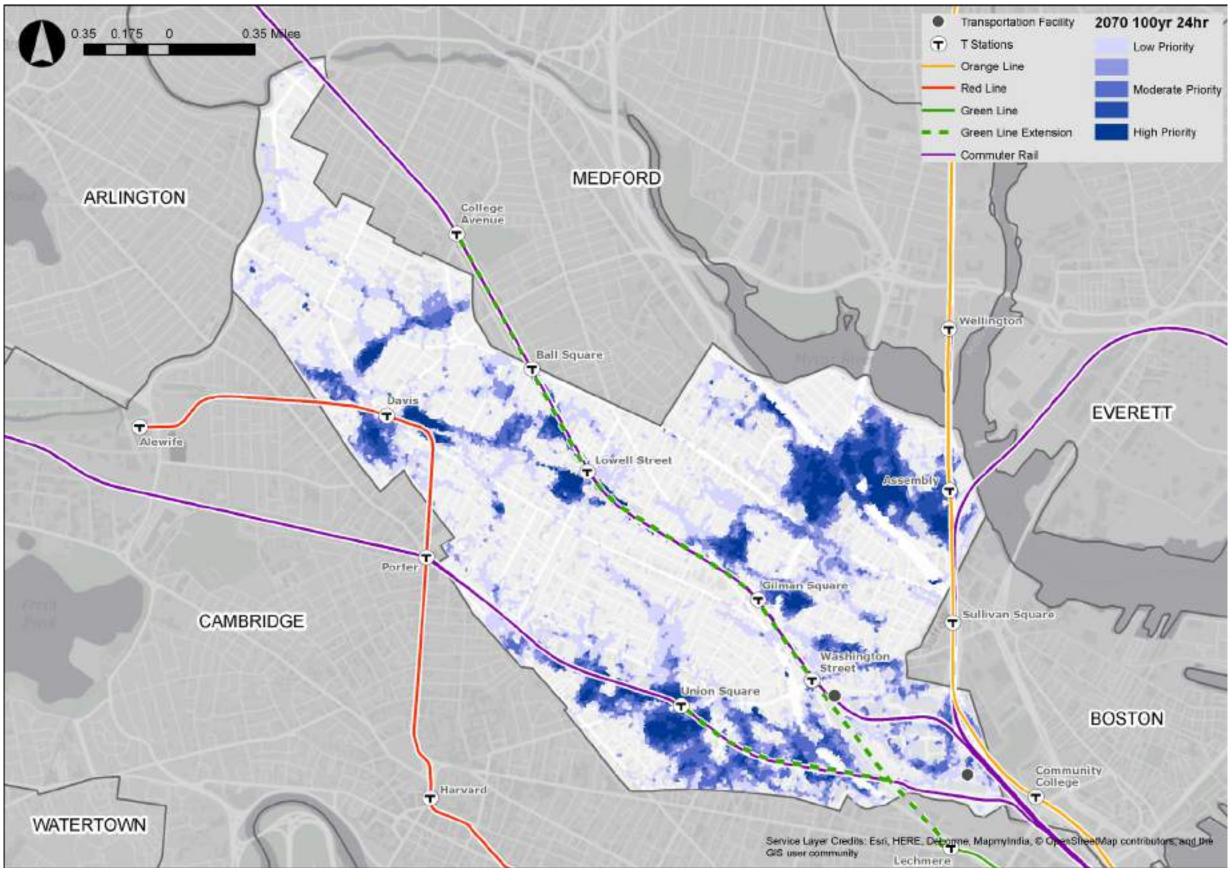


Figure 31: Exposure of the MBTA System to the 100-year 24-hour Precipitation Event in 2070

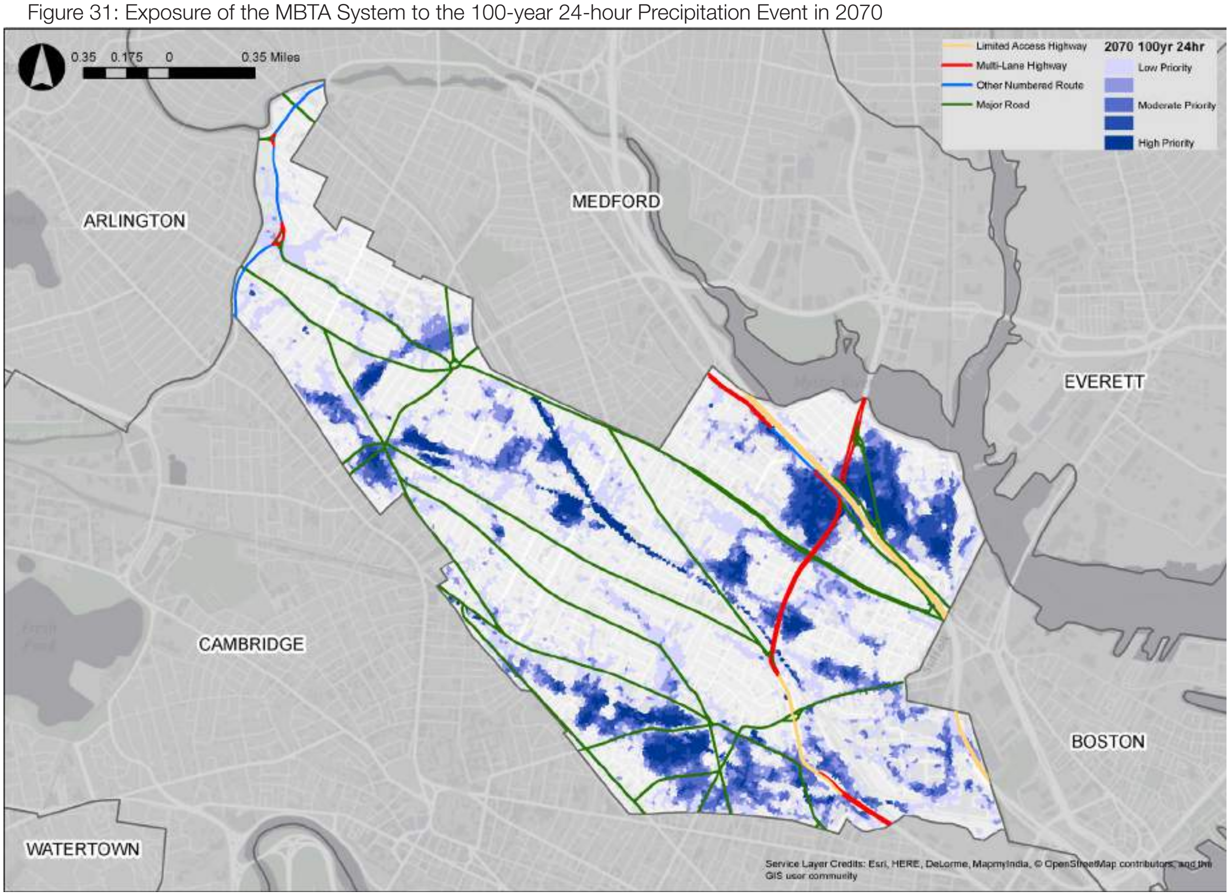


Figure 32: Exposure of Major Roadways to the 100-year 24-hour Precipitation Event in 2070

Square, Davis Square and Union Square areas, with conditions worsening between now and 2070. While most of the public transit stations in Somerville are located above ground, Davis Square Station is underground. The area around this station is projected to experience increasingly severe flooding between now and 2070 during 100-year storm events. Once flooding enters the tunnel at Davis Square Station, it will also travel into other parts of the MBTA system, which could result in significant train delays along the Red Line.

Major bike paths will also experience significant impacts from flooding. Bike paths are important from a mitigation perspective, because they provide alternative transportation to vehicular travel. Therefore, impacts to this system limit Somerville's mitigation efforts by negatively affecting an important mode of non-vehicular travel and might even contribute to a rise in emissions if commuters are forced to use more traditional (and perhaps more circuitous) modes of travel. Given that 7.8% of Somerville's commuter population commutes to work via bike,[31] bike path flooding could have a significant impact on the ability of bike commuters to get to work and to move around reliably throughout the city. This statistic only accounts for Somerville residents who commute via bike, it does not include residents of other cities who commute into Somerville via bike, which would compound the impacts associated with flooding and heat. In addition, flooding of the bike paths could cause cascading impacts to the transit system, as ridership would likely increase if bike paths were rendered unusable. Disruptions to the bike network during an emergency event could have impacts on regional commuters who do not normally bike, but may rely on biking when other modes of travel are impacted by flooding; following Superstorm Sandy, the New York City Department of Transportation estimated that the number of cyclist increased by nearly three times.[32]

Bike lanes along Somerville Avenue, Beacon Street and Washington Street are also located in areas with increased urban heat island (UHI) factors that also have irregular patterns of street trees, leaving sections of roadway unshaded and thus, decreasing the usability of the bike paths and increasing public transit ridership.

Heat will also impact the user experience of the transit system. Bus stops along Beacon Street, Washington Street, Somerville Avenue, Broadway and Pearl Street will be exposed to the highest heat conditions. In many cases, bus stops are open air and do not provide shade or cooling features. Depending on bus route frequency and reliability, this can result in prolonged exposure of the user to high temperatures and direct sun.

Sustained periods of high heat can also impact transportation infrastructure, including warping of pavement and impacts to rails, although that level of impact is not anticipated in Somerville. During periods of high temperatures, the MBTA system, which is the state's largest consumer of electricity, is vulnerable to power loss, blackouts and related disruptions due to increased loads on energy infrastructure from excessive energy demand from the use of air conditioning.

Energy Resources

Further contributing to the potential for blackouts and power outages, **the Mystic Generating Station in Everett, which is critical to the region's electricity supply, along with other energy (5 substations) and fuel facilities, is likely to experience impacts from coastal flooding by 2070.** While the Mystic Generating Station is a key asset within the larger regional energy supply, there is sufficient redundancy at

31 Somerville #1 in N.E., #5 in Nation for Bike Commuting. http://www.somervillema.gov/news/somerville-1-ne-5-nation-bike-commuting.

32 Transportation During and After Hurricane Sandy, 2012. http://wagner.nyu.edu/files/rudincenter/sandytransportation.pdf.

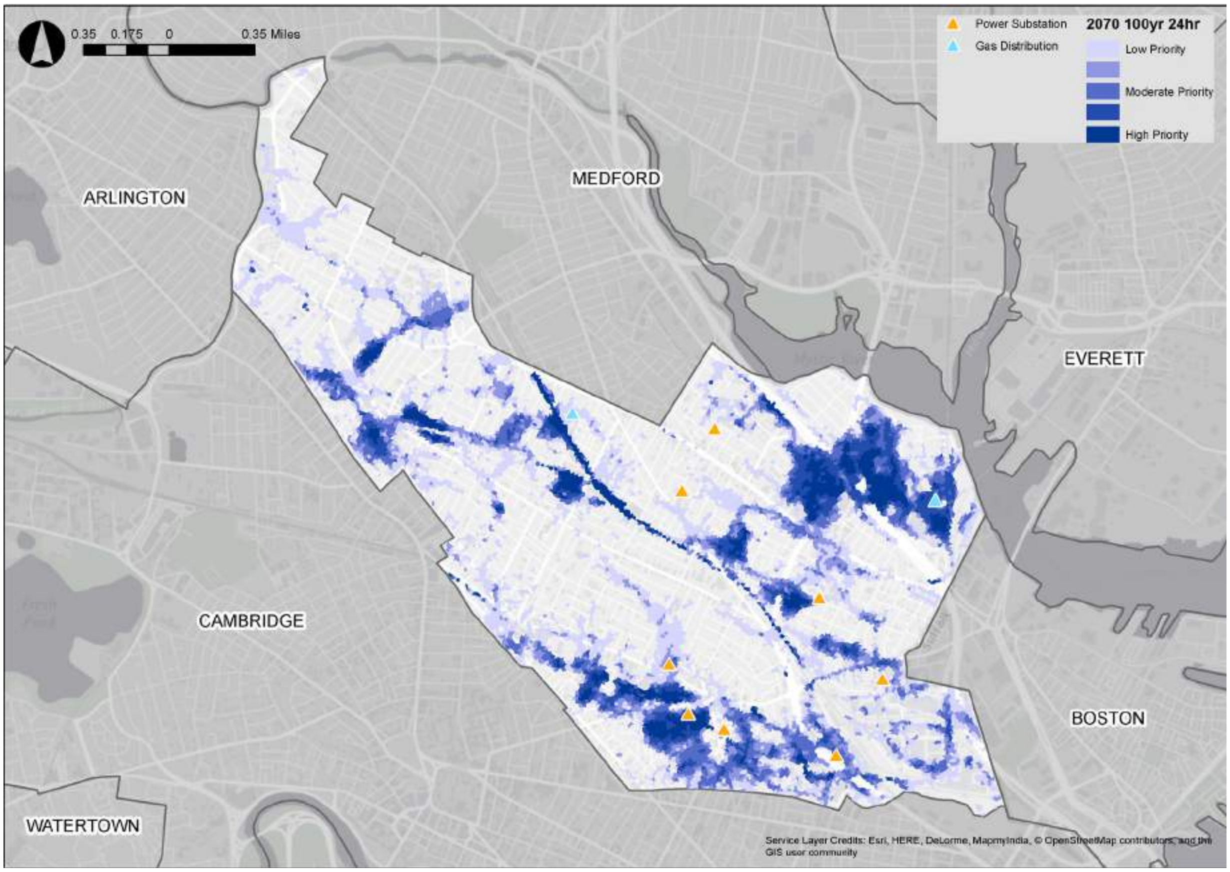


Figure 33: Exposure of Energy and Fuel Resources to the 100-year 24-hour Precipitation Event in 2070

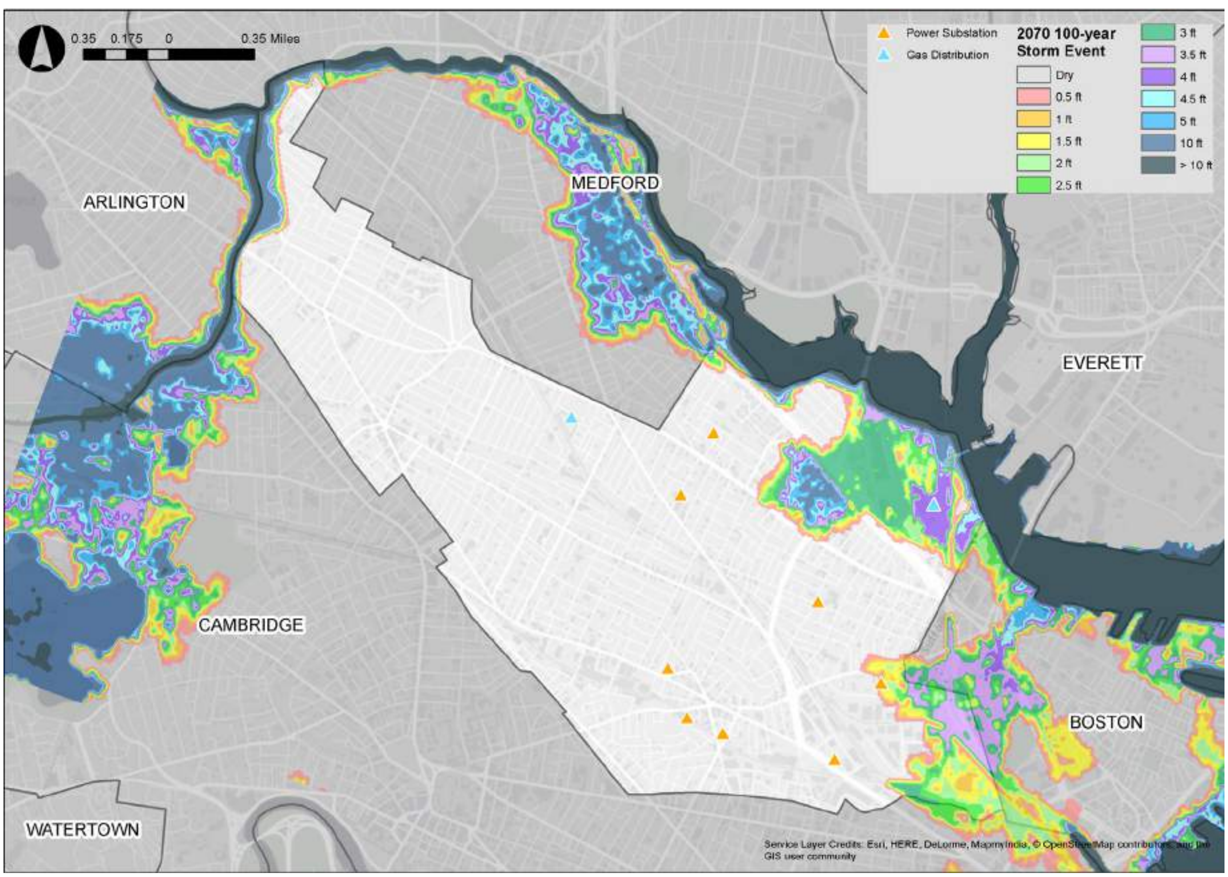


Figure 34: Exposure of Energy and Fuel Resources to the 100-year Coastal Storm Event in 2070

CASE STUDY:

Telecommunications Impacts during Superstorm Sandy

New York City, NY

Image Credit: http://www.nyc.gov/html/sirr/downloads/pdf/final_report/Ch_1_SandyImpacts_FINAL_singles.pdf

During Superstorm Sandy, the telecommunications systems were directly impacted by flooding events as well as related power outages. In the immediate aftermath of Sandy, as many as 1 million customers in New York City were impacted. In some areas, those impacts lasted 11 weeks and, in rare cases, some customers remained without service for more than 100 days. The more modern and hardened facilities fared better than their counterparts during this extreme storm event.

a regional level to provide continuous power if the Mystic Generating Station were impacted by a coastal flood event. Although there is sufficient redundancy for smaller flood events, larger and more regional events, such as what was experienced during Superstorm Sandy and regional heat waves, might sufficiently stress the overall system in a way that challenges that redundancy.

While the Mystic Generating Station is responsible for generation, the substations are key to the overall distribution of that electricity to homes and businesses. These substations reduce the voltage of the power traveling from the generating facilities to voltage levels that are consumable for individual buildings. Due to the direct exposure of transformer and transmission utilities during flooding events, explosions and fires are possible, which are dangerous and can be crippling to the distribution network if they are not contained. During Superstorm Sandy in New York City, a critical substaion was flooded with water traveling to the station through conduits, indicating the importance of flood protection for the facility as well as the transmission lines.

Although energy systems are often managed by third-party providers, the City should work with private providers and their regulators at the Public Utilities Commission (PUC) and Independent System Operators (ISO) to encourage resilient design and retrofitting for critical substations and energy facilities. The resilience of energy systems became a critical issue in New York City during Superstorm Sandy; exposed vulnerabilities included inadequacy of on-site back-up supplies, local shortages tied to a reliance on "just-in-time" deliveries, an inability to reach refueling and delivery destinations, and a lack of pre-arranged agreements on prioritization with respect to deliveries in emergency situations. Similar issues could affect Somerville during these types of events.

Telecommunications

Of similar importance to the regional electrical supply, telecommunications infrastructure provides critical daily services to the residents of Somerville and is essential during an emergency event; however, **insufficient data exists to make meaningful assessments of the telecommunication system within Somerville or the metro-region as a whole.** There is physical and geographic redundancy in cell tower sites throughout central Boston, however, further exploration is needed to understand if that provides sufficient capacity for current and projected growth and likewise to see if similar conditions exist in and around Somerville. Redundancy is a critical need during climate events and additional study into the overall capacity, carrier distribution and connections to the supporting utilities (specifically the back-up sources needed to power the towers) would be needed to provide a more accurate assessment of overall adaptive capacity. Within Somerville, the Verizon Switching Station has the potential to be impacted by precipitation flooding. However, further collaboration and discussion with Verizon is needed to determine the extent of the switching station's criticality and exposure. Given the experiences of New York City during Superstorm Sandy, there is reason for further study on the impact of climate change on telecommunications in Somerville.

Stormwater Infrastructure

Because the citywide inland flood modeling does not take into account the capacity of the city's drainage infrastructure, additional modeling and analysis is needed to understand whether the existing stormwater system is capable of accommodating for the anticipated frequency and intensity of future rainfall events. However, impacts from sea level rise and storm surge can result in loss of drainage capacity and increased inland flooding. This may be compounded by the fact that **Somerville's combined**

sewer overflows (CSOs) are susceptible to increased inundation from coastal flood events. Inundation of CSO infrastructure can result in the discharge of raw sewage and present a serious public health risk from pollution of flood waters.

There are 18 outfalls that are vulnerable to coastal flooding from sea level rise and storm surge, four of which are combined sewer overflows (CSOs), and an additional five to six outfalls that could be prone to precipitation events, two of which are CSOs. Similar impacts to what occurred in New York and New Jersey during Superstorm Sandy could affect the stormwater infrastructure in Somerville during extreme flood events. For example, the Passaic Valley released billions of gallons of raw and partially treated sewage to Upper New York Bay.

Damage to the pumping system could also be costly. The MWRA Sewer Pumping Station may also be vulnerable to impacts from coastal flooding. Flooding at the sewer pumping station may impact the electrical supply systems of the pumping station, disrupting pumping operations and resulting in sewage backup and flooding for areas served by the pumping station. This backup could include sewage backup into buildings. However, MWRA is currently rehabilitating the Alewife Sewer Pumping Station to adapt to climate change. The rehabilitation work at Alewife is being done to sustain flood levels of up to 2.5 feet above the 100-year flood elevation. MWRA is also upgrading the generation systems. The City of Somerville is also completing a similar assessment of the outfalls in Union Square in addition to performing an intensive stormwater modeling study for the Union Square area.

Social Vulnerability

Key Findings

- Vulnerable populations, including the elderly, disabled, children, low-income residents, residents with low educational attainment, and residents with limited English proficiency, are often disproportionately impacted by weather events and, therefore, need greater municipal support and resources to cope with the impacts of climate change.
- Ward Two & Inner Belt and East Somerville & Assembly Square are two of the neighborhoods with the highest levels of social vulnerability; these neighborhoods also have the highest concentration of urban heat island (UHI) factors, which are likely to exacerbate the heat exposure in these areas.
- Somerville has several major highways and commuter corridors crossing through its borders; these major traffic corridors are largely located in two of Somerville's most socially vulnerable neighborhoods, East Somerville & Assembly Square and Ward Two & Inner Belt.
- The area around Foss Park in the Ten Hills neighborhood, and on the border of East Somerville & Assembly Square, experiences the worst and widest exposure to precipitation, impacting vulnerable populations who live, work and rely on services in the area.
- Support services in Ten Hills, West Somerville, Assembly Square and Ward Two & Inner Belt are vulnerable to flood impacts that would negatively impact the vulnerable populations that rely on these services, including childcare facilities, elderly and public housing facilities, food resources, and religious centers.
- Reliance on public transportation, walking, and biking results in longer periods of physical exertion and heat exposure that will disproportionately affect vulnerable populations.
- Because air pollution increases as heat increases, climate change is expected to exacerbate existing air quality issues and create new air quality concerns for Somerville, including more severe allergy seasons and increasingly serious mold problems as a result of flooding.
- The current climate projections for Somerville call for both a warmer and wetter environment in the coming years. This change in conditions provides an attractive habitat to potential diseases carriers, such as mosquitos and ticks, leading to an increase in the transmission of diseases, such as Eastern Equine Encephalitis (EEE), Zika, West Nile Virus, Dengue Fever, and Lyme Disease.

Overview

The social vulnerability analysis focuses on the vulnerability of certain populations to climate stressors and disaster events. Certain demographic groups may be more vulnerable to these impacts due to a diminished adaptive capacity and ability to cope physically, mentally, and financially with environmental stressors. In addition to sudden shocks from climate events, vulnerable populations are also at risk from the longer-term, chronic stresses of climate change.

To understand the social vulnerability in Somerville, demographic data was used as a proxy for social indicators of sensitivity and adaptive capacity to climate stressors. These indicators were chosen based on public health industry standards for community determinants of heat vulnerability. Sensitivity indicators include age (over 65 and under 5) and poverty. Children and elderly individuals are more sensitive, physiologically, to extreme temperatures and lower income individuals often have less access to regular healthcare services, which results in preexisting health conditions that increase sensitivity to climate impacts.[33] Adaptive capacity indicators include educational attainment, language isolation, income, and living circumstances of the elderly. People with poor adaptive capacity may be less able to move out of harm's way during extreme weather, are likely to have fewer resources to adapt their homes to withstand flooding and extreme heat, are likely to be more dependent on public transportation and other public resources, and may have fewer resources to draw on in the case of an emergency. Statistically, race is highly correlated with lower income levels, higher poverty, and lower levels of education; due to that high correlation, we did not look at race as a separate indicator in our analysis of vulnerable populations. However, it is important to note that race and ethnicity are meaningful indicators of vulnerable populations and should be considered when developing adaptation actions. **Overall, social determinants of health lead to serious health disparities, which are expected to be amplified by climate change;[34,35] therefore, vulnerable populations will likely need greater municipal support and resources during extreme weather events.** Some of the vulnerabilities of these various groups are detailed below.

Elderly

Elderly individuals often have greater physical limitations during a climate event. These limitations include higher overall health vulnerability, such as greater susceptibility to heat disease and extreme heat and impacts from poor air quality and vector-borne diseases, among other illnesses. As a result of some of these vulnerabilities, older individuals – across all income brackets – have a greater reliance on support services, including senior centers and cooling centers during high heat events. Elderly residents that live alone may be more socially isolated and lack reliable access to transportation, which can make it more difficult for them to access support services or evacuate during emergency events. The City of Somerville currently provides transportation to seniors and disabled residents for daily needs as well as during storm events and high heat days; climate change is likely to increase demand from the city for these types of services as these events become more frequent.

Children

Similar to older adults, children often have greater physical limitations during a climate event and higher overall health vulnerability; they are more vulnerable to extreme heat, poor air quality, and vector-borne diseases. Children are also less self-sufficient, more reliant on adults for transportation and other needs, and less likely to cope emotionally during a disaster or climate event. In addition, impacts to children often have a ripple effect on families and the economy. If school is closed or daycares are unable to function, parents often need to find alternative childcare options, which may impact the ability of parents to go to work and therefore, impact the family's income as well as the productivity of the business where those parents are employed.

Income and Education

Poverty and educational attainment are closely correlated to one another and both factors contribute to public health, opportunities, and economic stability.[36] People with fewer years of education and lower incomes are more likely to be in worse health

33 Mapping Community Determinants of Heat Vulnerability, 2009. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2801183/

34 Healthy People 2020: Social Determinants of Health, 2014. https://www.healthypeople.gov/2020/topics-objectives/topic/social-determinants-of-health

35 The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment, 2016. https://health2016.globalchange.gov/downloads

36 Bureau of Labor Statistics: Employment Projects, 2015. https://www.bls.gov/emp/ep_chart_001.htm

Social Determinants of Health:

The social determinants of health are factors that shape one's health, such as employment and economic opportunity, educations, community and social interactions, access and quality of health care, quality of housing, and neighborhood resources. These factors along with personal choices and physical determinants, like exposure to pollution or extreme heat, interact to influence a person's overall health. Social determinants of health lead to serious health disparities, which are expected to be amplified by climate change. Improving the social determinants of health, such as reducing discrimination and increasing economic opportunity, will subsequently improve the adaptive capacity of vulnerable populations to climate stressors.

and have fewer economic opportunities.[37,38] These factors limit the adaptive capacity of individuals to respond to climate events and may be indicators of preexisting medical conditions that could be exacerbated by climate impacts. Residents with lower incomes often have additional challenges preparing for and recovering from extreme weather events that may be amplified by climate change. In many cases, financial constraints add additional stresses to existing vulnerabilities, such as age or existing health conditions. Lack of financial resources often translates to a lack of preparedness; lower income populations are less likely to have insurance, less likely to have access to air conditioning or other cooling options, more likely to live in areas of high vulnerability to flooding and other environmental justice concerns, and more likely to occupy rental properties, which affords them less control over the implementation of preparedness measures on their properties.[39] In Somerville, for example, some families without access to air conditioning rely on the Senior Centers and cooling centers during high heat days. In addition, lower-income populations nationwide typically have a higher reliance on public transportation, which may impact evacuation efforts during a disaster event.[40] Finally, lower income populations often experience increased difficulty in recovering from disaster due to financial constraints and lack of control of repairs to their rental properties.

Limited English Proficiency

Individuals with limited English proficiency experience a unique set of vulnerabilities during a climate event. Limited English proficiency can often result in greater social isolation, which presents significant communication challenges. People with limited understanding of English may be unaware of evacuation warnings and other crucial information and often have difficulty communicating with emergency response personnel and other individuals providing support services. In some cases, people with limited English proficiency may not be of legal status in the United States and therefore, reluctant to use available government support services. Somerville has a number of translators and services to assist immigrants with limited English proficiency; climate change impacts are likely to increase reliance on these services.

Importance of the Social Environment

The social environment assessment focuses on personal characteristics that exacerbate vulnerability during a climate or disaster event; however, although non-vulnerable populations are often more prepared for and have a better adaptive capacity during a climate event, it is important to note that these populations are also susceptible to many of these identified climate vulnerabilities. In many ways, understanding the impact of climate change on the social environment is the most important aspect of this analysis. Protecting and maintaining the quality of life of its residents is of the utmost concern to Somerville and this climate change vulnerability assessment was undertaken with the understanding that the residents of Somerville

An **urban heat island (UHI)** is a phenomenon where an area is significantly warmer than adjacent areas due to how much heat is being absorbed, produced or shed in that immediate area. Urban heat island effects are often associated with high density development and lack of vegetated green space.

37 Exploring the Social Determinants of Health: Education and Health, 2011. http://www.rwjf.org/content/dam/farm/reports/issue_briefs/2011/rwjf70447

38 Exploring the Social Determinants of Health: Income, Wealth, and Health, 2011. http://www.rwjf.org/content/dam/farm/reports/issue_briefs/2011/rwjf70448

39 Social Vulnerability and Climate Change: Synthesis of Literature, 2011. https://www.fs.fed.us/pnw/pubs/pnw_gtr838.pdf

40 According to the American Community Survey, 2015, approximately 6.9% of the population is below 100% of the poverty level, but 11.4% of people who rely on public transportation to get to work are below 100% of the poverty level. Additional information can be found here: American Community Survey, 2015. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

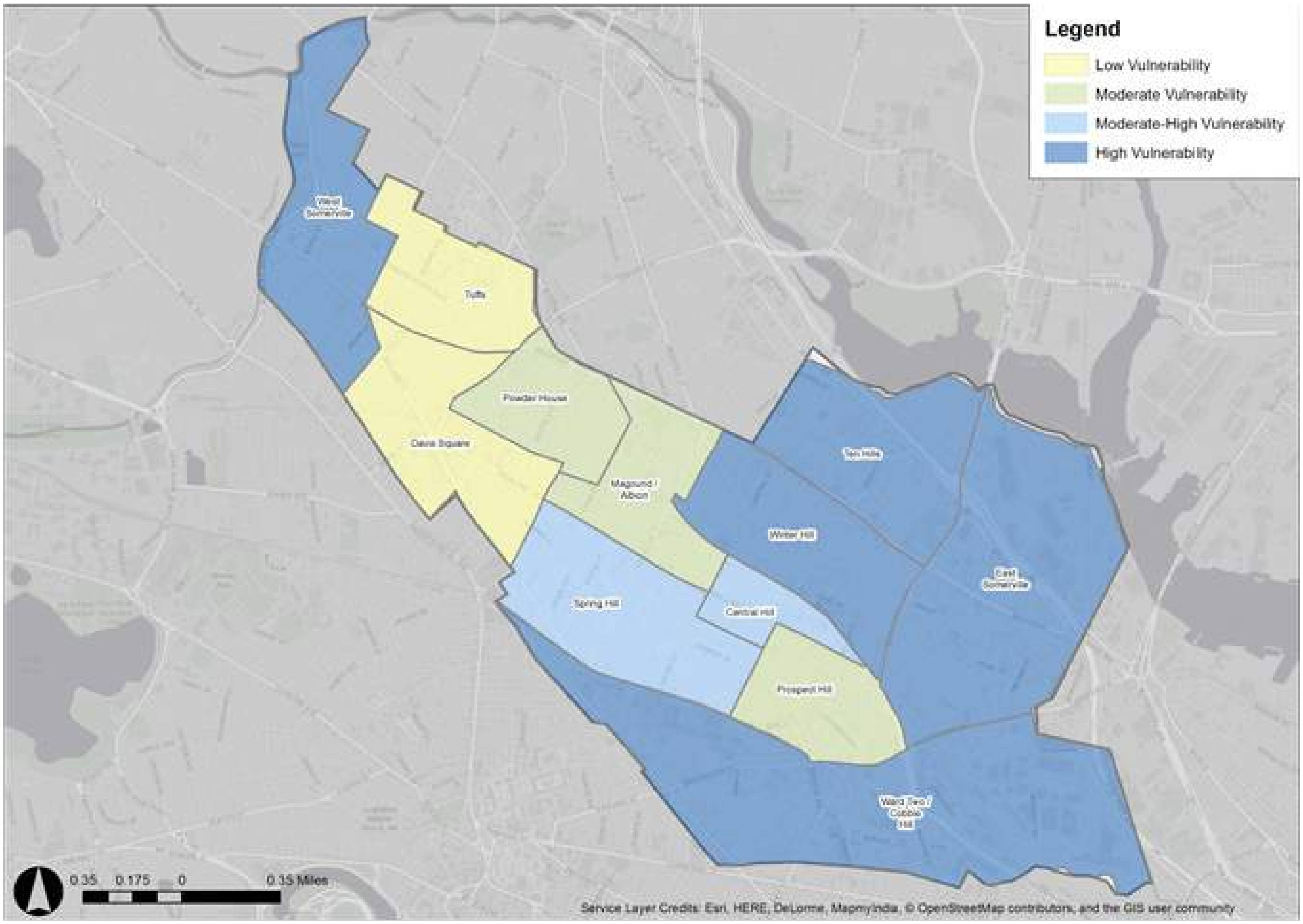


Figure 35: Concentration of Vulnerable Populations by Neighborhood

are Somerville's most important asset. All adaptation and mitigation efforts undertaken by the city are ultimately geared at protecting Somerville residents from the negative impacts to their health and their quality of life that may result from a changing climate.

Exposure and Vulnerability

Somerville's population is largely exposed to impacts from all three climate factors – sea level rise and storm surge, precipitation, and heat. That exposure is likely to be exacerbated amongst vulnerable populations. Figure 35 displays a high-level overview of the concentrations of vulnerable populations, by neighborhood, in Somerville. While it is important to understand the neighborhoods with increased social vulnerability, it is equally important to understand that social vulnerability is not always geographically focused. Individuals in neighborhoods with lower concentrations of social vulnerability may experience similar levels of vulnerability to individuals in neighborhoods with higher concentrations.

Extreme heat is of particular importance when assessing the vulnerability of vulnerable populations. While temperatures are expected to increase over time across Somerville, urban heat island (UHI) factors have the potential to either exacerbate or mitigate some

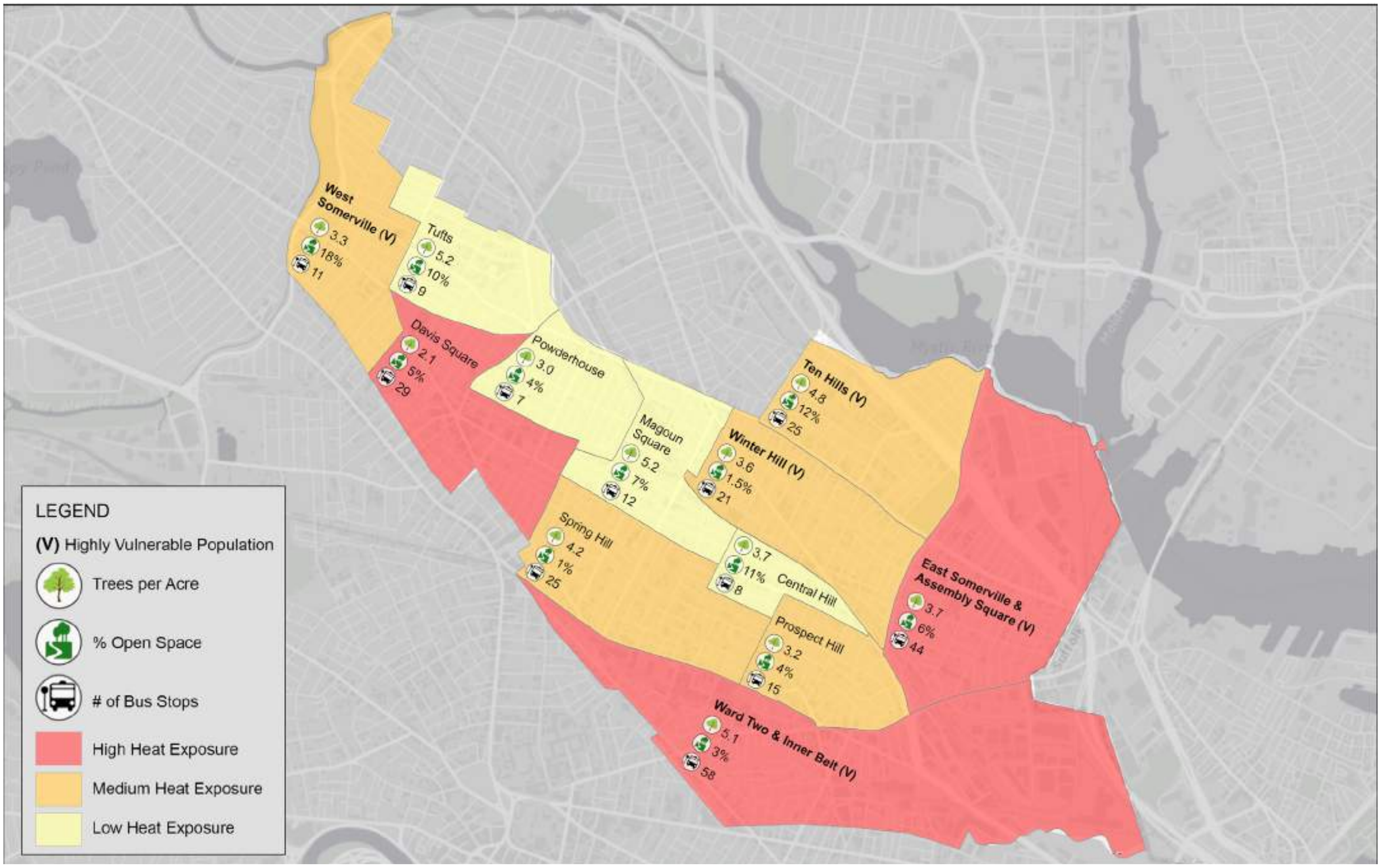


Figure 36: Urban Heat Island Exposure with Additional Attributes that May Alleviate Urban Heat Island Effect

of those heat impacts. **In Somerville, some of the neighborhoods that exhibit greater presence of UHI factors are also home to higher concentrations of socially vulnerable populations.** Figure 36 shows the outdoor heat exposure with additional statistics on attributes that could alleviate the UHI effect in each neighborhood.

From a neighborhood perspective, **Ward Two & Inner Belt and East Somerville & Assembly Square are two of the neighborhoods with the highest levels of social vulnerability** in Somerville. This vulnerability is compounded by the fact that **these neighborhoods also have the highest concentration of urban heat island (UHI) factors, which are likely to exacerbate the heat exposure in these areas.** In the neighborhoods identified as high levels of social vulnerability and high heat exposure, there are six water features or cooling centers. However, these locations are concentrated toward the center of Somerville, leaving longer walking distances for those residents living on the periphery. As population density increases around Union Square and Assembly Square, the need for more shade, cooling centers and water features may arise. In addition, accessibility and walkability analysis may be needed to ensure vulnerable residents can safely access existing and future cooling centers in a reasonable amount of time.

Of particular note, almost 40% of the city's bus stops are located in Ward Two & Inner Belt and East Somerville & Assembly Square. Heat exposure while waiting for buses on high heat days will disproportionately affect vulnerable residents, and this may be exacerbated if tree cover is decreased due to tree mortality related to climate change. Heat exposure is exacerbated at bus stops that do not have shelters.

One of the factors that contributes to UHI effects is the presence of highways and major commuter corridors that increase air quality concerns from higher levels of motor vehicle emissions. **Somerville has several major highways and commuter corridors crossing through its borders; these major traffic corridors are largely located in two of Somerville's most socially vulnerable neighborhoods, East Somerville & Assembly Square and Ward Two & Inner Belt.** This concentration of congestion adds an additional environmental justice concern, where lower-income and socially-isolated residents are disproportionately impacted. **Vulnerable populations often live in more climate vulnerable areas; therefore, the populations least able to cope with climate stressors are often the most affected.**

The area around Foss Park in the Ten Hills neighborhood, on the border of East Somerville & Assembly Square, experiences the worst and widest exposure to precipitation, impacting vulnerable populations who live, work and rely on services in the area. Other notable areas of exposure to flooding from precipitation include Washington Street in Ward Two & Inner Belt, and along the Commuter Rail corridor and adjacent properties, including the Pearl Street Park elderly housing facility in Winter Hill. Residents who rely on child care services around Foss Park may not be able to use these services as two child care centers are projected to experience up to three feet of coastal flood inundation by 2070. This can result in loss of income for parents who are unable to return to work. In addition, the two food centers in the immediate areas of Assembly Square and Foss Park are within projected coastal flood inundation areas of up to two feet and up to 10 feet, respectively.

Further compounding the exposure of the vulnerable populations, areas of Somerville along the Mystic River are the most exposed to inundation from sea level rise and storm surge during 100-year events in 2070. Exposed residential areas include Ten Hills (northeast of I-93 up to 1.5 feet and southwest of I-93 up to 10 feet), Assembly Square (up to four feet), areas of West Somerville along the Mystic River, and in the eastern section of Ward Two & Inner Belt (up to 3.5 feet). **Support services in these areas, including childcare, elderly and public housing facilities, food resources, and religious centers are vulnerable to flood impacts that would negatively impact the vulnerable populations that rely on these services.** There are nine elderly and public housing facilities vulnerable to flooding from sea level rise and 14 from precipitation impacts. In particular, elderly housing properties on Jacques Street and Washington Street are exposed to up to one foot and 2.5 feet of inundation, respectively. Cobble Hill Apartments on Washington Street is right on the edge of the projected inundation areas. Clarendon Hill Towers, along Broadway in West Somerville, provides public and elderly housing services and is projected to experience up to one foot of inundation. Residents in these neighborhoods also experience a higher degree of social vulnerability. Additional impacts include six schools vulnerable to precipitation events, three childcare services vulnerable to flooding from sea level rise and 13 from precipitation, six grocery stores/food resources vulnerable to flooding from sea level rise and 11 from precipitation, two religious centers impacted by flooding from sea level rise and 13 from precipitation. Religious centers are often the "first responders" for providing needed services to the public, including food and shelter for the homeless, mental health services, support groups, and refuge, shelter, and basic support during a disaster event. Impacts to these religious centers may have detrimental impacts on vulnerable populations and may also increase demand on municipal support services.

Environmental justice is the fair treatment and involvement of all people regardless of status, ability, race, and gender, with respect to environmental regulation and action.

Several vulnerable populations support services are vulnerable to sea level rise and storm surge, including 9 elderly and public housing facilities, 3 childcare centers, 6 grocery stores/food resources, and 2 religious centers. Similarly, facilities impacted by precipitation events could include 14 elderly and public housing facilities, 6 schools, 13 childcare centers, 11 grocery stores/food resources, and 13 religious centers.

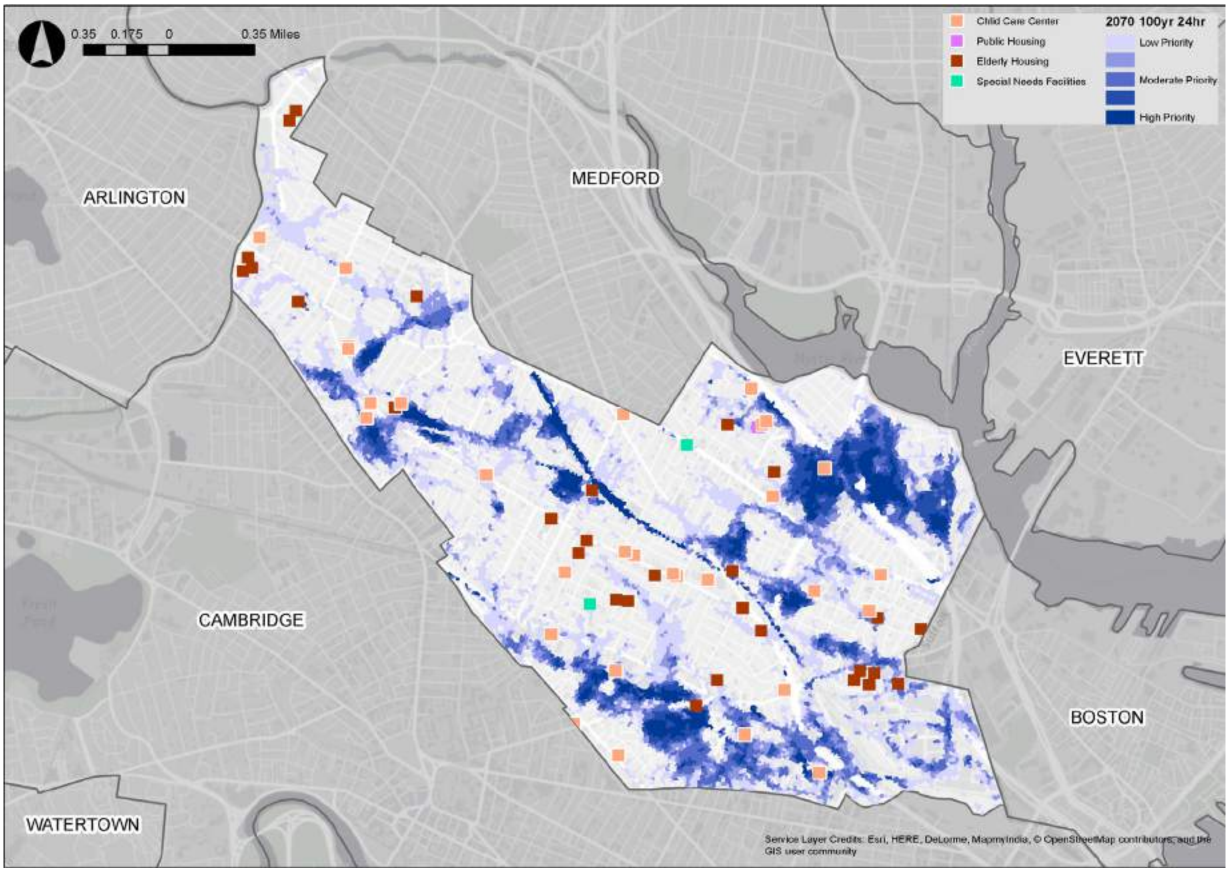


Figure 37: Exposure of Vulnerable Population Support Services to the 100-year 24-hour Precipitation Event in 2070

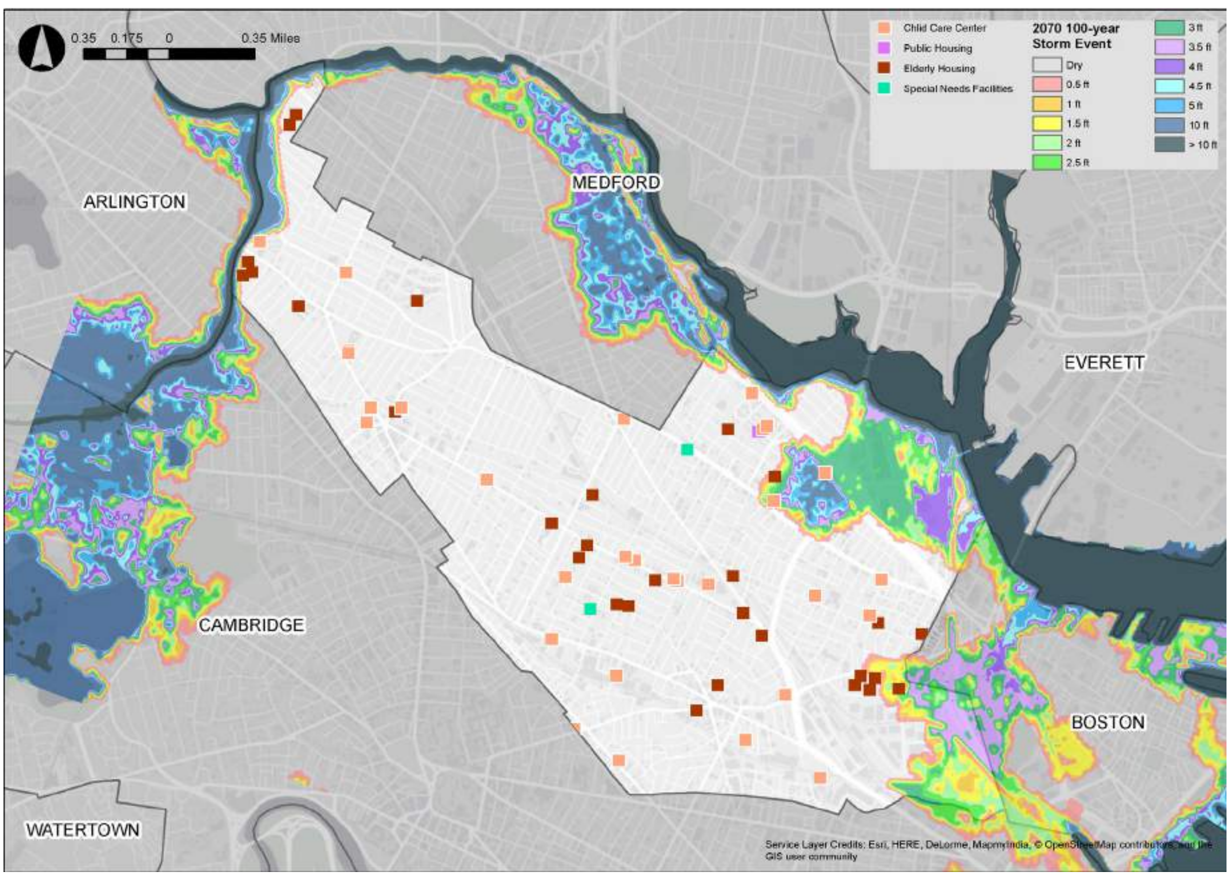


Figure 38: Exposure of Vulnerable Population Support Services to the 100-year Coastal Storm Event in 2070

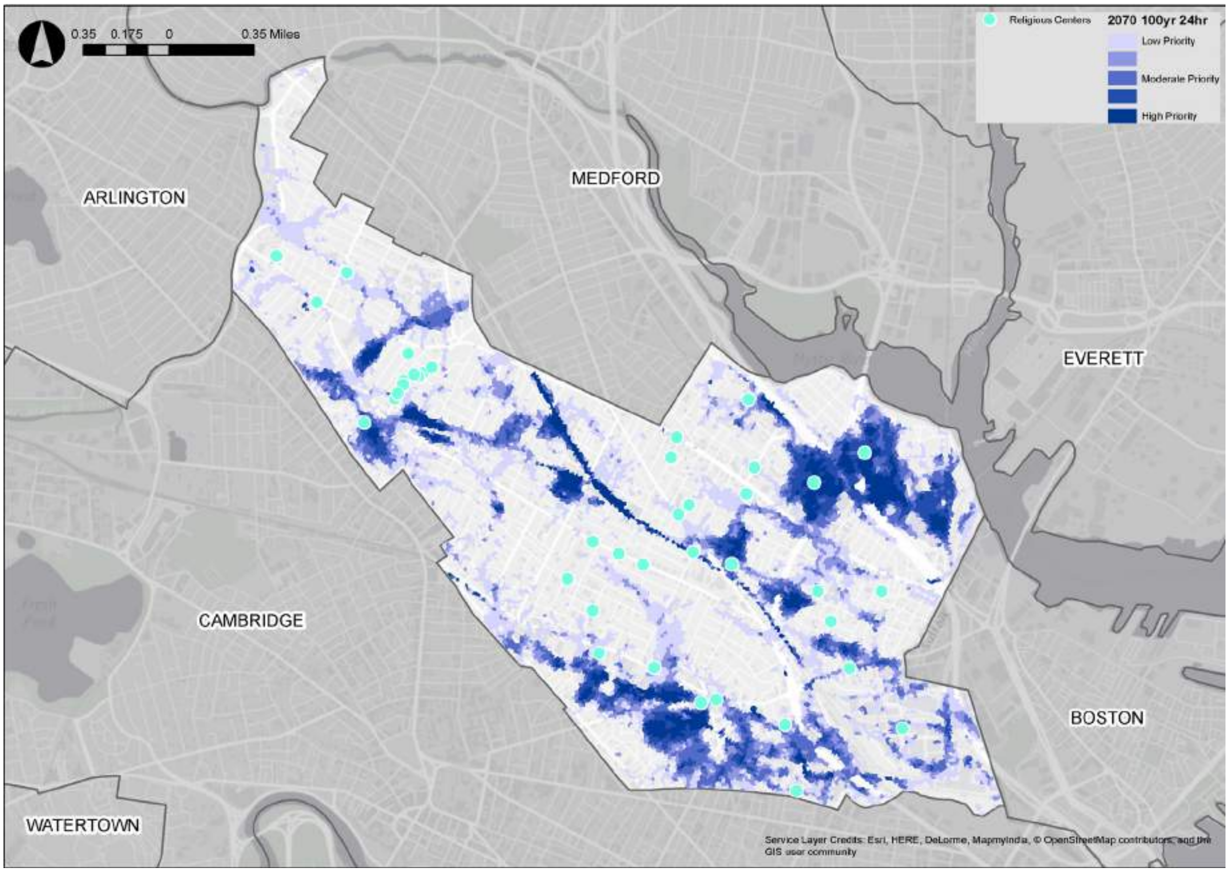


Figure 39: Exposure of Religious Centers to the 100-year 24-hour Precipitation Event in 2070

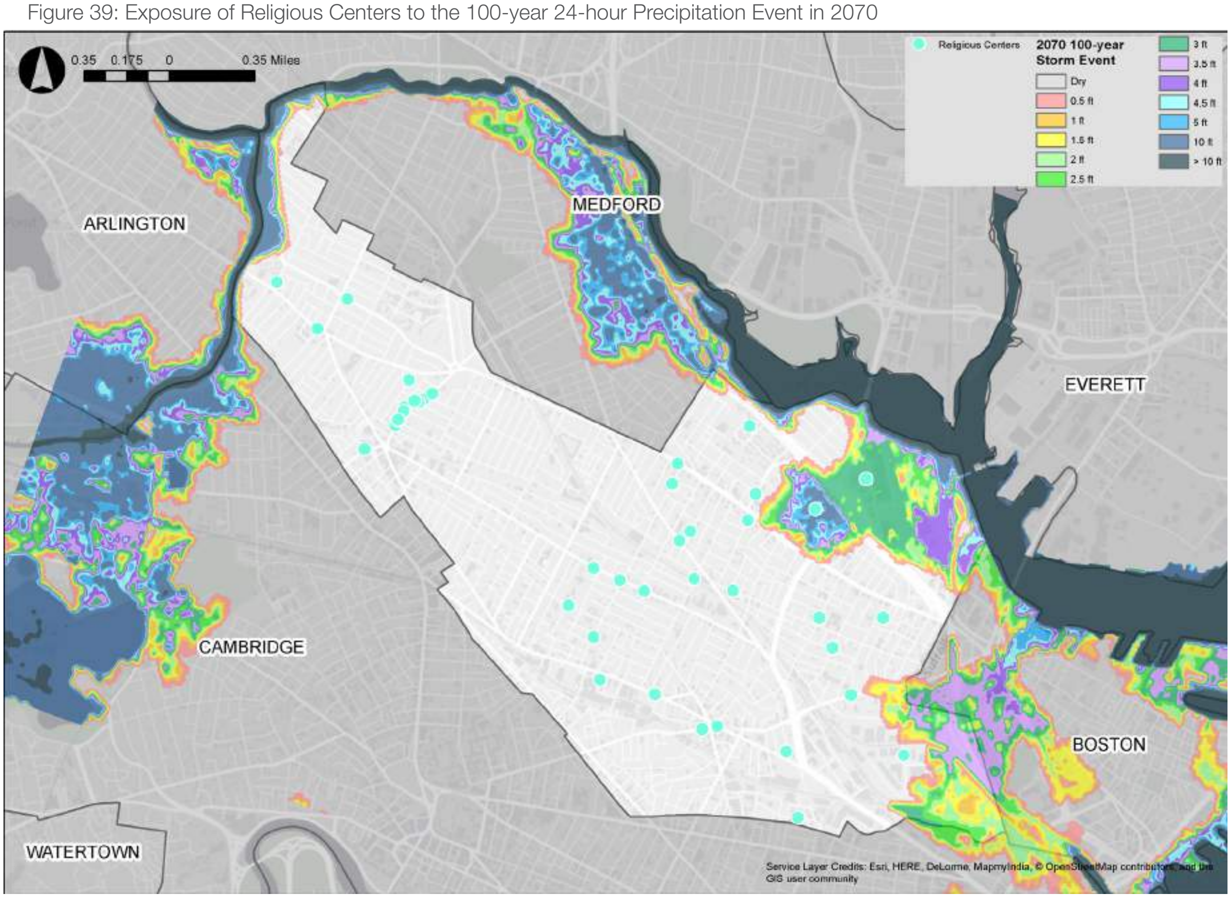


Figure 40: Exposure of Religious Centers to the 100-year Coastal Storm Event in 2070

While the vulnerable populations in the East Somerville & Assembly Square neighborhood are largely located south of Assembly Square, outside of the direct impacts from coastal flooding, the major public transportation lines and stations run through Assembly Square. Impacts to those rail lines and stations could significantly impede the mobility of the residents in these neighborhoods.

Roadways and other transportation networks tend to be focus areas for inundation due to the fact that flood storage, conveyance and drainage systems typically follow road networks. As a result, precipitation events often lead to transportation disruptions. This can disproportionately impact vulnerable populations who rely on trains and buses, as noted above. While residents who use private vehicles can navigate around flooded streets, buses and trains often stick to fixed routes and may not be able to easily reroute. When they do, communication to riders can be limited. This means that even if socially vulnerable individuals do not experience direct impacts to their homes as a result of inundation, they may be unable to reach work, food, services, or social resources. Additionally, **reliance on public transportation, walking and biking results in longer periods of physical exertion and heat exposure that will disproportionately affect vulnerable populations.** This may be exacerbated if tree cover is decreased due to tree mortality related to extended periods of high heat. Heavy reliance on public transportation also presents additional concerns during evacuations and emergency events.

Climate change will put additional stress on health – impacting elderly residents, children, those with pre-existing conditions, and low-income residents most significantly.[41] In particular, **because air pollution increases as heat increases, climate change is expected to exacerbate existing air quality issues and create new air quality concerns for Somerville, including more severe allergy seasons and increasingly serious mold problems as a result of flooding.** These are important concerns for Somerville as urban environments often have more severe air quality concerns and vulnerable populations often experience more severe impacts from degraded air quality.

In particular, particulate matter (especially tiny PM2.5 particles) is generated by fossil fuel combustion and has well-documented adverse health effects that can be influenced by climate change. Due to increasing pollution controls and a decrease of PM2.5 concentrations in the Boston metro region over time, climate change is unlikely to pose a serious threat to PM2.5-related health effects in Somerville. However, due to its high density and proximity to major traffic sources, such as I-93, some parts of Somerville may still be affected by PM2.5. For more information on air quality concerns in the Boston metropolitan region, please refer to Appendix F: Air Quality & Climate Change in Somerville.

Additional public health concerns will result from the increasing prevalence of vector-borne diseases. **The current climate projections for Somerville call for both a warmer and wetter environment in the coming years. This change in conditions provides an attractive habitat to potential diseases carriers – such as mosquitos and ticks – leading to an increase in the transmission of disease carried by these insects, including Eastern Equine Encephalitis (EEE), Zika, West Nile Virus, Dengue Fever, and Lyme Disease.**

41 The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment, 2016. https://health2016.globalchange.gov/downloads

Natural Environment

Key Findings

- Only 6% (161.8 acres) of Somerville's total land area is classified as open space. Because there is significantly limited access to open space and recreation areas for the residents of Somerville, it is vital to protect and enhance the city's open space wherever possible.
- Not only are trees, parks, and open spaces critical to climate change mitigation efforts, they are also vulnerable to the impacts of climate change. These green spaces take on many important community roles in Somerville and the limited number and quantity of open space places increased importance on protecting these assets from the impacts of climate change.
- Lincoln Park, Perry Park, Foss Park, and (to a slightly lesser extent) Conway Park in Union Square are projected to be the most vulnerable to inundation from a precipitation event.
- Draw Seven State Park, Mystic River Reservation and Foss Park are projected to be the most vulnerable to impacts from inundation related to SLR and storm surge.
- Parks and open spaces located in Ward Two & Inner Belt, East Somerville & Assembly Square, and Davis Square are projected to have increased risk to heat because of the prevalence of urban heat island factors in those neighborhoods.
- Heat vulnerability to the urban tree canopy is a compounding issue – trees are essential to providing shade and cooling during high heat events, but high heat also negatively impacts the health of the trees. Unhealthy trees are more susceptible to infestations because they are less likely to be able to fight off pests and diseases, and some treatments for pests, like those for Emerald Ash Borer, are ineffective on unhealthy trees. High temperatures and heat exposure, therefore, would exacerbate the vulnerability of Somerville's tree population to disease.

Overview

Somerville's natural environment is an incredibly valuable commodity. With the exception of the Mystic River, there are no recognized water bodies or streams within the city boundaries. Likewise, the density of development and legacy of land use within Somerville has resulted in minimal green space throughout the city. **Only 6% (161.8 acres) of Somerville's total land area is classified as open space. Because there is significantly limited access to open space and recreation areas for the residents of Somerville, it is vital to protect and enhance the city's open space wherever possible.**

Importance of the Natural Environment

Trees, parks and open space provide significant benefits to the social, environmental and economic landscapes in cities. Not only do green spaces improve quality of life by providing a sense of community identity and a place to gather, play and interact, but these spaces also address other community needs, including access to healthy foods (community gardens), cooling benefits, ecosystem protection, flood mitigation (water resources), improved public health, and climate change mitigation (removing carbon dioxide (CO2) from the atmosphere). Figure 41 provides an overview of some of the most important environmental, economic and social benefits of open space.

ENVIRONMENTAL BENEFITS	ECONOMIC BENEFITS	SOCIAL BENEFITS
Improved Visual Amenity	Increased Property Prices	Encouraging Physical Activity
Enhanced Urban Microclimate	Increased Land Values	Improving Childhood Development
Improved Air Quality	Faster Property Sales	Improved Mental Health
Reduced Flood Risk	Encouraging Inward Investment	Faster Hospital Recovery Rates
Better Water Quality	Reduced Energy Costs via Microclimate Regulation	Improved Physical Health
Improved Biodiversity	Improved Chances of Gaining Planning Permission	Improved Workplace Productivity
Reduced Ambient Noise	Improved Tourist and Recreation Facilities	Increasing Social Cohesion
Reducing Atmospheric Co_2	Lower Healthcare Costs	Reduction in Crime

Figure 41: Benefits of Green Infrastructure

Trees provide similar benefits to the overall health of the city, including:

• Providing shade and protection from UV radiation and reducing temperature through localized cooling and shading in cities;

• Reducing local wind speeds and providing shelter for buildings, thereby reducing fuel bills for heating;

• Reducing flood risks and the impact of rain storms. One study estimated that for every 5% increase in tree cover area, runoff is reduced by 25%;[42] and,

• Reducing atmospheric pollutants.

Bike paths, trails and sidewalks are also important elements of transportation networks that can be vulnerable to heat exposure. The Somerville Community Path is generally well shaded with several continuous tree canopies. However, sidewalks and bike lanes have wider variance with respect to areas of continuous shade. Bike lanes along Somerville Avenue, Beacon Street and Washington Street are in high heat exposure areas and have irregular patterns of street trees that leave sections of the roadways unshaded.

Exposure and Vulnerability

Not only are trees, parks and open spaces critical to climate change mitigation efforts, they are also vulnerable to the impacts of climate change. These green spaces take on many important community roles in Somerville and the limited number and quantity of open space places increased importance on protecting these assets from the impacts of climate change. Figures 42 and 43 show which open space resources are vulnerable to the impacts of flooding from precipitation and sea level rise and storm surge, respectively.

Lincoln Park, Perry Park, Foss Park, and (to a slightly lesser extent) Conway Park in Union Square are projected to be the most vulnerable to inundation from a precipitation event. These parks are all currently exposed to precipitation-related inundation from both the 10-year and 100-year event. However, exposure is expected to increase at all locations between now and 2070. According to the

42 Cities Alive, 2014. http://publications.arup.com/publications/c/cities_alive

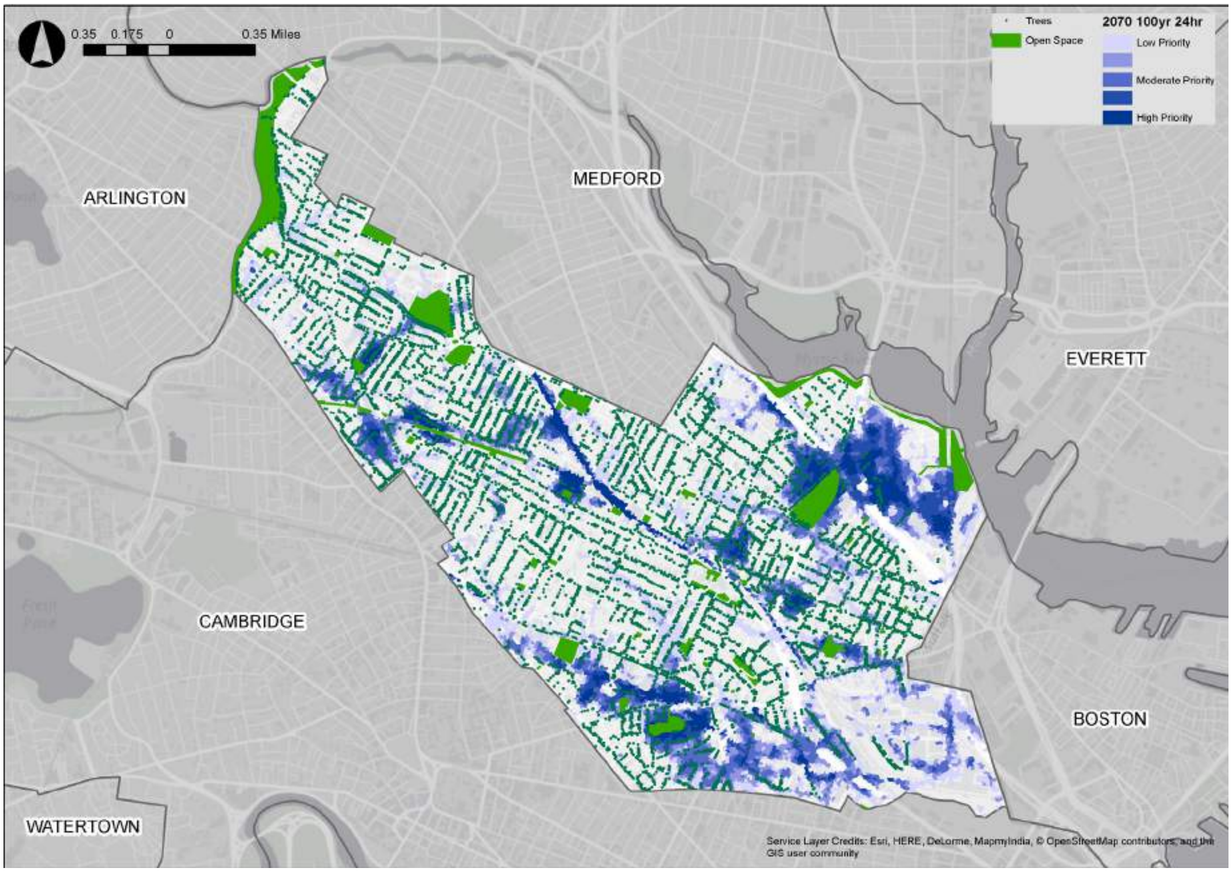


Figure 42: Exposure of Trees and Open Space to the 100-year 24-hour Precipitation Event in 2070

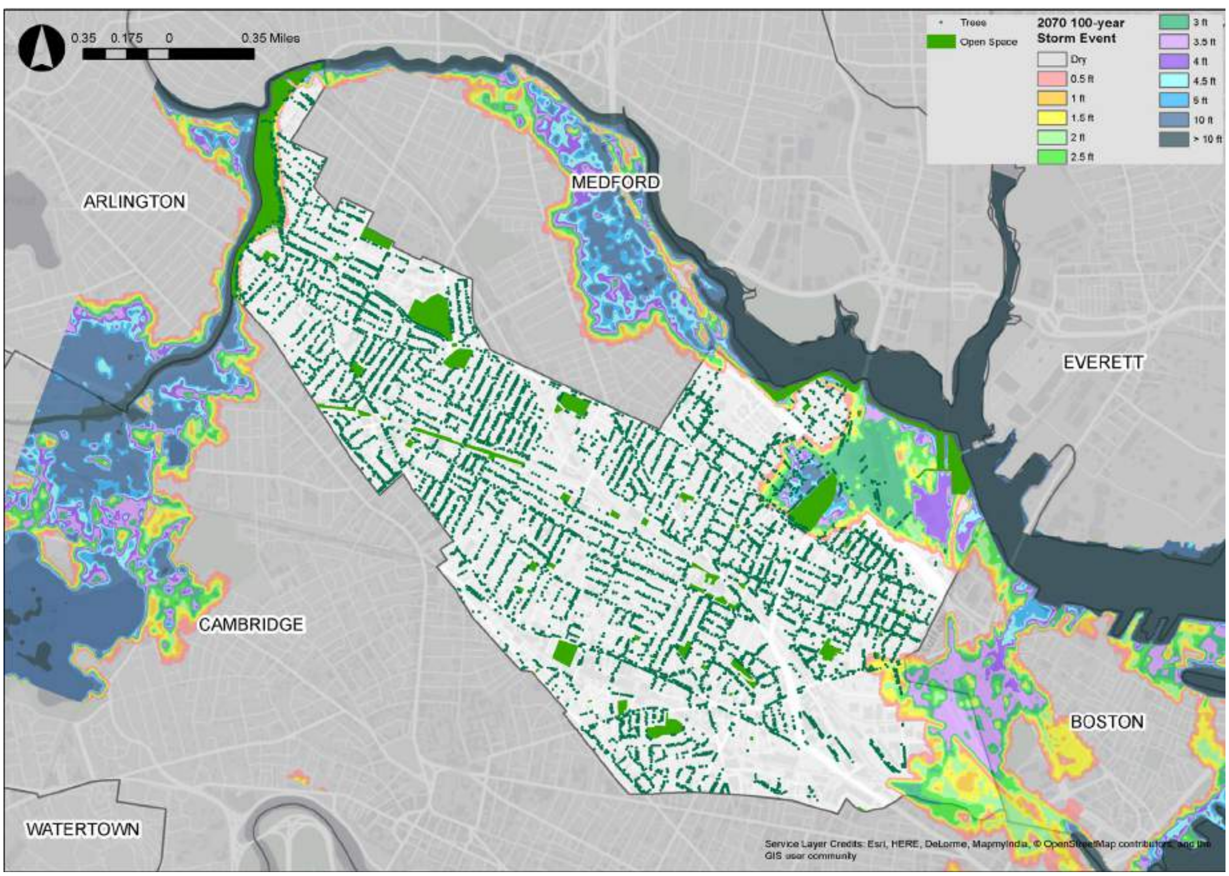


Figure 43: Exposure of Trees and Open Space to the 100-year Coastal Storm Event in 2070

modeling for precipitation events, 10-year storms in 2030 and 2070 will bring 15% and 30% more rainfall, respectively, than in the present day. This means that present day 10-year events (which bring 4.9 inches of precipitation) could have a higher chance of occurrence in 2030 and 2070, and thus be considered a chronic problem.

The natural features, including trees and plants would be exposed to stormwater runoff which could result in mortality and damage to these species. During rain events, in locations where combined sewer overflows are present, contamination-related damage could be exacerbated by exposure to wastewater. Stormwater runoff and wastewater in sewers combine and backup through storm drains, bringing contaminated water into tree basins and parks. In addition, if these precipitation events bring strong winds,[43] increased tree damage and tree mortality could also occur. Portions of Somerville's Community Path, particularly to the east of the Davis Square Station, are also vulnerable to precipitation events and the related impacts mentioned.

Draw Seven State Park, Mystic River Reservation and Foss Park are projected to be most vulnerable to impacts from inundation related to SLR and storm surge, including tree, plant, and grass damage and mortality due to salt water inundation and flood damage to recreational facilities. Most of the impacts related to sea level rise and storm surge will be acute impacts during flooding events by 2070. However, nearer term impacts (2030) are possible at Draw Seven Park and the Mystic River Reservation. In addition, due to their waterfront location, it is possible that sea level rise, alone, could result in inundation during twice daily tidal cycles at these two parks by 2030.

Draw Seven Park provides nine acres of parkland, including soccer fields, a bike path and walkway, and a picnic area. Flood impacts could limit use of all of these important community resources. Residents would suffer indirect impacts including loss of filtration and cooling effects from trees, loss of recreational facilities and loss of nearby access to cooling facilities, such as the Latta Brothers Memorial Pool at Foss Park, during and following major coastal flooding events.

Parks and open spaces located in Ward Two & Inner Belt, East Somerville & Assembly Square, and Davis Square are projected to have increased risk to heat because of the urban heat island factors in those neighborhoods. Although these parks have been identified as having increased risk because of the additional UHI factors in those neighborhoods, it is important to note that all parks in Somerville will be exposed to increased temperatures that could have significant impact on the functionality and usability of those parks. This is a chronic and cumulative problem that will be exacerbated as temperatures are projected to continue to rise every year.

While parks and open spaces are generally cooler than areas surrounded by buildings and pavement, heat vulnerability to the urban tree canopy is a compounding issue – trees are essential to providing shade and cooling during high heat events, but high heat also negatively impacts the health of the trees. Heat events can damage and kill trees, limiting their ability to provide cooling functions. **Unhealthy trees are more susceptible to infestations because they are less likely to be able to fight off pests and diseases, and some treatments for pests, like those for Emerald Ash Borer, are ineffective on unhealthy trees. High temperatures and heat exposure, therefore, would exacerbate the vulnerability of Somerville's tree population to disease.**

43 Wind was not included as part of the analysis; however high winds are often associated with major storms in the Northeast.

Economy

Key Findings

- The number of jobs in Somerville is relatively few compared to the active workforce living in Somerville, so it is essential to protect the existing jobs and continue to actively create new jobs.
- While the economic analysis focuses on physical damage, business continuity considerations will likely be more costly.
- Both coastal and precipitation-based flooding will negatively impact Somerville's economy and that of the larger region.
- By 2070, $155 million of total structural and content damages to residential buildings is expected following a 100-year flood event. These damages are concentrated in three neighborhoods: East Somerville & Assembly Square, Ten Hills, and West Somerville.
- Assembly Square is highly vulnerable to impacts from coastal flooding and is a key economic development area for the city.
- Union Square is also a key economic development area for the city and could suffer economic impacts of approximately $97 million in structural damage in 2070 from precipitation-based flooding.
- More than $105 million in lost business revenue and impacts to more than 1,000 employees are projected in 2070 following a 100-year flood event.

Overview

Climate change will have profound and wide-ranging impacts on the local and global economy. Because of the broad nature of climate change impacts on the economy and the limitations of this study, the economic analysis was limited to an assessment of:

1. Estimated costs of physical damage to buildings resulting from coastal flooding: How much value would be lost if the Amelia Earhart Dam were overtopped and if flood waters entered the Schrafft Center pathway?

2. Anticipated regional economic impacts from lost business revenue due to coastal flooding in Somerville: If Somerville businesses are affected by these floods, how much does that affect the overall Boston-area economy?

3. Case study of precipitation-related damage in an area where high-resolution sewer modeling exists: What would be the cost of structural damage around Union Square from a major storm in 2070 if no improvements were made?

Aspects of business continuity were not addressed nor were the compounding effects of heat or precipitation. Interruption in business continuity is nearly always more costly than direct physical damage, but also much more difficult to calculate. While not part of this scope, additional economic analyses may be necessary to prioritize across sectors and regional considerations.

This analysis is only a first step towards understanding the economic implications of climate change and should be used as an order of magnitude level assessment, rather than considering the specific dollar estimates. It is important to note that this assessment did not take into account economic impacts from temperature and precipitation nor did it account for flood impacts to other municipalities in the region that will impact Somerville and its residents or the cascading impacts to the economy that may result from the direct impacts of coastal flooding. For more information on the methodology and the limitations of this assessment, please refer to Appendix E: Regional Economic Analysis.

Importance of the Economy

The City of Somerville is committed to investing in economic development and transforming key opportunity areas, including Assembly Square and Union Square, into dynamic, mixed-use, and transit-oriented developments that serve as economic engines for Somerville.[44] The intention of these economic growth areas is to grow the commercial tax base and the availability of jobs within the city's borders and attract the next generation of entrepreneurs to Somerville. However, in order to ensure that the economy can continue to grow and thrive, it is important to understand its vulnerability to climate change.

Quality of life is inextricably tied to economic growth and the stability of the economy; therefore, a fully functioning economy is vital to the prosperity of any city or region. According to "SomerVision – Somerville's Comprehensive Plan," 25% of Somerville's tax base comes from commercial properties and the city is home to more than 20,000 jobs. **The number of jobs is relatively few compared to the active workforce living in Somerville, so it is essential to protect the existing jobs and businesses and continue to actively create new jobs.** In addition, the tax base is essential to the city's ability to provide excellent public services to its residents and continue to maintain its critical assets and infrastructure. At its core, economic growth and development is about the people of Somerville. Without a healthy local economy, local businesses, jobs, and commercial tax revenues would suffer and significantly impact the quality of life of Somerville's residents.

Improved value is the value of any improvements made to a parcel of land. Improvements are any changes to the property from its natural state, including the creation of roads, buildings and structures.

Structural damage is the anticipated damage to the physical structure on the property.

Content damage is an estimate of the damage to the contents of a commercial or residential structure. Contents include most items that are not part of the physical structure, such as furniture and decor.

Exposure and Vulnerability

Residential and Commercial Impacts

By 2070, $155 million of total structural and content damages to residential buildings is expected following a 100-year flood event. These damages are concentrated in three neighborhoods: East Somerville & Assembly Square, Ten Hills, and West Somerville. The anticipated residential damage to both contents and structure in 2070 represents approximately 1.5% of the total improved value of all residential structures in Somerville. In addition, the anticipated impacts to commercial buildings substantially increase relative to 2030 impacts: approximately $217 million of damage is expected during the 2070 100-year event. That damage would likely be concentrated across four neighborhoods: East Somerville & Assembly Square, Ten Hills, Ward Two & Inner Belt, and West Somerville. Figure 44[45] shows the damage analysis for the commercial and residential buildings in Somerville, based on a 100-year storm event occurring in the year 2070. In 2030, damage from the 100-year flood event is expected to be relatively minor, with only $1 million of commercial damage concentrated in the West Somerville neighborhood.

Preliminary estimates show East Somerville & Assembly Square, Ten Hills, and Ward Two & Inner Belt will be hardest hit by failure of the Amelia Earhart Dam. Assembly Square is highly vulnerable to impacts from coastal flooding and is

44 Somervision: City of Somerville Comprehensive Plan 2010-2030, 2012. https://www.somervillebydesign.com/planning/somervision/

45 Sources: Somerville Assessor, parcel database, 2016; Flooding forecast, 100-year flooding from sea level rise and storm surge in 2070, Woods Hole Group, 2016; Army Corps depth damage functions, commercial.

Neighborhood	Total Residential Improved Value (2016 dollars)	Total Residential Structural And Content Damage (2016 dollars)	Total Commercial Improved Value (2016 dollars)	Total Commercial Structural Damage (2016 dollars)
Central Hill	$203,000,000	$0	$142,000,000	$0
Davis Square	$1,154,000,000	$0	$280,000,000	$0
East Somerville & Assembly Square	$970,000,000	$41,000,000	$826,000,000	$188,000,000
Magoun Square	$698,000,000	$0	$48,000,000	$0
Powder House	$761,000,000	$0	$25,000,000	$0
Prospect Hill	$625,000,000	$0	$80,000,000	$0
Spring Hill	$1,321,000,000	$0	$186,000,000	$0
Ten Hills	$698,000,000	$110,000,000	$87,000,000	$3,000,000
Tufts	$490,000,000	$0	$366,000,000	$0
Ward Two & Inner Belt	$1,536,000,000	$0	$632,000,000	$20,000,000
West Somerville	$908,000,000	$3,000,000	$121,000,000	$6,000,000
Winter Hill	$1,013,000,000	$0	$98,000,000	$0
Total	**$10,377,000,000**	**$155,000,000**	**$2,890,000,000**	**$217,000,000**

Figure 44: Projected 2070 Residential and Commercial Coastal Flood Damage in a 100-year Storm Event

a key economic development area for the city. Therefore, flood impacts to this neighborhood could have a significant impact on Somerville's economy as well as the larger regional economy.

Regional Economic Impacts of Lost Business Revenue

A separate analysis was conducted to assess potential regional economic impacts of lost business revenue due to flooding associated with the 100-year flood event in 2070. These effects can be described as direct, indirect, or induced, depending on the nature of the change to the regional economy. This analysis provides an order of magnitude estimate of the level of business interruption for affected businesses and associated revenue losses that may occur due to coastal flooding events. The analysis estimates the "ripple effects" that these revenue losses would have on the regional economy.

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	860	$35,733,000	$46,379,000	$76,053,000
Indirect Effect	80	$5,655,000	$9,352,000	$14,822,000
Induced Effect	110	$5,178,000	$9,321,000	$14,506,000
Total Effect	**1,050**	**$46,566,000**	**$65,052,000**	**$105,381,000**

Figure 45: Projected 2070 Regional Economic Impacts in a 100-year Storm Event

More than $105 million in lost business revenue and impacts to more than 1,000 employees throughout the region are projected in 2070 following a 100-year coastal flood event. In addition, coastal and inland flooding will cause significant

Direct effects represent changes in output, income, value added, or employment attributable to a change in demand or a supply shock.

Indirect effects are changes in the output of industries that supply goods and services to those that are directly affected by the change in direct expenditures**.**

Induced effects reflect changes in household consumption arising from changes in employment and associated income. Induced effects also stem from reduced expenditures by commercial taxpayers.

Figure 46: Vulnerable Assets in Union Square

disruption to the transportation system. This will hamper the movement of people, goods, and services throughout the region, which will have a significant impact on the economy.

Precipitation-Related Impacts

Modeling the economic losses related to extreme rain events requires a high-resolution model of the stormwater system, which Somerville only possesses in Union Square and Assembly Square. For this study, Union Square was selected as a case study to begin to understand the potential economic impact of precipitation in the future. It is important to note, however, that these projections and impacts do not take into account ongoing and planned infrastructure improvements that are expected to alleviate flooding impacts in this neighborhood.

Residential and commercial properties in Union Square are projected to suffer economic impacts from the 100-year, 24-hour precipitation event of approximately $97 million in total structural damage, or 7.3% of improved value in 2070. Parcels along Somerville Avenue, Lake Street and Bow Street Place, are most vulnerable to damage. Some parcels along Prospect Street, Allen Street, Lake Street, and Bow Street Place are projected to sustain structural damages of more than 20% of their total value. In addition, parcels to the west and northwest of Union Square are projected to sustain damages between 15% and 20% of their total value. The Somerville Police Station and Fire Department are projected to sustain damages equal to between 20% and 25% of the total parcel value. Many of the parcels identified as vulnerable to damages from precipitation events are identified as development opportunity areas in the "Union Square Neighborhood Plan".[46]

46 Union Square Neighborhood Plan, 2016. http://www.somervillebydesign.com/wp-content/uploads/2016/08/Union-Square-NP-FINAL-WEB.pdf

Risk Assessment

Building off the vulnerability assessment, a risk assessment was conducted for each of the most vulnerable assets identified in the previous section. Risk was assessed as a function of probability and consequence in order to help the city prioritize the most at-risk assets to target in the climate change planning process. Probability is the likelihood that a system or asset will be impacted by a particular climate stressor and consequence refers to the magnitude of the repercussions associated with failure of that asset during a climate event.

The probability scores were based on the methodology detailed in Figure 47 and scored according to a scale of 1-3, where one is the lowest probability and three is the highest probability. Due to the limitations of the urban heat island data, only assets that were located in the highest vulnerability neighborhoods for urban heat island factors were scored in the risk assessment. Those assets were scored as high probability.

Probability	Sea Level Rise & Storm Surge	Precipitation	Heat
High (3)	Located in the Schrafft Center flood pathway and impacted in 2030	Impacted by the 2030 100-year storm event	Located in one of the areas with the most Urban Heat Island factors
Moderate (2)	Located by the Amelia Earhart Dam and impacted in 2070	Impacted by the 2070 100-year storm event	N/A
Low (1)	All other impacted assets	All other impacted assets	N/A

Figure 47: Probability Scoring Matrix for each Climate Factor

Consequence was assessed according to five factors: percent of population affected; impact on vulnerable populations; criticality of the asset; economic impact; and, environmental impact. Each factor was scored on a scale of 1-3 and then added together for a total consequence score from 1-15. The most at-risk assets were identified by the highest combination of probability and consequence (see Figure 48).

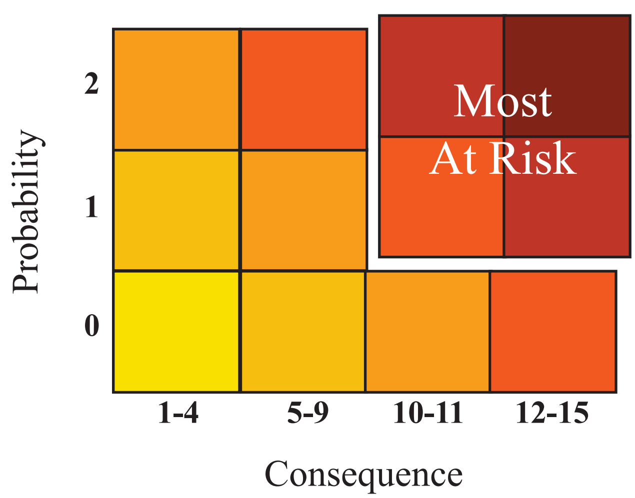


Figure 48: Risk Matrix

While this assessment largely highlights the major areas of vulnerability in the City of Somerville, it is important to note that there are several assets and types of climate exposure for which Somerville does not need to be concerned. In terms of key assets, energy infrastructure and healthcare facilities are largely insulated from the damaging impacts of climate events. While some of the energy infrastructure is vulnerable to climate impacts, there is sufficient redundancy within the system. An impact to one facility will not impact the regional power supply; however, a larger event that impacts multiple facilities may still have more serious impacts to the power grid. Moreover, although the healthcare network in Somerville may experience indirect impacts from climate change, such as an increased demand for services, the healthcare facilities within Somerville's borders are largely insulated from the direct impacts of precipitation-based and coastal flooding.

In addition, Somerville has minimal exposure to nighttime urban heat island hot spots. Nighttime hot spots are particularly important from a public health perspective, because higher nighttime temperatures often have a greater impact than daytime temperatures on the prevalence of heat-related illness.

For more information on the probability and consequence scoring of each asset, please refer to Appendix H: Vulnerability and Risk Assessment Tables. Figure 49 presents the most at-risk assets and systems within the City of Somerville, which are discussed in more detail in Section 6: Priority Focus Areas.

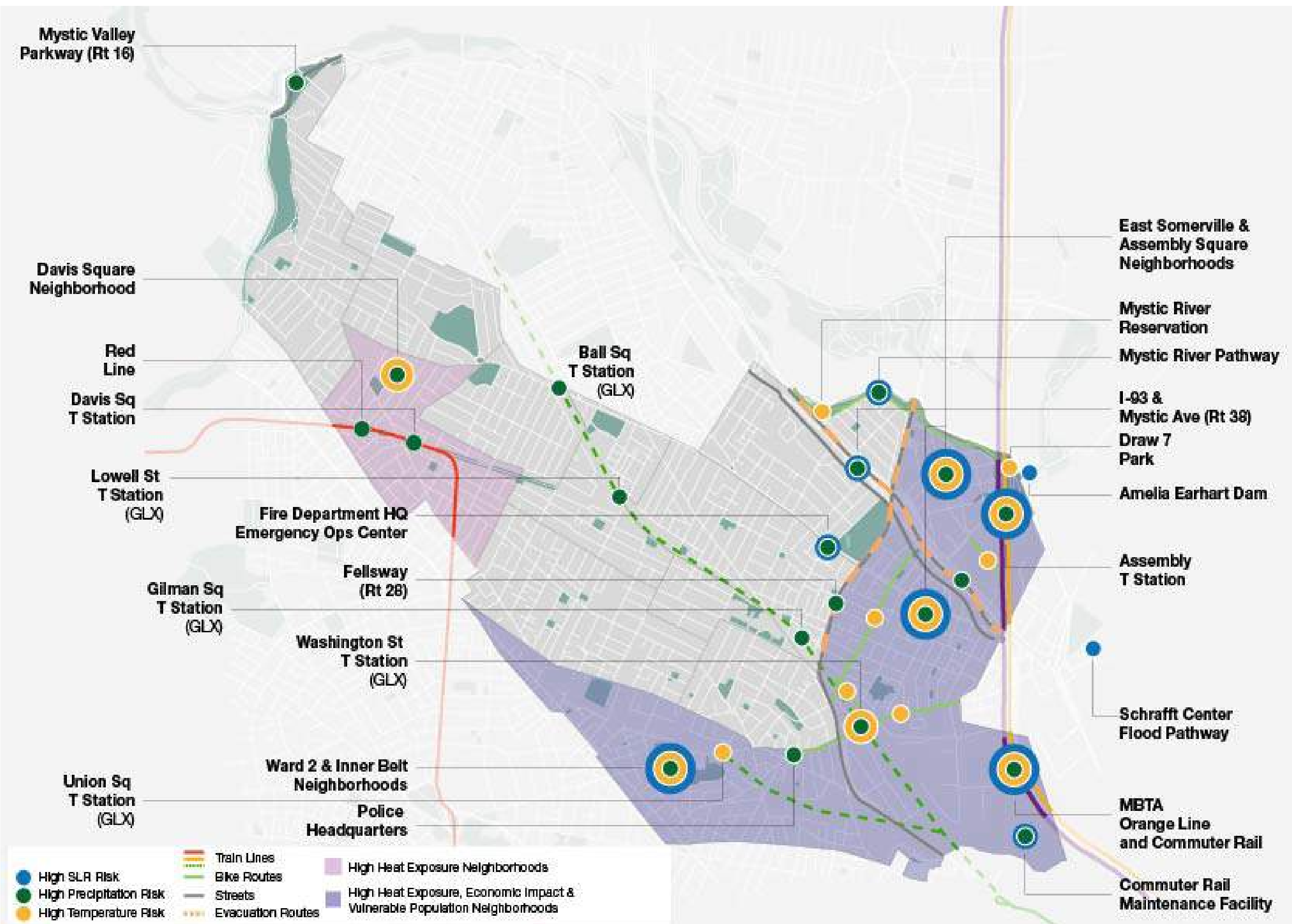


Figure 49: Key Priorities for the City of Somerville

Section 6: Priority Focus Areas

Image Source: Eric Herot. 2009. “Around Union Square.” Licensed under CC BY-NC 2.0. https://www.flickr.com/photos/eherot/4126516521/in/photostream/

Priority Focus Areas

The vulnerability and risk assessments were used as a framework to determine the top priority focus areas for the City of Somerville. The following table highlights the top priorities for the City of Somerville.

Impacted System/Asset	City's Role	Type of Impact
Transportation System	Both advocacy and action	Both chronic and acute
Amelia Earhart Dam	Both advocacy and action	Acute
Schrafft Center Flood Pathway	Both advocacy and action	Both chronic and acute
Union Square & Assembly Square Economic Develpment Concerns	Action	Both chronic and acute
Public Health Concerns for Vulnerable Populations	Action	Both chronic and acute
Fire Department Headquarters & Emergency Operations Center	Action	Both chronic and acute
Police Department Headquarters	Action	Both chronic and acute
Citywide Precipitations-based Flooding	Action	Both chronic and acute
CItywide Extreme Heat Impacts	Action	Both chronic and acute
Impacts to Open Space and Trees	Action	Both chronic and acute

Figure 50: Priority Focus Areas for the City of Somerville

PRIORITY 1: Precipitation-based flooding will impact much more of Somerville than coastal flooding.

1

By nature of Somerville's location and topography, much more of the city is exposed to precipitation flooding than coastal flooding. While coastal flood exposure is concentrated along the Mystic River and Alewife Brook, and near the Charles River, precipitation-based flood exposure is distributed throughout the city. Precipitation flood exposure is worse in areas with higher concentrations of impervious surfaces, such as roads, parking lots, larger buildings that do not manage runoff onsite, and where drainage systems are overcapacity. Such locations exist across Somerville, with areas of highest exposure concentrated in the Davis Square, Union Square, and Winter Hill neighborhoods. Precipitation flood exposure also tends to follow key transportation corridors, including the MBTA Commuter Rail line to West Medford, the proposed Green Line Extension, portions of I-93, Mystic Ave and Washington Street, and the Somerville Community Path between Lowell Street and Davis Square.

The most dramatic increases in precipitation flood exposure occur where existing exposure is already high. Most notably, exposure around Assembly Square and Foss Park increases in breadth and severity. Somerville can reduce exposure to precipitation flooding across the city through three key areas: policy and zoning updates, softening the landscape through the implementation of green infrastructure, and increasing capacity of existing drainage systems. In Assembly Square, Union Square and Davis Square, where precipitation flood exposure is concentrated, flood management overlays may be considered that require property owners to manage stormwater onsite, thus reducing spillover to public sewer systems. Developing new neighborhood parks, installing right-of-way bioswales and distributed soft infrastructure systems can reduce and slow the inflow of precipitation into sewer systems, reducing the likelihood and severity of flooding. Lastly, increasing the capacity of flood drainage and storage systems can reduce flooding.

While the identified areas are high priority concerns for risk of flooding from precipitation, it is important to note that the citywide modeling for precipitation did not account for the capacity of the stormwater drainage system to handle the projected increase in frequency and intensity of rainfall; the modeling was a high-level analysis that identified areas of potential concern based on the amount of rainfall and the topography of the City's landscape. In order to identify top concerns and prioritize drainage improvement projects, the City should complete detailed modeling to understand the capacity of the drainage system to accommodate for the projected increase in rainfall as a result of climate change. Prior to completing the full drainage assessment, historical information will provide insight into areas where updates to the drainage system may be required. For example, nuisance flooding has been reported at the Route 28 underpass along Mystic Avenue, at underpasses on Washington Street, McGrath Highway and Medford Street, and at the Police Department Headquarters, where the police fleet was flooded during the July 2010 storm event.

2

PRIORITY 2: Sea level rise and storm surge flooding associated with the flanking of the Amelia Earhart Dam may occur as early as 2035 if significant investment in infrastructure improvements is not made.

The Amelia Earhart Dam is located along the Mystic River near Assembly Square. Sea level rise and storm surge modeling for the area suggest that the dam may be regularly flanked during 1% annual storm events as early as 2035. Flanking differs from overtopping becuase the water flows around the edges of the dam, rather than actually overtopping the midsection of the dam. This flanking is expected to exacerbate shorefront (riverine) flooding in the Ten Hills and East Somerville & Assembly Square neighborhoods, resulting in 1 to 2 feet of flooding in those areas. While most of this flooding would be limited to the shorefront, there is a smaller pathway in East Somerville that would extend inland several blocks.

By 2070 (and as early as 2055), the dam will be overtopped during the 1% annual storm event, resulting in extensive and widespread flooding throughout the area. This flooding will impede freshwater flows from the Mystic River and further exacerbate the flooding. Ten Hills and East Somerville & Assembly Square will be significantly impacted by this failure of the dam, with flooding depths averaging several feet and as much as 10 feet in some areas during these events. Those volumes could be even greater if the coastal storms are accompanied by significant rainfall.

While the dam is of particular concern to Somerville, it does not fall within Somerville's jurisdiction. The dam is owned and operated by the Massachusetts Department of Conservation and Recreation (DCR). However, the dam plays an important role in regional flood protection and, as a result, several recent climate assessments in the region have raised concerns related to the failure of the dam to adequately provide protection during coastal storms.

3

PRIORITY 3: The Schrafft Center flood pathway in Boston, north of Sullivan Square, is of immediate concern to Somerville. It has the potential to flood under a present-day extreme event.

The Schrafft Center flood pathway in Boston, north of Sullivan Square, is also of immediate concern to Somerville. It has the potential to flood under a present-day extreme event. While the entry point for this pathway is not under Somerville's jurisdiction, flooding in this area could have significant implications in the Ward Two

& Inner Belt neighborhoods, along I-93. Under current conditions, there could be up to one foot of flooding along the western boundary of Ward Two & Inner Belt. By 2070, the extent and depth of that flooding may increase substantially and reach depths of up to three feet in some areas, as well as encroaching on the southeast section of the East Somerville & Assembly Square neighborhood. The City of Boston is currently developing design solutions to address this flood pathway; however, the City of Somerville should continue to advocate in this area to ensure that the solutions are ultimately implemented.

While it is important to highlight impacts of coastal flooding, it needs to be done in concert with potential precipitation impacts. Consideration must be made for jointly occurring rainfall and coastal storm events. Likewise, coastal flood barriers need to be thoughtfully designed to ensure that they do not impede the flow of runoff generated from rainfall and inadvertently block the water from flowing into the river and other drainage structures.

Lastly, by 2030, daily sea levels are estimated to rise as much as four to eight inches in the greater Boston region and from one to three feet by 2070.[47] However, sea level rise alone (in the absence of storms) will not result in flooding in Somerville. Therefore, there are no anticipated flood impacts in Somerville as a result of sea level rise alone.

PRIORITY 4: The Fire Department Headquarters and Emergency Operations Center and the Police Department Headquarters are both vulnerable to flooding, which presents significant challenges to both daily city operations and operations during an emergency event.

4

The Fire Department Headquarters and Emergency Operations Center, located in the same building along Broadway, are both currently exposed to precipitation flood risk. The Fire Department Headquarters and Emergency Operations Center are also located in close proximity to the coastal flood extents expected during the 100-year storm in 2070. Although the facility may not be directly impacted by this coastal flooding, access to the facility could be significantly impaired, which would disrupt the ability of both facilities to operate effectively during a flood event. The surrounding coastal flooding coupled with the flood risk from a precipitation storm event could exacerbate these challenges. The Police Department Headquarters, located in Union Square, is also exposed to present-day risk from precipitation events. While neither location is exposed to coastal flooding, exposure to precipitation flooding is expected to get progressively worse in 2030 and 2070.

Somerville has direct influence over the exposure to these important assets and can support near- and long-term risk reduction in a variety of ways. Moveable flood barriers, backflow preventers, backup generators and emergency operations planning can protect the buildings and ensure continuous operation throughout flooding events. The buildings also provide storage for police, fire and emergency vehicle fleets, ensuring that those fleets are protected from floodwaters is also critical. However, identifying alternate locations within Somerville to store vehicles in preparation of flooding events may prove more effective in ensuring access to vehicles is maintained during a flood event. In the longer term, Somerville may consider installing solar powered generation on the roofs of these two buildings and providing battery storage for solar power. Through allowing the buildings to "island," or run independently from the electric grid when necessary, the City can ensure continuous operation of the facilities.

47 Climate Ready Boston, 2016. https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf.

If flooding occurs more regularly and more severe flooding conditions arise, Somerville may ultimately consider relocating these buildings to areas with lower exposure or distributing operations amongst multiple buildings with lower exposure to flooding.

5

PRIORITY 5: The transportation system (including MBTA, major roadways, evacuation routes, and bike paths) is highly vulnerable to all three climate hazards – coastal flooding, precipitation, and heat.

Many elements of the transportation system are exposed to coastal and precipitation flooding. While infrastructure improvements are already underway to alleviate risks in some areas, such as Union Square, the overall transportation system will be at risk in the future if no adaptation measures are taken. These exposures will typically be associated with extreme events and do not threaten to chronically impact the transportation system. Specific assets exposed to coastal flooding are the Orange Line, the Green Line Extension, Assembly Square Station, I-93, Fellsway and Route 28. Exposure in 2030 is limited to portions of commuter rail lines and the waterfront trails; however, in 2070 coastal flooding is much more extensive.

The Orange Line, Red Line and Green Line Extension along with the Davis Square Station, Assembly Square Station, the proposed Gilman Square, Washington Street, Lowell Street, and Ball Square Stations, streets surrounding the proposed Union Square Station, I-93, and local roads around Union Square and Assembly Square will all be exposed to precipitation impacts. While direct exposure may vary, each of the stations are surrounded by high exposure areas, impacting station access and egress during and after precipitation events. Importantly, while exposure increases in physical area and in severity between the present day and 2070, most of these assets are still exposed to impacts from 1% annual storm events in the present-day.

Rails and roads will be more regularly exposed to high heat conditions which can result in slow and steady damage to the system over time. In addition to rail and road corridors, heat impacts the rolling stock (trains, buses and vehicles over time as well) – the need to run cooling systems for longer and more intense periods will lead to premature breakdown and shorter lifecycles for these vehicles. Bus stops and stations will be exposed as well; however, the impacts here will be experienced by transit riders more so than the assets. West Somerville, Union Square, East Somerville and Assembly Square are the most exposed to urban heat island factors.

The transportation system is highly interdependent and impacts to one portion of the system will have cascading effects on the rest of the system, affecting the residents of Somerville as well as the region at-large. The transportation system is also vital to daily life and without reliable transportation options, there will be cascading impacts in other areas, including workforce, freight, food access, job access and access to health care. Transportation access is particularly important to vulnerable populations, as they rely on fixed systems and are often stranded when public transportation is unavailable. In addition, exposure of the MBTA Commuter Rail Maintenance Facility in the Inner Belt area could result in further disruptions, delays and damage due to coastal flooding, precipitation, and heat exposure.

While many transportation assets are owned by the state, Somerville can improve the resilience of these assets through strategic improvements throughout the city and around the transportation facilities, such as increased tree canopies and flood storage systems. However, Somerville will also need to take an advocacy role, working with MBTA and MassDOT to protect the highway and transit networks from climate change.

Green Line Extension

The forthcoming Green Line Extension (GLX) will bring new transit service to Somerville's underserved areas. While presenting an opportunity for improved mobility of Somerville residents, the line and planned stations are in areas with exposure to climate change impacts. The ongoing planning, design and construction of the line and stations presents an opportunity to address these issues before they arise. Construction is already underway on large stormwater conveyance and detention systems along the GLX route.

6

PRIORITY 6: Union Square, Assembly Square, and the Inner Belt, Somerville's transformative economic development districts, are highly vulnerable to flooding impacts.

The ongoing development in these areas presents an opportunity to better prepare these neighborhoods for climate events and shape how they will experience and respond to future events by coupling infrastructure improvements with new development and construction. New development both finances infrastructure and presents an opportunity to develop buildings that can adapt to a wetter, hotter climate. Assembly Square and areas of the Inner Belt are vulnerable to flooding from storm surge through the Amelia Earhart Dam pathway and the Schrafft Center pathway, respectively. These areas are not expected to experience impacts from sea level rise alone and therefore, addressing the origin of the flooding should protect these important development areas during storm events. New development in Assembly Square incorporates strategies, such as mechanical equipment above the basement level, that provide more resilience to flooding relative to older building stock.

Precipitation events are also expected to impact Assembly Square and Union Square. Detailed drainage modeling of the Assembly Square area suggests that the drainage system has adequate capacity to handle the projected increase in the frequency and intensity of precipitation events. Union Square does not currently have the same level of adaptive capacity built into its drainage system; however, the City of Somerville is actively working to improve the water and sewer infrastructure in Union Square. The Somerville Avenue Sewer Separation and Streetscapes Restoration is an approximately $40 million project currently underway that will include a 0.8 million gallon storage box culvert and a complete streets restoration, with enhanced pedestrian, transit rider, and bike facilities, including green infrastructure and landscaping features. Sewer and water utility improvements are also included. Nearby, the Nunziato Field Stormwater Storage Project will create a 1.2 million gallon stormwater tank that will hold stormwater before it reaches the heart of Union Square.

7

PRIORITY 7: Temperature is a ubiquitous threat throughout the city and will be relatively more intense in some areas based on a combination of surface types, lack of vegetation and level of emissions.

In Somerville, temperature is projected to increase over time and may be an issue in the present-day with increasing periods of sustained heat in the summer months. Average historic temperatures could increase by as much as 17%, over present-day averages of approximately 50°F, by 2070. In addition, by 2070, annual days greater than 90°F could increase by as much as nine times, over historical averages of 11 days per year, with a possible result of one continuous heat wave lasting the entire extent of the summer.

That increase in temperature will be exacerbated by the presence of factors that contribute to urban heat island effects, such as lack of tree canopy and limited open space, high percentages of impervious surface, and high levels of emissions from vehicles, among others. While heat can be an important concern to particular types of assets, the actual ambient air temperatures would have to be extreme to have significant, critical-failure levels of impact to any of the infrastructure. However, the energy grid may experience noticeable impacts to its overall level of service during extreme heat events resulting from increased demand for cooling services. This increased demand could cause brown outs and other types of reduced service from increased demand and decreased transmission efficiency.

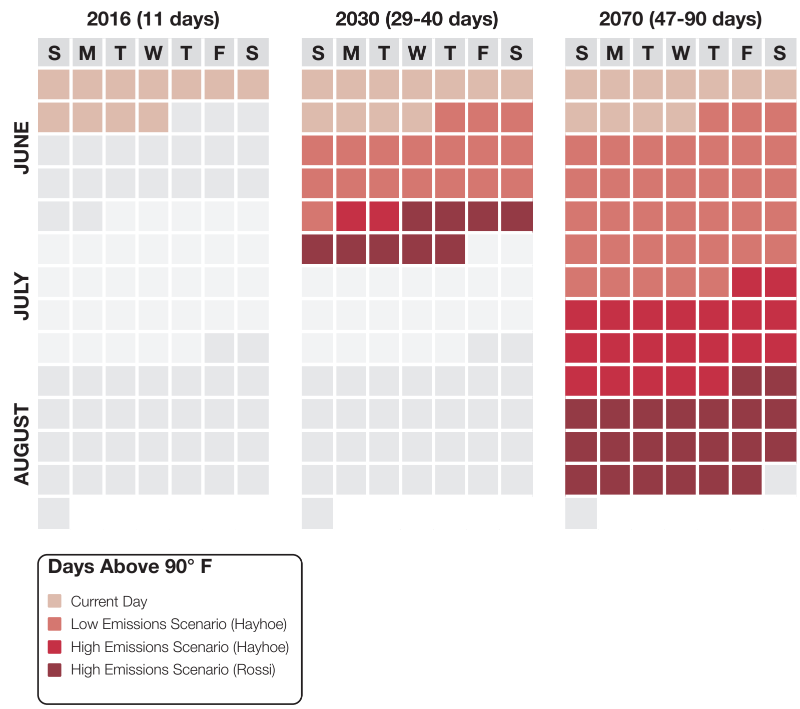


Figure 51: Comparison of Days above 90°F for Low and High Emissions Scenarios

Somerville's built environment and existing housing stock also contribute to increased heat exposure and UHI effects. While parks and open space are composed of natural surfaces that absorb carbon dioxide and reduce the impacts of extreme heat, materials used in the built environment are typically darker and thus, absorb large amounts of solar radiation, which makes the buildings very effective at holding in heat; this insulation results in higher temperatures in the areas surrounding buildings. The City of Somerville's built environment is extremely dense; the density of the landscape contributes to the urban heat island effect because heat lingers between the buildings. Thus, the impacts of increasing temperatures are exacerbated throughout the city.

In order to combat the effects of UHI, Somerville should consider policies that require or incentivize the use of lighter-colored building materials, the construction of green roofs or the dedication of a portion of a development area as open space, and the planting of street trees. Figures 52 and 53 detail some of the neighborhood-level and building-scale UHI concerns and thus, identify areas where Somerville could take direct action to reduce UHI, implement new building code requirements, and/or incentivize alternative construction techniques.

The most common housing structure in Somerville is the two-family home; thus, the building-scale analysis was conducted for the typical two-family structure. Contributing UHI factors include: dark-colored roofing and building materials; lack of landscaping or street trees on the parcel; paved driveways and additional impervious surfaces; and, direct exposure of windows to sunlight and uncoated windows that allow significant heat gain.

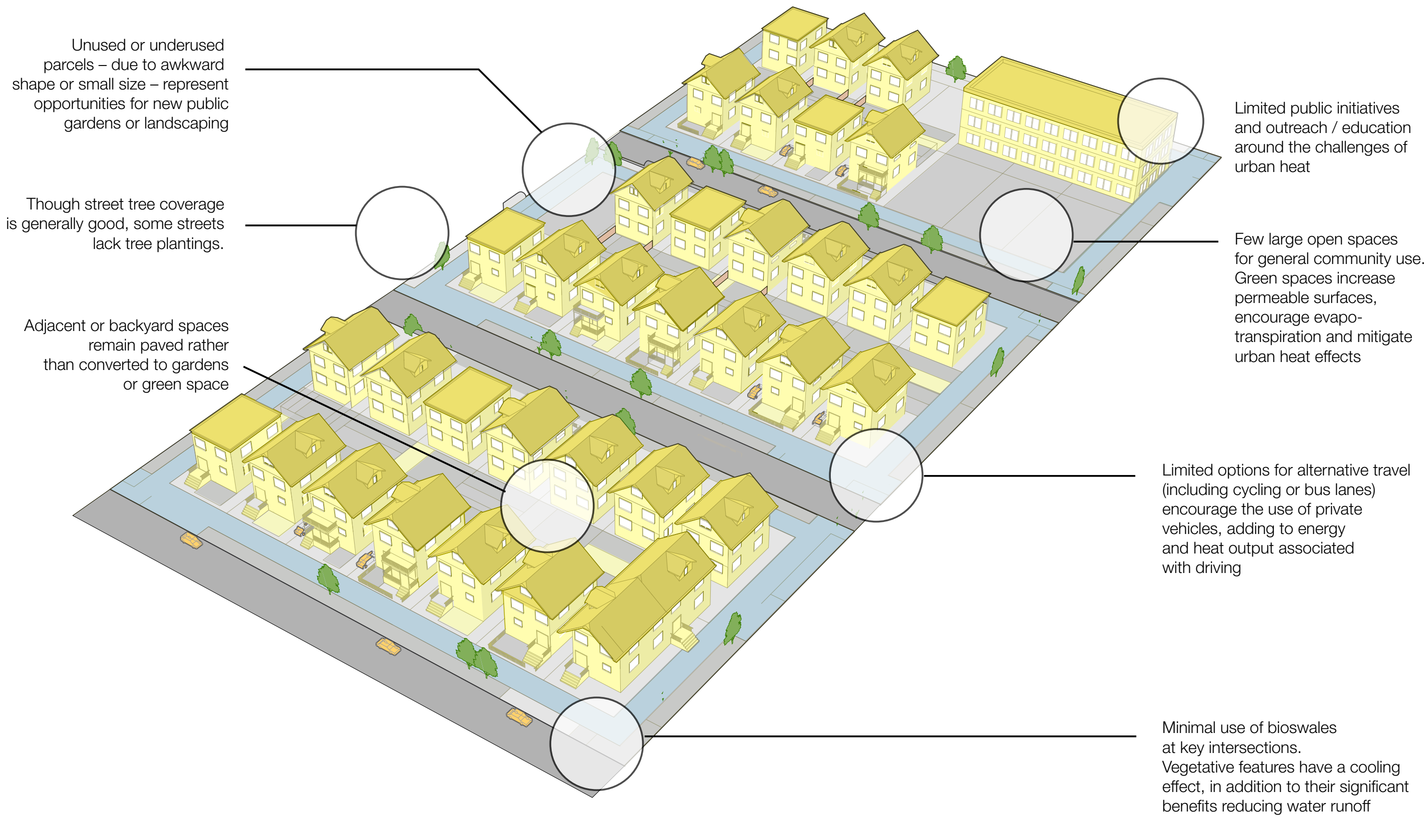


Figure 52: Potential Heat Concerns at a Neighborhood Level

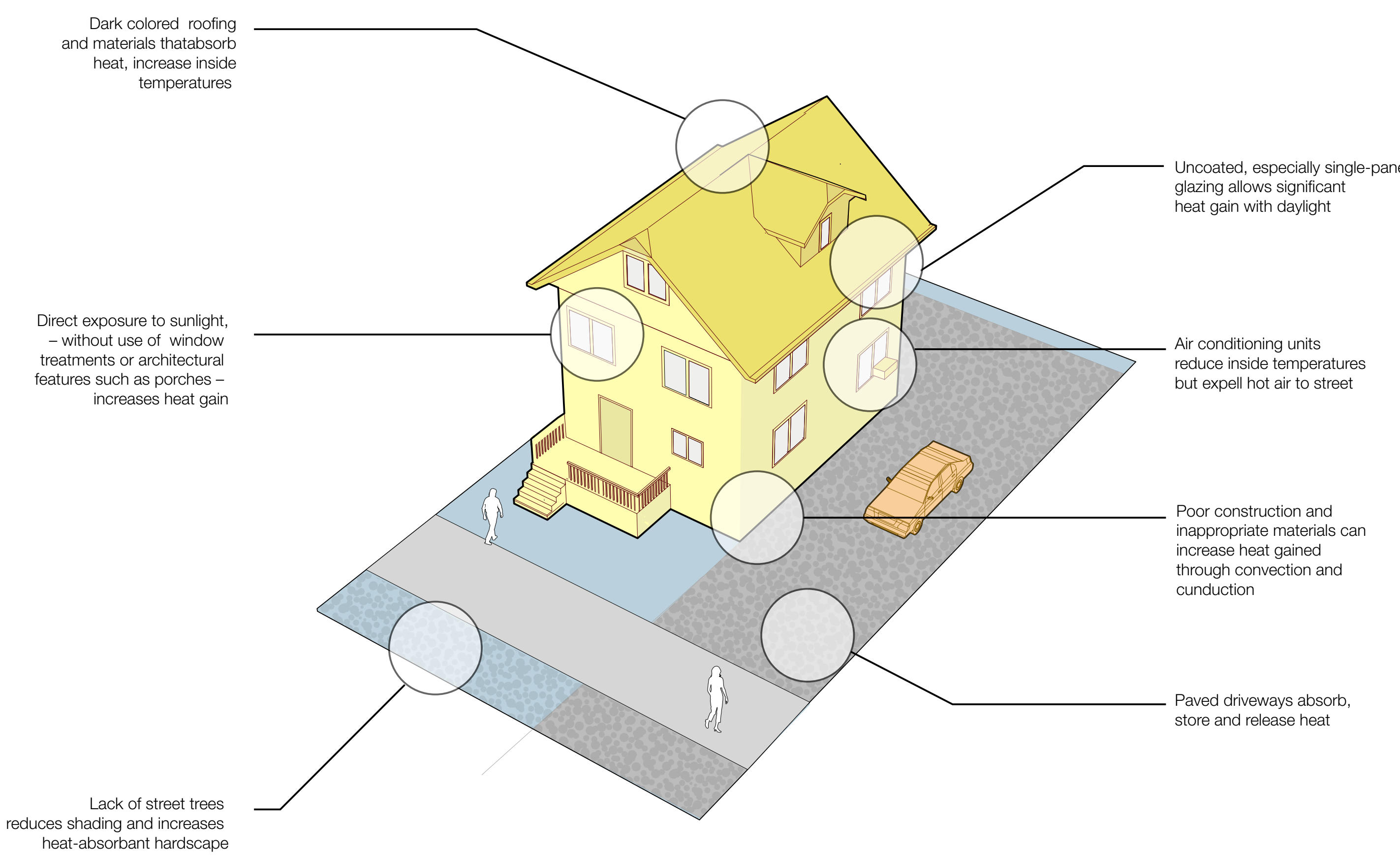


Figure 53: Potential Heat Concerns for a Typical Somerville Two-Family Structure

8

PRIORITY 8: Climate change presents the potential for serious public health impacts to vulnerable populations.

Vulnerable populations, including the elderly, young, disabled, limited English proficiency residents and low-income residents, typically stand to suffer more frequently and severely from climate-related impacts. Vulnerable populations within Somerville are concentrated in West Somerville, Ward Two & Inner Belt, East Somerville & Assembly Square, Ten Hills, and Winter Hill. When high concentrations of vulnerable populations are coupled with high exposure to coastal and precipitation flooding and heat risk, such as in East Somerville & Assembly Square, the personal and community impacts can be devastating.

Lower income residents have a more difficult time recovering from flooding damage due to limited or lack of insurance, and less disposable income to pay for repairs. As a result, residents may have to miss work, often without compensation, to recover from the damage, further increasing economic burdens. When houses with water damage are not repaired quickly, diseases and illnesses can spread more quickly, leading to more days without income. Residents who do not speak English may feel isolated and unable to ask for help. Elderly, young and disabled residents may be dependent upon others for care and support, while those they rely on are tied up or need to take care of themselves first. In heat wave or high heat conditions, vulnerable populations are more susceptible to heat-related illness and mortality because they spend more time outdoors (due to the nature of their work), because of their reliance on public transportation, and/or because of a lack of access to indoor cooling systems.

Likewise, warming climates allow for the propagation of vector-borne diseases carried by insects that might otherwise not survive in colder environments. Examples include West Nile Virus, Eastern Equine Encephalitis, Zika Virus, Lyme Disease and Dengue Fever. Air quality is another aspect that is often negatively impacted by extended periods of extreme heat, resulting in increased respiratory and cardiac health concerns.

In some cases, there are direct actions Somerville can take to reduce the climate exposure and the associated risks to vulnerable populations. For heat, increasing shade along transit corridors and providing more indoor and outdoor cooling centers can improve resilience during high heat conditions. This opportunity overlaps with the opportunity to shape the way Assembly Square and Union Square are redeveloped, since the developments are located in areas with more concentrated numbers of vulnerable populations. In terms of coastal and precipitation flooding, any public infrastructure projects in these areas can reduce flood risk and support vulnerable populations. However, residents who live in public housing may rely on Somerville to advocate to the Somerville Housing Authority for improvements to public housing complexes.

9

PRIORITY 9: Open space and trees are highly valuable asssets to Somerville and need to be protected and enhanced.

Open spaces and natural assets across Somerville are exposed to coastal flooding (Draw Seven Park, Foss Park, Mystic River Reservation), precipitation flooding (Foss Park, Lincoln Park, Glen Park, Albion Playground, Hodgkin’s-Curtin Park) and heat (citywide, but parks, trees and plants in Davis Square, Ward Two & Inner Belt, and East Somerville & Assembly Square have increased exposure based on UHI factors).

Unfortunately, Somerville only owns 37% of its open spaces.[48] Althought parks like Draw Seven and Foss Park are owned by the state, the city can advocate to the state for improvements to these important state-owned parks.

According to the Somerville Open Space and Recreation Plan, 2016-2021, the city is already undertaking several measures to prepare for, mitigate and adapt to climate change in parks under the city's jurisdiction, including:

• Selecting plant and turf species that are more resilient to warmer/more severe climates and are more drought tolerant;

• Employing sustainable practices in the maintenance of parks as they relate to materials used, plant health and the ecosystems of parks;

• Reducing water usage through plant species selection, sustainable maintenance practices, low-flow water heads in water features, as well as the capture and reuse of stormwater;

• Improving stormwater retention capacity in all parks through the use of permeable pavements, underground storage chambers to store water, and rain gardens;

• Increasing tree canopy on sidewalks, parks and open spaces to reduce urban heat island effects. This includes: surveying health and level of tree canopy citywide; directing resources for replanting and arbor-care as needed to ensure shade and healthy trees; selecting species of trees that adapt to heat, drought, pests and wind; and, continuing to revise tree plantings; and,

• Reducing energy consumption for park and field lights, and fountains by continually upgrading energy efficient systems and equipment.

However, it is important to note that increasing vegetation and improving stormwater retention will not protect the parks and surrounding infrastructure from the risks of flooding. Additional flood protection projects and inititatives should be undertaken by the city to supplement the mitigation and adaptation efforts currently underway.

While the location of many of Somerville's parks means they are exposed to flooding, their location can be used to their advantage. Draw Seven Park, while a state-owned park, is in an opportune location to develop flood protection landscaping to protect the infrastructure and building assets that are situated inland of the park. The city can look to develop future parks, and expand and/or redesign existing parks in strategic locations (along waterways and roadways and in areas with limited tree canopies) that can alleviate flooding and heat exposure. Strategic design of Somerville's existing and planned open spaces could lead to multi-functional parks that provide flood protection and recreation opportunities.

Conclusion

While many of these priorities can be addresses individually, several of these priorities and the larger concerns around climate change are actually systems-based issues that will require a coordinated, regional effort in order to create resilient adaptation solutions. The transportation system and Amelia Earhart Dam have been highlighted above. Other specific regional assets include the Mystic Generating Station in Everett, public service and safety organizations, healthcare facilities, and the food distribution network in the region.

48 Somerville Open Space & Recreation Plan, 2016-2021. http://archive.somervillema.gov/sites/default/files/documents/Somerville.%20OSRP%202016-2021_lowres.pdf.

The Mystic Generating Station has significance to Somerville as well as the larger Independent System Operators (ISO) in the Boston metropolitan region. Public service and safety organizations such as the District Attorney's Office, the District Court, the Police Department Headquarters, the Fire Department Headquarters and the Emergency Operations Center, all support larger regional needs and impacts to these facilities would likely result in significant impacts in other areas of the City.

Continuous and predictable access to healthcare services will also require a coordinated regional effort, given that impacts to one healthcare center or hospital in the region often results in increased demand for other healthcare services. Additionally, both the New England Produce Center in Chelsea and the Boston Market Terminal in Everett are extremely important food disstribution facilities that are highly vulnerable to coastal flooding; impacts to these facilities in addition to impacts to the major food distribution route around I-93 pose serious threats to the availability of fresh food throughout the region.[49] Finally, the impacts to Somerville's economy will have ripple effects throughout the larger regional economy.

This assessment represents a high-level prioritization of needs across a variety of assets, infrastructure, and populations in Somerville. While some solutions are within Somerville's purview and can be addressed by city government, other solutions, as noted above, will involve a more coordinated regional approach with shared ownership across the public and private sectors. In the next phase of the City's climate planning process, Somerville should leverage existing resources and opportunities to develop solutions that provide co-benefits and advance resilience across the built, natural, social and economic landscapes of the city.

49 Resilient Food Systems, Resilient Cities: Recommendations for the City of Boston, 2015. http://icic.org/wp-content/uploads/2016/04/ICIC_Food_Systems_final_revised_post.pdf?x96880.

Appendices

Appendix A: Climate Baseline

Appendix B: Emissions Scenarios

Appendix C: Heat Methodology

Appendix D: Precipitation Modeling Methodology

Appendix E: Regional Economic Analysis

Appendix F: Air Quality and Climate Change in Somerville

Appendix G: Vulnerable Populations Methodology

Appendix H: Vulnerability and Risk Assessment Tables

Appendix I: Union Square Economic Analysis

Appendix A
Climate Baseline

Memorandum

ARUP

To	Oliver Sellers-Garcia, City of Somerville	Date	December 22, 2016
Copies		Reference number	248138-00
From	Arup		
Subject	Establishing the Climate Baseline for the City of Somerville's Climate Change Vulnerability Assessment		

The climate baseline for this study will focus on the following areas: sea level rise and storm surge; precipitation; temperature; and wind. There has been considerable climate projection work in the greater Boston area. This study will draw heavily on those pre-existing sources, all of which have been peer-reviewed and vetted through previous studies.   The following text details both the sources and recommendations for each of the climate parameters to be leveraged as part of this study.

Planning Horizons

The majority of future climatology studies within the greater Boston area have adopted the time horizons of 2030 and 2070 to model possible futures. The approach allows for both a near-term and longer-term assessment of possible futures. With respect to temperature and precipitation projections, the time horizons of 2030 and 2070 actually represent the midpoint of a 30-year average. Technically speaking, when we refer to 2030 in these instances, it actually represents the averaging of possible futures spanning from 2015 to 2045 and likewise 2055 to 2085 for 2070. The reason for this smoothing of the data is to dampen the extreme signals that might be associated with decadal-level phenomena such as El Niño. However, when reporting on sea level rise and storm surge, 2030 and 2070 represent the "actual" model years themselves and are not a compilation of different model years.

We recommend adopting similar time horizons for the Somerville study. This allows for both standardization and comparison across the greater metro area, as well as making the most efficient use of data which has already been independently vetted and verified.

Climate Vulnerability Baseline

<u>Sea Level Rise and Storm Surge</u>

Methodology

Sea level rise (SLR) and storm surge pose significant risks to the metro-Boston region. Accurate modelling is essential in determining how often and at what depth flooding may occur under changing climate scenarios spanning the next 50 plus years. For this study, we intend to rely heavily on the MassDOT/Woods Hole Group probability-based model (BH-FRM) for sea level rise and storm surge. This approach has been peer-reviewed by numerous subject matter experts from academia and regulatory agencies and has been adopted as the state standard. The model is superior to the traditional FEMA approach since the WHG model incorporates future climatology including sea level rise and an evolution of storm types that are projected to occur.

While sea level rise (SLR), and SLR combined with storm events, can simply be evaluated by increasing the water surface elevation values and comparing the new water elevation with the topographic land elevations, this rudimentary "bathtub" approach does not accurately represent what may actually happen due to sea level rise, and is certainly unable to represent the dynamic nature of storm events. For example, the "bathtub" approach does not account for critical physical processes that occur during a storm event, including waves and winds; nor can it determine the volumetric flux of water that may be able to access certain areas. Therefore, the bathtub approach may be viable to provide a first order identification of potential areas that may be vulnerable to sea level rise, but should not be relied upon to assess risk for critical infrastructure.

Accurate sea level rise and storm surge modeling requires an improved representation of the physical processes, as well as accurate and higher resolution predictions of inundation due to the combination of sea level rise and storm surge for site-specific locations. Therefore, in order to assess the risk, evaluate the resiliency, and plan for mitigation and adaptation options in Somerville, a physics-based hydrodynamic modeling will be utilized to determine potential flooding. This type of coastal hydrodynamic modeling includes:

- An extensive understanding of the physical system as a whole
- Inclusion of all significant physical processes affecting water levels (e.g., riverine flows, tides, waves, winds, storm surge, sea level rise, wave set-up, etc.)
- Full consideration of the interaction between physical processes
- Characterization of forcing functions that correspond with real world observations
- Resolution that will be able to resolve physical and energetic processes, while also be able to identify site-specific locations that may require adaptation alternatives
- Inclusion of various types of extreme weather events, including tropical (hurricanes) and extra-tropical

A two-dimensional hydrodynamic model (ADCIRC), tightly coupled with a wave generation and transformation model (SWAN), will be applied to provide a complete and accurate representation of water surface elevations and flooding throughout the Boston Harbor area and surrounding upland. Specifically, the highly detailed model developed for the Massachusetts Department of Transportation (MassDOT) and the Federal Highway Administration (FHWA) for assessing potential vulnerabilities in the Central Artery tunnel system, will also be used to assess risk in areas expected to be influenced by coastal storms and sea level rise.

A probability-based flooding model reports both the yearly chance of flooding as well as the depth of flooding associated with particular events. The extent and depth of flooding will be depicted both in maps and in probability of exceedence tables that show anticipated depths of flooding for various storm events, ranging from 0.1% (1000-year storm) through a yearly occurrence, for both the 2030 and 2070 time horizons.

Memorandum

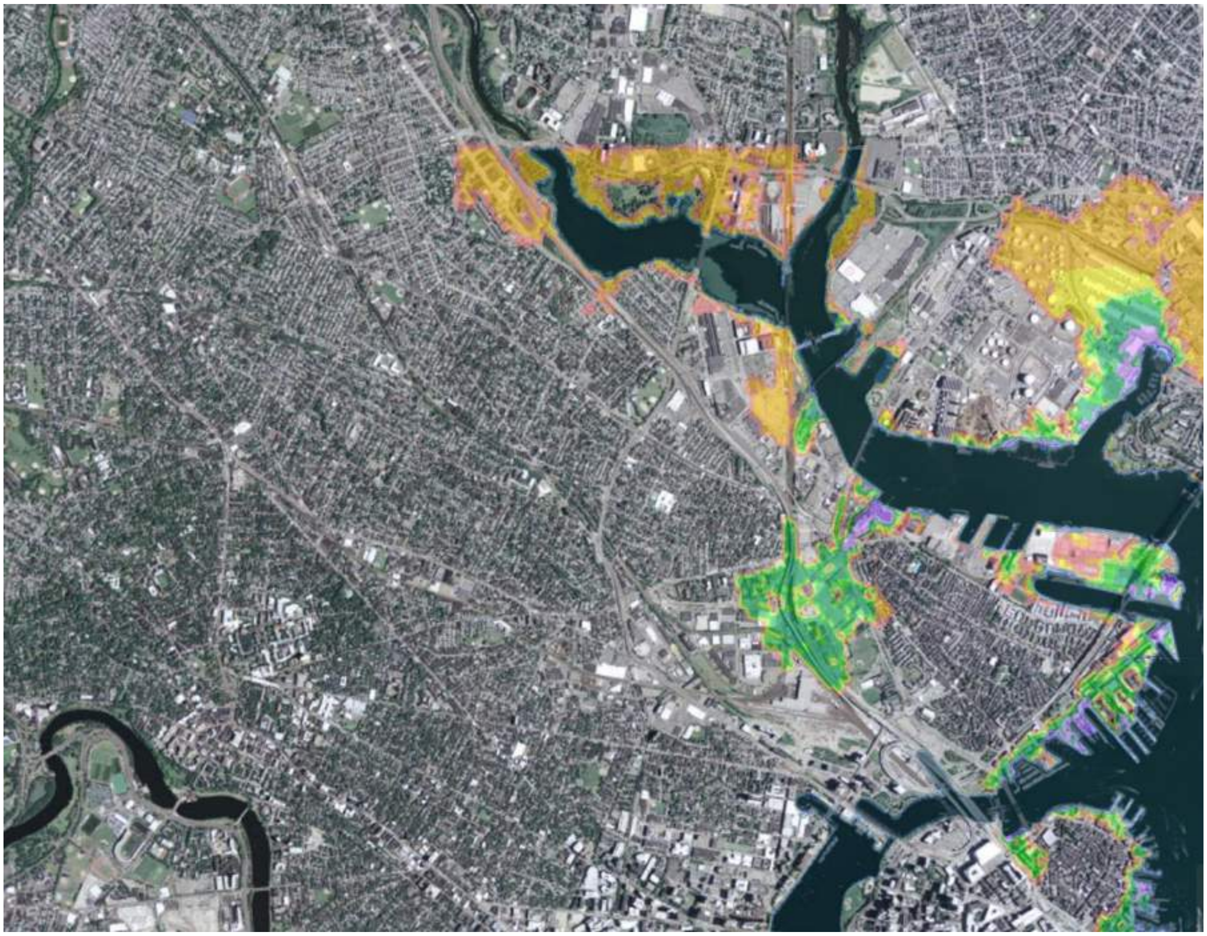


Figure 1. 2030 regional probability-based flooding

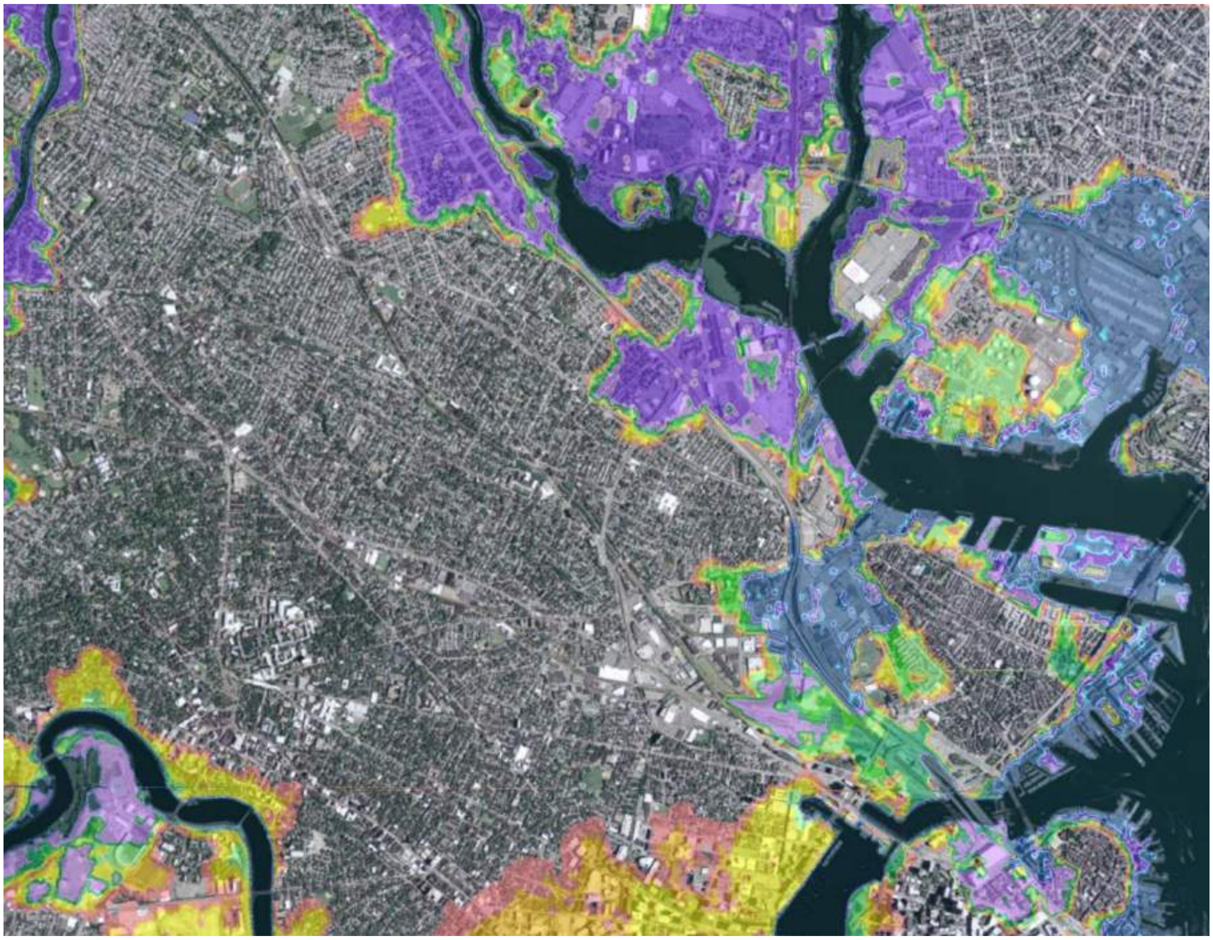


Figure 2. 2070 regional probability-based flooding

While a probability-based approach is useful in determining the likelihood of flooding in a given area for a given year, a consequence-based approach focuses both on the type of event that could cause the damage as well as the maximum extent and depth of possible flooding. Understanding the intensity of flooding associated with particular storm events is important from an emergency preparedness perspective and more closely approximates the hurricane hazards mapping produced by the Army Corps. We have been able to refine the Corp's model using the refined data in the WHG model. A consequence-based approach is also critical to be able to ensure business continuity and on-going functionality for "cannot fail" facilities – regardless of the impact. Examples of these resources include hospitals and public safety facilities, and the associated criticality of ensuring accessibility to these by essential staff and people-in-need.

The consequence-based flooding analysis focuses more on extreme events – those events with a low probability of occurrence but significant consequences. These will be modelled in order to determine the maximum foreseeable impact with respect to coastal flooding. The intent is to capture the worst storm typology for each geography and use that as a baseline. These events takes into consideration duration, significant wind speeds, and substantial flooding related to both a larger storm surge and coinciding with the period of the tidal cycle that would result in the worst case flooding for that event (e.g., for a hurricane a rising tide approximately 2 hours before high tide). The extreme storms will be a mix of historic data that define the event and future climatology. Six proposed flooding scenarios will be developed by optimizing storm conditions observed during previous events including hurricanes and nor'easters. In general, these storms represent a 1-in-1000 year event. These recommended scenarios are as follows:

(1) The Perfect Storm occurring with maximum parameters – A hybrid storm event grounded in reality, but perfectly timed with a rising tide and energized to represent an expected water surface elevation in line with a more extreme event (a 500 to 750 year event).
(2) A Great Nor'easter – This storm would be expected to occur once in a 500 to 1000 year period. The Nor'easter event is based on the Blizzard of 1978 climatology.
(3) A CAT 3 Hurricane with optimized parameters for New England impact - An extreme hurricane developed to represent a CAT 3 hurricane at landfall synced with a rising tide and hurricane parameters (track line, radius to maximum winds, etc.) geared towards impacts.
(4) A CAT 3 Hurricane with extreme precipitation values added. This will be a first order proxy in which the precipitation volume will be added directly to the water elevation data received from WHG – the precipitation and coastal flooding levels will not be joined in a model since this is a very involved modeling process which is beyond the scope of this project.
(5) The Surge Hurricane – Instead of using the CAT definition, this model will focus on the actual expected water surface elevation. We will create a hurricane, based on the complete realistic set we already have, but scale it such that it is capable of producing a specific water level elevation that is equal to a specific event. This will be a realistic hurricane in form and function, but synthetically energized and directed to produce an optimized surge condition.
(6) A Regional Surge Event independent of storm category - A representative surge condition corresponding to a once in a 750 to 1000 year water level. This scenario would encompass fewer dynamics (winds, waves, etc.), but would focus on a wide-spread regional surge condition. It does not focus on the form of the hurricane – only the large storm surge of the system (similar to a tsunami with respect to dynamics).

	Tide	**Wind**	**Track Line**	**Flood Elevation**
Perfect Storm	Rising tide (~ 2 hours before peak)	Hybrid grounded in reality	Hybrid grounded in reality	Based on spatial model results
Great Nor'easter	Based on 1978 Blizzard	Based on 1978 Blizzard	Based on 1978 Blizzard	Based on spatial model results
Cat 3 Hurricane optimized for NE	Synced with rising tide at landfall (~ 2 hours before peak)	Optimized for max impacts to New England, 111-129 mph	Optimized for max impacts to New England	Based on spatial model results

Cat 3 Hurricane + extreme precip	Synced with rising tide at landfall (~ 2 hours before peak)	Optimized for max impacts to New England, 111-129 mph, central pressure 945-964 mb	Optimized for max impacts to New England	Based on model results + precip volume from extreme rain event (e.g. 10 yr storm)
Surge Hurricane	Rising tide (~ 2 hours before peak)	Synthetically energized to produce optimized surge for Boston	Synthetically energized to produce optimized surge for Boston	Based on spatial model results
Regional Surge	With High tide	Spatial variations due to wind effects reduced, not a hurricane, no specific wind effects	No specific trackline	Based on spatial model results, large storm surge at the system similar to a tsunami

Table 1. Consequence-based flooding scenarios

Memorandum

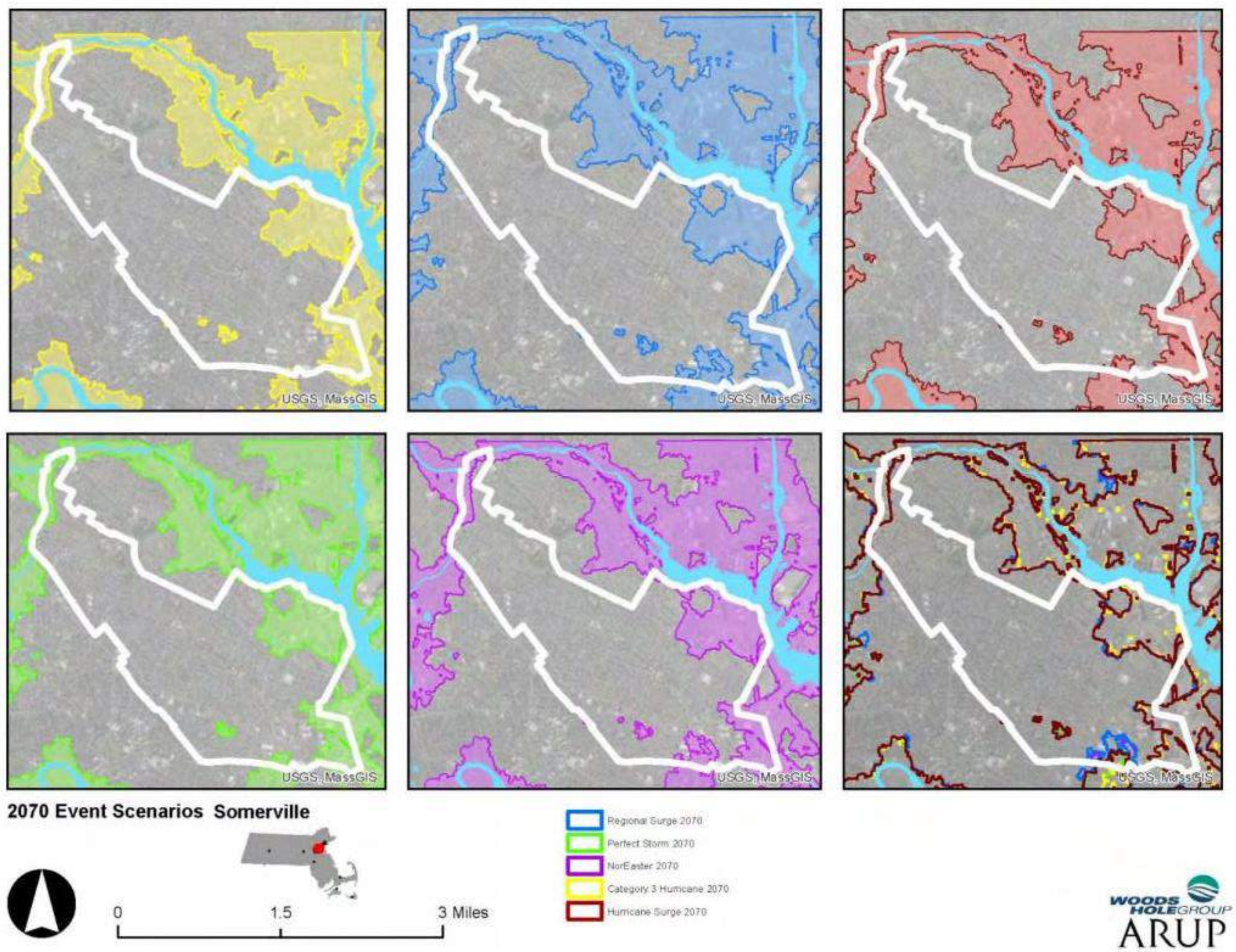


Figure 3. Consequence-based flooding scenarios for the City of Somerville

Historical Context

<u>Nor'easters</u>
There have been on the order of 300 nor'easters over the last 100 years, which results in a much higher probability of a nor'easter impacting the coastline than a hurricane, and some of these nor'easters have resulted in large surges (Perfect Storm – 4.1 feet; Sandy – 4.6 in Boston Harbor) that are comparable or exceed hurricanes. Also since nor'easters generally last at least one full tidal cycle, the chances of getting a higher total water level (syncing with high tide) are much better than for a hurricane. That is why most of the largest historic flood events in Boston are nor'easters.

<u>Hurricanes</u>
Historical analysis of hurricane data shows that since 1858, Boston has been impacted by an estimated 23 hurricanes of varying intensities. The most intense hurricanes to pass within 150 miles of Boston were two Category 3 hurricanes (sustained speeds of 111-129 mph), eight Category 2 hurricanes (96-110 mph) and 13 Category 1 hurricanes (74-95 mph). This translates roughly into a 1 in 100 year chance of encountering a Category 3 hurricane each year (Kleinfelder – Massport Disaster and Infrastructure

Resiliency Study, 2014). With respect to storm surge heights, an analysis spanning 1921-2012 indicates a 5.1 foot surge for a 100-year event, 5.9 feet for a 500 year event and 6.2 for a 1000-year event (Kirshen, Kleinfelder – Massport study, 2014).

Hurricane/Superstorm Sandy – 1:1,000 year event

For the New York and New Jersey area, this storm has been classified as a 600- to 650- year storm based on the surge itself or a 990-year event based on surge and tide. Other unusual aspects included the duration of the storm itself as well as its overall geographic extent (stretching from Chicago to the east coast). Highest wind recording from Sandy was 59.7 mph at Cape May, NJ. The highest recorded storm surge was 12.65 ft in Kings Point, NY (NOAA-NOS, Hurricane Sandy Water Level and Meteorological Report, 2013; p. 3).

Great New England Hurricane of 1938 (recurrence period unknown)

The Great New England Hurricane of 1938 is often cited and therefore provides a useful landmark. It ranks as the most significant and destructive of the major Northeast hurricane in the last 100 years. "The eye of the hurricane was observed in New Haven, Connecticut, 10 miles east of Milford. The center made landfall at the time of astronomical high tide, moving north at 50 mph. Unlike most storms, this hurricane did not weaken on its way toward Southern New England, due to its rapid forward speed and its track (National Weather Service, The Great Hurricane of 1938; http://www.weather.gov/box/1938hurricane)." Barnstable's All-Hazards Mitigation Report (2010) provides a good summary of the event:

"The 1938 Hurricane struck on September 21 at a high tide that coincided with the highest astronomical tide of the year, pushing a storm surge of 12 to 15 feet across the south coast and up the many bays and inlets. The destructive power of the storm surge was felt throughout the coastal community. Sections of Falmouth and New Bedford were submerged under as much as 8 feet of water. Winds of over 120 miles per hour blew across the coastal regions. Extensive damage occurred to roofs, trees, and crops. Widespread power outages occurred, which in some areas lasted several weeks…Parts of interior Connecticut and Massachusetts not only bore the brunt of high winds, but also experienced severe river flooding as rain from the hurricane combined with heavy rains earlier that week and produced rainfall totals of up to 17 inches. This resulted in some of the worst river flooding ever experienced in parts of Connecticut and Massachusetts. This powerful storm caused 564 deaths and over 1,700 injuries. Nearly 9,000 homes and businesses were destroyed with over 15,000 damaged. Damage to the fishing fleets in southern New England was catastrophic, with a total of 2,605 vessels destroyed and 3,369 damaged." Despite this significant damage in the south, it is interesting to note that in the Boston area, this does not even rank within the top 200 highest water elevation events (Kirk Bosma, WHG, personal communication, July 2015).

Hurricane Katrina – 1:250 year event

Hurricane Katrina made landfall in Louisiana as a Category 3 hurricane with maximum winds of 140 mph (Waple, Anne; "Hurricane Katrina"; December 2005; NOAA's National Climatic Data Center, Asheville, NC). The storm generated a 28-foot storm surge, the highest ever recorded for an Atlantic-based hurricane (Masters, Jeffrey, no date. U.S. storm surge records; Weather Underground; http://www.wunderground.com/hurricane/surge_us_records.asp). The event was also accompanied by as much as much as 15 inches of rain in a 24 hour period (Waple, Anne, 2005. Hurricane Katrina, Dec, 2005: NOAA's National Climatic Data Center, Ashville, NC). "The 28-foot surge that hit Mississippi's coast could be classified as a 400-year event, and the 19.5-foot surge in St. Bernard was that of a 250-

year storm. By the time Katrina reached New Orleans, the surge had been knocked down to between 10 and 13 feet" (The Editorial Board; Nola.com, 2013; Eight Years after Katrina, a stronger system of storm protections; Times-Picayune, August 18, 2013). The Army Corps of Engineers has been credited as citing this as a 1:250 year event.

Netherlands – 1:10,000 year event
The Netherlands designs for a one-in-10,000 year event. However, the overall surge and anticipated sea level rise are significantly lower that what is currently experienced and likely to be experienced along the East Coast. Surge levels for the catastrophic storm of 1953 which resulted in the deaths of 1800 people were 2.5 meters (8.2 feet) at their max. For comparison sake, maximum surge levels from Sandy were closer to 13 feet.

Regional Projections
Over the past decade, the global trend in relative sea level rise (RSLR) has been 0.11 inches per year. The RSLR is expected to increase by 3.2-7.4 feet in the metro-Boston region by 2100 and there is an anticipated sea level rise (SLR) of approximately 6-9 inches in the next fifteen years (source: CRB ppt).

Increases to SLR and storm surge are dependent on global emissions scenarios. As a baseline, projections for anticipated changes to the likely occurrence of the 1% annual storm event (or 100-year storm) under moderate and high emissions scenarios are as follows: the 1% annual storm event will become a 2.5% annual storm event under moderate emissions scenarios in 2030 and 2.8% under high emissions scenarios; 8.7% under moderate emissions scenarios in 2050 and 14% under high emissions scenarios; and in 2100, the 1% annual storm event will have a likely occurrence of 75 times per year under moderate emissions scenarios and 230 times per year under high emissions scenarios (source: BRAG report).

Precipitation

Methodology

Precipitation will be assessed according to three variables: (1) historic trends, (2) projected increases and (3) a translation of those increased volumes into mapped flooding results, where possible. Historic trend information will be presented as the 10-year, 100-year and 1000-year, 24-hour design storms, representing storms with a 10%, 1% and 0.1% probability of occurrence in any given year, respectively. Future projections will be based on SWMM model calculations for the 10-year and 100-year storm events; projections for the 1000-year storm event are not available. A high-level assessment will also be developed for how river flooding might be impacted by these increased precipitation volumes.

We anticipate relying heavily on the downscaled projections for precipitation that were developed by Katharine Hayhoe for the City of Cambridge. Hayhoe projects an increase in average precipitation of about 15-20% (or 6-10 inches) by the 2070. Additionally, Hayhoe's analysis anticipates an increase in precipitation intensity of more than 5% by the 2030s and more than 15% by the 2070s (source: Hayhoe 1). While the Cambridge precipitation data will likely provide a solid baseline for this study, there is also value in including other sources to expand the overall discussions. These include the SWMM-CAT and NASA's NEX-DCP30 with respect to future projections, as well as the NCDC and NOAA Atlas 14 just to understand the extent of extremes that have been experienced in the past. In our experience, we have found that it is often useful to provide information on past events to create a benchmark against which future, modelled projections can be viewed. It provides context and relevancy to what could otherwise be a somewhat abstract exercise. Likewise, although it may be determined that the downscaled data gathered as part of the City of Cambridge work will form the baseline here, we also feel it is important to compare those numbers against the projections from the EPA, NASA and NOAA tools both to understand the spread among them, the assumptions and data sources behind each and, most importantly, to provide the City of Somerville with the necessary "crib notes" to justify the data that was used to create the climate baselines.

With respect to precipitation, we anticipate working closely with the City of Somerville and its vendor, MWH, to determine which particular storm types, intensities and recurrence intervals would have the most relevance for this phase of this work. Currently, we have proposed the following three levels of focus:

(a) City-wide – "bathtub" approach

We will assume that all drainage pipes are surcharged (i.e., no precipitation to be accommodated in drainage system) and plot flooding based on projected precipitation levels

This will be a conservative estimate but will provide us with insight into the areas vulnerable to flooding; can be further vetted by studying 311 logs (especially for the July 10, 2010 storm) – known hot spots, and eventually refined with more specific detailed information for key areas

(b) Deeper dive at Union Square based on precip-only

MWH will do a complete model run at Union Square based on the climate parameters and storm types provided by Arup (developed in consultation with the City, MWH and WHG)

(c) Combined modelling at Assembly Row and West Somerville

If we can obtain permission to use existing hydrology models, then there is an opportunity to develop a joint assessment between the coastal and precip impacts and do one or two high-level runs showing the flooding results that would arise from a combined coastal and rain storm event.

We anticipate that precipitation will be driving the majority of flooding throughout Somerville until somewhere in the time period of 2035/2040. At that point, the WHG's model is projecting that the Amelia Earhart dam will be overtopped and flanked at regular intervals. Once the dam has been compromised, the associated ocean flooding will overwhelm precipitation-driven flooding that may be occurring at that time – at least in the eastern portions of Somerville. During these types of events, the coastal flooding model becomes more relevant in predicting the full extent and depth of inundation. However, it will also acerbate upstream flooding as surcharged streams and surface run-off are essentially dammed by the downstream coastal flooding. Outfall pipes also have the potential to become significant inlets during these events, driving more inland flooding. With that said, there will be portions of Somerville which will be dominated more by precipitation-based flooding, as well as periods when rain falls independently from coastal storms.

Regional Projections

From 1958-2010, the Northeast United States saw a 70% increase in precipitation for the heaviest 1% of daily precipitation events (source: CRB ppt). This increase was the largest increase in the United States and is projected to continue to increase; although magnitude will be dependent on the interplay with other climatic factors.

The Boston Water and Sewer Commission (BWSC) report projected that 10-year/24-hour precipitation events could increase by as much as 27% by 2100 if substantial strides are not made towards reducing emissions. Under a reduced emissions scenario, 10-year/24-hour precipitation events are still projected to increase 16% over the current baseline value of 5.24 inches. The table below details the projected increases, under a reduced emissions scenario and a historic emissions scenario (source: BRAG report).

10-year/24-hour Precipitation	*Baseline (1948-2011)*	*2030*	*2050*	*2070*	*2100*
AR4 B2 Scenario: Reduced Emissions	5.24in	+5%	+8%	+11%	+16%
AR4 A1FI Scenario: "Business as usual"	5.24in	+6%	+12%	+18%	+27%

Table 2. Projections of 10-year/24-hour precipitation values based on the BWSC report.

Temperature

Methodology

Temperature will be assessed based on historic records, with a particular focus on heat. The highest temperature recorded for the City of Somerville (or closest weather station) as well as a historic occurrence of heat waves will inform the assessment. Katharine Hayhoe's downscaled heat projections for the City of Cambridge will be used as a baseline for the general ratio of increase expected across the state as well as the increase in the number of days of extreme heat. Hayhoe's analysis projects an average increase in the City of Cambridge of 2-3 degrees F under both emissions scenarios by the 2030s and by 2070, a 4-5 degree F increase under lower emissions scenarios and a 7-8 degree F increase under higher emissions scenarios. Similarly, Hayhoe projects an increase in temperature extremes: days over 90 degrees F are projected to increase from the historical average of 11 days per year to between 20 and 30 days by the 2030s. By the 2070s these extreme heat days will increase to between 30 to 44 days per year under lower emissions scenarios and 55 to 70 days per year under higher emissions scenarios (source: Hayhoe 1). More recent work presented in the Boston's Climate Ready Boston indicates slightly higher levels. The graphic below summarizes that information.

Memorandum

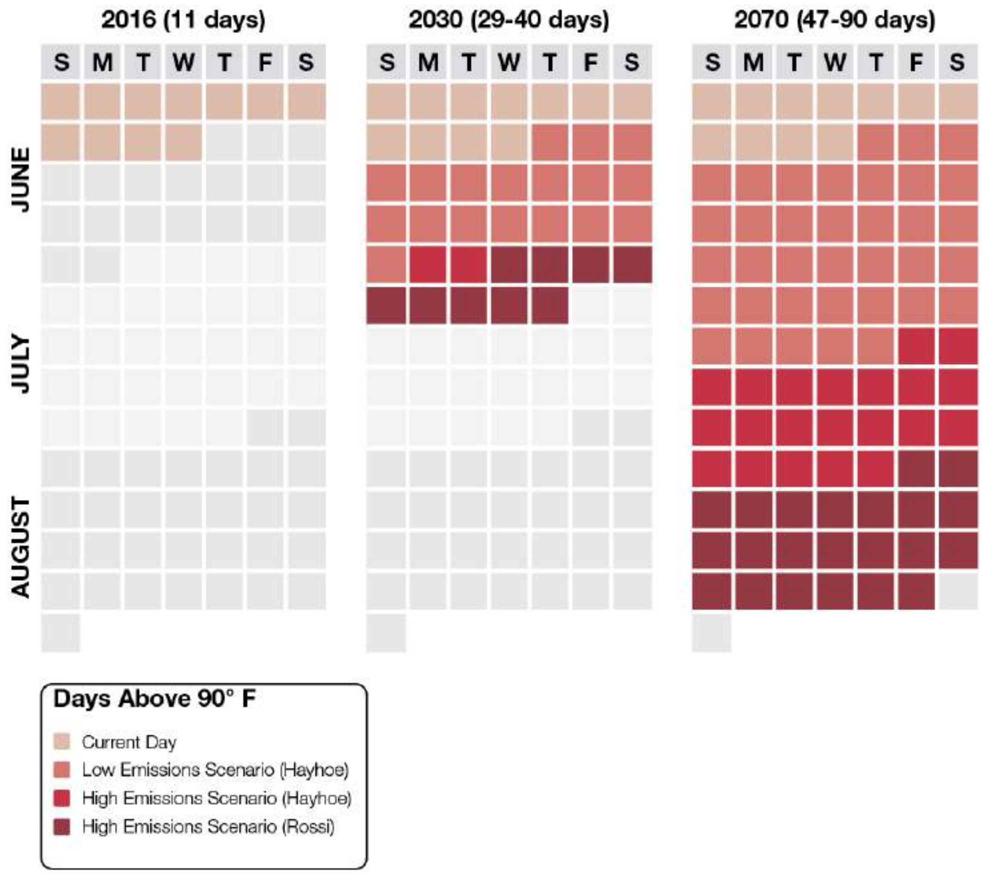


Figure 5. Projected shifts in temperature

Appendix B
Emissions Scenarios

Memorandum

ARUP

To	Oliver Sellers-Garcia, City of Somerville	Date	December 22, 2016
Copies		Reference number	248138-00
From	Arup	File reference	
Subject	Emissions Scenarios Technical Memorandum		

Overview of Emissions Scenarios

Emissions scenarios are used to project possible futures with respect to atmospheric carbon concentrations and related temperature levels There are three basic groupings: (1) business as usual – nothing is done to change our current trends in consumption, development and mix of energy types so carbon emissions and associate climate impact continue to increase; (2) some level of adjustment to carbon emissions resulting in a less dire carbon future; and (3) significant changes in current practices, societal and development considerations which fundamentally alter the overall trajectory of the current trend towards levels which are a slight reduction on today's levels.

Of the scenarios presented below, the RCP 4.5 scenario most closely aligns with COP 21 Paris commitment, a global agreement was reached to limit global warming to 2° C by 2100.   The Steering Committee indicated a preference to adopt a planning horizon that included aspects of mitigation as well as recognizing the extent of possible futures if those mitigation steps were not enacted. Based on this, we are recommending the use of two emission scenarios per time horizon – a low and a high which will closely approximate RCP 4.5 and 8.5 model projections.

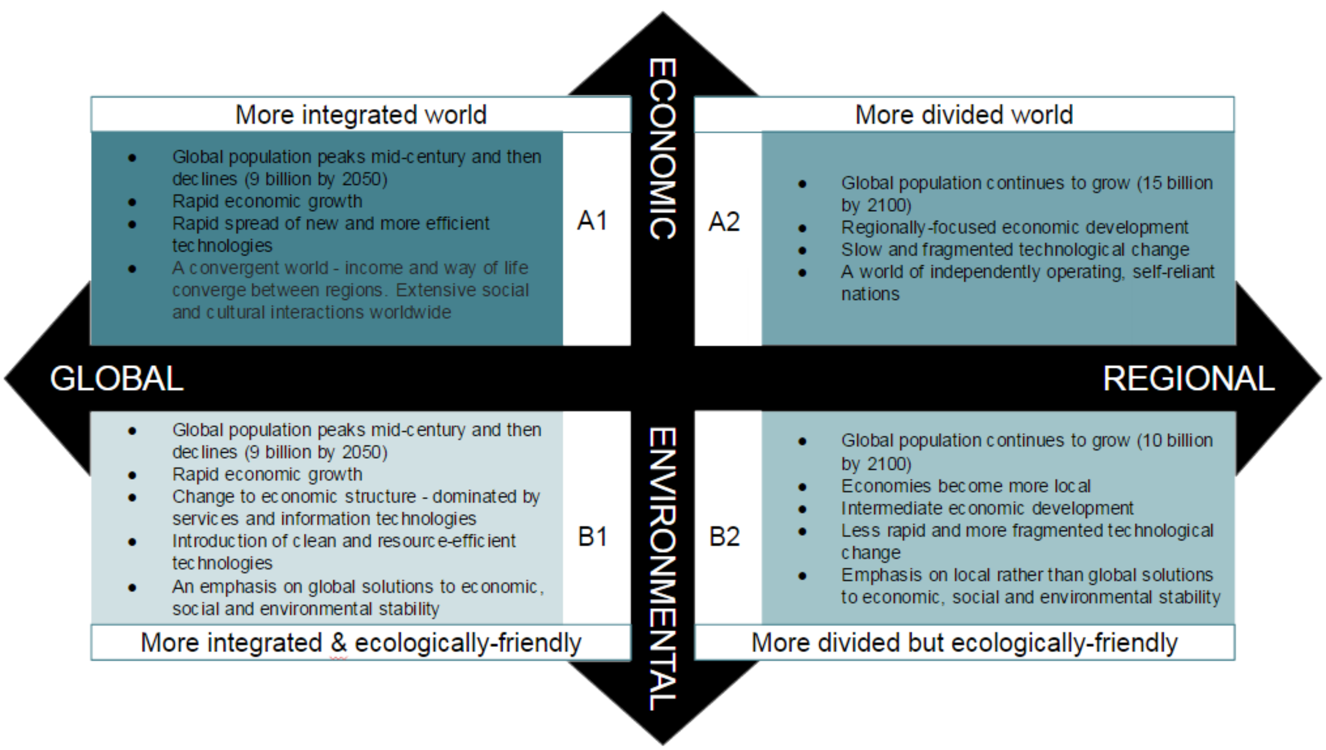
Coupled Model Intercomparison Project (CMIP)

The Coupled Model Intercomparison Project (CMIP) is a product of the World Climate Research Programme (WCRP). CMIP established a framework under which scientists can analyze Global Climate Models (GCMs) in a systematic fashion. Since its inception, CMIP has seen great support and participation from the international climate modeling community. The emissions scenarios produced by the Intergovernmental Panel on Climate Change (IPCC) are largely based on the research coming out of CMIP. Phase 3 of CMIP (CMIP3) provided the underlying assumptions for the scenarios detailed in the Special Report on Emissions Scenarios (SRES), which were used in both the Third Assessment Report (TAR) and the Fourth Assessment Report (AR4) of the IPCC. The SRES scenarios are explained in more detail below. CMIP Phase 5 (CMIP5) provided the underlying assumptions for the IPCC Fifth Assessment Report (AR5) that revised the scenarios from the SRES and laid out new scenarios, known as Representative Concentration Pathways (RCPs), also explained in more detail below.

One important note, the downscaled temperature and precipitation models produced by Katharine Hayhoe, which will be used as part of the vulnerability assessment for the City of Somerville, utilized the research produced in both CMIP3 and CMIP5 and do not directly correlate to either the SRES or the RCPs.

Special Report on Emissions Scenarios (SRES)

The SRES scenarios lay out a broad range of projections based on a variety of factors that could contribute to the anticipated effects of climate change. The scenarios take into account a variety of drivers and projected changes to human activity, including, but not limited to, greenhouse gas (GHG) emissions, land use developments, technological advancements, economic development, and consumption of fossil fuels, among others. The scenarios can be broadly grouped by the anticipated degree of future globalization and the degree to which human activity prioritizes the economy or the environment. The four main scenarios are: A1, A2, B2, and B1. Al is the highest emissions scenario, which can also be interpreted as a “business as usual” scenario; A2 is a medium-high scenario, B2 is a medium-low scenario, and B1 is a low emissions scenario. The figure below highlights some of the major assumptions underlying the four scenarios.



Representative Concentration Pathways (RCPs)

The IPCC finalized AR5 in November 2014. As part of that assessment, the IPCC established a new set of emissions scenarios, known as RCPs, to replace the previous scenarios established as part of the SRES. “RCPs are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. In addition, the term pathway is meant to emphasize that it is not only a specific long-term concentration…that is of interest, but also the trajectory that is taken over time to reach that outcome” (IPCC Expert Meeting Report, Towards New Scenarios For Analysis Of Emissions, Climate Change, Impacts, And Response Strategies, IPCC 2007). The four emissions scenarios presented are: RCP 8.5, RCP 6.0, RCP 4.5, and RCP 2.6, with RCP 8.5 being the highest emissions scenario and RCP 2.6, the lowest. The scenarios roughly correlate to the SRES scenarios in the following way:

- RCP 8.5 → A1
- RCP 6.0 → A2
- RCP 4.5 → B2
- RCP 2.6 → no predecessor

Each scenario is based largely on the anticipated greenhouse gas (GHG) emissions and the anticipated increase in global temperatures. The assumptions associated with each of the scenarios is as follows:

- RCP 8.5: expected temperature increase between 2.6 and 4.8°C by 2100 and emissions continue to rise throughout the 21st century;
- RCP 6.0: expected temperature increase between 1.4 and 3.1°C by 2100 and emissions peak around 2080 and then decline;
- RCP 4.5: expected temperature increase between 1.1 and 2.6°C by 2100 and emissions peak around 2040 and then decline; and,
- RCP 2.6: expected temperature increase between 0.3 and 1.7°C by 2100 and emissions peak between 2010-2020 and then decline.

The RCP projections also take into account a wide range of scientific and socioeconomic data, such as population growth, reliance on fossil fuels, adoption of climate policies, GDP, energy sources, technological advances, and integration of the world economies, among others. Some of the highlights of that data is detailed in the chart below:

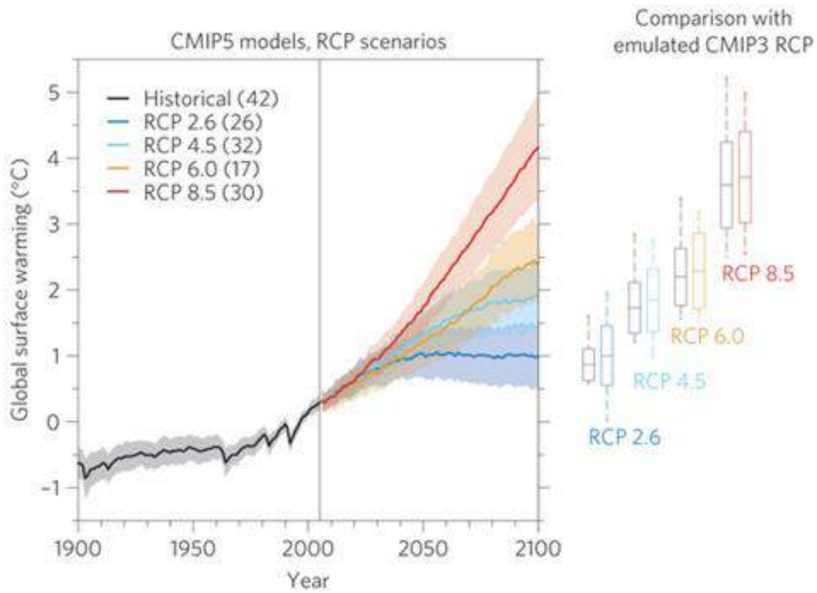
RCP Scenario	Characteristics	Type of Emissions
RCP 8.5	• Three times today's CO2 emissions by 2100 • Global population of 12 billion by 2100 • Heavy reliance on fossil fuels • High energy intensity • No climate policies	High "Business as usual"
RCP 6.0	• CO2 emissions are 75% of today's rate by 2060 and then decline to 25% • Heavy reliance on fossil fuels • Intermediate energy intensity • Stable methane emissions	Intermediate
RCP 4.5	• CO2 emissions increase slightly and then decline starting in 2040 • Lower energy intensity • Stable methane emissions • Stringent climate policies	Low
RCP 2.6	• CO2 emissions stay at today's level until 2020 and then become negative by 2100 • Low energy intensity • Methane emissions reduced by 40% • Global population of 9 billion by 2100	Very Low

At the recent United Nations Climate Change Conference, held in Paris, France in December 2015, commonly referred to as COP 21, a global agreement was reached to limit global warming to 2° C by 2100. More specifically, the commitments include (http://ec.europa.eu/clima/policies/international/negotiations/paris/index_en.htm):

- a long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels;
- to aim to limit the increase to 1.5°C, since this would significantly reduce risks and the impacts of climate change;
- on the need for global emissions to peak as soon as possible, recognizing that this will take longer for developing countries;
- to undertake rapid reductions thereafter in accordance with the best available science.

Although the RCP scenarios were released before this global agreement was negotiated, the scenario that roughly aligns to meeting this goal is RCP 4.5. The graphic below provides additional detail on the temperature projections associated with each of the pathway scenarios.

Memorandum



Recommended Scenarios

Based on comments received from Steering Committee members in May, it seemed that there was a preference to adopt a planning horizon that included aspects of mitigation as well as recognizing the extent of possible futures if those mitigation steps were not enacted. Based on this, we are recommending the use of two emission scenarios per time horizon – a low and a high which will closely approximate RCP 4.5 and 8.5 model projections.

References

Beginner's Guide to RCP

Nature Climate Change

Global Warming Wikipedia

IPCC

CMIP

SRES Wikipedia

COP 21 Paris Commitment

Appendix B of CCVA: Temperature and Precipitation Projections

Appendix C
Heat Methodology

Memorandum

To	Oliver Sellers-Garcia, City of Somerville	Date	December 22, 2016
Copies		Reference number	248138-00
From	Arup	File reference	
Subject	Indoor and Outdoor Heat Methodology		

Overview

Due to data limitations, the analysis of heat vulnerability for the City of Somerville is not intended to be a comprehensive analysis of urban heat island effects in the city. Instead, a methodology was developed, based on readily available to data, to present an initial analysis of the effects of temperature on the landscape of the city, so that the City of Somerville can further investigate heat impacts in those heat-prone areas. An analysis was completed for both indoor and outdoor heat methodology.

The outdoor heat methodology is based on the following variables:

1. Land Surface Temperature (data from TPL)
2. Industrial Land Uses
3. Impervious Surface: Using roadways and non-residential parking lots
4. Emissions: Using ADT values for major roadways
5. Tree Coverage: Using the total number of trees as a proxy for tree canopy
6. Open Space

The indoor heat methodology used all of the same variables as the outdoor heat analysis, and added two additional variables:

1. Building Type: Based on 3 categories (single-family, 2 & 3-family, 4+ units)
2. Air Conditioned Housing Units

Each of the variables were aggregated to a neighborhood scale in order to identify the neighborhoods within Somerville that are most vulnerable to impacts from high temperatures. The neighborhoods were then ranked from one to twelve with one meaning the least exposed/vulnerable and 12 being the most exposed/vulnerable. The ranking for each of the variables was then summed for each of the neighborhoods to generate an overall heat vulnerability score for the neighborhood, for both indoor heat and outdoor heat exposure. Those scores were divided according to relatively low, medium and high vulnerability. The maps below shows the final results of the both analyses.

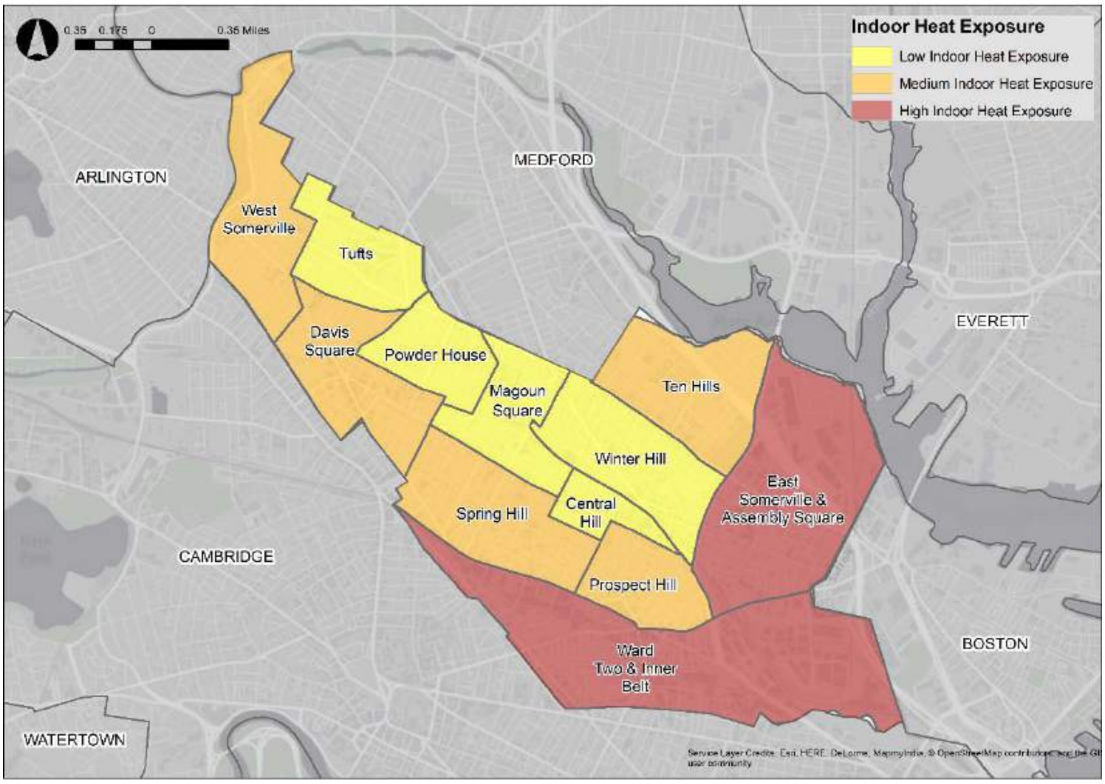


Figure 1: Indoor Heat Exposure Assessment

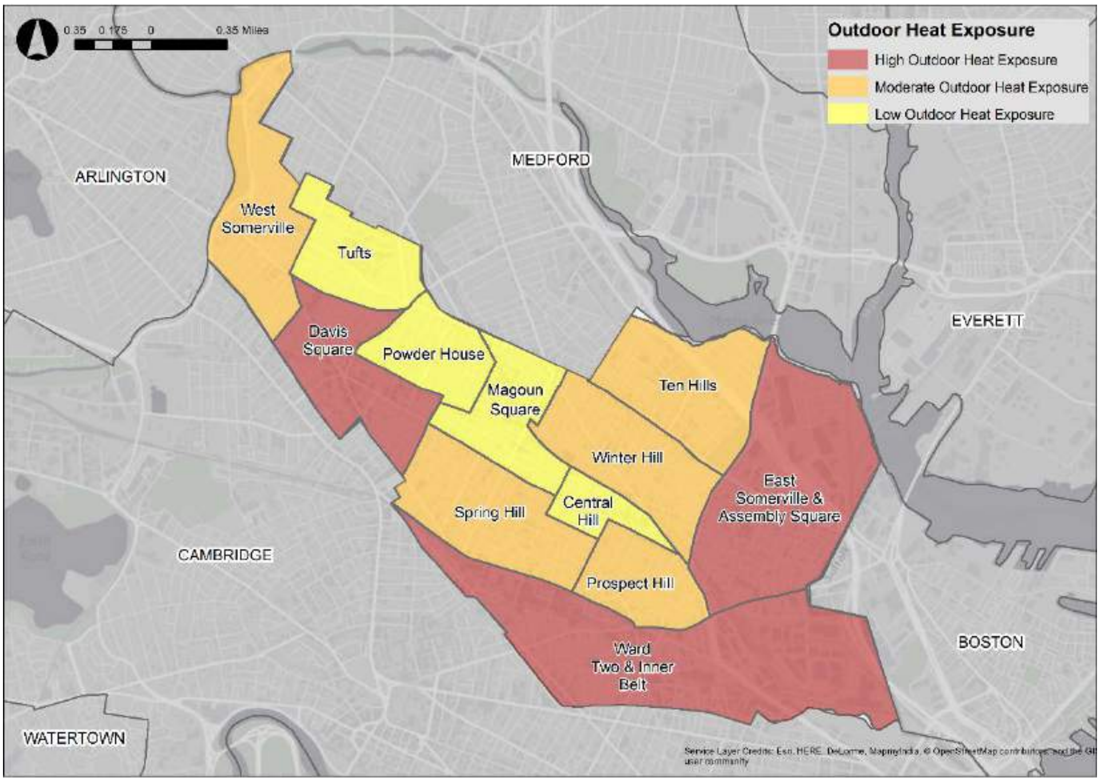


Figure 2: Outdoor Heat Exposure Assessment

The following is a description of each of the data sources used, how the variables were aggregated to the neighborhood scale, and their associated neighborhood ranking. For the full calculations, please refer to the attached excel spreadsheet.

Land Surface Temperature

As part of its Climate-Smart Cities program, the Trust for Public Land (TPL) is developing a national strategy to protect cities from increasing climate risks, including heat vulnerability. The strategy is geared at prioritizing areas that would benefit from targeted adaptation strategies. One of the main focuses of TPL's strategy is geared at cooling neighborhoods by planting trees and developing other strategies to reduce urban heat island impacts. In order to identify strategic areas that would benefit the most from cooling strategies, TPL developed a methodology for identifying land surface temperature "hot spots." The methodology used land surface temperature (LST) data from the Moderate Resolution Imaging Spectro (MODIS) radiometer satellite. The results of TPL's analysis identified both daytime and nighttime hot spots within the larger Boston metro region. The identified hot spots are ranked according to a relative ranking system for the Boston metro region, the relative ranking is not limited to the extents of the City of Somerville's boundary. While the analysis identified both daytime and nighttime hot spots in the Boston metro region, the heat vulnerability analysis for the City of Somerville uses only the daytime hot spots because there are relatively few nighttime hot spots within the border of Somerville, in comparison to the larger metro region; therefore, there was not adequate data to incorporate nighttime hot spots into this analysis. However, we recognize that nighttime hot spots often pose a greater health risk to vulnerable populations than daytime temperatures. More information on TPL's work in the Boston metro region can be found here: https://www.tpl.org/climate-smart-cities%E2%80%93boston.

The analysis for the City of Somerville utilizes the ranking system developed by TPL, where 3 is a moderate priority, 4 is a moderate to high priority, and 5 is high priority, and aggregates the data by neighborhood in order to develop a priority LST score for the neighborhood.

The following calculation was used to aggregate the data:

1. Join the TPL LST GIS layer to the Somerville Neighborhoods layer.

2. Export GIS attribute table for the joined layer.

3. Sum the total land area (in sq. ft) by identified priority ranking within each of the neighborhoods. This would result in a total land area for no priority, priority 3, priority 4, and priority 5 areas in each neighborhood.

Ex: Davis Square

<table>
<tr><th>TPL Priority Value</th><th>Land Area (sq.ft.)</th><th>Land Area Sum (by Priority Value)</th></tr>
<tr><td rowspan="2">0</td><td>69989.17104</td><td rowspan="2">81279.35871</td></tr>
<tr><td>11290.18767</td></tr>
<tr><td>3</td><td>4236544.332</td><td>4236544.332</td></tr>
<tr><td>4</td><td>3596610.512</td><td>3596610.512</td></tr>
<tr><td rowspan="3">5</td><td>6292.584906</td><td rowspan="3">815081.1239</td></tr>
<tr><td>85416.11074</td></tr>
<tr><td>723372.4282</td></tr>
</table>

4. Divide each of the priority total land area values by the total land area of the neighborhood to obtain a percentage for each of the priority values.

Ex: Davis Square

Total Neighborhood Land Area (sq.ft.) = 8729515.30165

% "0" Land Area:

"0" Priority Land Area / Total Neighborhood Land Area

= 81279.35871 / 8729515.30165

= 0.009

= 1%

% "3" Land Area:

"3" Priority Land Area / Total Neighborhood Land Area

= 4236544.332 / 8729515.30165

= 0.485

= 49%

% "4" Land Area:

"4" Priority Land Area / Total Neighborhood Land Area

= 3596610.512 / 8729515.30165

= 0.412

= 41%

% "5" Land Area:

"5" Priority Land Area/ Total Neighborhood Land Area

= 815081.1239 / 8729515.30165

= 0.093

= 9%

5. Multiply each of the percentages by the priority values.

Ex: Davis Square

"0" Weighted Priority:

*0.009 * 0 = 0.0*

"3" Weighted Priority:

*0.485 * 3 = 1.46*

"4" Weighted Priority:

*0.412 * 4 = 1.65*

"5" Weighted Priority:

*0.093 * 5 = 0.47*

6. Sum all of the weighted priority values to determine one weighted value for the neighborhood as a whole.

Ex: Davis Square

Heat Vulnerability Score = 0.0 + 1.46 + 1.65+ 0.47 = 3.6

The final land surface temperature vulnerability results and relative ranking by neighborhood are presented in the chart below:

Neighborhood	Vulnerability Score	Relative Ranking
Tufts	2.92	1
West Somerville	2.94	2
Powder House	3.12	3
Central Hill	3.26	4
Davis Square	3.57	5
Ten Hills	3.63	6
Magoun Square	3.656	7
Spring Hill	3.659	8
Prospect Hill	3.68	9
Winter Hill	3.82	10
East Somerville & Assembly Square	3.99	11
Ward Two & Inner Belt	4.47	12

Industrial Land Uses

Industrial land uses were assessed using the City of Somerville Assessor's data to determine a percent of industrial land use compared to the total land area of the neighborhood. The final results of the percent of industrial land use coverage and relative ranking by neighborhood are presented in the chart below:

Neighborhood	% Industrial Land Use	Relative Ranking
Ten Hills	0.00000 (0%)	1
Powderhouse	0.00000 (0%)	1
Central Hill	0.00000 (0%)	1
Tufts	0.00000 (0%)	1
Spring Hill	0.00058 (0%)	5
Winter Hill	0.00086 (0%)	6
Prospect Hill	0.00105 (0%)	7
Magoun Square	0.00164 (0%)	8
Davis Square	0.00288 (0%)	9
West Somerville	0.00938 (1%)	10
East Somerville & Assembly Square	0.01872 (2%)	11
Ward Two & Inner Belt	0.12701 (13%)	12

Impervious Surfaces

Impervious surfaces were assessed using the parking lots GIS layer provided by the City and also calculating the amount of surface area of the roads in that neighborhood to determine an order of magnitude understanding of the percent of impervious land area in the neighborhood. The final results of the percent of impervious surface and relative ranking by neighborhood are presented in the chart below:

Neighborhood	% Impervious	Relative Ranking
Tufts	14%	1
West Somerville	17%	2
Magoun Square	17%	3
Prospect Hill	19%	4
Powder House	19%	5
Winter Hill	20%	6
Central Hill	21%	7
Spring Hill	22%	8
Ten Hills	22%	9
Davis Square	23%	10
East Somerville & Assembly Square	25%	11
Ward Two & Inner Belt	26%	12

Emissions

ACT values were used as a proxy for emissions, based on data provided by MA DOT that included ADT values for many of the major roadways. Note that this is an order of magnitude assessment based on available data. Not all roadways has ADT values in the data set. Additionally, we only assessed major/high traffic roadways and did not assess ADTs associated with local roadways. The final results of the total emissions generated from the average daily trips on major roadways and the associated relative ranking by neighborhood are presented in the chart below:

Neighborhood	Total Emissions (ADT)	Relative Ranking
West Somerville	91622	1
Powder House	157261	2
Tufts	233599	3
Central Hill	275077	4
Ten Hills	389165	5
Davis Square	410775	6
Magoun Square	439128	7
Winter Hill	544344	8

Spring Hill	1007610	9
Prospect Hill	1161311	10
East Somerville & Assembly Square	2142642	11
Ward Two & Inner Belt	2502625	12

Tree Coverage

Tree coverage was based on the 2009 Tree Inventory completed by the City and was developed by determined a count of trees per acre in each neighborhood. This was intended to be a rough proxy for tree canopy. The final results of tree coverage, determined by number or trees per acre, and relative ranking by neighborhood are presented in the chart below:

Neighborhood	Tree Coverage (trees/acre)	Relative Ranking
Central Hill	5.2	1
Tufts	5.2	2
East Somerville & Assembly Square	5.1	3
Prospect Hill	4.8	4
Davis Square	4.2	5
West Somerville	3.7	6
Ward Two & Inner Belt	3.7	7
Ten Hills	3.6	8
Spring Hill	3.3	9
Magoun Square	3.2	10
Powder House	3.0	11
Winter Hill	2.1	12

Open Space

The open space analysis was based on the percent of open space compared to total land area in each neighborhood. The final results of the percent of open space and relative ranking by neighborhood are presented in the chart below:

Neighborhood	% Open Space	Relative Ranking
Ten Hills	18%	1
Magoun Square	12%	2
West Somerville	11%	3

Davis Square	10%	4
Powder House	9%	5
Central Hill	6%	6
Spring Hill	6%	7
Tufts	5%	8
Prospect Hill	4%	9
Winter Hill	3%	10
East Somerville & Assembly Square	1%	11
Ward Two & Inner Belt	1%	12

Building Type

The building type analysis was based on a weighted score of the types of housing in each neighborhood, as reported by the City of Somerville Assessor's office. Based on the description of the building in the Assessor's data, we assigned a score of "1" to single-family homes, a score of "2" to two-family and three-family homes, and a score of "3" to 4+ unit homes. (Note that condominiums and other housing types, not clearly designated in the Assessor's data, were not included in this analysis). We then counted the total number of each category of housing type in the neighborhood and developed a weighted score by multiplying the total count of each type by its associated score. The scores were then added together to determine a total weighted score for the neighborhood. The final results of the weighted building type analysis and relative ranking by neighborhood are presented in the chart below:

Neighborhood	Weighted Building Type Score	Relative Ranking
Central Hill	1.7478992	1
Tufts	1.9286988	11
Magoun Square	1.7572816	2
Powder House	1.8867133	8
Winter Hill	1.7683121	3
Spring Hill	1.8512331	5
Ten Hills	1.8552941	6
West Somerville	1.9214502	10
Prospect Hill	1.933871	12
Davis Square	1.784689	4
Ward Two & Inner Belt	1.8984	9
East Somerville & Assembly Square	1.8730025	7

Air Conditioning

The air conditioning analysis was based on the percent of buildings in the neighborhood with central air conditioning, as reported by the City of Somerville Assessor's office. The final results of the percent of air conditioning analysis and relative ranking by neighborhood are presented in the chart below:

Neighborhood	% Buildings with Central Air Conditioning	Relative Ranking
Central Hill	7.6%	12
Tufts	12.2%	7
Magoun Square	13.3%	4
Powder House	18.1%	2
Winter Hill	11.9%	9
Spring Hill	15.8%	3
Ten Hills	12.2%	6
West Somerville	12.1%	8
Prospect Hill	10.9%	10
Davis Square	21.0%	1
Ward Two & Inner Belt	12.5%	5
East Somerville & Assembly Square	9.4%	11

Outdoor Heat Exposure Results

Neighborhood	Land Surface Temperature	Industrial Land Use	Impervious Surface	Emissions	Tree Coverage	Open Space	Heat Vulnerability Score	Ranked Priorities
Tufts	1	1	1	3	2	8	16	Low
Central Hill	4	1	7	1	6	3	22	Low
Powder House	3	1	5	2	11	5	27	Low
Magoun Square	7	8	3	4	1	6	29	Low
Spring Hill	8	5	8	6	5	4	36	Medium
Winter Hill	10	6	6	5	8	1	36	Medium
Prospect Hill	9	7	4	7	10	2	39	Medium
West Somerville	2	10	2	9	9	7	39	Medium

Ten Hills	6	1	9	10	4	9	39	Medium
Davis Square	5	9	10	8	12	10	54	High
Ward Two & Inner Belt	12	12	12	11	3	11	61	High
East Somerville & Assembly Square	11	11	11	12	7	12	64	High

Indoor Heat Exposure Results

Neighborhood	Land Surface Temperature	Industrial Land Use	Impervious Surface	Emissions	Bldg Type	Tree Coverage	Open Space	AC	Heat Score	Ranked Priorities
Central Hill	4	1	7	1	1	6	3	12	23	Low
Tufts	1	1	1	3	11	2	8	7	34	Low
Magoun Square	7	8	3	4	2	1	6	4	31	Low
Powder House	3	1	5	2	8	11	5	2	35	Low
Winter Hill	10	6	6	5	3	8	1	9	39	Low
Spring Hill	8	5	8	6	5	5	4	3	41	Medium
Ten Hills	6	1	9	10	6	4	9	6	45	Medium
West Somerville	2	10	2	9	10	9	7	8	49	Medium
Prospect Hill	9	7	4	7	12	10	2	10	51	Medium
Davis Square	5	9	10	8	4	12	10	1	58	Medium
Ward Two & Inner Belt	12	12	12	11	9	3	11	5	70	High
East Somerville & Assembly Square	11	11	11	12	7	7	12	11	71	High

	Exposure									Sensitivity		AC								
Neighborhood	*TPL - Land Surface Temp Weighted Priorities*		*Ind Land Use*		*Impervious Surface (Roadway + Parking Lot)*		*Emissions (ADT values)*		*Exposure Tally*	*Vulnerable Populations*	*Ranking*	*Tree Coverage*		*Open Space*		*AC Tally*	*Final (EX+S+AC) Tally*		Exposure + AC Tally	
Tufts	2.92	1	0%	1	14%	1	233599	3	6	1	2	5.2	2	5%	8	10	*18*	Low	16	*Low*
Central Hill	3.26	4	0%	1	21%	7	91622	1	13	3	7	3.7	6	11%	3	9	*29*	Low	22	*Low*
Powder House	3.12	3	0%	1	19%	5	157261	2	11	2	5	3.0	11	9%	5	16	*32*	Low	27	*Low*
Magound/Albion	3.656	7	0%	8	17%	3	275077	4	22	2	5	5.2	1	6%	6	7	*34*	Low	29	*Low*
Spring Hill	3.659	8	0%	5	22%	8	410775	6	27	3	7	4.2	5	10%	4	9	*43*	Medium	36	*Medium*
Winter Hill	3.82	10	0%	6	20%	6	389165	5	27	4	12	3.6	8	18%	1	9	*48*	Medium	36	*Medium*
Prospect Hill	3.68	9	0%	7	19%	4	439128	7	27	2	5	3.2	10	12%	2	12	*44*	Medium	39	*Medium*
West Somerville	2.94	2	1%	10	17%	2	1007610	9	23	4	12	3.3	9	6%	7	16	*51*	Medium	39	*Medium*
Ten Hills	3.63	6	0%	1	22%	9	1161311	10	26	4	12	4.8	4	4%	9	13	*51*	Medium	39	*Medium*
Davis Square	3.57	5	0%	9	23%	10	544344	8	32	1	2	2.1	12	3%	10	22	*56*	High	54	*High*
Ward Two/Cobble Hill	4.47	12	13%	12	26%	12	2142642	11	47	4	12	5.1	3	1%	11	14	*73*	High	61	*High*
East Somerville	3.99	11	2%	11	25%	11	2502625	12	45	4	12	3.7	7	1%	12	19	*76*	High	64	*High*

	Exposure									Sensitivity			AC								
Neighborhood	*TPL - Land Surface Temp Weighted Priorities*		*Ind Land Use*		*Impervious Surface (Roadway + Parking Lot)*		*Emissions (ADT values)*		*Exposure Tally*	*Building Type Weighted Score*		*Sensitivity Tally*	*Tree Coverage*		*Open Space*		*Air Conditioning*		*AC Tally*	Final Exposure + only bldg (S) + AC Tally	
Central Hill	3.26	4	0%	1	21%	7	91622	1	13	1.7478992	1	8	3.7	6	11%	3	7.663%	12	9	23	*Low*
Tufts	2.92	1	0%	1	14%	1	233599	3	6	1.9286988	11	13	5.2	2	5%	8	12.173%	7	17	34	*Low*
Magoun Square	3.656	7	0%	8	17%	3	275077	4	22	1.7572816	2	7	5.2	1	6%	6	13.309%	4	7	31	*Low*
Powder House	3.12	3	0%	1	19%	5	157261	2	11	1.8867133	8	13	3.0	11	9%	5	18.052%	2	16	35	*Low*
Winter Hill	3.82	10	0%	6	20%	6	389165	5	27	1.7683121	3	15	3.6	8	18%	1	11.851%	9	9	39	*Low*
Spring Hill	3.659	8	0%	5	22%	8	410775	6	27	1.8512331	5	12	4.2	5	10%	4	15.757%	3	9	41	*Medium*
Ten Hills	3.63	6	0%	1	22%	9	1161311	10	26	1.8552941	6	18	4.8	4	4%	9	12.187%	6	13	45	*Medium*
West Somerville	2.94	2	1%	10	17%	2	1007610	9	23	1.9214502	10	22	3.3	9	6%	7	12.092%	8	16	49	*Medium*
Prospect Hill	3.68	9	0%	7	19%	4	439128	7	27	1.933871	12	17	3.2	10	12%	2	10.949%	10	12	51	*Medium*
Davis Square	3.57	5	0%	9	23%	10	544344	8	32	1.784689	4	6	2.1	12	3%	10	21.048%	1	22	58	*Medium*
Ward Two & Inner Belt	4.47	12	13%	12	26%	12	2142642	11	47	1.8984	9	21	5.1	3	1%	11	12.473%	5	14	70	*High*
East Somerville & Assembly Square	3.99	11	2%	11	25%	11	2502625	12	45	1.8730025	7	19	3.7	7	1%	12	9.424%	11	19	71	*High*

Appendix D
Precipitation Modeling Methodology

Memo

To:	Lisa Dickson ARUP	From:	David Bedoya MWH/Stantec
File:	Usbos102\Projects\Somerville Climate Change\05 Study\Tech memos	Date:	January 4, 2017

Reference: City of Somerville Climate Change Inundation Analysis

This memorandum describes the methodology used to develop inundation maps for the following:

1. Union and Assembly squares within Somerville, MA for present, mid-century (circa 2030), and late century (circa 2070) forecasted rainfall events. Storm events with a 10- and 100-year return period and a 24-hour duration were evaluated in this analysis.

2. City-wide flood maps using a bathtub approach for the same storm events.

1. Inundation Map Development in Assembly and Union Squares:

In order to create inundation maps for the Union Square and Assembly areas, the City's most up to date hydrologic and hydraulic model was used. This model was recently refined in great detail for areas immediately tributary to Union Square (see general area in Figure 1) and subsequently calibrated and validated as part of the *Union Square Utility and Transportation Improvements Project*. The hydraulic model, however, did not include any information on the sanitary or stormwater collection system in Assembly Square. Thus, the storm drain network was added to the model using design drawings from the *Assembly Square Access Improvements Project* dated February 4th, 2010 (see general area in Figure 2).

The delineation and hydrology of the tributary catchments in the Union Square area shown in Figure 1 was left intact as the model has been recently calibrated. On the other hand, catchment delineation of stormwater catchments in Assembly Square was performed using available contour lines and engineering judgment based on the provided design drawings. The hydrology for these catchments was set to the SWMM methodology[1] methodology, which uses relative percentages of impervious and pervious areas that were calculated with available land use data. Since flow meter data was not available for Assembly Square, this portion of the model remains uncalibrated and subject to change once calibration is performed.

Next, a ground model consisting of a two-dimensional, triangular mesh was created using the 2013-2014 LiDAR dataset available from MassGIS with a vertical accuracy of 0.17 feet (2.0 inches). The ground surface triangular mesh was overlaid over the collection system model and used to route excess flows originated in overflowing manholes.

Once the catchment hydrology, the underground conveyance system, and the ground surface were created the model was run for the 10-and 100-year storms for present, mid-century, and late century climate change rainfall conditions (see Table 1 for rainfall totals).

[1] Stormwater Management Model Reference Manual, Volume I- Hydrology (Revised), EPA/600/R-15/162A | January 2016 | www2.epa.gov/water-research

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Figure 1. Union Square model general pipe layout view

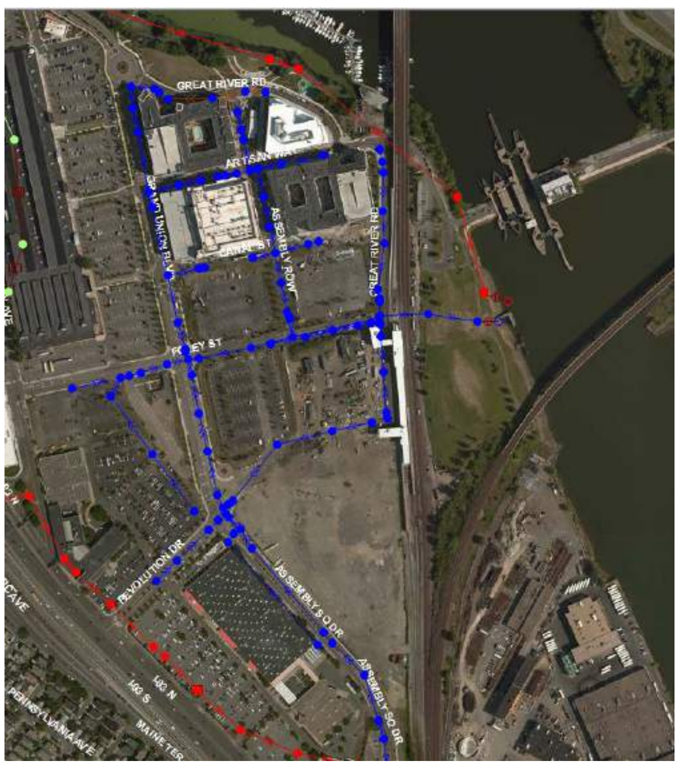


Figure 2. Assembly Square model general pipe layout view

Table 1. Rainfall totals (in inches) for the 10- and 100-year, 24-hour storm events in present conditions and in mid-and late-century climate change projections

Rainfall Frequency	Present	Projected Rainfall Totals	
		2030	2070
10-year, 24-hour	4.9	5.6	6.4
100-year, 24-hour	8.9	10.2	11.7

Since the Assembly Square stormwater system outfalls to the ocean downstream of the Amelia Earhart Dam (AED), as shown in Figure 2, tidal cycles for the present time and late century conditions, provided by WHG, were used as boundary conditions. Modeled tidal cycles along with assumed, concurrent rainfall intensities are depicted in Figure 3.

Increase in sea level rise is not expected to affect the Union Square system as it is landlocked without an outfall to a waterbody. This system drains to the MWRA regional system and therefore, changes in boundary conditions due to increased rainfall were captured by the hydraulic model as it includes the MWRA regional system as well.

Flood maps for Union and Assembly Square for the model runs described above are included in Appendix A.

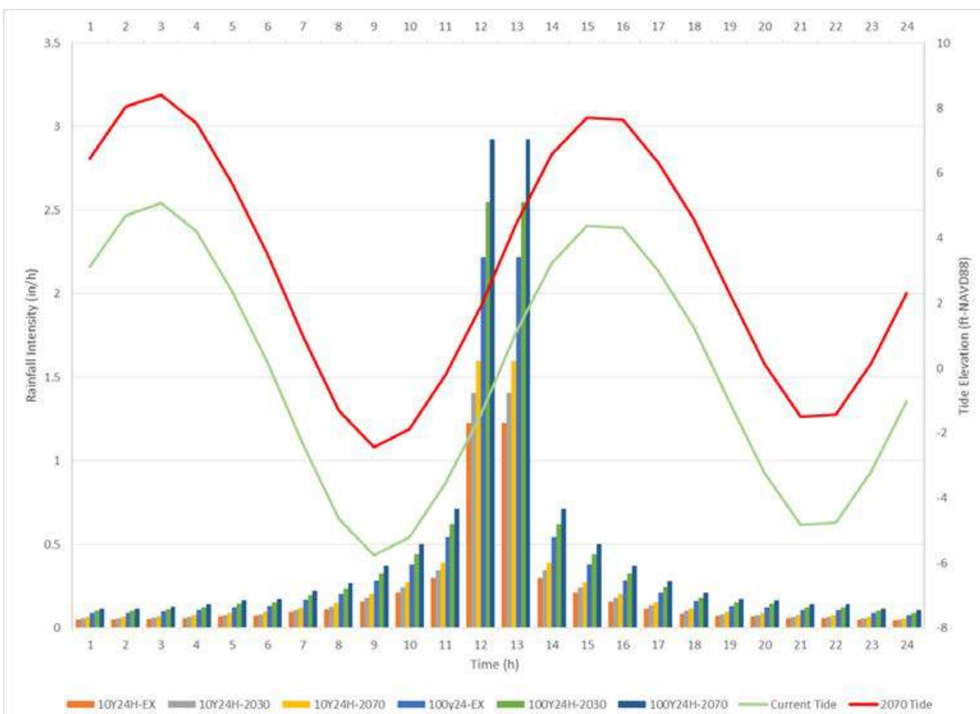


Figure 3. Tides and rainfall distribution used in the Union and Assembly squares inundation analysis

2. City-Wide Bathtub Analysis:

This analysis consisted of developing a city-wide Digital Terrain Model (DTM) using the same 2013-2014 LiDAR dataset used for Assembly and Union Square. Once the DTM was built, the same 10- and 100-year storms were applied over the DTM and the resulting surface runoff routed until it reached a local depression or left the city boundaries. The goal of this effort was to identify areas within the City of Somerville that may be vulnerable to flooding due to local topography.

In contrast to the Assembly and Union Square runs, the city-wide, bathtub runs did not include any underground conveyance conduits or nodes as the level of available model detail for different areas within the City varies greatly. Another main difference between the Assembly and Union Square versus the city-wide runs is that rainfall in the city-wide runs is physically modeled (i.e. rainfall falls on the ground surface like it would occur in reality). In the Union and Assembly Square models, rainfall is simulated with catchment rainfall-runoff conversions and loaded into collection system nodes, which is typical in most urban hydraulic models. In this case, only excess flows leaving the collection system due to insufficient pipe capacity are then routed on the ground surface. A summary of the main modeling differences between the modeling efforts are outlined in Table 2. City-wide flood maps for the model runs described above are included in Appendix B.

Table 2. Summary of modeling differences between inundation analyses

	Union Square	Assembly Square	City-Wide
DTM grid resolution (max. cell size)	800 sq-ft		4,000 sq-ft
Boundary Condition	MWRA Regional Model	Tidal Conditions	Critical flow conditions for flows leaving the City boundary
Rainfall-runoff Modeling	Catchment-based rainfall/runoff conversions loaded to system nodes (SWMM methodology)		Physically modeled (rainfall on the mesh)
Underground conveyance system	Included		Not included
Surface runoff modeling	Only excess flows beyond collection system capacity		All rainfall excess runoff

3. Discussion:

As shown in the flood maps in Appendix A, Union Square experiences very significant flooding along the Somerville Avenue corridor during the 10-year storm in present climate conditions. The areas of major vulnerability within Union Square are:

- The Somerville Avenue corridor between Union Square and Medford Street,
- the Prospect, Bennett, Newton, and Everett streets intersection,
- Lake Street,
- The Fire and Police Headquarters building by Merriam Street,
- The Medford Street underpass under the railroad tracks,
- Kingman Road by the railroad tracks,
- The intersection between Allen and Charlestown streets,

- Union Square proper between Stone Ave and Sanborn Court and properties confined by Somerville Avenue, Prospect and Allen streets.

As expected, the severity and extent of flooding increases with increased rainfall forecasted for the mid and late century with new flooded areas appearing as rainfall severity increases (e.g. Bow Street Place). During the 100-year events, the severity of flooding at the vulnerable locations by the Somerville Avenue corridor listed above is greatly exacerbated. Flood depths are, for the most part, greater than two feet across the board for current climate conditions and greatly exceeding 3 feet of depth at some locations. As expected the conditions worsen with the 2030 and 2070 time horizons.

In Assembly Square, the recently constructed stormwater system seems to be able to convey the 100-year, 24-hour, late century storm with marginal overflow (26,000 gallons) in current tidal conditions at the outfall (see tide cycle in Figure 3). In late century tide conditions that assumed a sea level rise of 3.3 feet across the whole tidal cycle (Figure 3), minor flooding (0.34MG) mostly less than 6 inches in depth would occur at the parking lot located between Foley Street, Grand Union Blvd., and Middlesex Avenue (see inundation maps in Appendix A). In mid and late century rainfall conditions, flooding depth and extent increases accordingly but the overall impact remains very limited as shown in figures in Appendix A.

Peak Hydraulic Grade Line (HGL) profiles in the 72-inch conduit on Foley Street during the late century, 100-year rainfall event with current and late century tidal cycles as outfall boundary conditions are also included in Appendix C. The figures show how the peak HGL is above ground at the Foley St parking lot in both scenarios but more so with the late century tide.

The City-wide bathtub analysis are a conservative representation of potential inundation extents and depths in the City of Somerville. These simulations are conservative because, in the modeling process, surface runoff was not allowed to infiltrate or drain through the underground collection system as the goal of this effort was to identify sinks and flow paths within City boundaries. Flood maps presented in Appendix B reveal how the following areas are major surface runoff sinks and therefore, of greater vulnerability due to local topography:

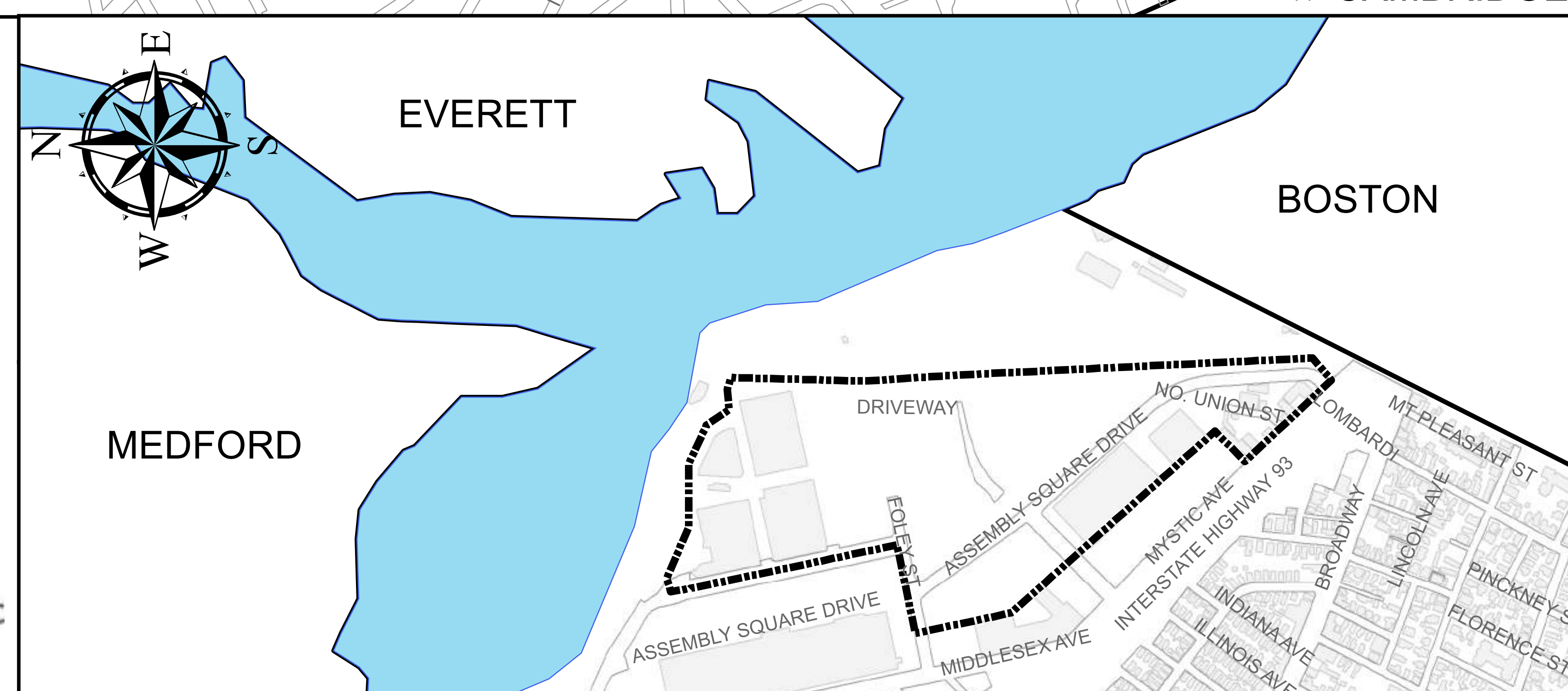
1. Assembly Square, with very limited flooding in the Foley Street and Grand Union Boulevard area as mentioned above.
2. Northeast side of Winter Hill between Temple Street and Route 28
3. Areas immediately south (e.g. Allen Street) and southeast (e.g. Medford St underpass) of Union Square
4. Brickbottom neighborhood area
5. Boynton Yards area
6. Vicinity of Davis Square (northwest and southeast)
7. Community Path at Grove St as well as between Highland Rd and Pearson Ave
8. Area between Simpson Avenue, Paulina St, Holland St, and Broadway
9. Lowell Street at Maxwells Green and Princeton Street
10. Marshall St at Stickney Avenue
11. Area between Pearl, Flint, and Cross streets,

12. Capuano School area
13. Lincoln Park neighborhood and Argenziano School area
14. Neighborhood between Somerville Avenue, Washington Street, Beacon Street and Park Street, and
15. MBTA commuter rail corridor

Appendix A

Union Square and Assembly Square Flood Maps

Union Square and Assembly Square, Somerville, MA
Maximum Flood Depth
10-year, 24-hour Event, Existing Climate



Legend

Modeled 2D Area

Building Footprints

Flood Depth (ft)

- > 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- > 3.0

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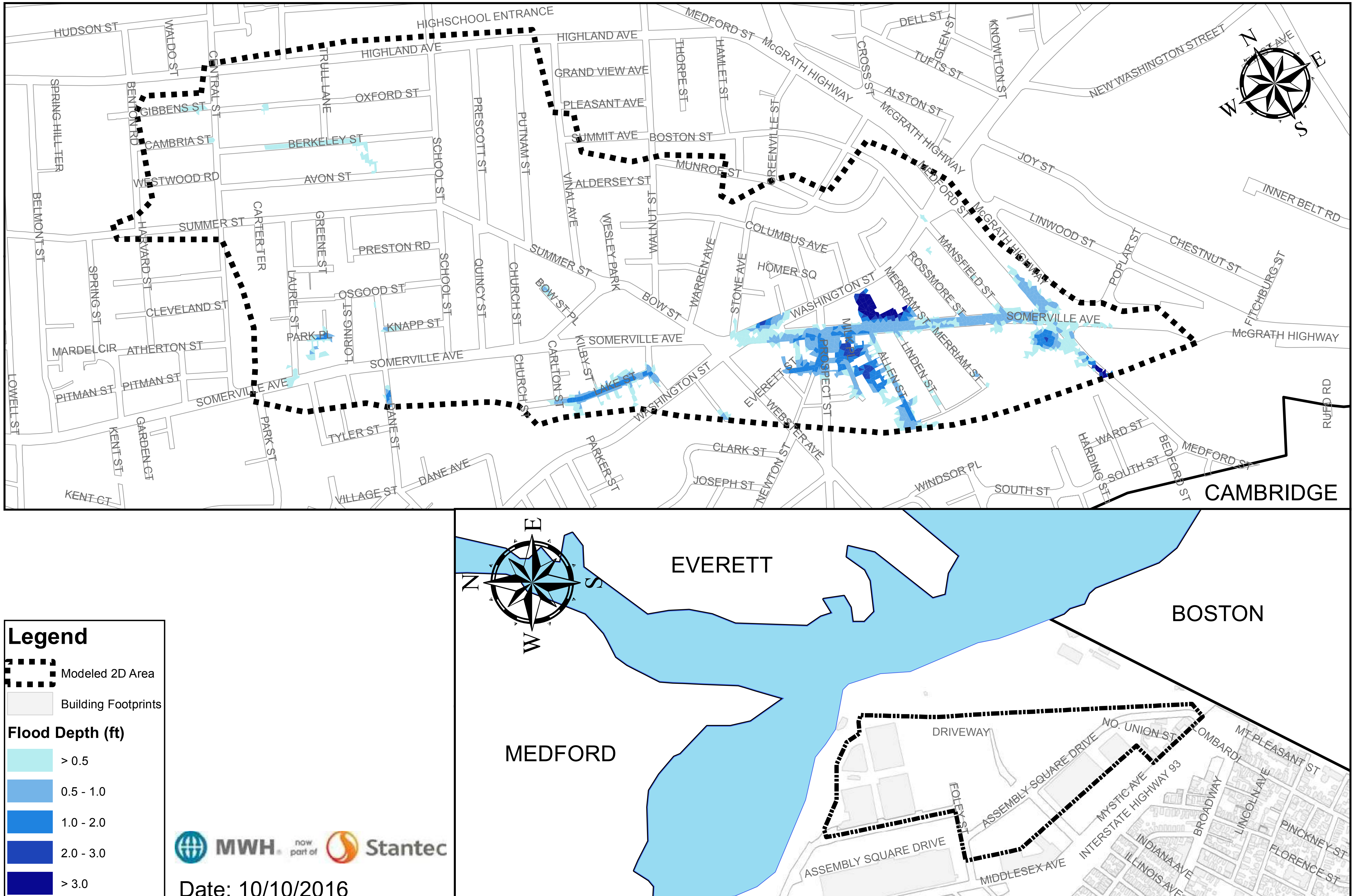
Date: 10/10/2016

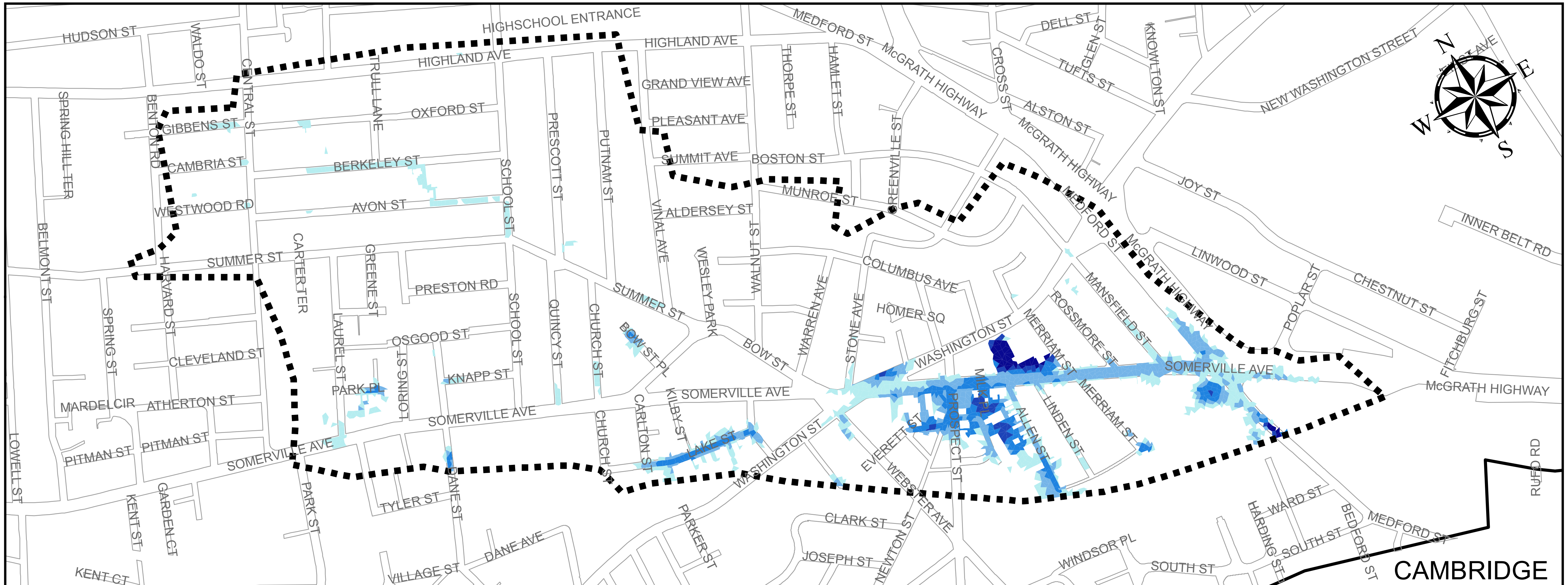
Union Square and Assembly Square, Somerville, MA
Maximum Flood Depth
10-year, 24-hour Event, 2030 Horizon

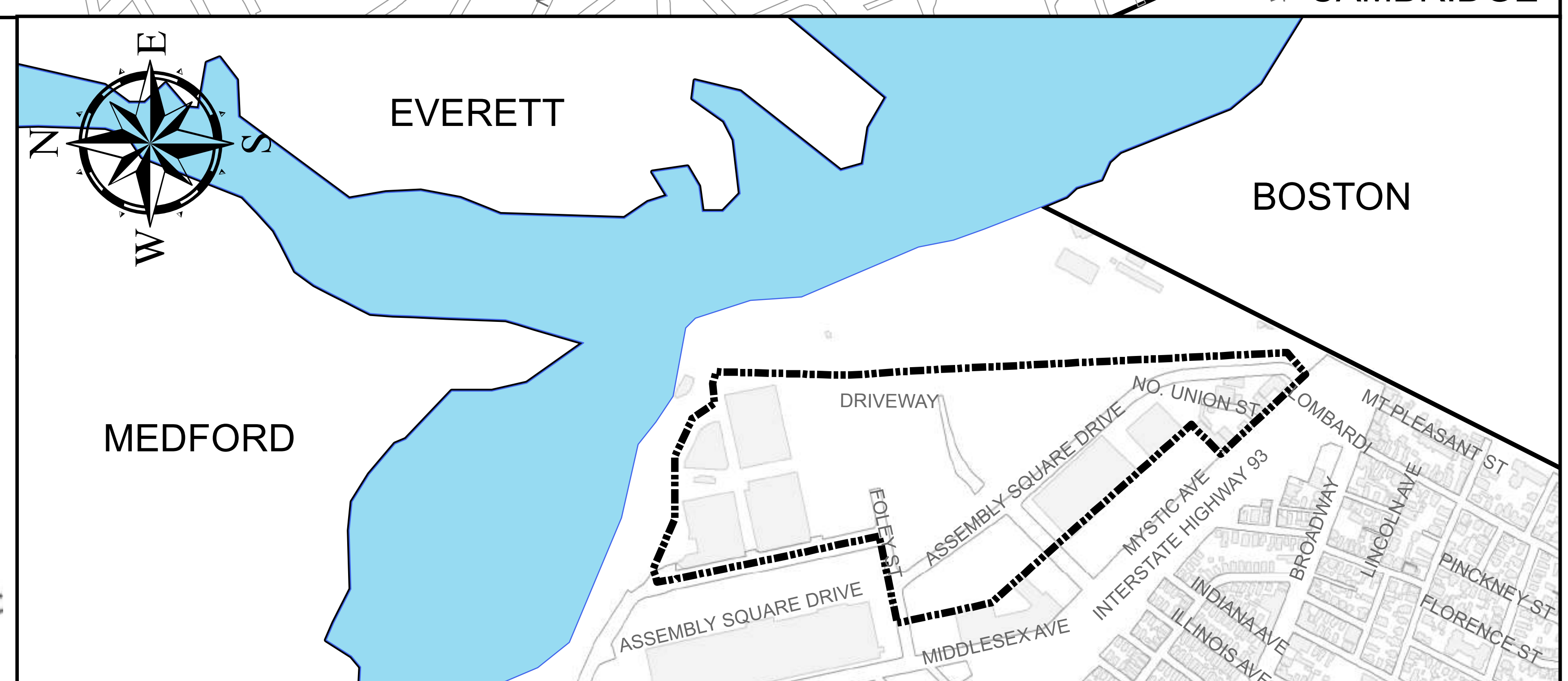


MWH now part of Stantec

Date: 10/10/2016

Union Square and Assembly Square, Somerville, MA
Maximum Flood Depth
10-year, 24-hour Event, 2070 Horizon





Legend

Modeled 2D Area

Building Footprints

Flood Depth (ft)

> 0.5

0.5 - 1.0

1.0 - 2.0

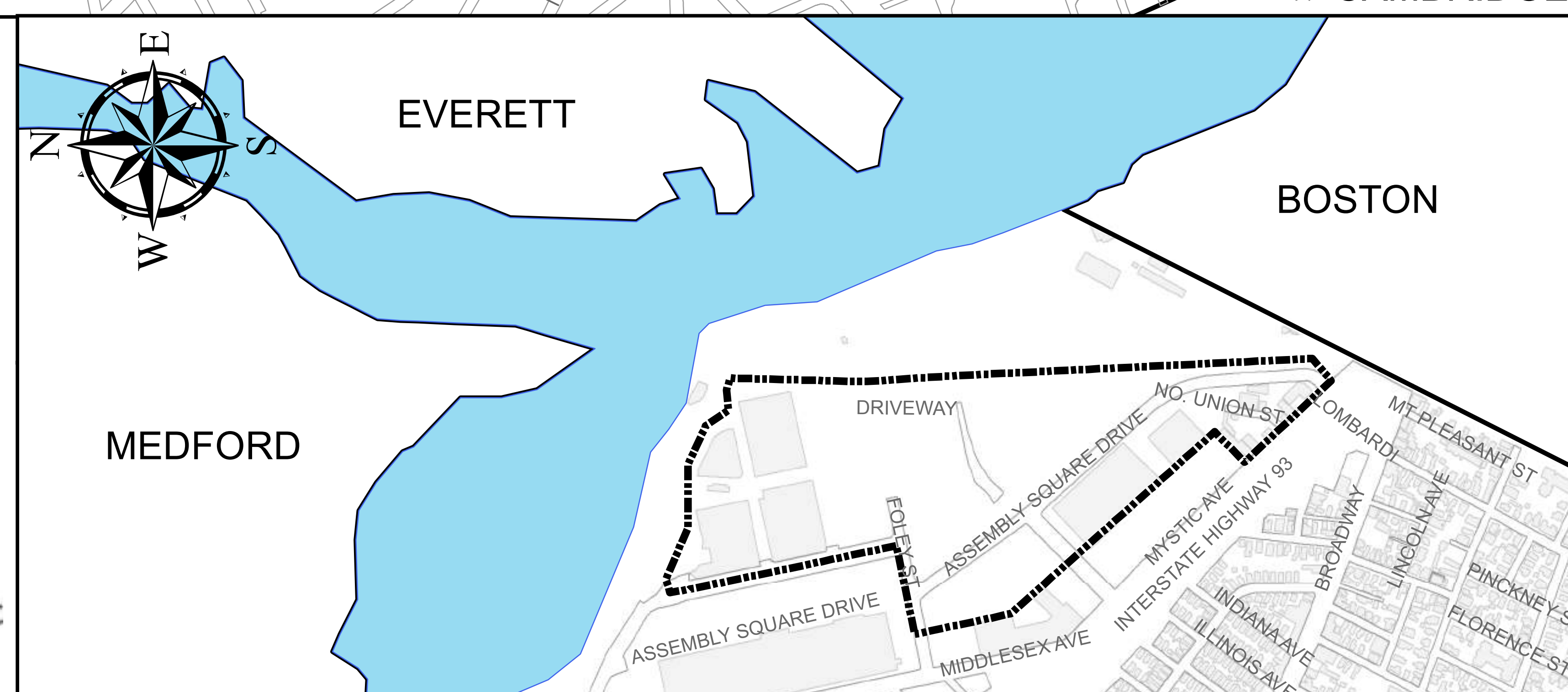
2.0 - 3.0

> 3.0

MWH. now part of Stantec

Date: 10/10/2016

Union Square and Assembly Square, Somerville, MA
Maximum Flood Depth
100-year, 24-hour Event, Existing Climate



Legend

- Modeled 2D Area
- Building Footprints

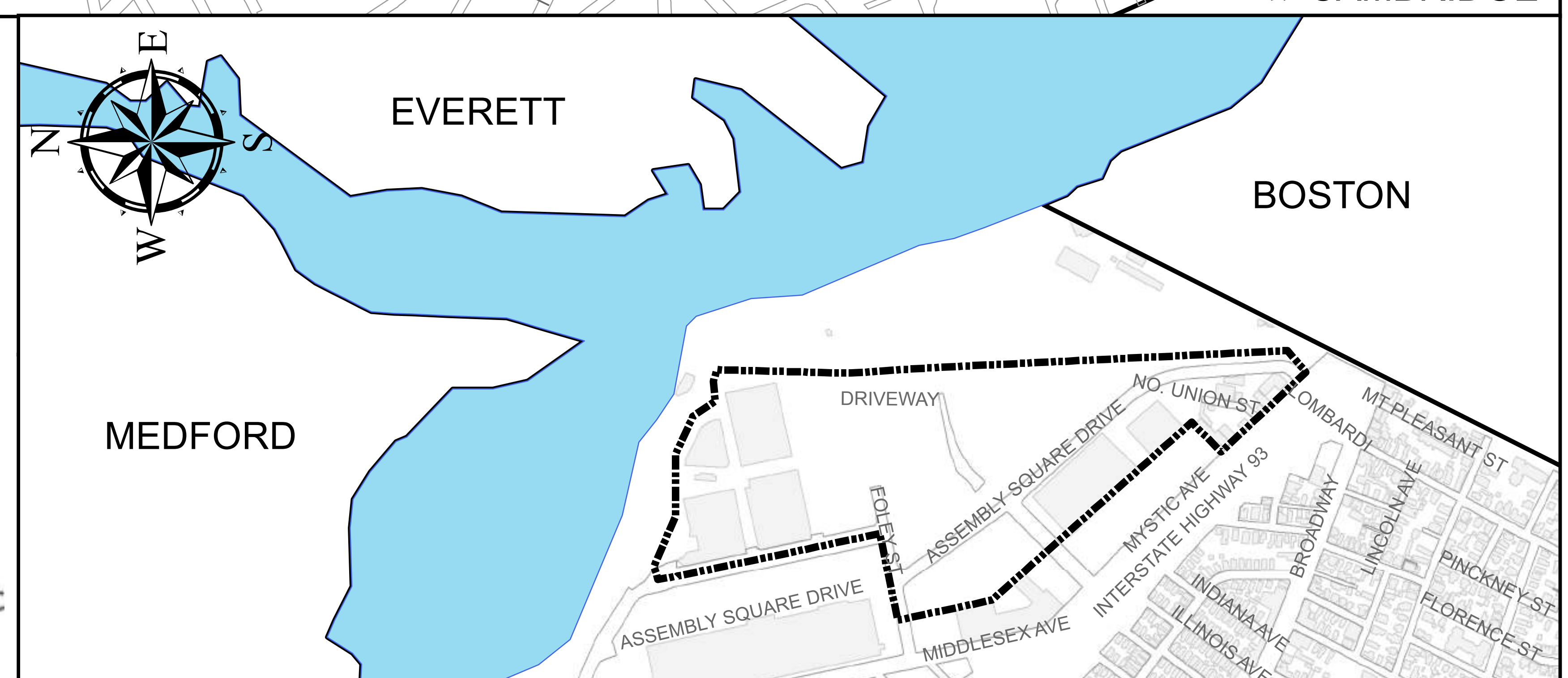
Flood Depth (ft)

- > 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- > 3.0

MWH now part of Stantec

Date: 10/10/2016

Union Square and Assembly Square, Somerville, MA
Maximum Flood Depth
100-year, 24-hour Event, 2030 Horizon



Legend

- Modeled 2D Area
- Building Footprints

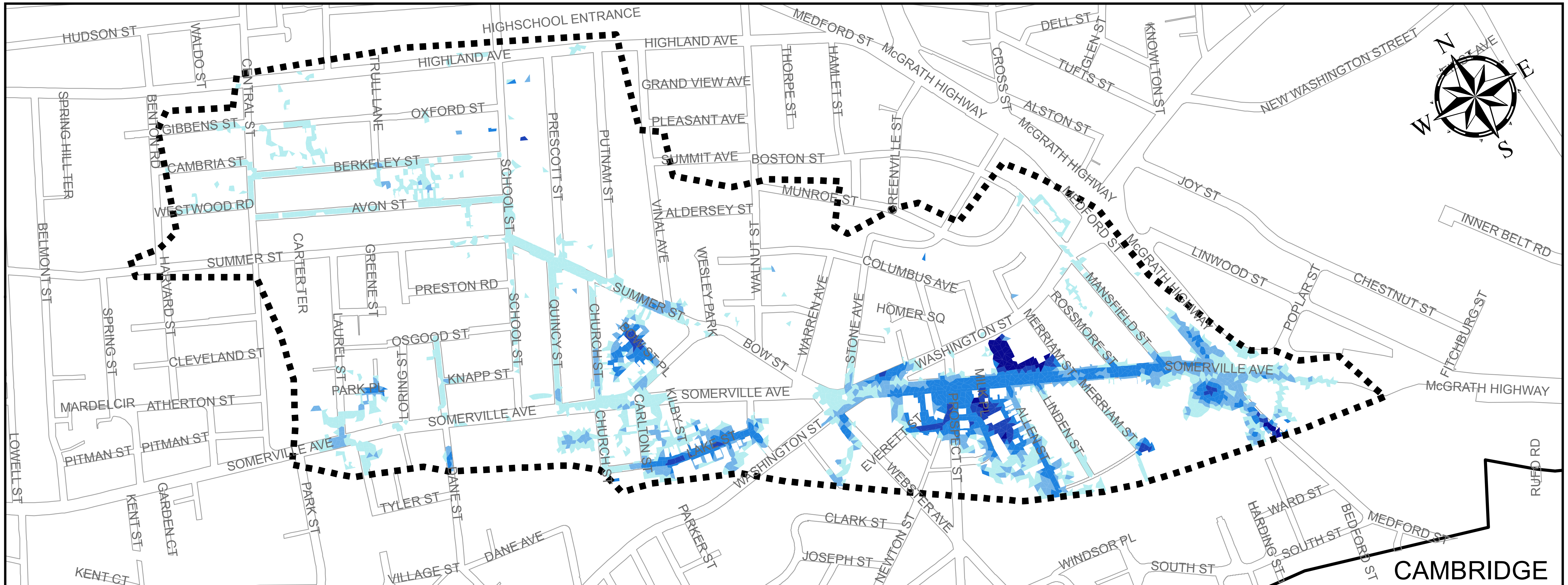
Flood Depth (ft)

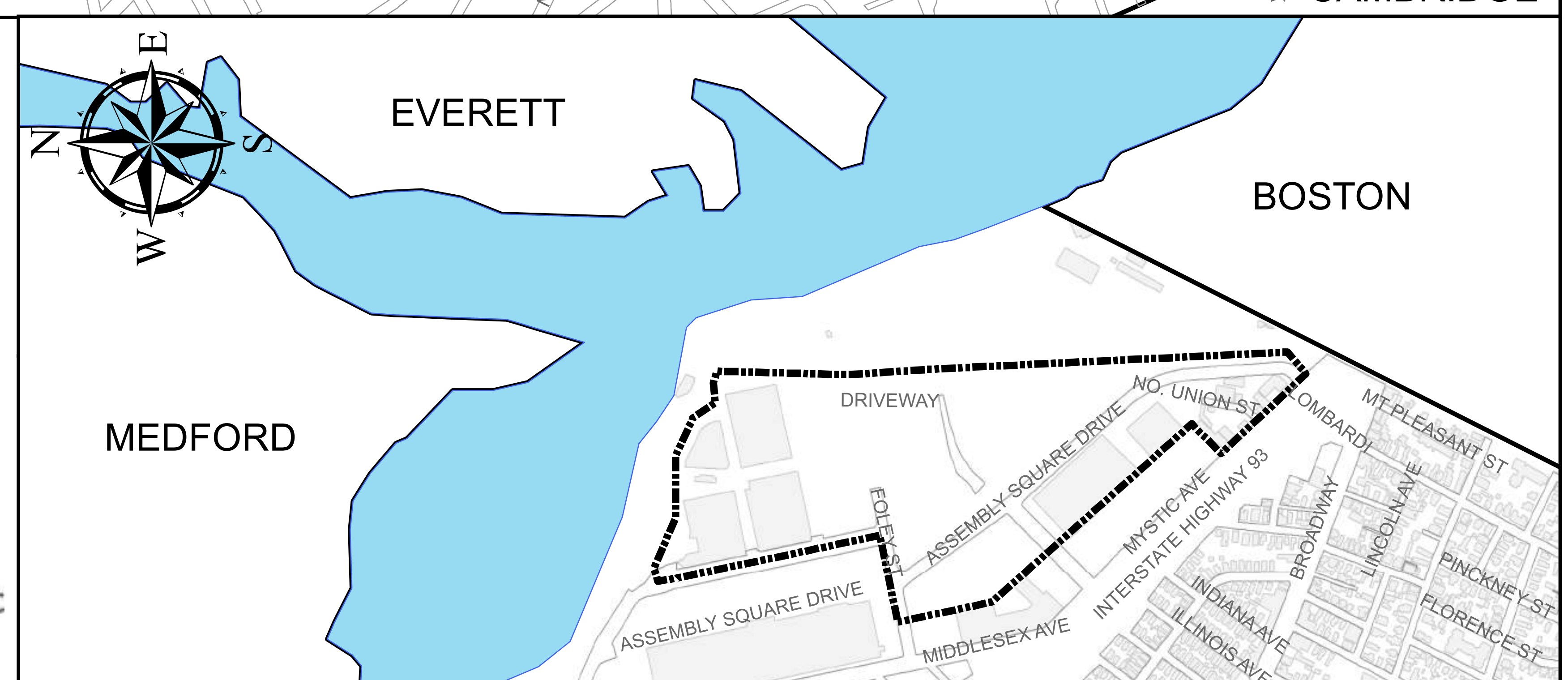
- > 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- > 3.0

MWH now part of Stantec

Date: 10/10/2016

Union Square and Assembly Square, Somerville, MA
Maximum Flood Depth
100-year, 24-hour Event, 2070 Horizon





Legend

	Modeled 2D Area
	Building Footprints

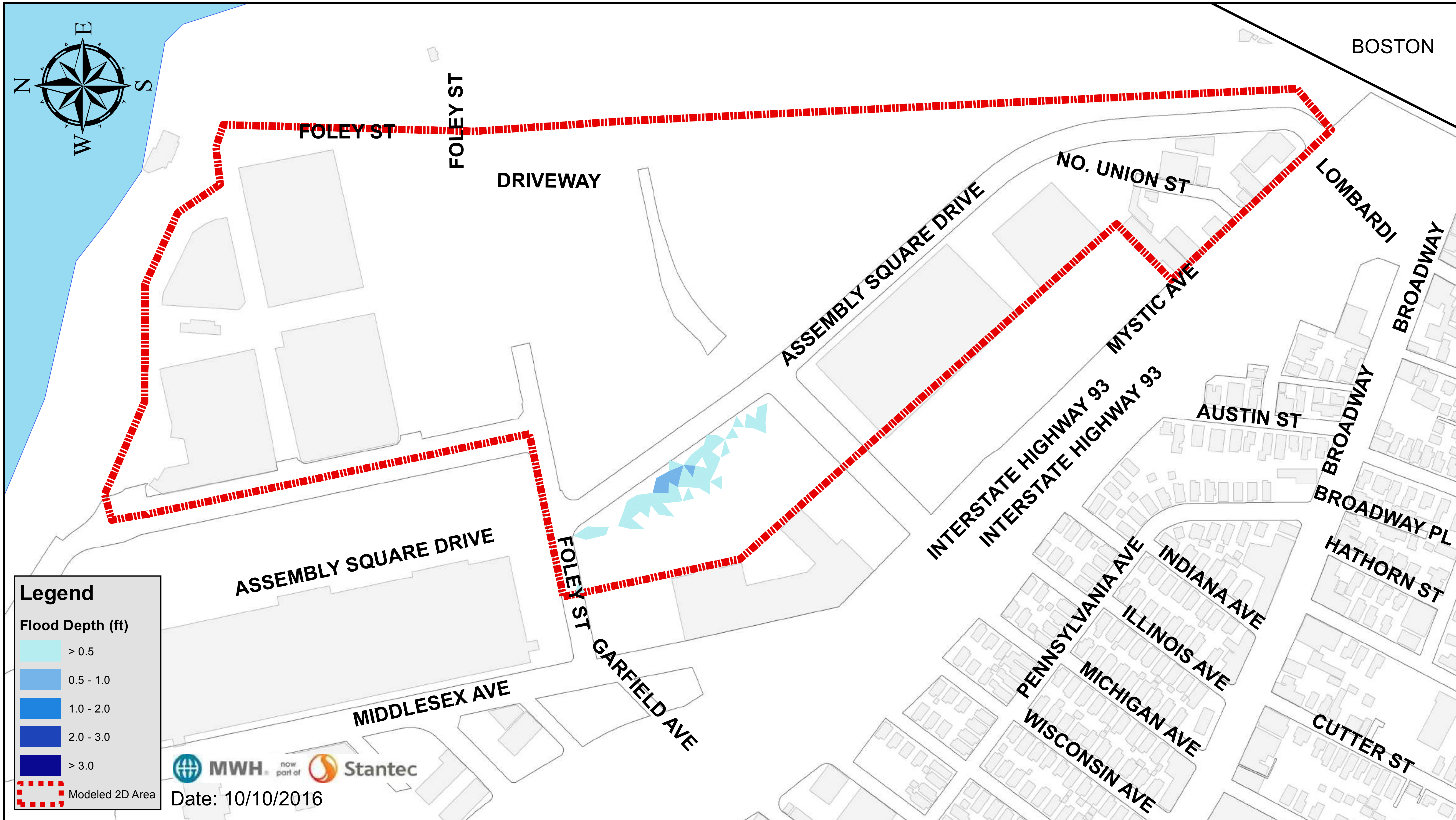
Flood Depth (ft)

	> 0.5
	0.5 - 1.0
	1.0 - 2.0
	2.0 - 3.0
	> 3.0

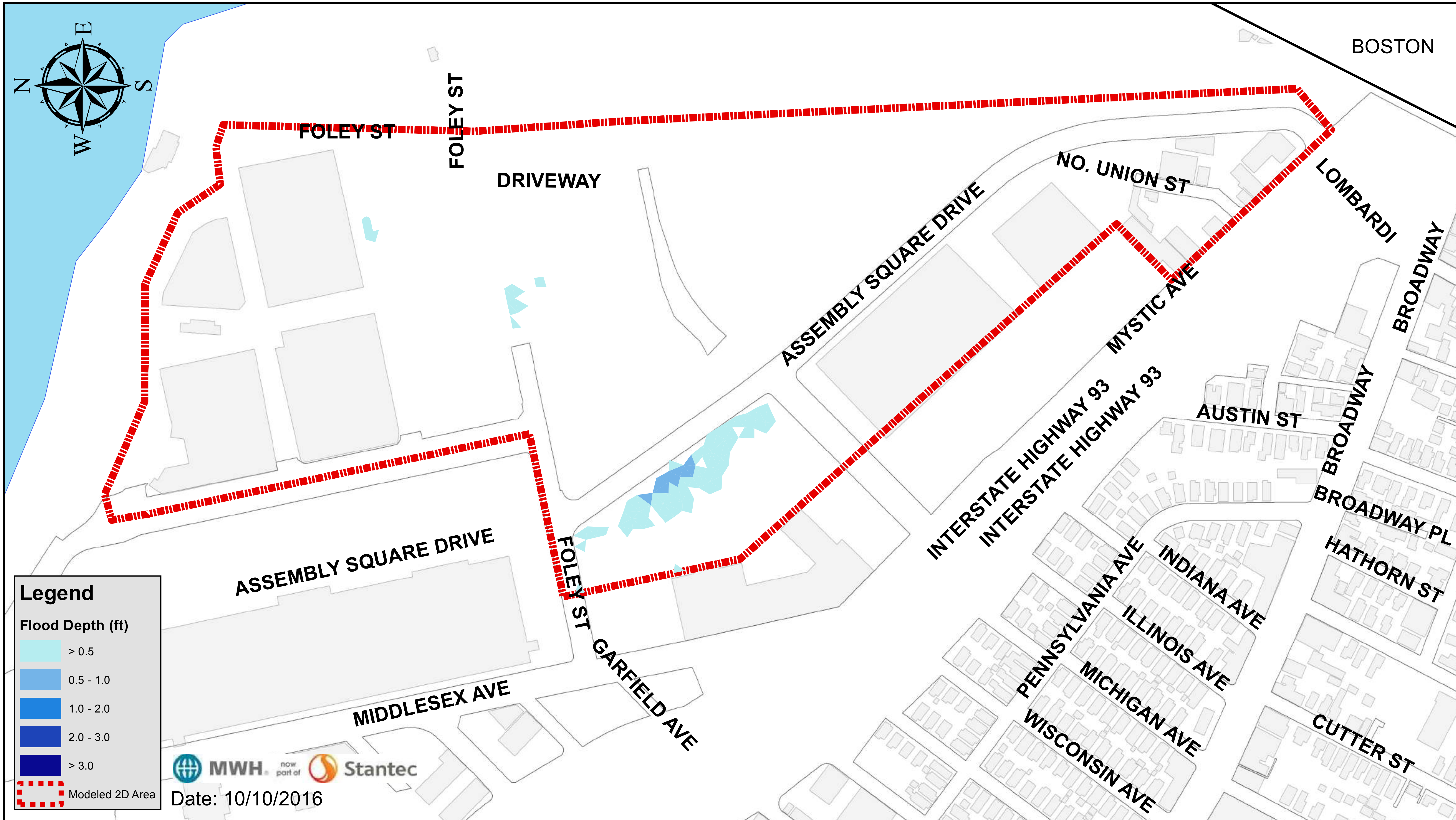
MWH now part of Stantec

Date: 10/10/2016

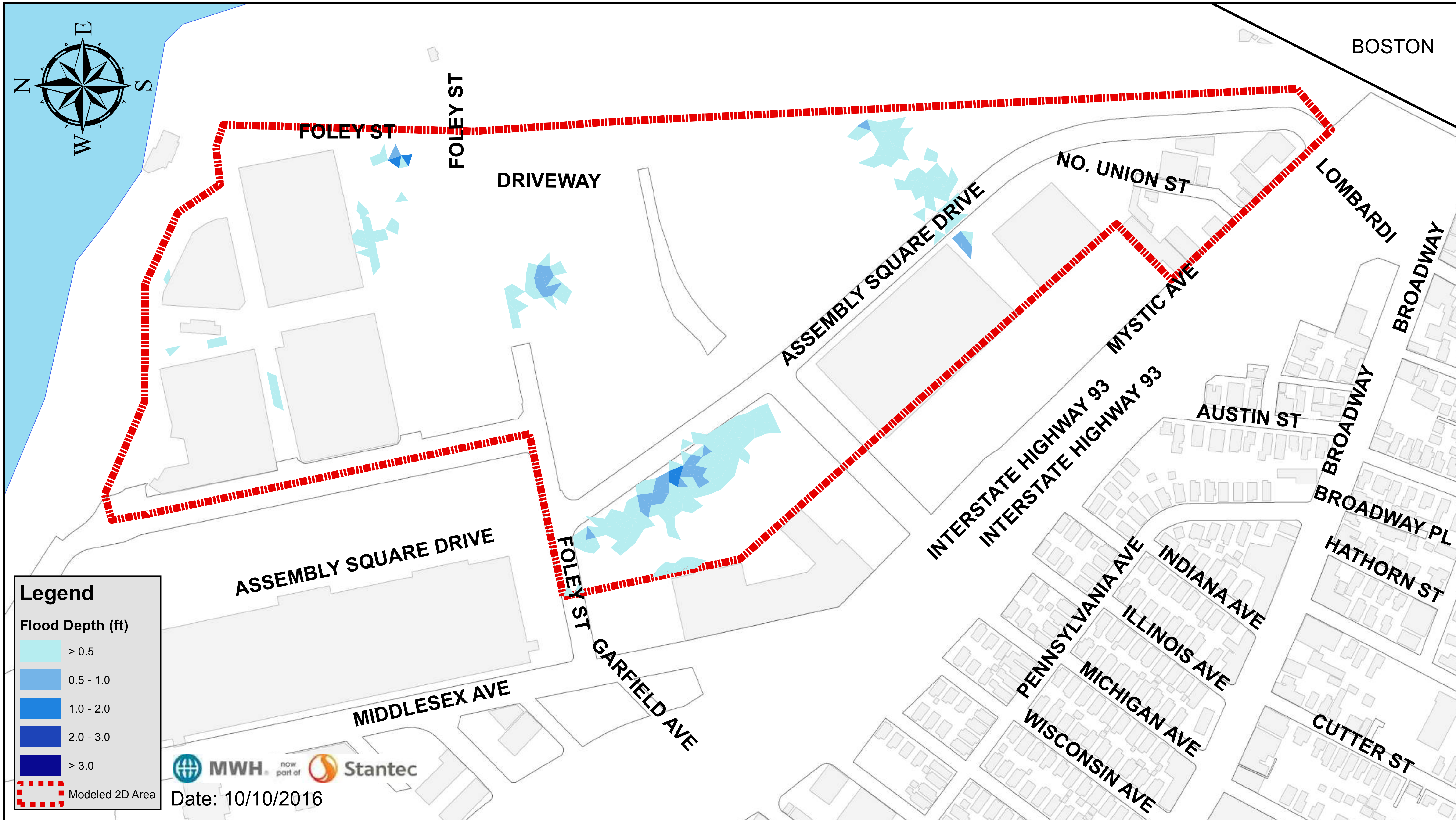
Maximum Flood Depth in Assembly Square, Somerville, MA
100-year, 24-hour Event, Existing Climate
2070 Tide Conditions



Maximum Flood Depth in Assembly Square, Somerville, MA
100-year, 24-hour Event, 2030 Rainfall
2070 Tide Conditions



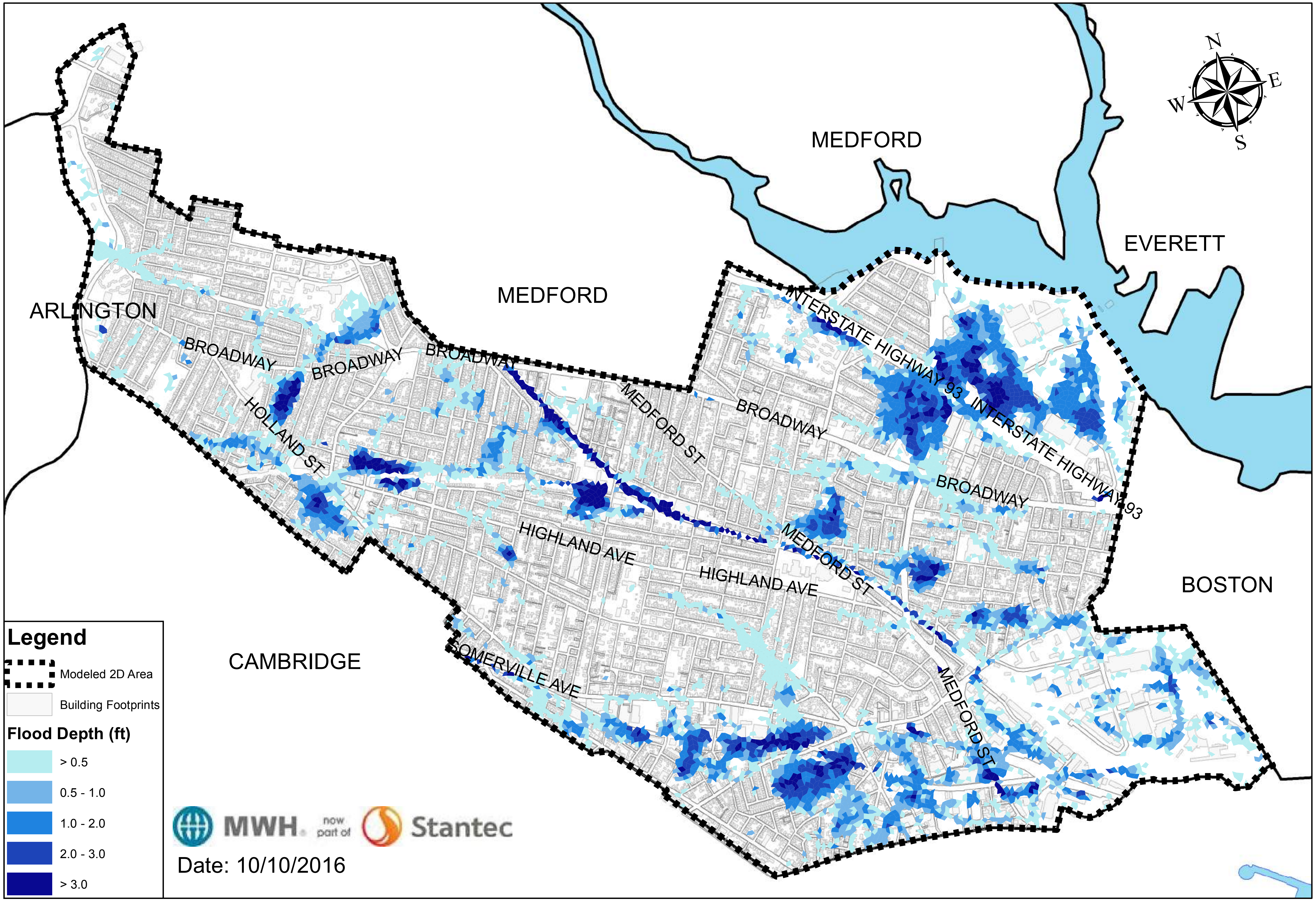
Maximum Flood Depth in Assembly Square, Somerville, MA
100-year, 24-hour Event, 2070 Rainfall
2070 Tide Conditions



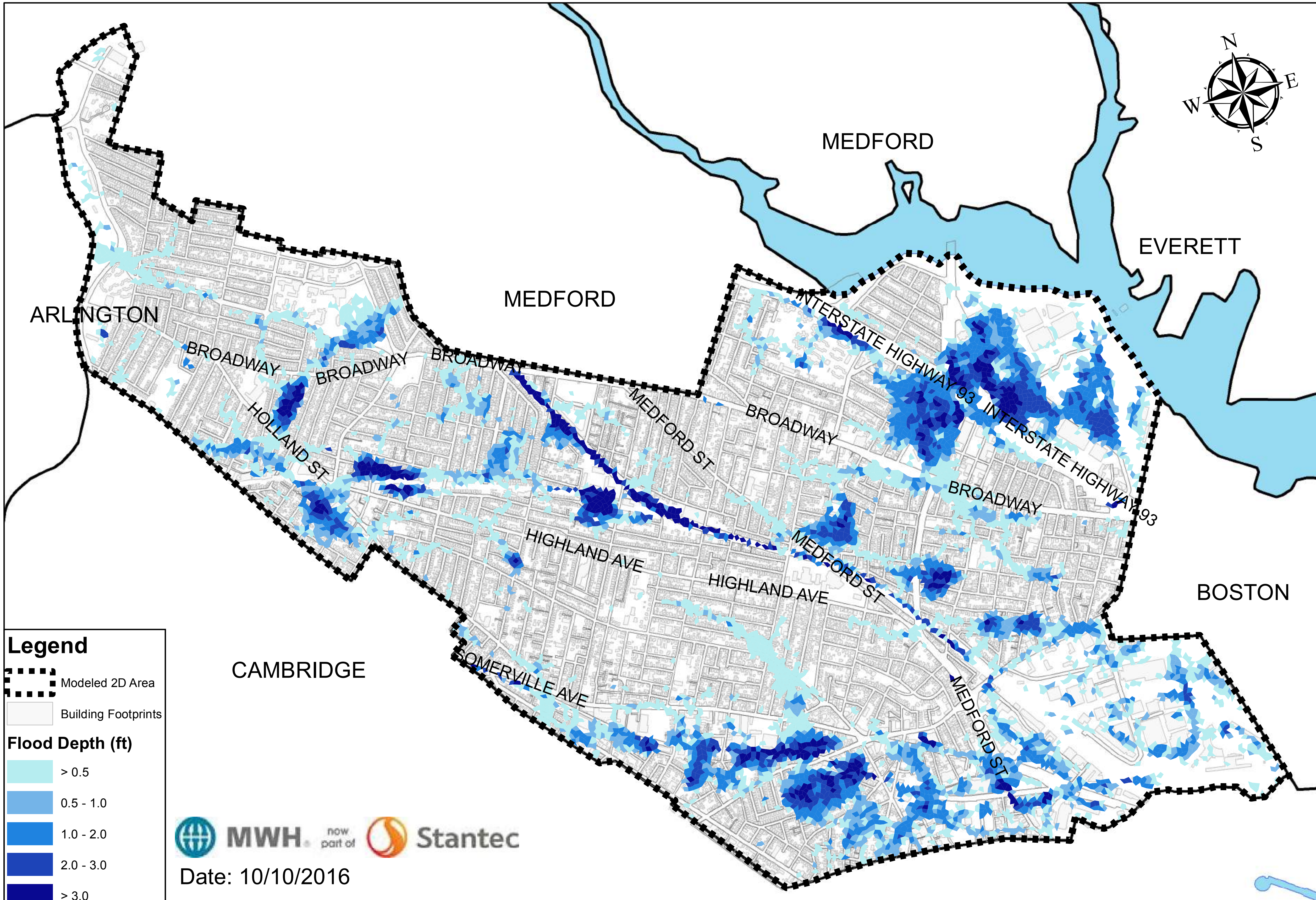
Appendix B

Bathtub Analysis, City-Wide Inundation Maps

City-Wide Bathtub Analysis, Somerville, MA
Maximum Flood Depth
10-year, 24-hour Event, Existing Climate

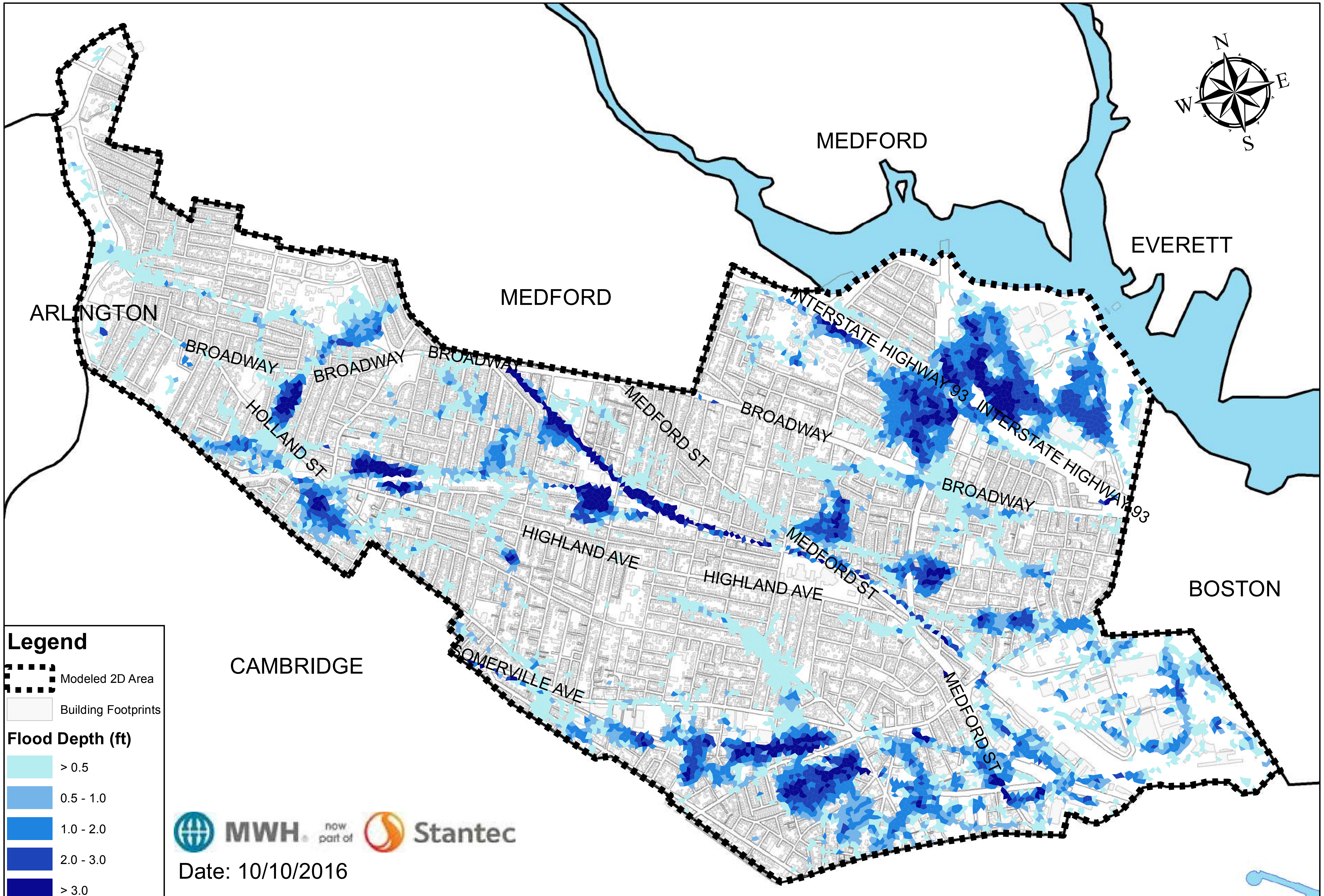


City-Wide Bathtub Analysis, Somerville, MA
Maximum Flood Depth
10-year, 24-hour Event, 2030 Horizon

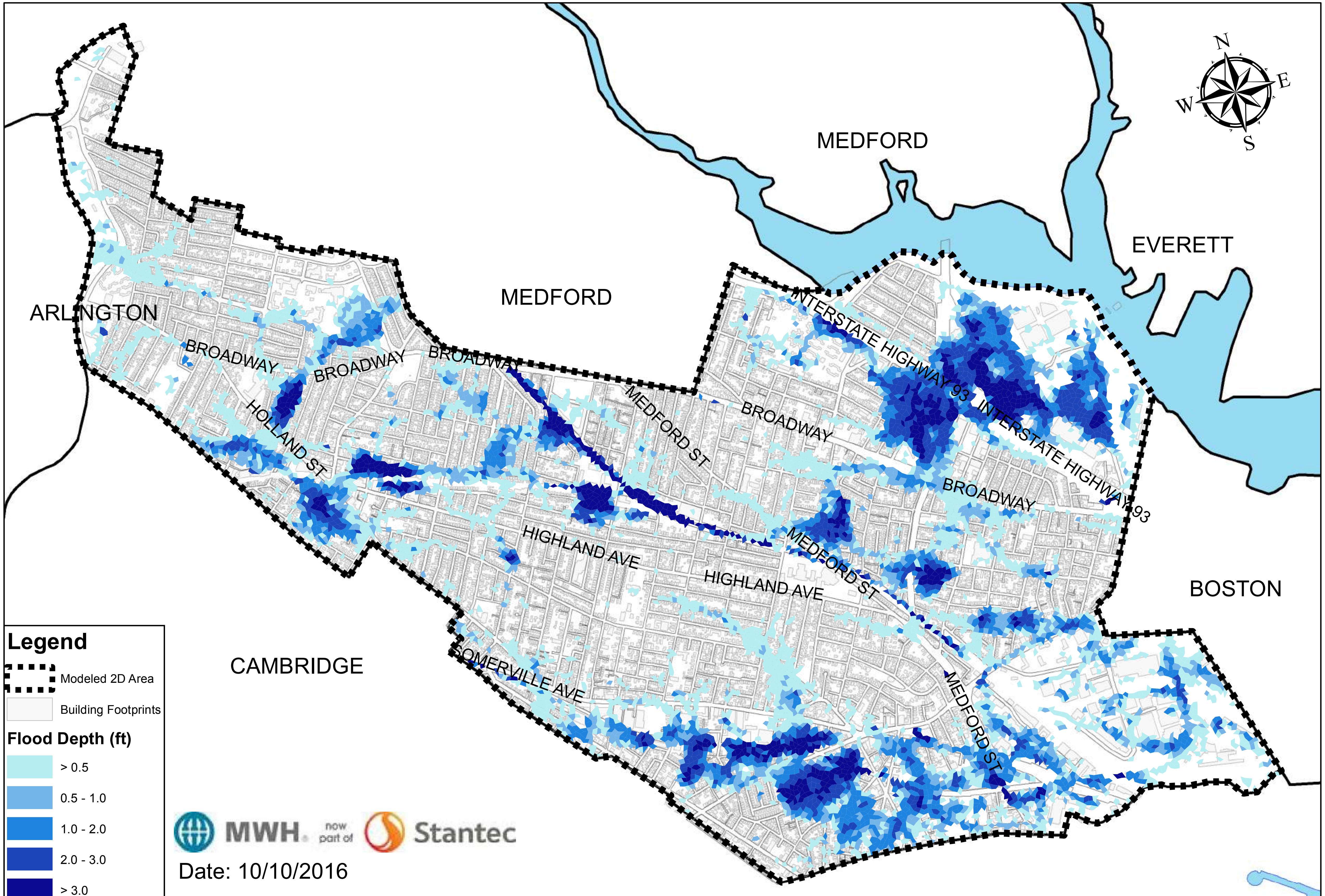


Date: 10/10/2016

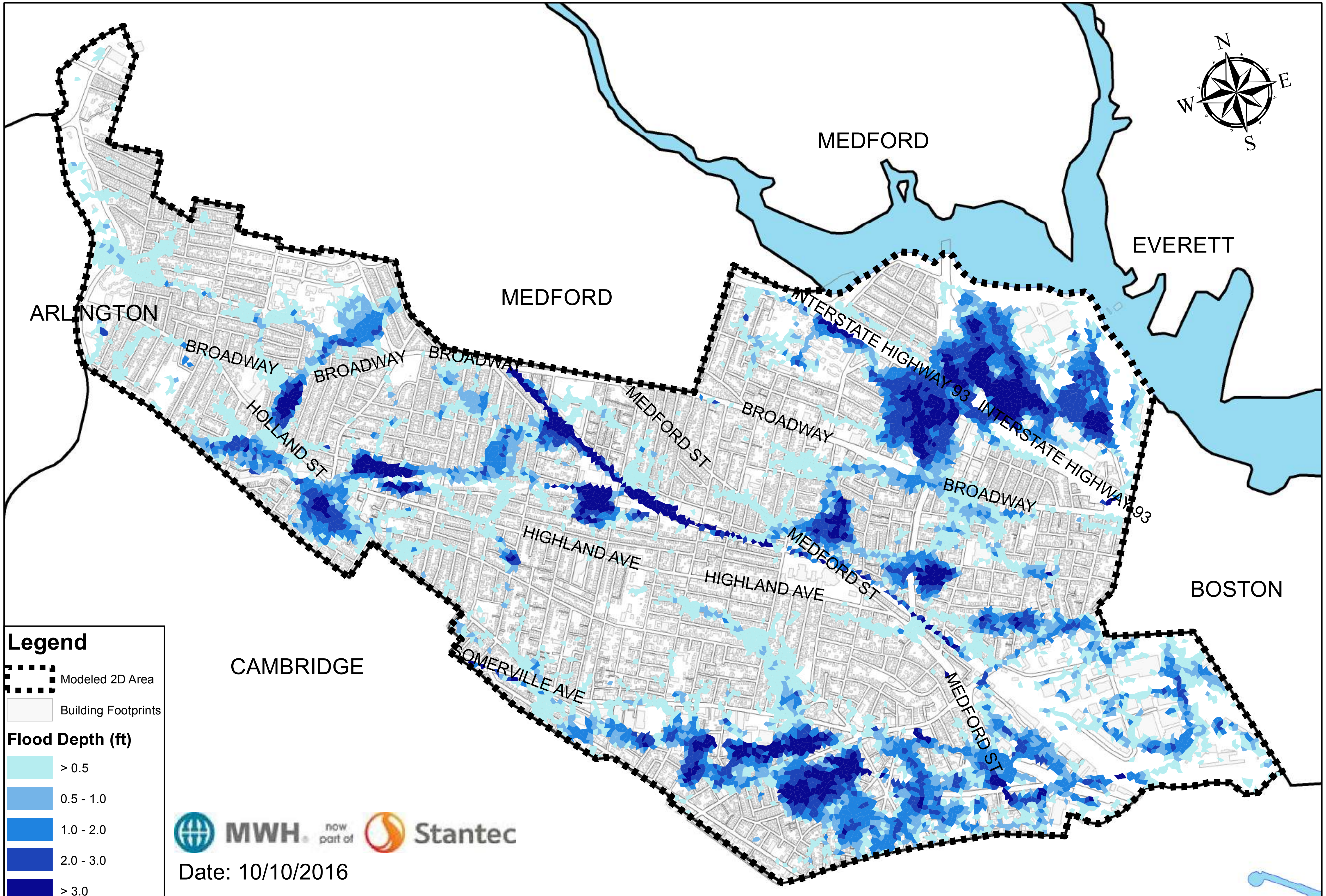
City-Wide Bathtub Analysis, Somerville, MA
Maximum Flood Depth
10-year, 24-hour Event, 2070 Horizon



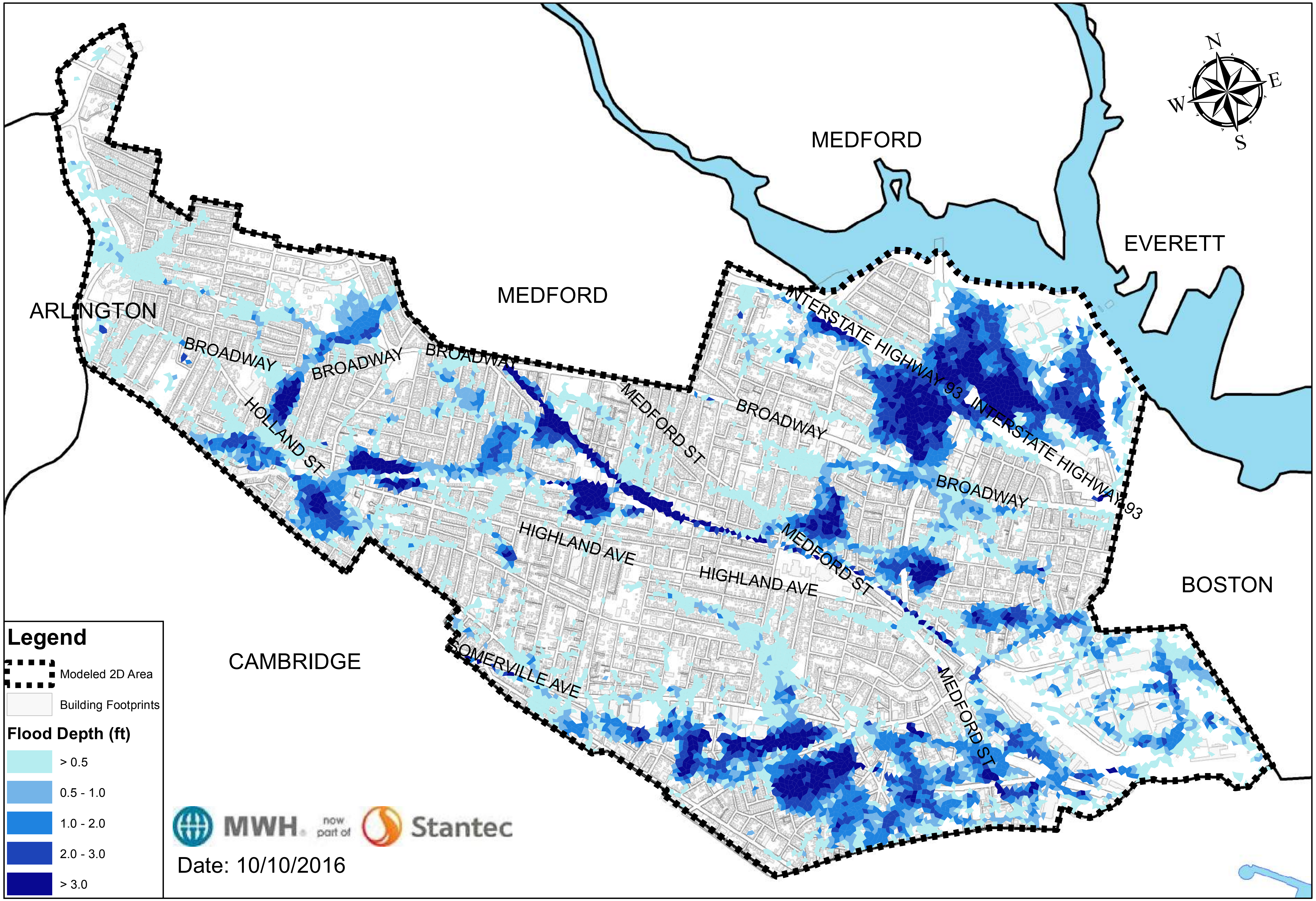
City-Wide Bathtub Analysis, Somerville, MA
Maximum Flood Depth
100-year, 24-hour Event, Existing Climate



City-Wide Bathtub Analysis Somerville, MA
Maximum Flood Depth
100-year, 24-hour Event, 2030 Horizon

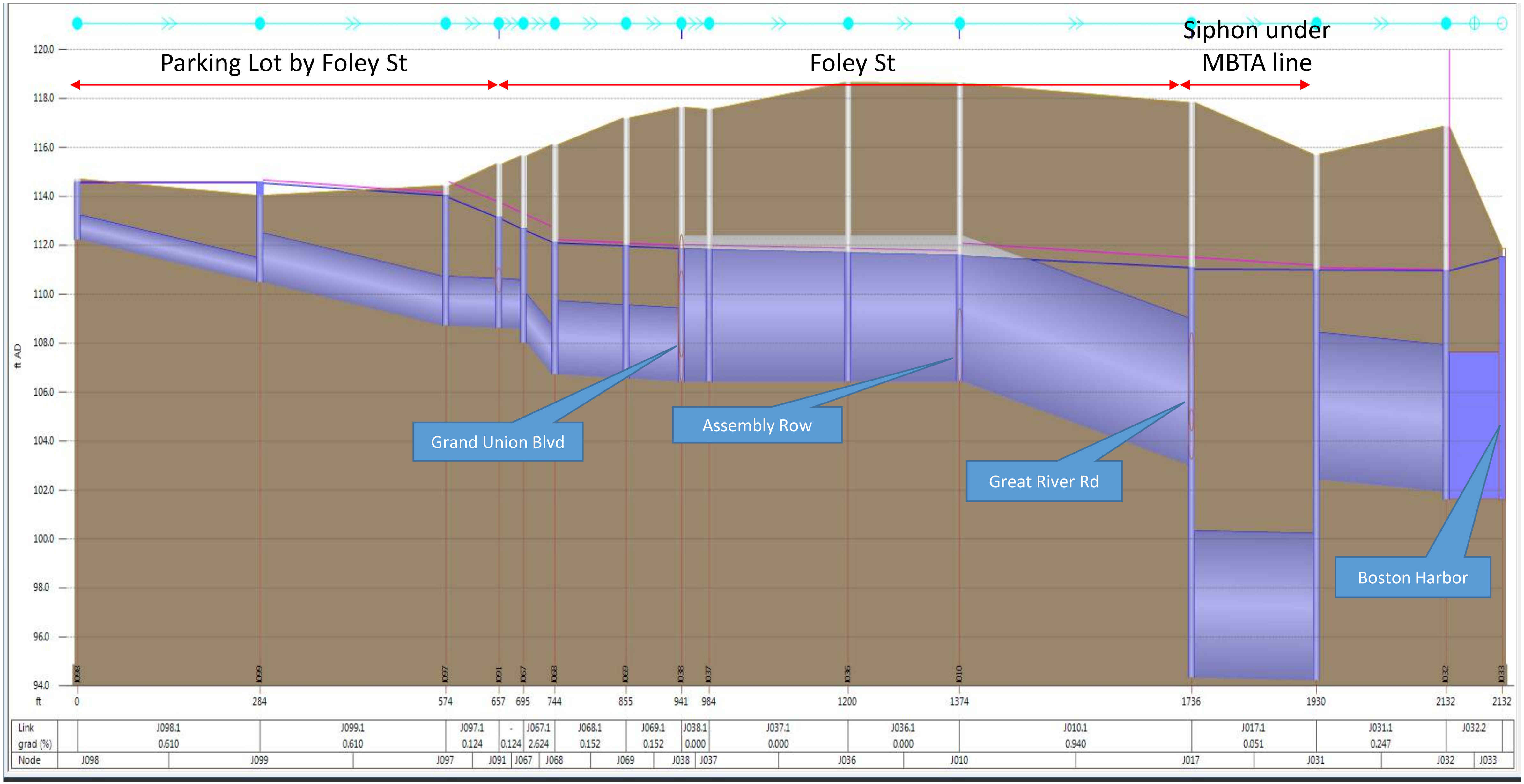


City-Wide Bathtub Analysis, Somerville, MA
Maximum Flood Depth
100-year, 24-hour Event, 2070 Horizon

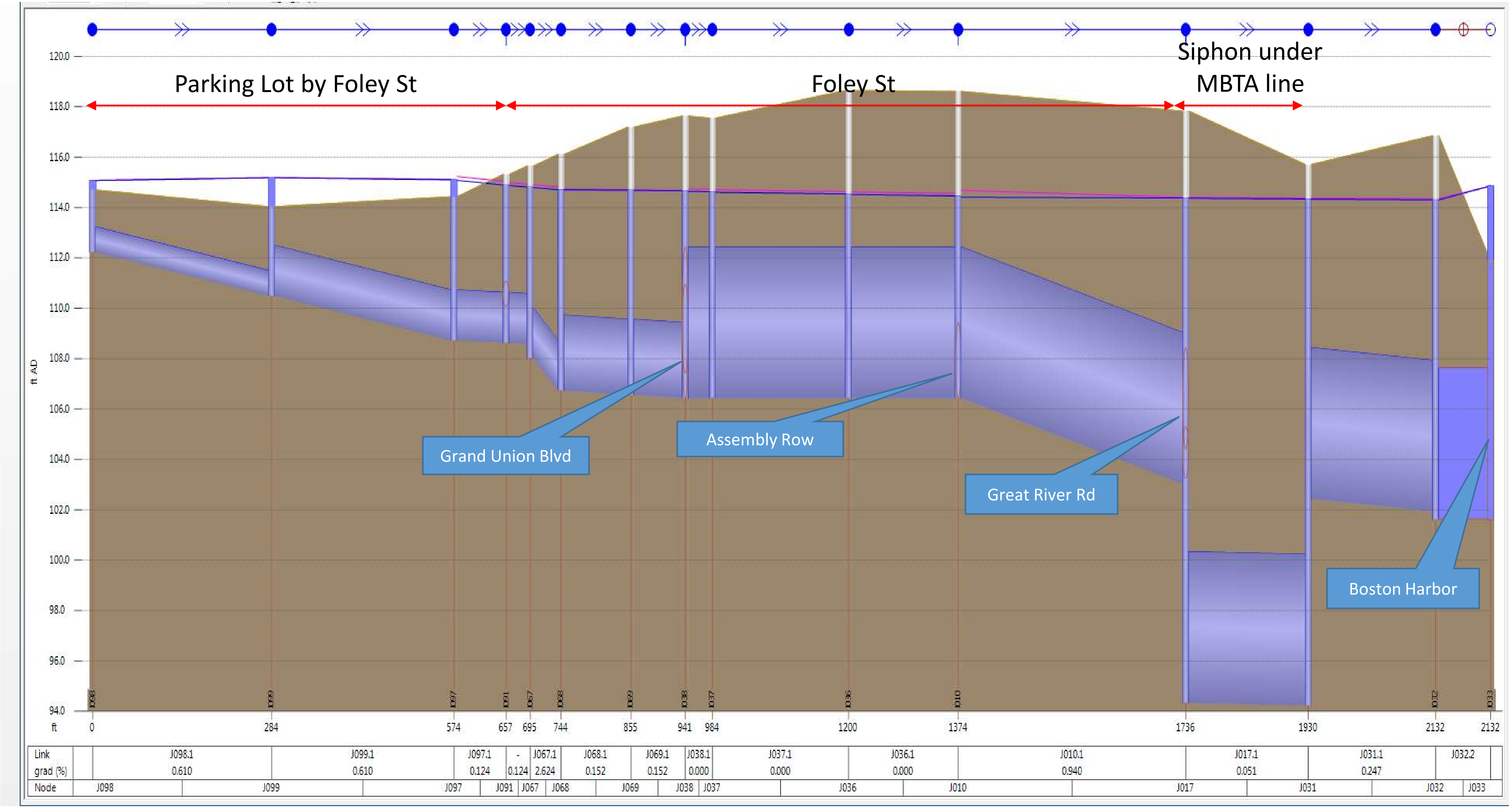


Appendix C

Foley Street Drain Peak HGL Profiles



Peak HGL profile along the Foley St drain for the 100-year, 24-hr 2070 storm with current, normal tide conditions



Peak HGL profile along the Foley St drain for the 100-year, 24-hour, 2070 storm with normal tide conditions projected for 2070

Appendix E
Regional Economic Analysis

Memorandum

ARUP

To	Oliver Sellers-Garcia, City of Somerville	Date	December 22, 2016
Copies		Reference number	248138-00
From	Industrial Economics/Arup	File reference	
Subject	Estimating Economic Impacts of Flood Events in the City of Somerville		

In support of ARUP's broader effort to assess climate change vulnerability in Somerville, IEc examined the vulnerability of Somerville's economic systems. Specifically, we estimated potential monetary damages to residential and commercial buildings from storm surge flood events, as well as the regional economic impacts of lost business revenue due to inundation or flooding.

Estimating the Flood Damages to Residential and Commercial Buildings

We combined flood forecasts, estimates of current assessed structural value, established relationships between flood depth and value, and economic forecasts to estimate flood damages to residential and commercial buildings associated with future sea level rise and storm surge scenarios in the City of Somerville.

First, we overlaid forecast storm surge flood maps for various scenarios provided by Woods Hole Group with 2015 parcel-level City of Somerville Tax Assessor data for the City of Somerville. Combining these two spatial data sources allowed us to estimate the average expected flood depth within each parcel under each flood scenario within the City. As shown, most of the flooding is anticipated to occur within three neighborhoods, East Somerville, Ward Two, and Ten Hills. Additionally, the Tax Assessor data allowed us to identify parcel characteristics, such as the improved value of structures within the parcel, whether each parcel is residential or commercial, and whether each parcel is single-story or multi-story.

Next, we applied the U.S. Army Corps of Engineers' depth-damage functions to estimate the damages likely to be caused by the anticipated flooding and inundation events. These depth-damage functions provide a mathematical relationship between the depth of flood water above or below the first floor of a building and the amount of monetary damage that is expected to be attributed to that water. We used separate depth-damage functions for commercial versus residential parcels and single versus multi-story buildings. The depth-damage functions provided us with estimates of the percent damage to each parcel's structural value for each flood event. In order to estimate the total forecast structural damage to each parcel, we multiplied the estimated percent structural damage by the total improved parcel value from the assessor data. We then aggregated the estimated structural damages associated with each individual parcel to the neighborhood level[11].

For residential buildings, the Army Corps also provides depth-damage functions which relate flood depth to building content damage as a percent of structural value. These depth-damage functions incorporate estimates of the relationship between a residential building's structural value and content value. As a result, we also estimated total monetary damages to the contents of residential buildings by parcel and neighborhood. However, the Army Corps does not provide comparable depth-damage functions for commercial properties. The commercial depth-damage functions only estimate the percentage of the total content value of a commercial property that is lost, and do not relate percent content damage to structural value.

Estimating the Extent of Business Interruption from Flood Events

In order to forecast the level of future business interruption, four data elements are needed: the level of future flooding expected for commercial parcels (which comes from the depth-damage analysis); the type of businesses likely to be located in each parcel (from assessors data); the categories and value of assets that would be affected (especially if they are fixed or moveable); and a number of site-specific conditions that affect whether a business is likely to be able to operate or quickly remobilize following an event (such as access routes, parking conditions, location of business within a building, and more). For purposes of this analysis, which attempts to provide an order of magnitude level of understanding of the potential flood effects, we have developed a simplified method for estimating regional economic impacts associated with business interruption, which is comprised of two primary parts: estimating the extent of business interruption from flood events, and estimating the regional economic implications of that business interruption.

Specifically, we combined the flood damage estimates for potentially affected commercial parcels within the City data from the Economic Census by industry as follows:

1. After identifying the potentially flooded parcels by residential and commercial categories as a result of sea level rise and storm surge, we then examined each potentially flooded commercial parcel by subcategory. The Somerville Assessor data classifies parcels within the City into a number of specific commercial subcategories (PCC Descriptions and Style Descriptions) that include, for example, auto repair, hotel, sand and gravel, clubs/lodges, warehouses, and others. There were anticipated to be 130 parcels affected for the 2070 1000-year return time flood event; and 111 for the 2070 100-year flood event.

2. After identifying the subcategories for potentially flooded commercial parcels, we then matched these categories to North American Industry Classification System (NAICS) industries, as reported in the Economic Census. For example, "car wash" was matched to

[1] We adjusted all improved parcel values and damage estimates to account for planned future development and expected growth in property values. We estimated future growth in property values by combining a forecast of real per capita GDP growth out to 2070 and an elasticity value approximating the relationship between increases in real GDP growth and increases in property values. Overall, we projected an 82 percent increase in all Somerville property values between 2016 and 2070. We also increased the improved values of parcels in 10 parcels within Assembly Square by an additional 30 percent to approximate the additional developments and associated increased values in this area.

NAICS 811192, Car Washes. In some cases, less specific NAICS codes could be determined, e.g. “Store” in the Assessor database was assumed to represent NAICS 44-45, Retail. The Economic Census is the U.S. Government's official five-year measure of American business and the economy. In 2012, over four million businesses received the survey. For each industry, the survey reports the number of establishments, level of employment, and revenues by sector for the City of Somerville as well as Middlesex County. Some data is withheld at the City level for confidentiality reasons.

3. We then estimated annual average revenues by NAICS code for affected businesses from the 2012 Economic Census data, and inflated these revenues to 2015 dollars using a commonly used broad-based inflation index, the GDP deflator. Where data was withheld at the City level, we used Middlesex County level data to determine average annual revenues for each business at the identified NAICS level.

4. Next, we assumed that the percent of estimated content damage from the USACE depth-damage functions could be used as a proxy for understanding the level of business interruption at each parcel. That is, if a parcel labeled “car wash” was found to be flooded at 25 percent content damage in a 100-year flood in 2070, and the Economic Census reported the average annual revenues for that car wash at $400,000, then revenue losses were assumed to be $100,000, or 25 percent of estimated annual revenues[22]. The average percent impacted by commercial businesses was 48 percent across all affected parcels.

5. Finally, we aggregated the affected revenues by NAICS industry. These results are presented in [Table X and Table Y –tables summarizing business impacts by industry for 1000 and 100-year flood events in 2070]. As shown, business revenue impacts are estimated to be approximately $150 million in a 100-year storm event, and $176 million in a 1000-year event in 2070. Although this extent of interruption at individual businesses is highly uncertain, it does give some understanding of the potential scale of impacts. While large, these revenues would have represented less than seven percent of annual business revenue in the City of Somerville in 2012.

Table X. Estimated Lost Business Revenues due to Interruption in the City of Somerville Associated with a 100-year Storm Event in 2070

NAICS Code	NAICS/IMPLAN Description	IMPLAN Industry	Total Revenue Loss (2015$)
8111	Automotive repair and maintenance	504	$789,000
811192	Car washes	505	$129,000
62	Health Care and Social Assistance	478	$2,017,000
493	Warehousing and Storage	416	$6,521,000
518210	Data processing, hosting, and related services	430	$567,000

[2] In the Assembly Square area, we found that the parcels labeled “retail” contain multiple business establishments. As such, rather than assume that each parcel had a standard retail business income, we assumed that each identified business in each parcel had a standard retail income. The businesses within each parcel were identified from the directory provided on the Assembly Row website: http://www.assemblyrow.com/pdfs/directory-1-6-16

Memorandum

4471	Gasoline stations	402	$2,105,000
62411	Child and youth services	485	$362,000
721110	Hotels (except casino hotels) and motels	499	$8,054,000
444130	Hardware stores	399	$364,000
812930	Parking lots and garages	512	$1,078,000
72251	Restaurants and other eating places	501	$6,941,000
484	Truck transportation	411	$2,453,000
4451	Grocery stores	400	$4,890,000
512131	Motion picture theaters (except drive-ins)	423	$378,000
31-33 - Manufacturing	Urethane and other foam product (except polystyrene) manufacturing	193	$1,245,000
	Canned fruits and vegetables manufacturing	81	$667,000
	Bread and bakery product, except frozen, manufacturing	94	$607,000
	Chocolate and confectionery manufacturing from cacao beans	77	$550,000
	Printing	154	$546,000
	Motor vehicle body manufacturing	346	$462,000
	Distilleries	110	$228,000
	Breweries	108	$228,000
	Primary battery manufacturing	337	$227,000
44-45 Retail	Retail - Food and beverage stores	400	$33,972,000
	Retail - Building material and garden equipment and supplies stores	399	$16,887,000
	Retail - General merchandise stores	405	$14,039,000
	Retail - Health and personal care stores	401	$13,281,000
	Retail - Motor vehicle and parts dealers	396	$11,349,000
	Retail - Furniture and home furnishings stores	397	$9,185,000
	Retail - Clothing and clothing accessories stores	403	$8,958,000
54 Professional, Scientific, and Technical Services	Custom computer programming services	451	$1,707,000
	Architectural, engineering, and related services	449	$815,000
	Scientific research and development services	456	$513,000
Total			$152,116,000

Memorandum

In some cases, the IMPLAN model allows for more specificity in industry codes than were available through the Assessor data/Economic Census data for affected parcels. In these cases, we used base data from IMPLAN for the zip codes in Somerville to estimate the most common industries in the City. For example, for the Retail sector, losses were distributed proportionally among the top retail sectors of food and beverage, building material and garden supply, general merchandise, health and personal care stores, motor vehicle and parts dealers, furniture and home furnishing stores, and clothing and accessories stores.

Table Y. Estimated Lost Business Revenues due to Interruption in the City of Somerville Associated with a 1000-year Storm Event in 2070

NAICS Code	NAICS/IMPLAN Description	IMPLAN Industry	Total Revenue Loss (2015$)
8111	Automotive repair and maintenance	504	$1,328,000
811192	Car washes	505	$203,000
62	Health Care and Social Assistance	478	$2,176,000
493	Warehousing and Storage	416	$8,248,000
518210	Data processing, hosting, and related services	430	$567,000
4471	Gasoline stations	402	$4,424,000
62411	Child and youth services	485	$362,000
721110	Hotels (except casino hotels) and motels	499	$9,908,000
444130	Hardware stores	399	$574,000
812930	Parking lots and garages	512	$1,107,000
72251	Restaurants and other eating places	501	$8,035,000
484	Truck transportation	411	$3,069,000
4451	Grocery stores	400	$5,173,000
512131	Motion picture theaters (except drive-ins)	423	$457,000
31-33 - Manufacturing	Urethane and other foam product (except polystyrene) manufacturing	193	$1,729,000
	Canned fruits and vegetables manufacturing	81	$927,000
	Bread and bakery product, except frozen, manufacturing	94	$843,000
	Chocolate and confectionery manufacturing from cacao beans	77	$764,000
	Printing	154	$759,000

	Motor vehicle body manufacturing	346	$642,000
	Distilleries	110	$316,000
	Breweries	108	$316,000
	Primary battery manufacturing	337	$315,000
44-45 Retail	Retail - Food and beverage stores	400	$37,942,000
	Retail - Building material and garden equipment and supplies stores	399	$18,860,000
	Retail - General merchandise stores	405	$15,680,000
	Retail - Health and personal care stores	401	$14,833,000
	Retail - Motor vehicle and parts dealers	396	$12,675,000
	Retail - Furniture and home furnishings stores	397	$10,259,000
	Retail - Clothing and clothing accessories stores	403	$10,004,000
54 Professional, Scientific, and Technical Services	Custom computer programming services	451	$1,867,000
	Architectural, engineering, and related services	449	$1,215,000
	Scientific research and development services	456	$422,000
Total			$177,998,000
In some cases, the IMPLAN model allows for more specificity in industry codes than were available through the Assessor data/Economic Census data for affected parcels. In these cases, we used base data from IMPLAN for the zip codes in Somerville to estimate the most common industries in the City. For example, for the Retail sector, losses were distributed proportionally among the top retail sectors of food and beverage, building material and garden supply, general merchandise, health and personal care stores, motor vehicle and parts dealers, furniture and home furnishing stores, and clothing and accessories stores.			

Regional Economic Modeling

The IMPLAN model was used to estimate regional economic impacts of future flooding events on commercial and industrial entities. IMPLAN is commonly used by state and federal agencies for policy planning and evaluation purposes. By examining the interconnections between industries in our region, IMPLAN allows us to estimate how revenues of economic sectors affected by climate change (e.g., tourism, manufacturing, retail, etc.) would affect other economically linked sectors in the broader regional economy (the "multiplier effect"). These changes can be measured in terms of impacts to economic output, value added (similar to gross regional product), employment, and labor income associated with the changes in industry revenues, as follows:

- **Employment Demand** reflects the impact of a change on labor requirements within an area, and is measured in worker-years. A worker-year is equivalent to one job lasting 12 months, two jobs lasting six months, three jobs lasting four months, etc. The U.S. Bureau of Labor Statistics and the Bureau of Economic Analysis employ the same measure, but use the term "job" rather than "worker-year" in reporting national employment statistics.
- **Labor Income** includes wages, worker benefits, and proprietor income.
- **Value Added** is defined as the difference between an industry's or establishment's total output and the costs of its intermediate inputs. This measure is analogous in many ways to the measurement of gross domestic product (GDP).
- **Output** represents the value of industry production. For manufacturers, output is defined as sales plus or minus the change in manufacturing inventory. In the retail and wholesale sectors, output is defined simply as the gross margin on sales.

The analysis used 2015 data for the City of Somerville zip codes in IMPLAN version 3.1. The model classifies all industries into IMPLAN sectors, which represent aggregations of North American Industry Classification System (NAICS) codes (in this version, IMPLAN aggregates industries into 536 sectors). IMPLAN draws upon data from federal and state agencies, including the Bureau of Economic Analysis and the Bureau of Labor Statistics that describe the interrelationships between industry producers and consumers. IMPLAN combines these data, which describe market monetary flows, with "social accounts" that describe non-market monetary flows, such as payments made between households, or between households and governments. The IMPLAN data describing these monetary flows generate the multipliers that we rely upon in this analysis to general the regional economic impacts of potential flood events.

These effects can be described as direct, indirect, or induced, depending on the nature of the change.

- **Direct effects** represent changes in output attributable to a change in demand or a supply shock[3].
- **Indirect effects** are changes in the output of industries that supply goods and services to those that are directly affected by the change in direct expenditures.
- **Induced effects** reflect changes in household consumption arising from changes in employment and associated income. Induced effects also stem from reduced expenditures by commercial taxpayers.

[3] Output is the value of all goods and services produced.

Memorandum

For this analysis, we apply the business revenue losses estimated above to the IMPLAN model[4]. Here, we aggregate the direct, indirect, and induced effects to calculate the total regional economic impacts of these changes.

The results for the 2070 sea level rise/storm surge 100 and 1000-yr flood events are presented below. We note that these results are only for impacts that would be anticipated to occur within the City of Somerville, and does not include other regional effects that "leak out" of the City, the City has many business links to other municipalities in the metropolitan Boston area which are not fully captured in these results. Also, regional effects of flood events in other municipalities that may occur simultaneously to the flood modeled which could affect the City of Somerville indirectly are not included here.

Table. Z Regional Economic Impacts in the City of Somerville Associated with a 100-year Storm Event in 2070

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	860	$35,733,000	$46,379,000	$76,053,000
Indirect Effect	80	$5,655,000	$9,352,000	$14,822,000
Induced Effect	110	$5,178,000	$9,321,000	$14,506,000
Total Effect	1,050	$46,566,000	$65,052,000	$105,381,000

Table aa. Regional Economic Impacts in the City of Somerville Associated with a 1000-year Storm Event in 2070

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	940	$39,550,000	$51,407,000	$84,982,000
Indirect Effect	90	$6,277,000	$10,311,000	$16,365,000
Induced Effect	120	$5,734,000	$10,321,000	$16,063,000
Total Effect	1,150	$51,561,000	$72,039,000	$117,410,000

[4] In some cases, the IMPLAN model allows for more specificity in industry codes than were available through the Assessor data/Economic Census data for affected parcels. In these cases, we used base data from IMPLAN for the zip codes in Somerville to estimate the most common industries in the City. For example, for the retail sector, losses were distributed proportionally among the top retail sectors of food and beverage, building material and garden supply, general merchandise, health and personal care stores, motor vehicle and parts dealers, furniture and home furnishing stores, and clothing and accessories stores.

Appendix F
Air Quality and Climate Change in Somerville

Memorandum

ARUP

To	Oliver Sellers-Garcia, City of Somerville	Date	September 16, 2016
Copies		Reference number	
From	Dr. Pat Kinney & Arup	File reference	
Subject	Air Quality and Climate Change in Somerville		

One of the often-cited effects of climate change on human health is its effect on worsening air quality; climate factors such as temperature, rainfall and wind patterns can affect spatial and temporal patterns of air pollution. But what does that mean for air quality in Somerville? While there haven't been any studies specifically addressing this question, we can make some general observations based on our general knowledge of air pollution trends in the Boston area and the effects of climate change.

Climate can affect traditional air pollutants like ozone and particulate matter, which is the main focus of this section. But climate can also can affect air quality in more subtle ways. For example, rising carbon dioxide levels and warming temperatures are leading to earlier and potentially more severe pollen seasons, which is bad news for allergy sufferers. Climate change also leads to greater risk of wildfires, with their attendant smoke pollution. While not a common problem in eastern Massachusetts, we do sometimes see elevated particulate matter levels in our region due to fire smoke transported by winds from Canada, where fires are common. Climate change can also affect indoor air quality. The large coastal storms and associated flooding associated with climate change can lead to serious mold problems in our homes after the floodwaters recede.

Ozone and particulate matter (especially tiny PM2.5 particles) are two pollutants generated by fossil fuel combustion which have well-documented adverse health effects, and which can be influenced by climate change. Ozone is responsible for smog events that occur on hot, sunny days in summer. When inhaled, ozone burns the nose and lungs, and can lead to acute illness and even death in extreme cases. More ozone is seen on hot days, and when air masses stagnate over eastern Massachusetts, two phenomena that are expected to worsen due to climate change. However, due to tighter emission controls on the gases that form ozone, levels in the Boston area have been improving over the past 30 years, and are expected to continue to do so. Currently the Boston region is in compliance with the ozone standard, even though the standard has been made more strict over the past decade.

PM2.5, i.e. the concentration of particles smaller than 2.5 microns in diameter (about 1/60th the diameter of a human hair), is less sensitive to climate change than is ozone, but it still could be affected by future changes. Like ozone, PM2.5 has a variety of severe health effects, and like ozone, concentrations in the Boston area have come down over time. This, along with further expected pollution controls in the future, suggest that climate change is unlikely to pose a serious threat to PM2.5-related health effects in Somerville. This is not to say that we should ignore PM2.5 pollution. In fact, due to its high density and proximity to major traffic sources such as Rt. 93 and McGrath Highway, PM2.5 may still be a concern in some parts of Somerville.

Recently, the US Global Change Research Program published a landmark report on the health impacts of climate change, including a whole chapter on air quality impacts While nationwide in scope, the findings are relevant to Somerville and other northeastern US cities where air pollution remains a threat to health. The report concluded that climate change will make it harder for us to continue making progress in reducing ozone concentrations. We will need to enact stronger emission reductions on ozone precursor pollutants to achieve our air quality goals in the future. The report also highlighted the climate change will increase the frequency and severity of naturally occurring wildfires in the US, which can worsen both PM2.5 and ozone pollution. Finally, the report noted that levels of some airborne allergens such as pollen from trees and weeds will increase, leading to increases in asthma episodes and other allergic illnesses.

References:

USGCRP, 2016: *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. http://dx.doi.org/10.7930/J0R49NQX

Appendix G
Vulnerable Populations Methodology

Memorandum

ARUP

To	Oliver Sellers-Garcia, City of Somerville	Date	December 22, 2016
Copies		Reference number	248138-00
From	Arup	File reference	
Subject	City of Somerville Vulnerability Assessment: Vulnerable Populations Methodology		

Overview

This assessment of the vulnerable populations in the City of Somerville is based on a modified version of the ICLEI methodology for ranking vulnerability. This approach uses U.S. Census tract data, aggregated by neighborhood, to rank the sensitivity and adaptive capacity of Somerville residents. Poverty, age, education, language isolation and elderly living alone were used as indicators. This assessment is not intended to provide a comprehensive or in-depth review of the strengths and vulnerabilities of individual residents or the services and support systems available to the residents. Social vulnerability is complex and no single assessment can capture all of the dimensions. This methodology offers a high-level review of the spatial distribution of the most vulnerable residents in the City of Somerville.

Methodology

Definitions and Data Sources

Vulnerability is defined as a combination of a population's sensitivity to climate factors (sensitivity) and their ability to adapt to changes in climate (adaptive capacity). Demographic data from the 2011 American Community Survey (ACS) was used as a proxy for social indicators of sensitivity and adaptive capacity. Social indicators of sensitivity include:

1. Poverty: defined as the % of households whose income in the last 12 months was below poverty level;
2. Old age: defined as the % of people over age 65; and,
3. Youth: defined as the % of people below age 5.

Social indicators of adaptive capacity include:

4. Poverty: defined as the % of households whose income in the last 12 months was below poverty level;

5. Education: defined as the % of people with a high school diploma or higher;
6. Language Isolation: defined as % of households speaking a language other than English at home; and,
7. Elderly Living Alone: defined as the % of people over age 65 that live alone.

Calculations

Data was downloaded for each of the 18 census tracts in the City of Somerville and aggregated into 11 neighborhoods, based on data provided by the City of Somerville's GIS Department and Planning Department. The social indicators for each neighborhood were determined by averaging each of the data points from the census tracts located within the neighborhood boundaries. It is important to note that the neighborhood boundaries and census tract boundaries do not align. For the purposes of this assessment, adjustments were made to the neighborhood boundaries to better align to the census tract boundaries.

Ranking and Scoring (per indicator)

For each of the sensitivity indicators, the neighborhoods were ranked in order from lowest to highest values and then divided into quartiles in order to assign a sensitivity score from one to four. A score of S1 reflects the lowest sensitivity relative to the other neighborhoods in Somerville. Similarly, a score of S4 reflects high sensitivity.

The adaptive capacity indicators were similarly ranked and scored; however, the ranking system varied depending on the indicator. For the adaptive capacity indicators relating to poverty, language and elderly living along, the neighborhoods were ranked from highest to lowest, with the highest percentage indicating less adaptive capacity in the population and therefore, receiving the lowest score. Conversely, the adaptive capacity indicator relating to educational attainment for each of the neighborhoods was ranked from lowest to highest, with the lowest percentage indicating less adaptive capacity and therefore, receiving the lowest score. Neighborhoods were scored on an adaptive capacity scale of zero to three. A score of AC0 reflects the least adaptive capacity while a score of AC3 reflects a high adaptive capacity. Refer to the attached spreadsheet for more information on the ranking and scoring.

Total Sensitivity and Adaptive Capacity Scores

The sensitivity and adaptive capacity indicators were aggregated according to neighborhoods. We took two approaches to scoring the aggregated indicators: an absolute score and a relative score. The various processes for determining total sensitivity and adaptive capacity scores are as follows:

Absolute Sensitivity

1. Add all sensitivity scores to get a total score: Poverty Score + Old Age Score + Youth Score

   <u>Ex. Davis Square:</u>

   Poverty Score =1

Old Age Score = 2

Youth Score = 2

Calculation: Total Score = 1 + 2 + 2 = 5

2. Determine the highest possible score for each neighborhood and divide the highest possible score into quartiles

   Total possible score for each sensitivity indicator = 4

   Highest possible score = # of sensitivity indicators (3) x possible score (4) = 12

   Calculation: 12 / 4 = 3; Q1 = 0-3, Q2 = 3-6, Q3 = 6-9, Q4 = 9-12

3. Compare the total score for each neighborhood to the quartiles and assign an aggregate sensitivity score based on that quartile. Total scores in the first quartile receive an aggregate score of S1 (low sensitivity) and total scores in the fourth quartile receive an aggregate score of S4 (high sensitivity).

   Ex. Davis Square

   Total Score = 5

   Falls in Q2 (3-6)

   Davis Square has a sensitivity score of S2.

Relative Sensitivity

1. Add all sensitivity scores to get a total score: Poverty Score + Old Age Score + Youth Score

   Ex. Davis Square:

   Poverty Score =1

   Old Age Score = 2

   Youth Score = 2

   Calculation: Total Score = 1 + 2 + 2 = 5

2. Rank all neighborhoods based on their total scores, with a rank of 1 being the lowest total sensitivity score.

Neighborhood	Total Sensitivity Score	Sensitivity Rank
Tufts	4	1
Davis Square	5	2
Powderhouse	7	3
Ward 2 & Inner Belt	7	4
Prospect Hill	8	5
Magoun Square	8	6

Spring Hill/Central Hill	9	7
West Somerville	9	8
Winter Hill	9	9
Ten Hills	10	10
East Somerville & Assembly Square	11	11

3. Divide the sensitivity rank into quartiles

   Highest sensitivity rank = 11

   Calculation: 11 / 4 = 2.75; Q1 = 0-2.75, Q2 = 2.75-5.5, Q3 = 5.5-8.25, Q4 = 8.25-11

4. Compare the sensitivity rank for each neighborhood to the quartiles and assign an aggregate sensitivity score based on that quartile. Total scores in the first quartile receive an aggregate score of S1 (low sensitivity) and total scores in the fourth quartile receive an aggregate score of S4 (high sensitivity).

   <u>Ex. Davis Square</u>

   Sensitivity Rank = 2

   Falls in Q1 (0-2.75)

   Davis Square has a sensitivity score of S1.

Absolute Adaptive Capacity

1. Add all adaptive scores to get a total score: Poverty Score + Education Score + Language Isolation Score + Elderly Living Alone Score

   <u>Ex. Davis Square:</u>

   Poverty Score = 3

   Education Score = 3

   Language Isolation Score = 3

   Elderly Living Alone = 3

   Calculation: Total Score = 3 + 3 + 3 + 3 = 12

2. Determine the highest possible score for each neighborhood and divide the highest possible score into quartiles

   Total possible score for each adaptive capacity indicator = 3

   Highest possible score = # of adaptive capacity indicators (4) x possible score (3) = 12

   Calculation: 12 / 4 = 3; Q1 = 0-3, Q2 = 3-6, Q3 = 6-9, Q4 = 9-12

3. Compare the total score for each neighborhood to the quartiles and assign an aggregate adaptive capacity score based on that quartile. Total scores in the first quartile receive an aggregate score of AC0 (low adaptive capacity) and total scores in the fourth quartile receive an aggregate score of AC3 (high adaptive capacity).

   Ex. Davis Square

   Total Score = 12

   Falls in Q4 (9-12)

   Davis Square has an adaptive capacity score of AC3.

Relative Adaptive Capacity

1. Add all adaptive scores to get a total score: Poverty Score + Education Score + Language Isolation Score + Elderly Living Alone Score

   Ex. Davis Square:

   Poverty Score = 3

   Education Score = 3

   Language Isolation Score = 3

   Elderly Living Alone = 3

   Calculation: Total Score = 3 + 3 + 3 + 3 = 12

2. Rank all neighborhoods based on their total scores, with a rank of 1 being the lowest total sensitivity score.

Neighborhood	Total AC Score	AC Rank
East Somerville & Assembly Square	0	1
Ten Hills	1	2
West Somerville	2	3
Winter Hill	4	4
Ward 2 & Inner Belt	4	5
Prospect Hill	5	6
Spring Hill/Central Hill	6	7
Powderhouse	7	8
Magoun Square	8	9
Tufts	11	10
Davis Square	12	11

3. Divide the adaptive capacity rank into quartiles

   Highest adaptive capacity rank = 11

Calculation: 11 / 4 = 2.75; Q1 = 0-2.75, Q2 = 2.75-5.5, Q3 = 5.5-8.25, Q4 = 8.25-11

4. Compare the adaptive capacity rank for each neighborhood to the quartiles and assign an aggregate adaptive capacity score based on that quartile. Total scores in the first quartile receive an aggregate score of AC0 (low adaptive capacity) and total scores in the fourth quartile receive an aggregate score of AC3 (high adaptive capacity).

   Ex. Davis Square

   Adaptive Capacity Rank = 11

   Falls in Q4 (8.25-11)

   Davis Square has an adaptive capacity score of AC3.

Refer to the attached map to see the spatial layout of census tracts and neighborhoods and the attached spreadsheet for more information on the underlying calculations for the neighborhood sensitivity and adaptive capacity indicators.

Social Vulnerability Assessment

The aggregate sensitivity and adaptive capacity scores are used to determine social vulnerability for each of the neighborhoods in Somerville. Because this analysis assesses both relative and absolute adaptive capacity in Somerville, there are two variations of neighborhood vulnerability. The following charts indicate neighborhood vulnerability, with the most vulnerable neighborhoods plotting in the top right (dark red) portion of the chart and the least vulnerable plotting in the bottom left (yellow) portion of the chart.

		ABSOLUTE Sensitivity (Low → High)			
		S1	S2	S3	S4
ABSOLUTE Adaptive Capacity (Low → High)	AC0			West Somerville	Ten Hills East Somerville & Assembly Square
	AC1			Winter Hill Spring Hill/Central Hill Ward 2 & Inner Belt Prospect Hill	
	AC2			Magoun Square Powderhouse	
	AC3		Tufts Davis Square		

		RELATIVE Sensitivity (Low → High)			
		S1	S2	S3	S4
RELATIVE Adaptive Capacity (Low → High)	AC0				Ten Hills East Somerville & Assembly Square
	AC1		Ward 2 & Inner Belt	West Somerville	Winter Hill
	AC2		Powderhouse Prospect Hill	Spring Hill/Central Hill	
	AC3	Tufts Davis Square		Magoun Square	

Appendix H
Vulnerability and Risk Assessment Tables

			Sea Level Rise and Storm Surge					Precipitation					Temperature				
			Vulnerability			Risk		Vulnerability			Risk		Vulnerability			Risk	
Type of Resource	Name of Resource	Address	Exposure	Sensitivity	Adaptive Capacity	Probability	Consequence	Exposure	Sensitivity	Adaptive Capacity	Probability	Consequence	Exposure	Sensitivity	Adaptive Capacity	Probability	Consequence
Dam	Amelia Earhart Dam	Near Assembly Square along Mystic	> 10ft	4	0	Moderate	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Courthouses	Somerville District Court	175 Fellsway	2.5 ft	3	0	Moderate	7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	District Attorney's Office	21 McGrath Highway	0.5 ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Schools	Arthur D Healey School PK-8	5 Meacham Street	N/A	N/A	N/A	N/A	N/A	0.5-1.0ft	2	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Next Wave Junior High School 6-8	8 Bonair Street	N/A	N/A	N/A	N/A	N/A	0.5-2.0ft	3	0	High	10	N/A	N/A	N/A	N/A	N/A
	Full Circle High School 9-12	8 Bonair Street	N/A	N/A	N/A	N/A	N/A	0.5-2.0ft	3	0	High	10	N/A	N/A	N/A	N/A	N/A
	East Somerville Community School K-8	50 Cross Street	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3	0	High	10	N/A	N/A	N/A	N/A	N/A
	Capuano Early Childhood Center PK-K	150 Glen Street	N/A	N/A	N/A	N/A	N/A	3.0-12.0ft	4	0	High	10	N/A	N/A	N/A	N/A	N/A
	Albert F Argenziano School at Lincoln Park PK-8	290 Washington Street	N/A	N/A	N/A	N/A	N/A	2.0-3.0ft	3	0	High	10	N/A	N/A	N/A	N/A	N/A
	John F Kennedy School K-8	5 Cherry Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Benjamin G Brown School K-5	201 Willow Avenue	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	West Somerville Neighborhood School PK-8	177 Powderhouse Blvd	N/A	N/A	N/A	N/A	N/A	0.5-1.0ft	2	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Winter Hill Community School PK-8	115 Sycamore Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fire Stations	Somerville Fire Department HQ/Emergency Operations Center	266 Broadway	0.5 ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Union Square Fire Station	255 Somerville Ave	N/A	N/A	N/A	N/A	N/A	3.0-12.0ft	4	1	High	10	N/A	N/A	N/A	N/A	N/A
	Fire Station	515 Somerville Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Lowell Street Fire Station	651 Somerville Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Teele Square Fire Station	6 Newbury Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Police Stations	Police Station (East Substation)	81 Broadway	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Police Station (West Substation)	1114 Broadway	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Police Headquarters	220 Washington Street	N/A	N/A	N/A	N/A	N/A	3.0-12.0ft	4	0	High	13	N/A	N/A	N/A	N/A	N/A
Hospitals & Medical Facilities	Broadway Health Center	300 Broadway	0.5 ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Somerville Hospital (Cambridge Health Alliance)	230 Highland Avenue	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	East Somerville Health Center	42 Cross Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Union Square Health Center	337 Somerville Ave	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3	1	High	9	N/A	N/A	N/A	N/A	N/A
	Central Street Health Center	26 Central Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	internal Medicine Associates	236 Highland Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Harvard Vanguard Medical Associates	40 Holland Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Board of Health/Annex	50 Evergreen Avenue	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cooling Centers	Cooling Center (Ward Two/Cobble Hill)	9 New Washington St	1.5 ft	3	1	High	7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cooling Center (West Somerville)	110 Alewife Brook Parkway	2 ft	3	1	Moderate	7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cooling Center (East Somerville)	235 Broadway	0.5 ft	1	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cooling Center (East Somerville)	165 Broadway	N/A	N/A	N/A	N/A	N/A	0.5-1.0ft	2	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cooling Center (East Somerville)	115 Broadway	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cooling Center (Central Hill)	79 Highland Avenue	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cooling Center (Ward Two/Cobble Hill)	570 Somerville Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cooling Center (Davis Square)	40 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Elderly Housing	Cobble Hill Apartments	50, 60, 70, 84 Washington St	0.5 ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Clarendon Hill Towers	1370, 1374, 1366 Broadway	0.5 ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Ralph & Jenny Memorial Center	New Washington St	2.5 ft	3	0			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Corbett	32 Jacques Street	1 ft	2	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Pearl Street Park	240 Pearl Street	N/A	N/A	N/A	N/A	N/A	0.5-2.0ft	3	0	High		N/A	N/A	N/A	N/A	N/A
	Bryant Manor	75 Myrtle Street	N/A	N/A	N/A	N/A	N/A	0.5-2.0ft	3	0	High		N/A	N/A	N/A	N/A	N/A
	Brady Towers	252 Medford Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Hagan Manor	268 Washington St	N/A	N/A	N/A	N/A	N/A	1.0-3.0ft	3	0	High		N/A	N/A	N/A	N/A	N/A
	Properzi Manor	13-25 Warren Avenue	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	John Jeanna Jugan Pavilion	186 Highland Avenue	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Hutchins Transitional Care	230 Highland Avenue	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Visiting Nursing Association	259 Lowell Street	N/A	N/A	N/A	N/A	N/A	0.1-2.0ft	3	0	High		N/A	N/A	N/A	N/A	N/A
	Ciampa Manor	27 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Saltonstall Senior	121 Riverside Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Capen Court Apartment Building	2 Capen Court	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Weston Manor	15 Weston Avenue	N/A	N/A	N/A	N/A	N/A	2.0-3.0ft	3	0	High		N/A	N/A	N/A	N/A	N/A
	Corbett	125 Jacques Street	N/A	N/A	N/A	N/A	N/A	0.1-2.0ft	3	0	High		N/A	N/A	N/A	N/A	N/A
Special Needs Housing	Somerville Section Eight House	Memorial Drive	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Monmouth House	17 Monmouth St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Prospect House	386 Broadway	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Childcare	Little Busy Bodies Day Care	100 Fellsway W	3 ft	3	1			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Elizabeth Peabody House	277 Broadway	2 ft	3	1			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CAAS Headstart	125c Alewife Brook Parkway	0.5 ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CAAS Headstart	35a Memorial Road	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Mystic Three	35c Memorial Road	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3	1	High		N/A	N/A	N/A	N/A	N/A
	Mystic Learning Center	530 Mystic Avenue Rm. 103	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Broadway Babies Daycare	88 Broadway	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Bellas Manitas Learning Center	59 Cross St	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3	1	High		N/A	N/A	N/A	N/A	N/A
	Agapanto Day Care	31 Franklin St	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3	1	High		N/A	N/A	N/A	N/A	N/A
	CAAS Headstart	29 Allen St	N/A	N/A	N/A	N/A	N/A	1.0-3.0ft	3	1	High		N/A	N/A	N/A	N/A	N/A
	Cambridge/Somerville Early Intervention	61 Medford St	N/A	N/A	N/A	N/A	N/A	1.0-3.0ft	3	1	High		N/A	N/A	N/A	N/A	N/A
	Peabody Ames Child Care	24 Dane St	N/A	N/A	N/A	N/A	N/A	1.0-3.0ft	3	1	High		N/A	N/A	N/A	N/A	N/A
	Bright Future Day Care	311 Highland Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Kesher Hebrew School	13 Garden Court	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Mulberry Child Care	18 Holland Street	N/A	N/A	N/A	N/A	N/A	1.0-3.0ft	3	1	High		N/A	N/A	N/A	N/A	N/A

	Kinder Care Centers	18-40 Holland Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cambridge Economic Opportunity Committee Preschool	10 Winslow Avenue	N/A	N/A	N/A	N/A	N/A	0.5-2.0ft	3	1	High		N/A	N/A	N/A	N/A	N/A
	Open Center for Children	155 Powderhouse Blvd	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Places of Worship	Christian Assembly	9 Cummings St	3 ft	3	1			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Christ Episcopal Church	66 Fellsway West	4.5 ft	4	1			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Grace Baptist Church	59 Cross St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Alliance Assembly of God & W Oem	85 Washington St	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	World Revival Church	50 Inner Belt Road	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	Alliance Assembly of God (South St)	21 South St	N/A	N/A	N/A	N/A	N/A	0.5-1.0ft	2		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Iglesia de Dios Pentacostal Movement International	26 Mansfield St	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	Alliance Assembly of God (Union Sq)	59 Union Square	N/A	N/A	N/A	N/A	N/A	0.5-3.0ft	4				N/A	N/A	N/A	N/A	N/A
	St. Joseph's	264 Washington St	N/A	N/A	N/A	N/A	N/A	2.0-3.0ft	4				N/A	N/A	N/A	N/A	N/A
	Boston Japanese Christian Church	397 Somerville Avenue #1	N/A	N/A	N/A	N/A	N/A	0.5-1.0ft	2		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	St. Anthony's	12 Properzi Way	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Greek Orthodox Dormition of the Virgin Mary	29 Central St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Bethel Evangelical Church	233 Pearl Street	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	Maranatha Christian Church	164 School Street	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	St. Ann's	50 Thurston St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	St. Ann's	399 Medford St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Vida Real Church	404 Broadway	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Evangelical Haitian Church of Somerville	30 Temple Street	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Horeb Haitian Baptist Church	60 River Road	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	Clarendon Hill Presbyterian Church	155 Powderhouse Blvd	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	St. James Episcopal Church	1170 Broadway (Teele Sq)	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	The Church of Jesus Christ of Latter-Day Saints	99 Dover St	N/A	N/A	N/A	N/A	N/A	1.0-3.0ft	3				N/A	N/A	N/A	N/A	N/A
	College Ave Methodist Church	14 Chapel St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Community Baptist Church	31 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	First Congregational Church	95 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Haitian Bible Baptist Church	45 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Highrock Church	14 Chapel St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Holy Bible Baptist Church	64 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Korean Methodist Church	68 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Portuguese Seventh Day Adventist	89 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Saint Paul Evangelical Church	45 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Unity Church of God	6 William St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Transportation	Fitchburg Commuter Rail	Ward Two near Boston Border	0.5-3.0 ft	4	0	High	10	0.1-12.0ft	4	1	High	10	N/A	N/A	N/A	N/A	N/A
	Lowell Commuter Rail	Ward Two near Boston Border & along Mystic near Arlington/Medford Border	0.5-10.0 ft	4	0	High	10	0.1-12.0ft	4	1	High	10	N/A	N/A	N/A	N/A	N/A
	Newburyport/Rockport Commuter Rail	Ward Two near Boston Border & Assembly area	0.5-10.0 ft	4	0	High	10	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Haverhill Commuter Rail	Ward Two near Boston Border & Assembly area	0.5-10.0 ft	4	0	High	10	0.1-12.0ft	4	1	High	10	N/A	N/A	N/A	N/A	N/A
	Orange Line	Ward Two near Boston Border & Assembly area (& Sullivan Square area - outside Somerville Boundary)	0.5-10.0 ft	4	0	High	12	0.1-12.0ft	4	1	High	12	N/A	N/A	N/A	N/A	N/A
	Assembly Row Station	Assembly Row	3.5 ft	4	0	High	10	1.0-3.0ft	4	1	High	10	N/A	N/A	N/A	N/A	N/A
	Washington Street Station (Green Line Extension)	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	0.1-12.0ft	4	1	High	10	High				High
	Union Square Station (Green Line Extension)	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High				High
	Ball Square Station (GLX)	Powder House	N/A	N/A	N/A	N/A	N/A	0.1-12.0ft	4	1	High	10	N/A	N/A	N/A	N/A	N/A
	Lowell Street Station (GLX)	Magoun Square	N/A	N/A	N/A	N/A	N/A	3.01-12.0ft	4	1	High	10	N/A	N/A	N/A	N/A	N/A
	Gilman Square Station (GLX)	Winter Hill	N/A	N/A	N/A	N/A	N/A	0.1-2.0 ft	4	1	High	10	N/A	N/A	N/A	N/A	N/A
	Sullivan Station	In Charlestown/Boston on Somerville Border	3.5 ft	4	0	High	11	2.0-2.5 ft	4	1	High	11	N/A	N/A	N/A	N/A	N/A
	Amtrak Commuter Rail Maintenance Facility	In Ward Two near Boston Border	1.0 ft	3	0	High	12	0.1-3.0ft	4	0	High	12	N/A	N/A	N/A	N/A	N/A
	Orange Line/Haverhill Commuter Rail Bridge	Crossing Mystic from Somerville into Medford (near Assembly)	10.0 ft	4	0	Moderate	12	0.1-0.5ft	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Newburyport/Rockport Communter Rail Bridge	Crossing Mystic from Somerville into Everett (near Assembly)	10.0 ft	4	0	Moderate	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Lowell Commuter Rail Bridge	Crossing Mystic from Somerville into Medford (near Arlington border)	10.0 ft	4	0	Moderate	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Davis Square Station	Davis Square	N/A	N/A	N/A	N/A	N/A	1.0-2.0 ft	4	1	High	12	N/A	N/A	N/A	N/A	N/A
	Red Line		N/A	N/A	N/A	N/A	N/A	0.5 -3.0 ft	4	1	High	13	N/A	N/A	N/A	N/A	N/A
	Bus Stops	East Somerville & Assembly Square	0.5-10.0 ft	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	5
	Bus Stops	Davis Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	4
	Bus Stops	Ward Two & Inner Belt	0.5-10.0 ft	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	4
Bike Paths	Alewife Greenway Multi-use Path	along Alewife Brook	10.0 ft	4	0	Moderate	11	>0.5ft	4	0	High	11	N/A	N/A	N/A	N/A	N/A
	Mystic River Pathway	near Ten Hills/Assembly Sq/East Somerville	10.0 ft	4	0	High	12	>0.5ft	4	0	High	12	N/A	N/A	N/A	N/A	N/A
	Assembly Square Drive	East Somerville & Assembly Square	0.5-10.0 ft; most 3ft	4	1	Moderate	8	>0.5ft	4	1	High	8	High	High	Low	Moderate	5
	Cross St	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	5
	Tufts St	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	5
	Powderhouse Blvd	near Alewife Brook	0.5-10.0ft	4	1	Moderate	7	>0.5ft	4	1	High	7	N/A	N/A	N/A	N/A	N/A
	Elm St	Davis Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Willow Ave	Davis Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Highland Ave	Davis Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Holland St	Davis Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4

	Community Path	Davis Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	College Ave	Davis Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Cameron Ave	Davis Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Broadway	Davis Square	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Medford St	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Joy St	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Dane St	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Beacon St	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Park St	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Somerville Ave	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Cedar Street					N/A	N/A	>0.5ft	4	1	High	7					
	Prospect St	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	>0.5ft	4	1	High	7	High	High	Low	Moderate	4
	Washington Street	East Somerville & Assembly Square and Ward Two & Inner Belt	0.5-2.0ft; most 1.5ft	4	1	High	7	>0.5ft	4	1	High	7	High	High	Low	Moderate	5
	Triple Ave	near Assembly area	0.5 ft	1	1	N/A	N/A	>0.5ft	4	1	High	7	N/A	N/A	N/A	N/A	N/A
Energy & Utilities	Amerigas Propane (Gas Distribution)	47 Foley Street	4.0ft	4	1	Moderate	8	3.01-12.0ft	4	1	High	8	N/A	N/A	N/A	N/A	N/A
	Mystic Generating Station (Everett)	75 Mystic Avenue	1.0-2.5ft	4	0	Moderate	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Mystic Substation	75 Mystic Avenue	1.0ft	3	0	High	13	0.1-0.50ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Prospect Substation	51 Prospect St	N/A	N/A	N/A	N/A	N/A	1.01-2.0ft	3	0	High	13	N/A	N/A	N/A	N/A	N/A
	Bow Street Substation	Bow Street Place	N/A	N/A	N/A	N/A	N/A	1.01-2.0ft	3	0	High	10	N/A	N/A	N/A	N/A	N/A
	Washington Street Substation	290 Washington St	N/A	N/A	N/A	N/A	N/A	3.01-12.0ft	4	0	High	10	N/A	N/A	N/A	N/A	N/A
	Linwood Street Substation	Linwood St	N/A	N/A	N/A	N/A	N/A	1.01-2.0ft	3	0	High	10	N/A	N/A	N/A	N/A	N/A
	MWRA Sewer Pumping Station	392 Alewife Brook Parkway	10.0ft	4	0	Moderate	13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	MWRA Pumping Station Shaft 9	East Albion Street	N/A	N/A	N/A	N/A	N/A	0.1-0.50ft	1	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DPW Fuel Distribution Center	1 Franey Road	N/A	N/A	N/A	N/A	N/A	0.1-0.50ft	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Verizon Central Office Switching Station	111 Central Street	N/A	N/A	N/A	N/A	N/A	3.01-12.0ft	4	0	High	13	N/A	N/A	N/A	N/A	N/A
Open Space	Foss Park		0.5-10.0ft	4	0	Moderate	9	High	4	0	High	9	N/A	N/A	N/A	N/A	N/A
	Draw 7 Park	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		High	Low	Moderate	5
	Mystic River Reservation	East Somerville & Assembly Square	0.5-10.0ft	4	0	Moderate	11	Moderate	2	0	N/A	N/A	High	High	Low	Moderate	5
	Harris Playground	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	5
	15-25 Cross Street East	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	5
	Perkins Park	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	5
	Symphony Park	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	5
	Florence Playground	East Somerville & Assembly Square	0.5-1.0ft	2	0	N/A	N/A	Moderate	2	N/A	N/A	N/A	High	High	Low	Moderate	5
	Alewife Brook Reservation		0.5-10.0ft	4	0	Moderate	10	Low	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Glen Street Park	East Somerville & Assembly Square	N/A	N/A	N/A	N/A	N/A	High	4	0	High	8	High	High	Low	Moderate	5
	Lincoln Park	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	High	4	0	High	8	High	High	Low	Moderate	4
	Perry Park	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	High	4	0	High	8	High	High	Low	Moderate	4
	Palmacci	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	4
	Durrell Playground and Community Garden	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	4
	Osgood Community Garden		N/A	N/A	N/A	N/A	N/A	Low	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Conway Park	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	Low	1	0	N/A	N/A	High	High	Low	Moderate	4
	Somerville Junction Park		N/A	N/A	N/A	N/A	N/A	High	4	0	High	8	N/A	N/A	N/A	N/A	N/A
	Trum Field Park		N/A	N/A	N/A	N/A	N/A	Low	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Community Path	Davis Square	N/A	N/A	N/A	N/A	N/A	High	4	0	High	10	High	High	Low	Moderate	4
	Tufts University Fields		N/A	N/A	N/A	N/A	N/A	High	4	0	High	8	N/A	N/A	N/A	N/A	N/A
	Allen Street Playground	Ward Two & Inner Belt	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	4
	Davis Square	Davis Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	4
	Kenney Park	Davis Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	
	Minuteman Trail Extension	Davis Square	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High	High	Low	Moderate	4
	Hodgkins-Curtin Park	Davis Square	N/A	N/A	N/A	N/A	N/A	High	4	0	High	8	High	High	Low	Moderate	4
Food Resources	Stop and Shop	775 McGrath Highway	5.0-10.0ft	4				3.0-12.0ft	4				N/A	N/A	N/A	N/A	N/A
	Elizabeth Peabody House Food Pantry	277 Broadway	0.5-2.5ft	3				0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cobble Hill Apartments Bag Program	74 Washington St	0.5-1.5ft	3				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Somerville Mobile Farmers Market (July-October)	226 Powderhouse Blvd	0.5ft	1		N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Somerville Mobile Farmers Market (July-October)	530 Mystic Ave	0.5ft	1		N/A	N/A	3.0-12.0ft	4				N/A	N/A	N/A	N/A	N/A
	Greater Boston Food Bank Mobile Market - Bag Program	1366 Broadway	0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	First Congregational Church of Somerville Project SOUP - Community Meals	89 College Avenue	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Somerville Community Baptist Church - Sommunity Meals	31 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Holy Bible Baptist Church - Food Pantry	64 College Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Project SOUP West Emergency Pantry - Food Pantry	1 Davis Square	N/A	N/A	N/A	N/A	N/A	0.5-1.0ft	2		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Davis Square Farmers Market	Day St & Herbert St	N/A	N/A	N/A	N/A	N/A	3.0-12.0ft	4				N/A	N/A	N/A	N/A	N/A
	McKinnon's	239 Elm St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Greek Orthodox Church	29 Central St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Star Market	275 Beacon St	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	Catholic Charities - Food Pantry	270 Washington St	N/A	N/A	N/A	N/A	N/A	0.1-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	Union Square Farmers Market	Corner of Prospect St/ Washington St/ Somerville Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Market Basket	400 Somerville Ave	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Whole Foods	45 Beacon St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Shaw's Market	14 McGrath Hwy	N/A	N/A	N/A	N/A	N/A	1.0-2.0ft	3				N/A	N/A	N/A	N/A	N/A
	Come to the Table: East Somerville Community Meals	149 Broadway	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Somerville Hispanic Association for Community Development	59 Cross St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A

	Project SOUP West Emergency Pantry - Food Pantry	15 Franklin St	N/A	N/A	N/A	N/A	N/A	0.1-0.5ft	1		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Roadways	Interstate 93					High	13	0.1-12.0ft	4		High	13	N/A	N/A	N/A	N/A	N/A
	Fellsway (Rt. 28)					Moderate	12	0.1-12.0ft	4		High	12	N/A	N/A	N/A	N/A	N/A
	McGrath Highway (Rt. 28)					Moderate	13	0.1-12.0ft	4		High	13	N/A	N/A	N/A	N/A	N/A
	Mystic Valley Parkway (Rt. 16)					Moderate	13	0.1-12.0ft	4		High	13	N/A	N/A	N/A	N/A	N/A
	Alewife Brook Parkway (Rt. 16)					Moderate	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Mystic Valley-Alewife Brook Rotary (Rt. 16)					Moderate	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Mystic Avenue (Rt. 38)					High	13				High	13	N/A	N/A	N/A	N/A	N/A
	Route 28/Fellsway Road Bridge crossing Mystic					Moderate	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Boston Avenue Bridge crossing Mystic					Moderate	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Evacuation Routes	Q					Moderate	13	High	4	1	High	13	N/A	N/A	N/A	N/A	N/A
	R					Moderate	13	High	4	1	High	13	N/A	N/A	N/A	N/A	N/A
	CN					Moderate	13	High	4	1	High	13	N/A	N/A	N/A	N/A	N/A
	CW					Moderate	13	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CS					Moderate	13	Moderate	2	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DG					Moderate	13	Low	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DF		N/A	N/A	N/A	N/A	N/A	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CZ		N/A	N/A	N/A	N/A	N/A	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DJ		N/A	N/A	N/A	N/A	N/A	Low	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DI		N/A	N/A	N/A	N/A	N/A	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DL		N/A	N/A	N/A	N/A	N/A	Low	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DK		N/A	N/A	N/A	N/A	N/A	Low	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	MT		N/A	N/A	N/A	N/A	N/A	Low	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CG		N/A	N/A	N/A	N/A	N/A	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CI		N/A	N/A	N/A	N/A	N/A	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CT		N/A	N/A	N/A	N/A	N/A	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CU		N/A	N/A	N/A	N/A	N/A	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	MU		N/A	N/A	N/A	N/A	N/A	High	4	1	High	13	N/A	N/A	N/A	N/A	N/A
	CM		N/A	N/A	N/A	N/A	N/A	High	4	1	High	13	N/A	N/A	N/A	N/A	N/A
	Supplemental		N/A	N/A	N/A	N/A	N/A	Moderate	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DZ					Moderate	13	Low	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A

CONDENSED RISK TABLES

SLR

	0-9	10-11	12-15
High	Ward Two Cooling Center (9 New Washington) Washington St Bike Path	Fitchburg Commuter Rail Lowell Commuter Rail Newburyport Commuter Rail Haverhill Commuter Rail Assembly Row Station Sullivan Station	Orange Line Commuter Rail Maintenance Facility Mystic River Pathway Mystic Substation I-93 Mystic Avenue (Rt. 38)
Moderate	Somerville District Court West Somerville Cooling Center Assembly Square Drive Bike Path Powderhouse Blvd Bike Path Amerigas Propane Foss Park	Newburyport Commuter Rail Bridge Lowell Commuter Rail Bridge Alewife Greenway Path Draw 7 Park Mystic River Reservation Alewife Brook Reservation	Amelia Earhart Dam Orange Line/Haverhill Commuter Rail Bridge Mystic Generating Station MWRA Sewer Pumping Station Fellsway (Rt. 28) McGrath Highway (Rt. 28) Mystic Valley Parkway (Rt. 16) Rt.28/Fellsway Bridge Boston Ave Bridge Q Evacuation Route R Evacuation Route CN Evacuation Route CW Evacuation Route CS Evacuation Route DG Evacuation Route DZ Evacuation Route
Low			

Heat

	0-9	10-11	12-15
High			
Moderate		Davis Square Bus Stops Ward 2 & Inner Belt Bus Stops Elm St Bike Path Willow Ave Bike Path Highlave Ave Bike Path Holland St Bike Path Community Path College Ave Bike Path Cameron Ave Bike Path Broadway Bike Path Medford St Bike Path Joy St Bike Path Dane St Bike Path Beacon St Bike Path Park St Bike Path Somerville Ave Bike Path Prospect St Bike Path Lincoln Park Perry Park Palmacci Durrell Playground and Community Garden Conway Park Allen Street Playground Davis Square Minuteman Train Extension Hodgkins-Curtin Park	Washington Street Station (Green Line Extension) Union Square Station (Green Line Extension) East Somerville & Assembly Square Bus Stops Assembly Square Drive Bike Path Cross St Bike Path Tufts St Bike Path Washington St Bike Path Draw 7 Park Mystic River Reservation Harris Playground 15-25 Cross Street East Park Perkins Park Symphony Park Florence Playground Glen Street Park
Low			

Precip

	0-9	10-11	12-15
High	Union Square Health Center Assembly Square Drive Bike Path Washington Street Bike Path Triple Ave Bike Path Cross St Bike Path Tufts St Bike Path Powderhouse Blvd Bike Path Elm St Bike Path Willow Ave Bike Path Highland Ave Bike Path Holland St Bike Path Community Path College Ave Bike Path Cameron AveBike Path Broadway Bike Path Medford St Bike Path Joy St Bike Path Dane St Bike Path Beacon St Bike Path Prospect St Bike Path Park St Bike Path Somerville Ave Bike Path Cedar St Bike Path Amerigas Propane Foss Park Glen Street Park Lincoln Park Perry Park Somerville Junction Park Tufts University Fields Hodgkins-Curtin Park	Union Square Fire Station Fitchburg Commuter Rail Lowell Commuter Rail Haverhill Commuter Rail Assembly Row Station Sullivan Square Station Washington Street Station (GLX) Ball Square Station (GLX) Lowell Street Station (GLX) Gilman Square Station (GLX) Alewife Greenway Path Bow Street Substation Washington Street Substation Linwood Street Substation Next Wave Junior High School 6-8 Full Circle High School 9-12 East Somerville Community School K-8 Capuano Early Childhood Center PK-K Albert F Argenziano School at Lincoln Park PK-8	Police HQ Orange Line Amtrak Commuter Rail Maintenance Facility Davis Square Station Red Line Mystic River Pathway Prospect Substation Verizon Central Switching Station I-93 Fellsway (Rt. 28) McGrath Highway (Rt. 28) Mystic Valley Parkway (Rt. 16) Mystic Avenue (Rt. 38) Q Evacuation Route R Evacuation Route CN Evacuation Route CM Evacuation Route MU Evacuation Route
Moderate			
Low			

Appendix I
Union Square
Economic Analysis

Memorandum

ARUP

To	Oliver Sellers-Garcia, City of Somerville	Date	March 15, 2017
Copies		Reference number	248138-00
From	Industrial Economics/Arup	File reference	
Subject	Economic Inputs of Flood Events in the City of Somerville: Union Square Supplemental Analysis		

IEc conducted a supplemental analysis of the potential impacts of a 24-hour 100-year precipitation flood event in 2070 in the Union Square neighborhood. This analysis followed the same general steps as the storm surge analysis. We estimated flood depths by parcel using spatial flood data produced by MWH Global and calculated the associated structural damages using the Army Corps depth-damage functions.[1] The table below provides the estimated structural damages in 2070 for Union Square in comparison to the total improved value of structures in the Union Square neighborhood. As in the storm surge analysis, we assume that the structural (improved) value of all affected parcels increase, after correcting for inflation, by approximately 1.1 percent per year between 2016 and 2070 (or 82 percent over the time period for analysis). We also increased the value of parcels that fell within the "Development Opportunity Areas" identified in the Union Square Neighborhood Plan by an additional 30 percent to account for the greater potential for property value growth in these areas.[2]

Impacts of a 24-hour 100-Year Flood on Union Square in 2070 on Residential and Commercial Properties

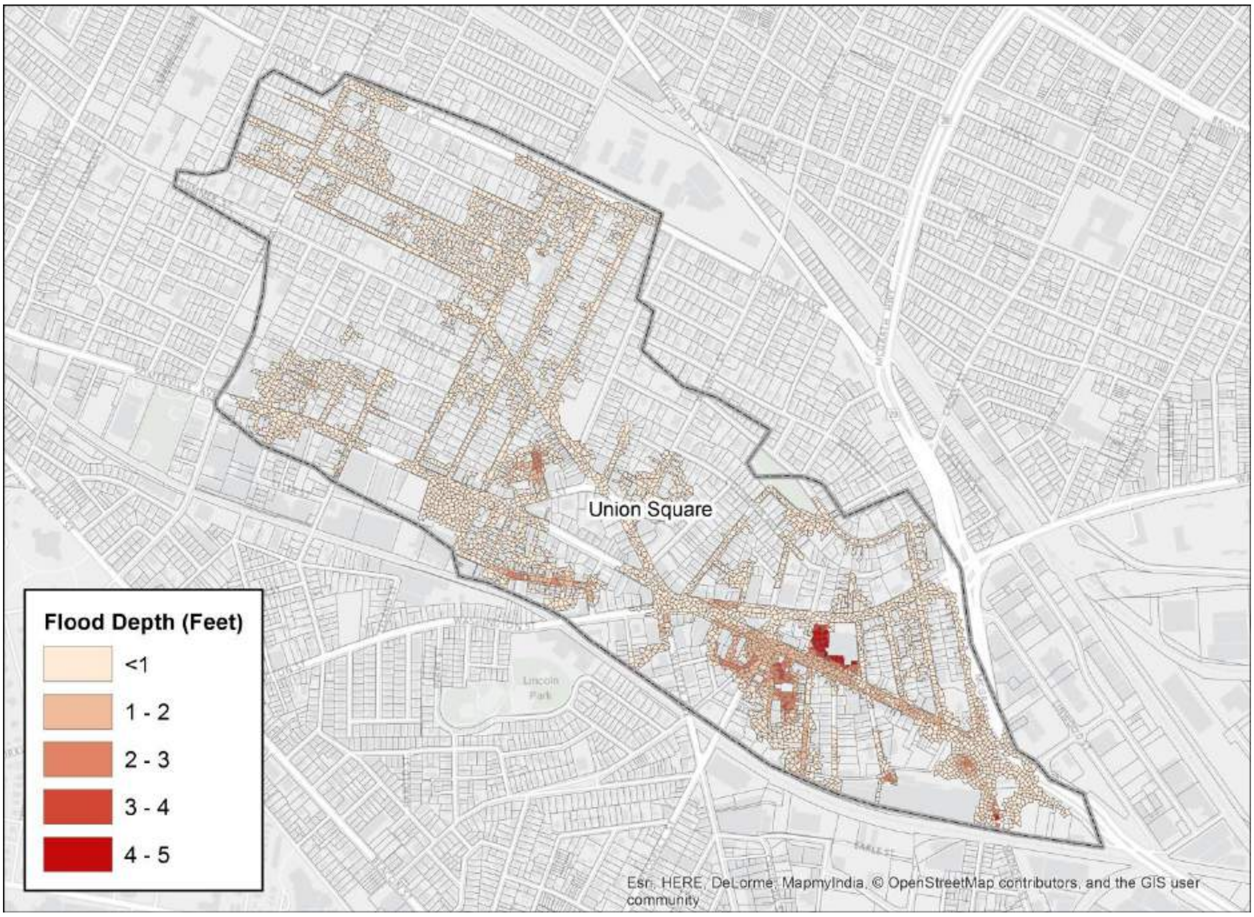
Parcel Type	Total Improved Value of Affected Parcels (2016 Dollars)	Total Structural Damage (2016 Dollars)	Structural Damage as a Percent of Improved Value
Residential	$1,080,000,000	$78,000,000	7.2%
Commercial	$253,000,000	$20,000,000	7.8%
Total	$1,333,000,000	$97,000,000	7.3%

Sources: Somerville Assessor, parcel database, 2016; Flooding forecast, 100 year flood in 2070, 24-hour precipitation event, MWH Global, 2016; Army Corps depth damage functions, residential and commercial.

[1] The precipitation flood data from MWH was provided in a different format than the storm surge flood data provided by Woods Hole Group. The MWH flood depth data excludes building footprints. As a result, IEc calculated the average flood depth in a parcel as the unweighted average of each flood depth estimate that overlapped with the portion of the parcel outside of the building footprint.

[2] The Neighborhood Plan is accessible at: http://www.somervillebydesign.com/neighborhood-planning/union-square/. The specific development opportunity areas are defined on page 129 of the plan.

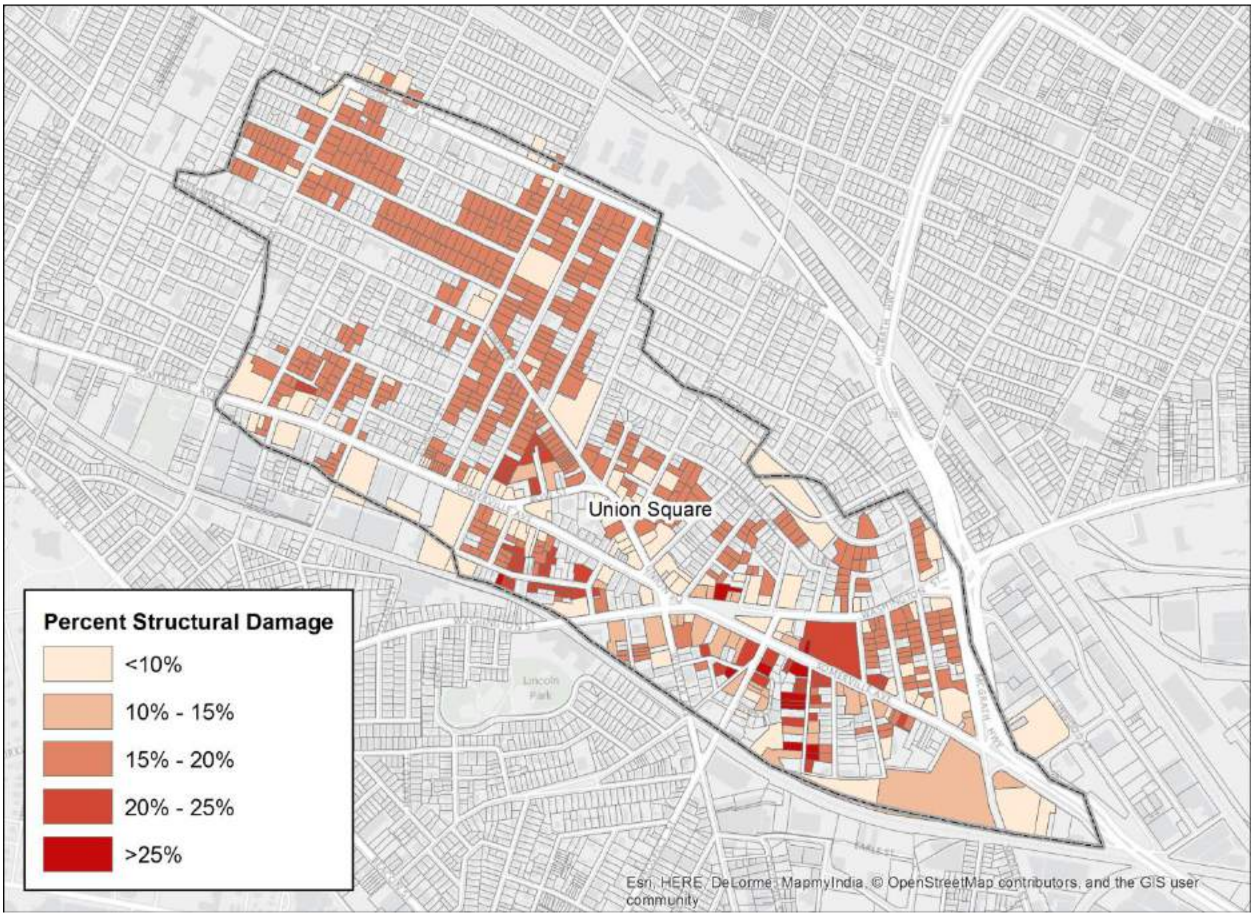
Union Square Flood Depths – 100-Yr 24-Hr Precipitation Event (2070)



Sources: Somerville Assessor, parcel database, 2016; Flooding forecast, 100 year flood in 2070, 24-hour precipitation event, MWH Global, 2016.

Memorandum

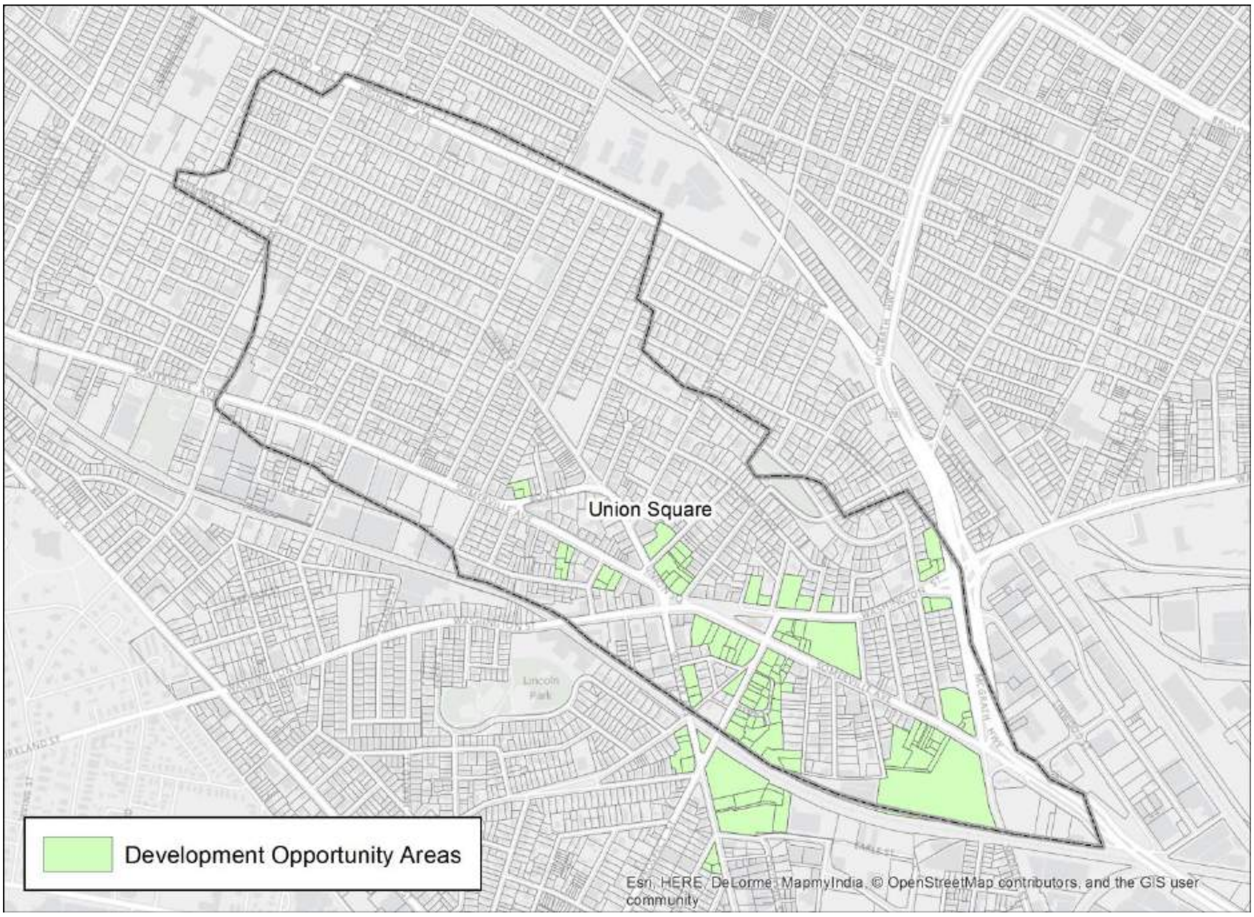
Union Square Percent Structural Damage – 100-Yr 24-Hr Precipitation Event (2070)



Sources: Somerville Assessor, parcel database, 2016; Flooding forecast, 100 year flood in 2070, 24-hour precipitation event, MWH Global, 2016; Army Corps depth damage functions, residential and commercial.

Memorandum

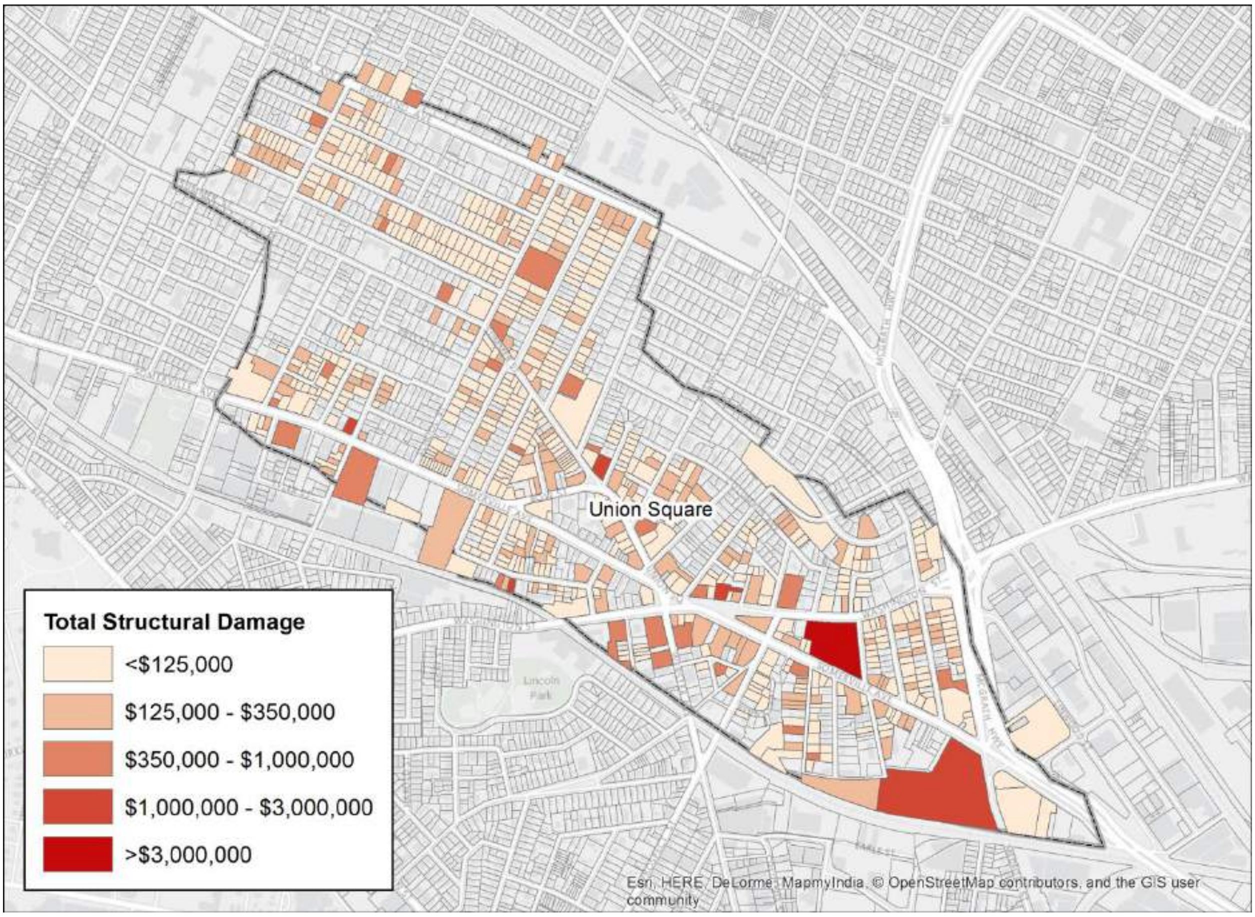
Exhibit X. Development Opportunity Areas in Union Square, as defined by the Union Square Neighborhood Plan



Source: Union Square Neighborhood Plan, City of Somerville, 2016.

Memorandum

Union Square Total Structural Damage – 100-Yr 24-Hr Precipitation Event (2070)



Sources: Somerville Assessor, parcel database, 2016; Flooding forecast, 100 year flood in 2070, 24-hour precipitation event, MWH Global, 2016; Army Corps depth damage functions, residential and commercial; Union Square Neighborhood Plan, City of Somerville, 2016.