



Developing Policy Recommendations to Reduce Waterfront Flood Vulnerability in Boston

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Submitted by:

Joshua Graff
Elie Karam
Joshua Ledee
Jacquelyn Nassar

Approved by:

Seth Tuler
Paul Mathisen

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The Boston Harbor Association
Julie Wormser

Boston Project Center
Worcester Polytechnic Institute

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Abstract:

Our team worked with The Boston Harbor Association to help Boston prepare for future flood risk due to sea level rise. The goal was to create policy recommendations to inform planning efforts for flood risk vulnerability reduction of the Boston Harbor waterfront. Using the results of the MA Department of Transportation's hydrodynamic model our team assessed the vulnerability of various assets within our case study and developed a risk-consequence prioritization framework to assist decision makers in analyzing risk. Our literature review and interviews with global experts informed our assessment and recommendations for flood resilience which were provided to city planners.

Executive Summary:

Climate Change

Climate change has generated major global concern as the earth's temperature rises and glaciers and arctic sea ice melt. Projections infer that average ocean levels will rise between three and six feet within the next one hundred years. This expected rise in conjunction with storm surges is expected to overflow coastal dunes, seawalls and other features of shorelines, putting residential and commercial areas, as well as critical infrastructure such as electrical systems, highways and trains underwater. Millions of people around the world have already been affected or displaced by periodic flooding, which is set to occur more frequently due to sea level rise.

The global impact of climate change will be dramatic for people who live along the coast. Although there is clear scientific evidence that the climate is changing, there is still uncertainty on how climate change will affect society. Since there is unclear information about the future of flooding, there is less incentive for the federal government to fund a flood resilient effort for the community. Cities would rather use the funding for current issues because they do not want to over invest into a property that they are unsure about the effect flooding will have on it. Also policy makers or those running for an office position are more likely to appeal to the community by trying to address current issues instead of dealing with long term concerns that don't have much evidence to support those concerns.

Goal and Project Statement

The goal of this project was to create policy recommendations for the City of Boston to inform planning efforts to reduce the vulnerability of Boston's waterfront due to flood risk. Our goal is to contribute to the *Imagine Boston 2030* CityWide Project, the first central planning initiative in Boston in the last 50 years. We utilized the maps and associated output data from the MassDOT flood model to assess the risk posed to Boston's waterfront, specifically in our designated case study area, Columbia Point, between 2013, 2030, and 2070. Using the model output, we were able to determine the areas that will be affected by flooding. We applied a framework that can be used to identify risks to assets as tolerable or intolerable, taking into consideration both the likelihood of flooding and the consequences of flood damage. We then identified possible strategies from other cities that could be applied to this area to mitigate flood risk. These recommendations for city planners will contribute not only to the *Imagine Boston 2030* citywide project, but also the future of climate resilience in Boston.

Methods

We laid out three main objectives to develop our recommendations:

First, we outlined and analyzed a case study area along the Columbia Point waterfront as a basis for our recommendations for Boston's waterfront property. Second, we interviewed experts of water management and flood risk mitigation to aggregate evidence and perspectives from various locations. These first two objectives contributed to the execution of our third objective of developing policy recommendations for city planners and officials.

Our group conducted a case study of Columbia Point, an area with a variety of assets, to develop our evidence on the potential vulnerability of specific assets to flooding. Through this case study we collected examples of flood vulnerability in the area to create a framework that can be implemented by the rest of the city. This was determined by cross referencing locations of assets with flood likelihood projection maps. From that risk analysis we developed a list of risk mitigation techniques that might be useful in the area.

For the case study, we documented various assets within the Columbia Point neighborhood that are likely to experience flood damage. This risk was determined by creating map overlays developed from simulations of a hydrodynamic model, produced by the Massachusetts Department of Transportation, and applied to a detailed map with assets found in the area. This model has strong potential for advising city planners and developers on future development and renovations, allowing them to consider the probability of flooding, as well as the depth of the flood waters in a given area before beginning construction. Using the model, analysts were able to develop maps that are able to project the current probability of flooding as well as provide us with insight to future levels of flooding. This model takes into account such factors as sea level rise, storm surges, and wind patterns. Maps generated by the model show the "exceedance probability" (the likelihood that water will exceed ground elevation) and flood depth projections for the years 2030, 2070, and 2100. These maps can be used to identify locations, structures, and assets that lie within different flood risk levels.

We utilized the hydrodynamic model to document 15 different assets and assess their vulnerability. The maps aided in determining the likelihood as well as the depth of flooding in the years 2030 and 2070 and provided information on how it would affect these specific assets. Based on the information from the model, we identified that these assets were vulnerable because they were located in zones prone to flooding, and showed features susceptible to the inundation of flood waters.

We then applied a risk-based approach to identifying assets that are most at risk, with risk being a function of likelihood of flooding and the consequences of flooding. This approach can assist policy makers. For example, if likelihood of flooding is high for a given area, such as a flood exceedance probability greater than 1%, and poses a relatively low consequence to the surrounding area and its inhabitants, or vice versa (a low likelihood of flooding that poses a high

consequence), the risk is considered to be moderately tolerable or moderately intolerable. This would demonstrate that the need for an effective action to reduce risk is moderately prioritized. If the likelihood of flooding is high for a region and the consequence of the flood is also high, then it is considered intolerable to flooding and action must be taken.

Tolerable vs. Intolerable Risk

Tolerability and intolerability are terms that we use to express what is socially acceptable to be flooded. For example, schools are considered intolerable since they are generally used as shelters during storm events. Similarly, a hospital is considered a matter of high consequence because the building is housing a large number of people who are not able to evacuate and are depending on machinery within the hospital for their health and, therefore, may lead to death and injury. Because both the likelihood and consequence are high, the result is high vulnerability to the structure and people for the given asset, making it intolerable to flooding. Parks, fields, and parking lots might be considered tolerable as they are not essential to the community during a storm event and in most cases, will not result in any long term damage as a result of temporary flooding. We illustrated the application of the risk-based approach with examples from the assets we analyzed in that area.

Identify Potential Flood Mitigation Strategies for Assets in Columbia Point Area

As part of developing policy recommendations to address flood risk of vulnerable assets in Columbia point, we conducted interview to better support our evidence and analysis of our field study and better understand how to assess vulnerability issues, we conducted interviews with experts from around the world to acquire information on how particular cities and nations work with water and flooding. The interviews were intended to gain a global perspective to strategies used in various cities to obtain a better grasp of the different flood resilient strategies that can be implemented for the Boston Harbor. This will benefit us in gaining information on approaches that can be included within our policy recommendations for the Boston 2030 project plan. With this in mind, we interviewed experts from several cities based on their work related to adapting to the threat of water. Through our literature review, we were able to select cities that have experienced or continue to deal with crises due to flooding. Over time, they have all developed policies that implement strategies and technologies such as barriers and infrastructures, as well as incentivization actions. We spoke with representatives from the following cities:

- Hamburg, Germany
- Boston, Massachusetts
- New York, New York
- New Orleans, Louisiana

The third objective was to present the City of Boston and their Imagine Boston 2030 project plan with policy recommendations that suggests various flood resilience strategies that can be implemented to alleviate flood water damage. We expected to determine which policies

are best suitable to integrate for the Boston waterfront, and how they are able to enforce these policies. The impacts of flooding are detrimental to the City of Boston as well any other city along a coastline. To mitigate damage from this flooding, various technologies and strategies can be adapted. We analyzed adaptive strategies for commercial, residential, and transportation systems throughout the city of Boston and the world. In order for these techniques to work effectively and efficiently, we need to engage the community through insurance incentives, such as premium reductions.

Consequence Ranking and Vulnerability Analysis

Our primary ranking of consequence was completed using an approximation of the number of people affected by the asset. Assets that were located in high traffic area were deemed to be highly populated areas and needed to be prioritized. Also the type of population and people who would be affected was a factor taken into consideration when determining vulnerability.

Asset Prioritization

Current policy does not involve a risk-consequence analysis to determine the actions required for the mitigation of risk of an asset (Julie Wormser, personal communication, 2015). We recommend that a community prioritize and invest appropriately in assets whose damage would have an impact on a large population. For our study and recommendations, we used an approximation of number of people who are dependent on the asset to gauge its individual, neighborhood, and regional consequence. A limitation of our study was the use of only a single method of prioritization. Other measures of consequence are viable options to prioritize the importance of assets examples of those measures may include:

- Vulnerability of the people affected.
- Financial value of assets affected (FEMA, 2013).
- Ownership of asset at risk (Muller, 2013).

The best method of prioritization can be determined by those drafting the policy at hand to best suit the constituents and political environment of the city. By focusing risk-mitigation efforts on assets determined to have greater consequence, the effects of damage from a major flooding event could be reduced. This consequence-based management of risk is designed to provide a basis for making decisions that build resilience into the assets deemed critical to the population.

Recommendations for Policy Actions for Consideration in Boston

Our team developed a set of policy recommendations, incorporating possible mandatory actions to incentivize the community to build resiliency. The policies tie together potential mandatory resiliency practices with insurance premiums and property taxes, as well as voluntary actions, such as tying building codes with the environmental conditions.

For example, building codes can be reviewed and updated based on flood projections for 2030 and 2070 depicting the level of flooding a given building may be exposed to for its

entire lifecycle. Based on the environmental conditions, the federal government can require property owners to fortify their homes and businesses to better protect against flooding damage. Another requirement would ensure that new buildings are not erected in flood zones unless they take proactive actions to reduce their vulnerability and potential consequences of future flooding. For properties that are already in place, the buildings can be required to be resilient for the remainder of their lifespan. These buildings can accomplish this by fortifying vulnerable aspects such as windows, doorways, and vents. Policies could encourage property owners who retrofit their buildings to these codes by providing government benefit and aid.

Memorandum

As a means of input on the Imagine Boston 2030 CityWide Project, we drafted a memorandum to the planning team with our findings and recommendations. Designed to communicate the findings of our research in concise and precise terms, the memorandum outlines both our work with the MassDOT model and our recommendations for future policy decisions. In this memo we outline the relationships between flood likelihood, consequence, and the tolerance of this risk, and tie these relationships to recommended government and community actions.

Conclusion

Through our literature review and the utilization of MassDOT's flood maps, it was clear that the effects of global sea level rise associated with climate change are placing assets at risk in Boston. Our research and interviews with experts provided us with information regarding resilience strategies utilized in cities around the world, as well as some of the policies that were installed to ensure widespread adaptation. Concluding, we were able to generate deliverables, based on the lessons learned through our field work that can be applied to Boston's waterfront, that will be recommended to the Imagine Boston 2030 project team.

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Chapter 1: Introduction

Climate change has generated major concern around the globe as the earth's temperature rises and glaciers and arctic sea ice melt (NCA, 2014). The Intergovernmental Panel on Climate Change (IPCC) projects that average ocean levels will rise between three and six feet within the next one hundred years (IPCC, 2012). This expected rise in conjunction with storm surges is expected to overflow coastal dunes, seawalls and other features of shorelines, putting residential and commercial areas, as well as critical infrastructure such as electrical systems, highways and trains underwater (TBHA, 2013). Millions of people around the world have already been affected or displaced by periodic flooding, which is set to occur more frequently due to sea level rise (TBHA, 2013).

The global impact of climate change will be far reaching to the people who live along the coast. According to the National Oceanic and Atmospheric Administration (NOAA), in 2010 nearly 39% of the United States' population lives on the shoreline and this percentage will rise by about 8% in 2020 (NOAA, 2014). Of the 64 million people living in New England, 1.6 million of them live within the Federal Emergency Management Agency's (FEMA) coastal flood zone (NCA, 2014). Boston is ranked as the eighth most-at-risk coastal city from flooding when taking into consideration potential loss from annual income (Greenovate Boston, 2014). Aside from commercial areas, coastal residents are vulnerable to direct property damage, loss of life, injury associated with tropical storms and Nor'easters. For example, in October of 2012, the East Coast experienced one of the most disastrous storms in recent history, Super storm Sandy (TBHA, 2013). Fortunately, Boston did not experience severe flooding because, coincidentally, Hurricane Sandy hit the city five hours after high tide (Schworm, 2013). It is likely that Boston would have experienced a 100-year flood event if the storm had hit at high tide. Boston must develop and implement resilience strategies to prevent flood related damages and can look to other coastal cities for successful strategies.

To address these concerns, some coastal cities have developed strategies to mitigate or live with flooding. In TBHA's report, *Design for Living with Water*, 12 case studies are included that describe how cities around the world are implementing strategies to decrease potential flood damage without losing the vibrancy and livability of their communities (TBHA 2014). Successful examples of living with water can be seen in Hamburg, Germany, New York, New York, and Baltimore, Maryland. Various flood resilient technologies have been implemented and proposed all across the world to fortify and protect cities vulnerable to flooding and mitigate the damage. Of these different technologies, we studied a select few that we found highly relevant to Boston, as listed below:

- The HafenCity in Hamburg, Germany (HafenCity, 2015)
- The Thames Flood Barrier in London, England (Castella, 2014)
- The North Sea Protection Barriers in The Netherlands (Holland, 2015)

These strategies, however, are large public works projects directed by the respective governments. Incentivizing policies are necessary to ensure a widespread adoption of flood resilient strategies in the coastal Boston area.

Just as city planners and developers in cities across the globe have worked to protect infrastructure and property from water damage, Boston, too, has laid the foundation of flood readiness (Muller, 2015). For example, in 2009 Boston's Mayor Menino created the Climate Action Leadership committee and Community Advisory Act. The committee was established to provide goals and solutions to concerns dealing with climate change.

Efforts to develop policies that concentrate on flood preparedness have revealed significant barriers in achieving widespread adoption. First, uncertainty about the future of the climate and populations in coastal areas can hinder adaptation work (Smith, 2014). Second, property developers face disincentives in creating flood resilient buildings and infrastructure due to the very flood insurance designed to protect them (Brannon, 2011). For instance, by promising aid after a flood, developers face an economic incentive to not mitigate risk or build resilience into a building from the beginning of a building's life cycle. Third, some civic leaders and organizations are aware of the risk of flooding but have failed to make any critical changes in policy that forces people to prepare for potential flooding in a way that is effective. Some city developers claimed that difficulties in access to information were more of an issue than complete lack of information (Moser et al, 2008).

The goal of this project was to create policy recommendations for the City of Boston to inform planning efforts to reduce the vulnerability of Boston's waterfront due to flood risk. Our recommendations were provided to the Imagine Boston 2030 project plan, the first project plan implemented for Boston in the last 50 years (Share Your Vision, 2015). Their goal is to plan for a redeveloped Boston that promotes a healthy environment and population. We utilized a recently developed flood risk model to estimate probability of flooding and the depth of the floodwaters, to assess the risk posed to Boston's waterfront. We focused our study on the case study area of Columbia Point, during two time periods: the present to 2030, and 2070 to 2100. We applied a framework that can be used to characterize risks to assets as tolerable or intolerable, taking into consideration both the likelihood of flooding and the consequences of flood damage (Dow et al 2014). We then identified possible strategies from other cities that could be applied to this area to mitigate flood risk by preventing flooding or reducing vulnerability to flood waters. Examples of strategies to address risk include plans for fortifications and barriers to flooding, which will only happen with the implementation of

policies such as new zoning and building guidelines, or insurance incentives. These recommendations for city planners were reviewed by city officials and will contribute not only to the Imagine Boston 2030 citywide project, but also the future of climate resilience in Boston. This work demonstrates the utility of good models.

Chapter 2: Background

This chapter introduces the topics of climate change, sea level rise, and its relation to flooding, as well as the potential impact that this can have to Boston as well as the world. We will first provide definitions of terms that we will be referencing often throughout the text. Secondly, we discuss the causes and consequences of climate change. Then, the chapter explains the risk of flooding to the City of Boston. Following, the impacts of flooding are discussed to further analyze the critical consequences of flooding. We conclude with a brief overview of the MassDOT's flood model as its data is utilized heavily throughout this project.

2.1 Definitions of Important Terminology

In this section, you will find definitions of various terms used to describe serious events such as flooding and the impacts that they may have upon humans, structures, and the environment.

The effects of flood damage will be most evident in structures and assets that are vulnerable to and at risk of flooding. Turner et al. describe **vulnerability** as the degree to which a system, subsystem, or system component is likely to experience harm due to **exposure** to a hazard, either a perturbation or stress/stressor" (Turner et al., 2003). The likelihood and consequences of flooding, together, define the concept of risk. Turner et al. defines **risk** "as a function of the perturbation, stressor, or stress, and the vulnerability of the exposed unit." Risk is primarily used to address how a large area or group of people will be impacted whereas vulnerability entails a more in depth assessment of the area to determine the factors that affect how each individual asset is impacted.

Vulnerability varies greatly among parties at risk, because the **consequences** that are likely to occur due to poor infrastructure or the type of assets that will be affected will be vary based on their use. For neighborhoods and the community infrastructure in general, risk of flooding is mostly affected by the height of construction relative to the surrounding area and the height above the sea level as well as how close they live to the coastline. The height of the actual foundation of the facility, as well as the height of the properties of the facility determines the likelihood that the asset will encounter water damage in a flood scenario. Such properties include the height of windows, doorways, and vents. Low lying properties cause the facility to become more vulnerable to the risk of flooding because of the higher risk of inundation of water. Property damage of this magnitude can result in serious consequences, such as financial setbacks, loss of homes, or relocation.

Vulnerability is not to be confused with **sensitivity**, which is determined by the "human-environment conditions of the system, that may be social or biophysical." These conditions

define how well the system is able to cope with certain exposures. Systems that are able to undergo changes and varying conditions while still maintaining a state desirable by its inhabitants are considered to be **resilient** (Turner et al., 2003). This section should be referenced when any of the above bolded terms are encountered throughout this report.

2.2 Causes and Consequences of Climate Change

The main evidence for global climate change is the general trend of rising average global temperatures. Since the 1880s, the average global temperature has increased by 1.4°F (Figure 1). A recent study by the NOAA and NASA illustrates that the 10 warmest years in the 134-year record all have occurred since 2000, with the exception of 1998 (NASA, 2014). After the 1940s, there was a sharp increase in temperature. This corresponds to fossil fuel use increase, which also introduced an increase in the production of greenhouse gases (EPA, 2010). Petroleum, for example, became the most used fuel in the U.S. due to the increased consumption of the automobile industry (ProCon, 2013). Also in the 1950s, natural gas became a major fuel to heat US homes with the construction of natural gas pipelines (ProCon, 2013). Although natural gas improved the lives of many by providing a more accessible form of heat, it had a critical consequence with the emission of pollutants into the atmosphere and contributing to climate change in the world. This second industrial revolution had an international reach evident to this day and poses global ramifications.

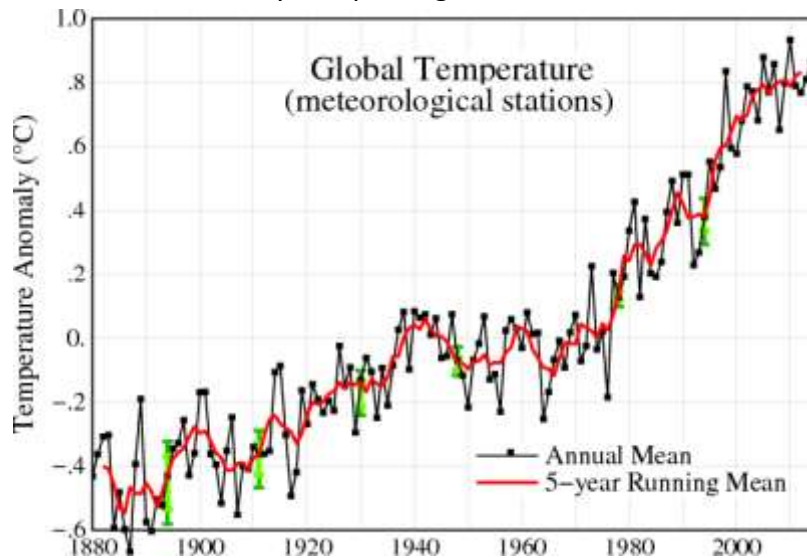


Figure 1: Shows the average increase of global temperatures since 1880 (NOAA, 2011)

2.2.1 Climate Change and Flooding

Studies show that climate change is increasing both the likelihood and severity of storms and damage due to flooding. Studies indicate that extreme weather events such as heat waves and large storms are likely to become more frequent and intense with human-induced climate change (EPA, 2014). Many cities, including Boston, have been affected by this climate change and are beginning to address the threat. Several key factors are affected by climate change: sea level rise, changes in precipitation patterns, and increased storm severity. These factors ultimately play a part in the increased frequency and severity in flooding along coastlines.

2.2.2 Sea Level Rise

Global temperature rise not only causes the thermal expansion of ocean water, but also leads to the melting of polar ice caps, which has been shown to contribute to the escalation of the volume of water in the ocean (EPA, 2014). The United States National Climate Assessment has provided four estimates in their report that represent potential future conditions associated with different scenarios of ocean warming and ice sheet melting. The scenarios are contained in Figure 2 (Parris, 2012). Figure 2 displays the average rise in sea level since 1900, as well as the expected sea level rise in the next century.

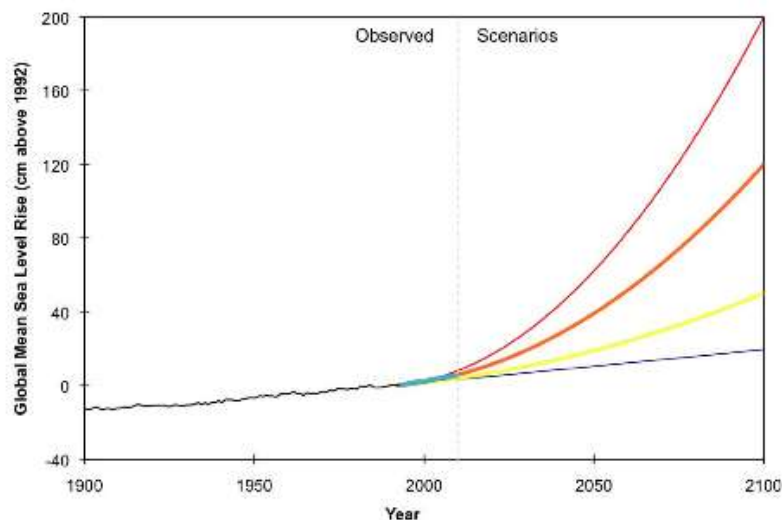


Figure 2: Four global mean sea level rise scenarios for 1992 to 2100 (Parris, 2012)

2.2.3: Change in Precipitation Patterns

An increase in global temperature causes warmer air to hold more moisture, which can lead to an increase in precipitation (National Wildlife Federation, 2009). Changes in precipitation are likely to be geographically uneven. For example, weather patterns will cause

some areas to have very little precipitation and cause droughts, causing other areas, such as the Northeast, receive a significant rise in precipitation and an increase of risk of flooding (EPA, 2014). The Northeast has received an increase in precipitation by 5 inches, or more than 10 percent since 1900 (NCA, 2014).

Figure 3 shows the total amount of annual precipitation received in Boston. It illustrates an upward trend in precipitation events, punctuated by yearly fluctuations. In Massachusetts, yearly precipitation is estimated to increase by about 10 percent in the spring and summer, 15 percent in the fall, and 20 to 60 percent in the winter by the year 2100 (New England Aquarium, 2014). Although this increase in precipitation may present itself as fluctuations in the long term, the increase will become apparent in flooding events.

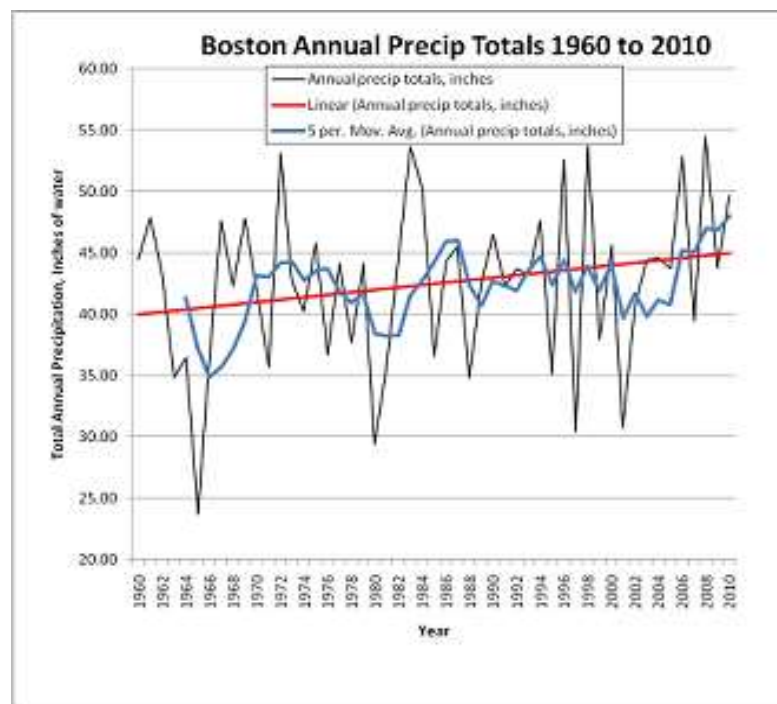


Figure 3: Amount of annual precipitation in Boston since 1960 (EEA, 2014)

On average, severe precipitation events occur every 20 years. However, it is estimated that, by the year 2100 severe precipitation events will occur every four to fifteen years. A rise in global temperatures causes the warmer oceans to increase the amount of water that evaporates into the air. When the moisture filled air moves over land into a storm system, it can produce much heavier precipitation and increase the likeliness of 100-year storms occurring (EPA, 2014).

A high percentage of rainfall in the US has recently begun to occur in single day events. For example, nine of the top 10 years for extreme one-day precipitation events have occurred since 1990 (EPA, 2014). The prevalence of extreme single-day precipitation events remained

fairly steady between 1910 and the 1980s, but has risen substantially since then (NOAA, 2014). An example of a severe precipitation event is Hurricane Mitch in 1988, where flooding and heavy precipitation killed 11,000 people in Central America (Cimons, 2013). A similar case in the U.S. is Hurricane Katrina; this storm caused tides to rise twenty-eight feet above the normal tide levels that produced significant damage along the southern coastlines of the United States (NHC, 2008). Figure 4 displays the percentage of land area where greater than the average annual precipitation has resulted from these extreme precipitation events. The Northeast in particular saw more than a 70% increase in the amount of precipitation falling during severe precipitation events (NCA, 2014). Increased precipitation, along with the other effects of climate change, will likely become evident over larger scales of time.

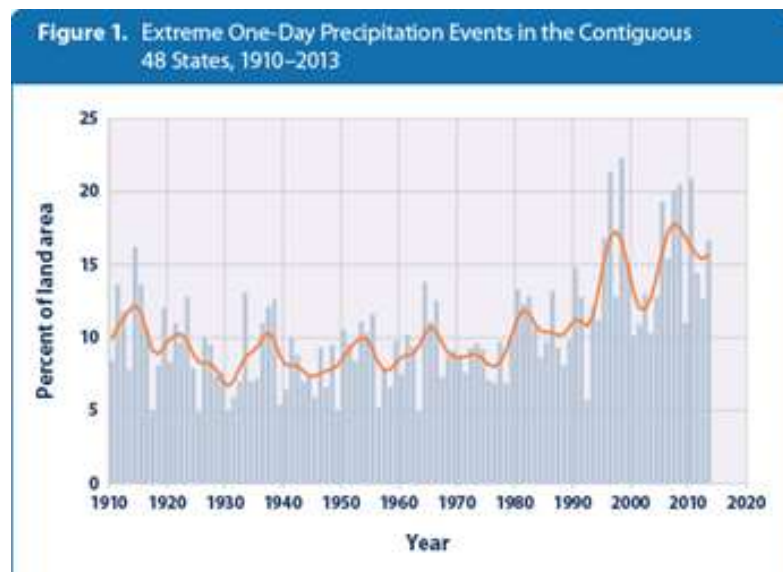


Figure 4: Area affected by severe precipitation events (NOAA, 2014)

2.2.4 Flood Recurrence Rates

A common term for characterizing flooding and precipitation events is the “100-year storm” (Perlman, 2015). This describes the meteorological event that would statistically happen once in a 100-year span of time. Another way of stating this is that there is a 1.0% probability of occurring in any given year. In other words, floods caused by such events are expected to be rare. In actuality, however, the event is not restricted to occurring only once in a 100-year period because each event has an independent probability of occurring (other events do not directly affect the intensity of it). In the last three years alone, there have been five storms in New England, including Hurricane Sandy, that, if they were to have hit during peak storm surge, would have been 100-year flood events (Wormser, 2015).

The 100-year flood metric is most commonly used as the dividing line between common and uncommon, where those living within the “100-year flood zone” are considered to be within the local floodplain. The increased intensity of precipitation and storm surges combined with SLR are all factors that greatly increase the likelihood of a 100-year flood event occurring (TBHA 2013).

2.3 Boston’s Vulnerability to and Likelihood of Flooding



Figure 5: Theorized storm flooding in the Back Bay (Lamm, 2013)

The City of Boston is especially vulnerable to coastal flooding, which occurs when a large storm or heavy rainfall causes the sea to surge inland (storm surge) (TBHA, 2013). Climate change is increasing coastal New England’s likelihood of flooding because higher sea levels will allow waves and storm surges to reach further inland. For example, Hurricane Sandy is a most recent example of a serious storm on the harbor. Hurricane Sandy caused only minimal exceedance of the water’s average height at the time that the storm hit land (Wormser, 2012). The low tide of the harbor proved beneficial as the storm surge had minimal effect on the properties surrounding the basin. New York City experienced the same storm at high tide with catastrophic results. While Boston has not experienced a major coastal flooding event in recent history, the destruction to New York City demonstrates the need for serious preparation and planning.

Current flood models predict that Boston will experience one to two feet in sea level rise by 2050, and a possible three to six feet increase by 2100; which, when combined with storm surge, would inundate the buildings and infrastructure of Boston with floodwater and cause extreme damage (TBHA, 2013). There also appears to be a link between hurricane intensity and ocean surface temperature suggesting that hurricane intensity may be increasing as well (NOAA, 2011). Figure 5 suggests potential flooding in the Back Bay due to the combination of

rising sea levels and storm surge (Lamm, 2013). Coastal residents, business owners, and their property and infrastructure are increasingly susceptible to damage from storm surge and tidal flooding.

In May of 2006, a severe flood occurred along the New England shore that resulted from an unusually low-pressure system in the United States. The storm had drawn an abundant amount of moisture from the Atlantic Ocean, most over New England. This produced constant, heavy rain that caused overflowing of rivers in Massachusetts; thousands of people were evacuated from their homes (Ballou, 2013). Events such as this are only going to increase in severity and frequency.

2.3.1 MassDOT Hydrodynamic Model for Boston

The Massachusetts Department of Transportation launched a project to develop an advanced flood risk model that assesses the vulnerability of Boston to flooding. UMass-Boston, Woods Hole Group Inc. and the University of New Hampshire collaborated in the development of this hydrodynamic model (MassDOT-FHWA, 2015). The model “simulates the effects of tides, storm surge, wind, waves, wave setup, river discharge, sea level rise, and future climate change scenarios” (MassDOT-FHWA, 2015). It implements changes in climate to coincide with the various storm intensities. The model calculates the likelihood of flooding and depth of flooding for the entire Boston and Cambridge area, and provides limited information for other neighboring areas: Maine, Rhode Island, New Hampshire, Connecticut and other parts of Massachusetts surrounding the Boston focus area. The map projections can be seen in Appendix 4.

While FEMA has recently released an updated bathtub model that addresses future flood depths, their maps do not include future projections and changes, which are the primary concern due to climate change (MassDOT-FHWA, 2015). The model is capable of analyzing risk to specific buildings and structures, a feature that is currently limited only to a handful of buildings within the Boston and Cambridge area (MassDOT-FHWA, 2015). For example, one way this feature is being utilized is by pinpointing the underground tunnels that are the most vulnerable or that are along the flood pathways of the city. Along these pathways, water causes damage to infrastructure and buildings, as well as anyone present. This model can be used, therefore, to educate residents and property owners in these pathways and locations.

2.3.2 Vulnerability Assessments in Boston

Boston has implemented strategies to assess the areas of high vulnerability (TBHA, 2013). For example, the Boston Water and Sewer Commission incorporated the effects of sea rise level and more intense precipitation into its 25-year capital plan for the storm and wastewater system. The Boston Redevelopment Authority (BRA) approved a preparedness

survey that all large projects under review are required to complete in order to assure resilience to flooding (Dalzell, 2013). These tools help the city and residents determine who is most vulnerable to potential flooding and where the risk of damage due to flooding is greatest which is vital in preventing the impacts of flooding.

2.4 Impacts of Flooding

Flooding has posed dangerous ramifications along coastal cities around the globe. Flood impact can be characterized in into two categories: direct and indirect, which are subdivided into tangible and intangible damage. Examples of these types of damages can be found in Table 1 below:

Table 1: Examples of Direct/Indirect damage and Tangible/Intangible damage (FLOODsite, 2009)

	Tangible Damage	Intangible Damage
Direct Damage	Damage to buildings	Loss of Life
	Damage to Infrastructure	Negative Health Effects
	Damage to buildings	Loss of Ecological goods
Indirect Damage	Disruption of Traffic	Inconvenience of Post-Flood Recovery
	Loss of Business Production	Increased vulnerability to flood survivors

Direct flood damage is a result from the action of floodwaters and occurs at the time of flooding. This can include damage to buildings, residential properties, roads, businesses and public infrastructure, agriculture, as well as impacting immediate health effects of individuals (EarthSci, 2014). Examples of components of infrastructures directly affected by flooding are heating equipment, ventilation, and air conditioning units at ground levels or below. All of these essential utilities will be damaged if the waters flood to their levels (FEMA, 2014).

Indirect damages occur as a side effect of direct damage and arise from the disruptions to physical and economic activities caused by flooding, such as reduced productivity of public services, transportation, trades, loss of sales, as well as indirect health effects such as the spread of mold or diseases (NWS, 2011).

Secondly, flood damage can be classified as tangible or intangible damage, which depends on the ability to assign monetary value. Tangible damages are categorized as monetary losses and are affected financially due to flooding. These damages may occur as direct or indirect damage. On the other hand, intangible damage arises from adverse social and environmental effects caused by flooding, including factors such as the bereavement because of loss of life and limb, stress, and anxiety (EarthSci, 2014).

Lastly, the impacts of flood damage can be broken down into the categories of: public health impacts, economic impacts, social impacts, and ecological effects of flooding (Aerts, 2012).

2.4.1 Health Impacts of Flooding

Health impacts from flooding are associated with water damage and severe weather. Complications such as respiratory issues, gastrointestinal infections, geographical range of animals carrying diseases, and mental health issues can arise (Mendell, 2011).

Respiratory issues emerge from indirect flood damage due to the increase of mold content. Mold grows in warm, damp, and humid condition. The increase in precipitation causes dampness in buildings, which escalates the growth of mold and fungi (EPA, 2014). Short term exposure to mold can lead to minor problems such as nasal congestion, eye and skin irritation, and wheezing, while long term exposure can generate problems such as fevers, shortness of breath, obstructive lung disease, lung infections, hypersensitivity pneumonitis bronchitis, and asthma (Mendell, 2011).

Crucial health impacts of flooding that arises from indirect flood damage are gastrointestinal illnesses that emerges from various foodborne, waterborne, and animal-borne diseases caused by flooding, coupled with water contamination of bodies of water used for recreation (such as beaches and lakes). This results from failed wastewater treatment and chemical contaminants (EPA, 2014). The most common illness contracted from contamination at beaches is gastroenteritis, an inflammation of the stomach and the intestines that can cause symptoms such as vomiting, headaches, and fever. Also heavy rainfall and flooding can advance the spread of waterborne parasites such as *Cryptosporidium* and *Giardia* that are sometimes found in drinking water. These parasites can cause gastrointestinal distress and in severe cases, death (USGCRP, 2009).

The geographical range of animals carrying diseases increases due to the global rise in temperature. For example, ticks are known to carry Lyme disease and are more active in temperatures above 45 F and 85% humidity. With the rise in temperatures and an increase in damp environments due to rise in sea level and flooding, ticks have more habitat to thrive and spread Lyme disease to other organisms (EPA, 2014). Mental health issues are a result of

indirect and intangible flood damage. Many individuals can be affected by experiencing stress and anxiety during flood recovery (Mendell, 2011).

2.4.2 Economic Impacts of Flooding

One of the most detrimental consequences of flooding is the economic impact that it could potentially cause to an area. Storms along with the hydrostatic force of floodwaters can cause direct, tangible damage by destroying foundations, walls, and windows of property buildings. For example, Super storm Sandy completely dismantled 900 buildings and severely damaged over 12,000 more in New York and New Jersey (Newman, 2012). The structural damage was estimated to be \$50 billion, and 2.66 million people were left without power due to direct damage to power lines from flood waters and strong winds (Stone, 2012).

The aftermath of an intense flooding event can cause economic impacts on residents that are considered intangible, such as the inability to recover financially or even emotionally due to massive damage to properties (Zimmerman, 2015). For example, after Hurricane Katrina, about 800,000 homes were lost to water and damage and wind intensity, and many were left homeless and not able to receive economic funding to rebuild (Katrina Impacts, 2012). As of 2012, 7 years after the event, the homeless count still sat at 4900 (Cockerham, 2012). The government was not able to provide funding for all the damages caused by the storm, so many civilians without home insurance were left without any option but to suffer to homelessness.

Flooding can cause intangible economic impacts that can affect areas directly, as well as indirectly to another area. For instance, agricultural dilemmas such as loss of crops, livestock, and wildlife on farmlands can cause economic impacts on the many individuals that are dependent on these assets to support themselves and their families, as well as can indirectly impact areas that receive the benefit of those said assets. This can be seen in Bangkok, Thailand, the world's largest exporter of rice. In October of 2011, heavy rains in led to extreme flooding and not only caused 283 deaths, but also destroyed ten percent of the nation's rice farms. The damage was worth 72 billion baht (about 2 million US dollars) to the agricultural sector of Thailand, and affected the future economy of Thailand (Fernquest, 2011). This not only caused direct damage the individuals who make a living off their farmland, but it also caused upward pressure on the world food prices and an indirect damage (Rom, 2011).

2.4.3 Social Impacts of Flooding

The social lives of many individuals can be negatively impacted during flooding and severe storms due to indirect flood damage. Members of a flooded community can lose assets of significant value. They can experience an extensive amount of stress and hardship endured through the process of repairing and replacing the loss of property and possessions (EPA, 2014). Flooding can also affect the quality of life for many individuals and loss of livelihood.

Communities may be compelled to relocate in response to being financially unable to repair property, or in response to the risk of flooding in the area (APFM, 2013). Individuals had to change their lifestyle and daily routines to accommodate the effects of flooding, such as finding different methods of commuting to work or communicating with family members. For example, following Super storm Sandy; most schools in New York and New Jersey were closed, along with subway system being unable to run. Communication was also limited due to power outages (Newman, 2012).

2.4.4 Ecological Impacts of Flooding

Flooding can have negative ecological impacts on the environment through the considerable amount of salt water that inundates flooded areas. The increase in salty floodwater can cause a substantial growth of algae along flooded areas, while other vegetation such as flowers and produce will be killed from the saltwater (Sims, 2012). Also, floods can disrupt normal drainage systems in cities that overwhelm sewage systems. The presence of raw sewage mixed with floodwater can lead to unclean water pooling in public areas and impacts the environment as well as the health of the general public (TBHA, 2013).

2.5 Vulnerability as a Prioritization Framework

The consequence of damage is highly dependent on the community in which the structure or asset is placed. A common example for understanding this correlation is comparing the theoretical inundation of a hospital or a baseball field. In the event a baseball field is flooded, it can be expected to survive with little damage to it or human life. The flooding of a hospital's first floor, however, could have fatal effects on those depending on the constant availability of its services and utilities. By prioritizing assets based on their vulnerability to flooding and the consequence of their flooding to the community, an accurate, aggregate understanding can be developed.

A prioritization framework diagram such as the one in Figure 6 is based on risk and vulnerability to determine prioritization of action. The framework is used to illustrate how "risks that cannot be managed to remain within a tolerable level exceed the limit to adaptation and become intolerable. The shading around the limits indicates that actors' views of what is acceptable, tolerable or intolerable risk may vary" (Dow et al, 2013). Using both risk and vulnerability in conjunction can create a systematic approach to prioritizing the kinds of adaptations an asset requires based on the likelihood of the event, flooding, and the frequency of the event.

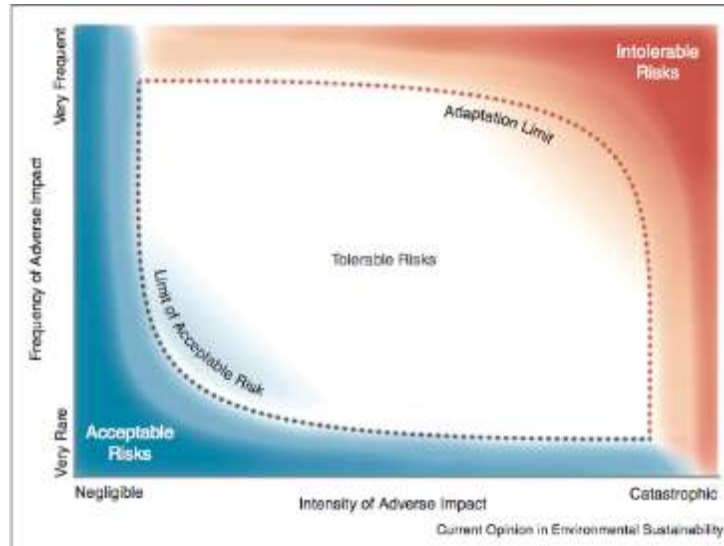


Figure 6: Risk Tolerance (Dow et al, 2013)

Some research groups measure vulnerability to flooding in relation to the North American Datum of 1988 (NAVD88), which is the vertical measurement in relation to a point of origin on land (TBHA, 2013) (Survey, 2014). Boston’s average high tide, for example is measured at 4.8 feet NAVD, while the storm surge during a 100-year flood is theoretically 9.8 feet NAVD. By 2100, the 100-year storm surge is predicted to exceed 12 feet NAVD. In Boston, vulnerable infrastructure and buildings have been defined as having structures below 10 feet NAVD; these are likely to be affected by today’s storms or high tides. Whereas those structures considered having low vulnerability are built higher than 13 feet NAVD, and are not likely to be affected by these high tides or storms.

2.6 Background Summary

Climate change and the resulting gradual warming of the planet have shown to be increasing global sea level as well as the frequency of extreme precipitation events (EPA, 2014). Together, these factors elevate the risk of flooding to people living in coastal areas around the world, and more specifically those living on the Boston Harbor shoreline (TBHA, 2013). The Massachusetts Department of Transportation has produced a hydrodynamic model of projected flooding for use to determine areas at risk in and around Boston (MassDOT-FHWA, 2015). In the following chapter we will discuss what we did to achieve our goal of developing recommendations for Boston and the steps we took to do it.

Chapter 3: Methodology

The goal of this project was to create policy recommendations for the City of Boston to inform planning efforts to reduce the vulnerability of Boston’s waterfront due to flood risk. We focused on creating recommendations for the upcoming citywide planning project, Imagine Boston 2030, designed to prepare the city for a new century (Share Your Vision, 2015).

We established three main objectives to develop our recommendations. First, we outlined and analyzed a case study area along the Columbia Point waterfront as a basis for our recommendations for Boston’s waterfront property. In our second objective we interviewed experts of water management and flood risk mitigation to aggregate evidence and perspectives from various locations. These first two objectives contributed to the execution of our third objective of developing policy recommendations for city planners and officials. This progression is explained in Figure 7, an organization of our work plan.



Figure 7: Process Management

3.1 First Objective: Case Study and Categorization

Our group conducted a case study to develop our evidence on the potential vulnerability of specific assets to flooding outside that which we learned in our literature review. Through this case study we collected real examples of flood vulnerability in the area. This was determined by cross-referencing locations of assets with flood likelihood projection maps. From that risk analysis we developed a list of risk mitigation techniques that might be useful in the area.

The sponsor identified the Columbia Point area as a good case study area because it is at risk of flooding based on the MassDOT model, and possesses diverse assets that make it possible to generalize some of our findings to other parts of the city. Some of these assets include:

- The John F. Kennedy (JFK) Train Station, an important means of transportation to and from the area.
- The University of Massachusetts (UMass) Boston.
- Various local churches, libraries, museums, and schools.

Analyzing this area (Figure 8) would act as an example for other parts of the city.



Figure 8: Satellite imagery of case study (Google)

3.1.1 Document Assets in Case Study

Our team documented various assets within the Columbia Point area found to be at risk of water damage due to flooding. This risk was determined through analysis of the simulations provided within the MassDOT’s hydrodynamic models. These maps show the “exceedance probability” (the likelihood that water will exceed ground elevation) and flood depth projections for the years 2030, 2070, and 2100. To restrict the scope of our study, we only analyzed the maps from 2030 and 2070. The calculations in these predictions included variables such as sea level rise, storm surge, wind patterns, currents, waves, rainfall, and drainage capacity (MassDOT-FHWA, 2015). These maps can be used to identify locations, structures, and assets that lie within different flood risk levels. The data produced by these maps currently describe the likelihood of flooding in the event of a theoretical 100-year storm. These multi-layered probabilities make the interpretation of the data by those inexperienced in statistical interpretation challenging. In Figure 8, a satellite image of the assets we chose to investigate is

shown with overlays of the 2030 and 2070 exceedance probability of the hydrodynamic model. In figure 9, a satellite image of the assets we chose to investigate is shown with overlays of the 2030 and 2070 exceedance probability of the hydrodynamic model.



Figure 9: Aerial View of Columbia Point Case Study Area with 2030 and 2070 Model Overlay

The map shown in figure 9 was our primary tool for analysis of risk in the case study. The numbers on the map represent individual assets that we visited during our field study to further assess their level of vulnerability. The border of Figure 9 defines the total area within which our case study research was conducted. We included fifteen assets in our case study that we identified as important to the community and had potential for serious social impact if flooded. The shading on the overlay is a representation of the exceedance probabilities for a given area. In the 2030 map overlay, areas designated in red face the least risk of flooding, with a 0.2% probability, while yellow is at 0.5%, and green with a projected 1% annual flood probability (MassDOT-FHWA, 2015).

The assets were selected by first referencing Google Earth maps to determine which properties fell within the parameters of our case study. This parameter was defined by the limited coverage of Columbia Point within the projected flood maps. We then made a trip to our case study area, where we utilized a program called Tap Forms, a customizable database application, which allowed us to develop a create a form that we felt met our needs. We used the TapForms (see www.tapforms.com for more information) application to document details pertaining to assets that reflect vulnerability such as: locations of vents, electrical equipment, doors and windows and whether the asset was in a high traffic area with the potential to impact a large population (see section 2.4 Impacts of Flooding). These factors were chosen to reflect their respective asset's vulnerability because they are open, exposed areas that allow for water to enter the building and cause moderate to severe damage. These data were then analyzed and used to divide our list of assets into various categories of vulnerability.

3.1.2 Develop a Risk and Vulnerability Categorization of Assets

Through data collection on our field study, we were able to determine individual asset vulnerability based on the factors described in 3.1.1 with which we were able to define categories of flood risk regions of high, medium and low risk (Tips for Prioritizing Using the Traffic Light Method, 2015). Areas of risk were determined using the FEMA flood probability (1% likelihood) as a level of tolerable risk according to FEMA’s 2015 risk analysis (FEMA, 2015). The Tables 2 and 3 below illustrate the determined coloring of our flood map overlay using the 2030 and 2070 MassDOT models, respectively, scaling the colors to cover broader spectrums. As 1% is considered the threshold of tolerable risk, we used this to be our maximum level of tolerability, represented in green. Likewise, red and yellow are less severe, representing probabilities of 0.2% and 0.5%, respectively. According to the 2070 MassDOT models, the lowest exceedance probability is 2%, twice the threshold of tolerable risk and therefore the medium probability predicts a flood five times per year and high probability predicts flooding twice a year (FEMA 2015).

Table 2: Exceedance Probability Color key for 2030

Color on Map	Likelihood of Flooding	Exceedance Probability
Red	Low probability of flooding	0.2%
Yellow	Medium probability of flooding	0.5%
Green	High probability of flooding	≥ 1%

Table 3: Exceedance Probability Color key for 2070

Color on Map	Likelihood of Flooding	Exceedance Probability
Green	Low probability of flooding	2%
Purple	Medium probability of flooding	20%
Blue	High probability of flooding	50%

Assets were sorted into a matrix that weighed consequence of flooding to the respective asset and likelihood of flooding to that area. We based our matrix on the categorization framework developed by Dow et al (2013; see Figure 6 in chapter 2.5.1). Quadrants were defined as follows:

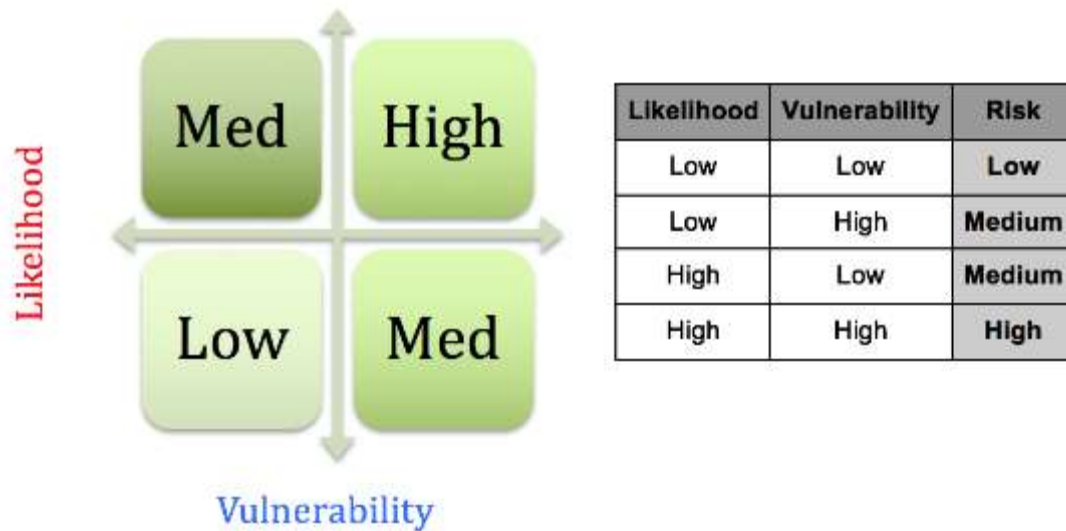


Figure 10: Matrix of Likelihood of Flooding vs. Vulnerability

The United States government uses the 1% annual exceedance flood as the basis for the National Flood Insurance Program (NFIP). This range was considered to be “a fair balance between protecting the public and overly stringent regulation” (Holmes, 2010). Based on this regulation, we were able to define our threshold that determines the consequences of flood damage. If likelihood of flooding is high for a given area, such as a flood exceedance probability greater than 1%, and poses a relatively low consequence to the surrounding area and its inhabitants, or vice versa (a low likelihood of flooding that poses a high consequence), the risk is considered to be moderately tolerable or moderately intolerable, which demonstrates that the need for an effective action to reduce risk is moderately prioritized. If the likelihood of flooding is high for a region and the consequence of the flood is also high, then it is considered intolerable to flooding and action must be taken.

Tolerability and intolerability are terms that we use to express what is socially acceptable to be flooded. For example, schools are considered intolerable since they are generally used as shelters during storm events. Similarly, a hospital is considered a matter of high consequence because the building is housing a large number of people who are not able to evacuate and are depending on machinery within the hospital for their health and, therefore, may lead to death and injury. Because both the likelihood and consequence are high, the result is high vulnerability to structure and people involved within the asset, making it intolerable to flooding. Parks, fields, and parking lots might be considered tolerable as they are not essential during a storm event and in most cases, will not result in any long term damage as a result of temporary flooding.

3.1.2 Flood Analysis

To determine the vulnerability of assets within our case study area, we first analyzed levels of flooding by referencing bathtub models provided by TBHA as well as high resolution maps extracted from MassDOT's new hydrodynamic model. We limited our case study's parameter by the extent that MassDOT's model covered within Columbia Point. Unfortunately, only part of our desired case study area was included in these maps.

For the 15 assets that we selected for this case study, we referenced the MassDOT's 2030 and 2070 probability/flood depth maps to provide a listing of that information based on asset location. This provided us with a clear understanding of each asset's individual risk from flooding and the physical factors that increased each asset's vulnerability. Having a compiled list proved useful when comparing to resilience strategies used in other cities.

3.2 Second Objective: Conduct Interviews with Global Experts

To better support our evidence and analysis of our field study and better understand how to assess vulnerability issues, we conducted interviews with experts from the US and Europe to acquire information on how particular cities and nations have adapted to their risk from flooding. Our first step to accomplish this objective was intended to gain a global perspective to strategies used in various cities to obtain a better grasp of the different flood resilient strategies that can be implemented for the Boston Harbor. This will benefit us in gaining information on approaches that can be included within our policy recommendations for the Boston 2030 project plan. We interviewed experts from several cities based on their work adapting to the threat of water. Through our literature review presented in the Background chapter, we were able to select cities that have experienced or continue to deal with crises due to flooding. Over time, they have all developed policies that implement strategies and technologies such as barriers and infrastructures, as well as incentivizing actions. We spoke with representatives from the following cities:

- Hamburg, Germany
- Boston, Massachusetts
- New York, New York
- New Orleans, Louisiana

3.2.1 Interviews Conducted

The cities listed in the previous section were selected through in depth research into flood resilience around the world as well as recommendations from local professionals. We used some flood related keywords to help search for these cities. The following is a list of example keywords used:

- Flood resilience
- Coastal flooding resilience
- HafenCity, Hamburg
- Dutch Flood Resilience

The representatives we decided to talk to were chosen based on their position in offices of government or organizations that dealt specifically with the city's relationship with water, or with planning and zoning within the city. We designed our interviews to be phone surveys of experienced professionals. We based our questions on research we conducted into the background of each person, their respective city and the work done there regarding flood management. We created templates with general interview questions as well as questions specific to a person's particular project and experience. The interview summary can be found in Appendix 3.

We interviewed:

- Britta Restemeyer: Ph.D. researcher who is currently working on design strategies for policy and decision-makers to increase flood resilience in urban areas.
- Trevor Johnson: a resilience planner for the New York Department of Planning who explained regulatory barriers that the government had to overcome since experiencing devastating flooding events in recent history and have since worked to implement many resilience strategies as a result.
- Dale Morris: a senior economist at the Royal Netherlands Embassy in Washington, DC, who directs the Dutch Government's Water Management network in Louisiana, Florida, and California in relation to sustainability, flood risk mitigation, and climate change adaptation.
- Chris Busch: Waterfront planner with the Boston Redevelopment Authority

Since our main focus is based in the Boston area, it was especially useful to interview Chris Busch, a senior waterfront planner for the Boston Redevelopment Authority (BRA). He conducts planning initiatives for specific city neighborhoods throughout the City of Boston with an emphasis on initiatives related to the waterfront, which is very beneficial to our research of zoning policies and city planning and development. Based on our interviews, we were able to determine the most suitable strategies to recommend for the Columbia Point area to protect the area from flooding.

3.3 Third Objective: Develop Policy Recommendations

The third objective aims to present the City of Boston and their Imagine Boston 2030 project plan with policy recommendations that suggest various flood resilience strategies that

can be implemented to alleviate floodwater damage. We hope that the policies will benefit the City in providing possible solutions to a critical issue that Boston potentially faces. We expect to determine which policies are best suitable to integrate for the Boston waterfront, and how they are able to enforce these policies.

3.3.1 Determine what practices could be put in place to protect these assets

There are many innovative flood resilience strategies used across the globe that can greatly benefit areas currently at risk of flooding. To apply the strategies used in the other cities that we studied to Boston, we used our vulnerability framework to determine the most vulnerable parts of several buildings in our case study. We provided various adaptation strategies that we would recommend seeing implemented in Boston to help reduce potential vulnerability to flooding.

The strategies that we determined to be best suitable for Boston were based on our assessment of the assets we analyzed and their surrounding areas. The assets were then examined individually for vulnerable characteristics, such as low lying windows, doorways, vents, electrical equipment, or if they were located in an area that will experience future flooding, based on the data provided by the MassDOT model. Using the information learned from background research and our interviews, we established strategies that could be used for these assets. For example, the properties that we found that lie close to the coastline in an area with a high probability of flooding as well as experiencing waters at high depths, such as the residential apartments, should implement strategies of barricading windows, doorways, and vents. Another option is to construct natural buffers such as rain gardens to absorb floodwaters, or a concrete barrier such as a small dike system to protect the individual asset.

Using the flood resilience strategies that we found to be best suitable to adapt to vulnerable areas, we were able to establish a set of policy recommendations to mitigate the risk of flooding in Columbia Point.

Chapter 4: Findings and Analysis

Our project included the development of a set of policy recommendations for the City of Boston and their Imagine Boston 2030 plan to redevelop the waterfront and reduce vulnerability due to flooding. In this chapter, we discuss our analysis of the MassDOT's hydrodynamic model data that leads to the findings of our research from our case study area, Columbia Point. The model provided a new level of detail that was useful and substantive in creating policy recommendations for city officials and planners of the Imagine Boston 2030 planning team. We created a prioritized risk-based framework based on our findings from the assets within the case study area, Columbia Point, which can be applied to the waterfront of the City of Boston.

In this chapter we present two major findings about flood resilience and policy:

1. The assets in the Columbia Point area are likely to experience flooding.
2. A risk-consequence prioritization framework can be applied to assets.

4.1 Defining Asset Risk and Consequence

Our primary ranking of consequence was done using an approximation of the number of people affected by the asset. The nature of our study limited our approximation of population to the intuition of the researchers. Each asset's population approximation was based on the general "common sense" of each team member. We estimated the population based on our knowledge of similar assets. Quantitative and qualitative rankings of assets for prioritization could be done using a number of measures by other teams; our framework was produced as an example of the process.

As a means for illustrating our concept of prioritization, we used population affected by the flooding to rank consequence. High value assets were those located in high traffic areas and associated with large populations. For example, Morrissey Boulevard is a densely populated area with high traffic that contains many important assets that are important to the community. If this area were to be flooded, the damage could cause loss of supermarkets, banks, police stations, and housing; all of which are important components to the community.

Using this approach, residential areas, schools, and major forms of transportation were prioritized because of their level of impact to a large population, regardless of the intensity flooding they could be receiving. Damage to these assets can cause critical consequences since it affects a large scale of the population to a given area. Because of this, based on our prioritization model, the risk is determined to be intolerable and the issues should be assessed immediately. We found large, commercial buildings in highly floodable areas to be considered high in priority as well due to their increased likelihood. The amount of employees in a given

company was also determined to be a major factor that marked them as high priority through this study. Other definitions may lead to different prioritizations than the way we have analyzed the assets but our team maintained the prioritization framework previously explained throughout our study.

4.2 Assets are Vulnerable in the Columbia Point Region

Our investigation of the Columbia Point area revealed that this community is unprepared for the dangers of flooding. Buildings and residences in the area (as shown by photos in Appendix 1) are vulnerable to flooding. These assets have vulnerable architecture low to the ground, well within floodable zones. With apparent residents on the ground floor, some buildings also have vents and windows on the ground level. Without mitigation these vulnerabilities would have tremendous ramifications on anyone living in the building, creating an environment for mold, mildew, and disease (EPA, 2014).

Non-residential developments in the Columbia Point area are also vulnerable. The Bayside Expo Center lies entirely within a flood zone and has external electrical equipment and large entrances to the building at ground level (MassDOT-FHWA, 2015). Water damage could at best put these buildings temporarily out of use while they are cleaned, or at worst cause them to be condemned for damage (FEMA, 2013). Damage to these assets is likely to cause little effect to human health, because of the nature of the use, but their absence will have a social impact on the community.

The assets in our case study have varying likelihood of flooding, as well as varying to flooding that might occur. The summation of these factors is the risk posed to the structure by flooding. Figure 11 describes the relationship between likelihood and vulnerability as they relate to risk, and can be interpreted to fit our data as well.

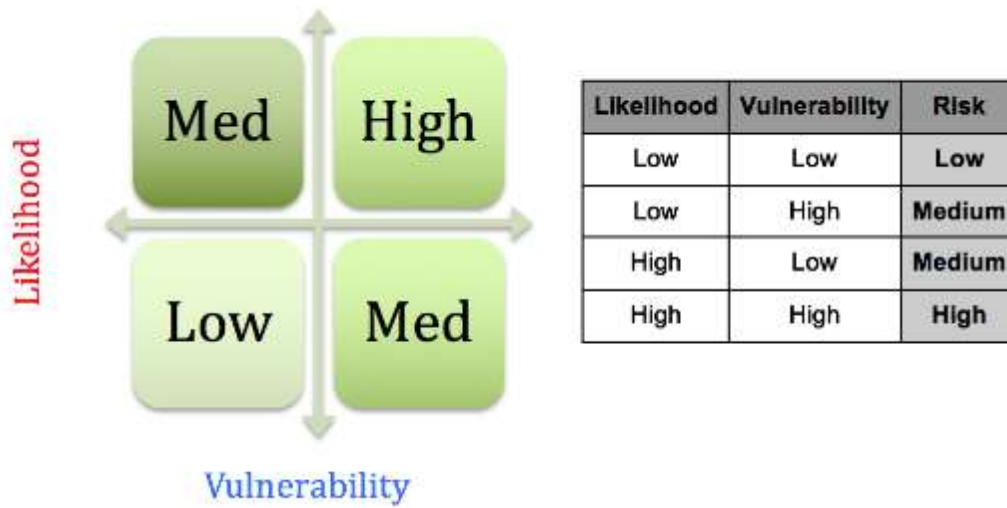


Figure 11: Matrix of Likelihood of Flooding vs. Vulnerability

An application of this model to the assets in our case study reveals an approximation of the risk to each of the structures. The results of this risk analysis for the 2030 projection are provided in the Table 4, and descriptions below. The same risk analysis table for 2070 is available in Table 5.

Table 4: 2030 Risk Assessments for Case Study Assets

Asset Name	Flooding likelihood	Vulnerability	Risk
State Police Station, South Boston	Low	Low	Low
JFK/UMass Train Station	High	Low	Medium
Doubletree Hilton Hotel	High	Low	Medium
Bayside Expo Center	High	High	High
First Community Health Center	High	High	High
Harbor Point Luxury Apartments	High	High	High
John W McCormack School	Low	Low	Low
Paul A Dever School	Low	Low	Low
Peninsula Luxury Apartments	Low	Low	Low
Star Market	High	Low	Medium
Santander Bank	High	Low	Medium
State Police Community Action Team	Low	Low	Low
St Christopher's Church	Low	High	Medium
Greater Media Inc.	High	Low	Medium
Columbia Park	Low	High	Medium

Table 5: 2070 Risk Assessments for Case Study Assets

Asset Name	Flooding likelihood	Vulnerability	Risk
State Police Station, South Boston	High	High	High
JFK/UMass Train Station	High	High	High
Doubletree Hilton Hotel	High	High	High
Bayside Expo Center	High	High	High
First Community Health Center	High	High	High
Harbor Point Luxury Apartments	High	High	High
John W McCormack School	High	High	High
Paul A Dever School	High	High	High
Peninsula Luxury Apartments	High	High	High
Star Market	High	High	High
Santander Bank	High	High	High
State Police Community Action Team	High	High	High
St Christopher's Church	High	High	High
Greater Media Inc.	High	High	High
Columbia Park	High	High	High

4.3 Assets within Case study are likely to experience flooding

4.3.1 Finding #1: The assets in the Columbia Point area are likely to experience flooding
 In section 3.1 of our Methodology Chapter we reviewed our analysis of Columbia Point. Table 6 below lays out our findings from our field study evaluation using TapForms (see www.tapforms.com for more information). We documented various aspects of each asset that we chose to focus on when determining their individual vulnerability.

Table 6: Risk assessment for case study

Map #	Asset Name	Flood Depth (ft.) 2030*	Flood Depth (ft.) 2070*	Likelihood of Flooding (%) 2030**	Likelihood of Flooding (%) 2070**	Vent locations	Door locations	Window locations	Electrical Equipment
1	State Police Station, South Boston	<0.5	2.5	0.3	2	1 ft. above ground	Elevated by stairs facing away from water	First floor and basement	Roof
2	JFK/UMass Train Station	N/A	2.5	1.0	50	N/A	Elevated	Elevated	N/A
3	Doubletree Hilton Hotel	N/A	4	1.0	50	Ground floor	Ground level	Close to Ground	HVAC
4	Bayside Expo Center	1.5	5	1.0	50	N/A	Several doors at ground level	First floor	Ground level
5	First Community Health Center	0.5	5	1.0	50	N/A	Ground	First floor	N/A
6	Harbor Point Luxury Apartments	0.5 - 1.5	2.5	0.5	20	N/A	Ground level	First floor	Yes
7	John W McCormack School	N/A	2.5	0.2	50	1ft above ground level	Elevated with stairs	Second floor	Ground level
8	Paul A Dever School	0.5	2.5	0.2	50	1ft above ground level	Ground level	Second floor	N/A
9	Peninsula Luxury Apartments	N/A	2.5	0.2	20	6 inches above ground level	Elevated with stairs	Second floor	Yes at ground level
10	Star Market	N/A	4	0.7	50	N/A	Elevated	None	Ground level
11	Santander Bank	N/A	4	1.0	20	N/A	N/A	Ground level	Roof
12	State Police Community Action Team	N/A	2.5	0.2	2	Ground floor	Ground level	First floor	Roof
13	St Christopher's Church	0.5	4	0.3	2	None	Raised with stairs	Basement level	Ground level
14	Greater Media Inc.	0.5	2.5	0.75	20	Above doorways	At ground level	4 feet above ground level	Yes
15	Columbia Park	1.5	4	0.2	50	N/A	N/A	N/A	N/A

*Based on data provided in maps created with the MassDOT hydrodynamic model, we were able to provide the projected flood depth for the high 2030 and 2070 flood depth maps. The flood depths are depths at the 1% exceedance probability.

**Listed assets by the probability of that location to flood according to MassDOT's 2030 and 2070 exceedance probability map. Any asset with a probability of 1% or more is considered intolerable.

We analyzed our findings of several exemplary assets, listed below:

1. State Police Station

Our work with the hydrodynamic model showed the State Police Station, close to the shoreline on Columbia Point, had approximately a .3% likelihood of flooding, as well as a flood depth less than 0.5 feet by the year 2030. By the year 2070, these will rise to 2% exceedance and a flood depth of 2.5 feet. From the outside. However, this building appeared to be prepared for projected flooding through at least 2030. By placing electrical equipment on the rooftop, and having apparent elevated entrances to the building, it is likely that with minimal preparation the building could survive a flood situation in the years 2030 and 2070. The consequences to this asset if flooding were to occur include moving the police station while the building is inundated, and monetary loss to replace damaged equipment.



Figure 12: State Police Station of Dorchester, MA has raised doorways and windows (original photo)

2. JFK/UMass Station

The JFK/UMass Station, an MBTA transportation hub, is an important asset used for transportation in Dorchester, MA. The model showed 1.0% flood probability with negligible flood depths in 2030. The flood probability and depth will rise to 50% and 2.5 feet respectively by the year 2070. Although all doors and windows are elevated, the buses are docked at ground level and the electrical equipment and tracks also reside at ground level. Seawater inundation would damage the electrical equipment and corrode the tracks. Flooding would also shut the station down and leave no source of public transportation for the area, affecting a large amount of the local population. Due to its regional impact and high annual likelihood of flooding, the JFK/UMass Station would have a large consequence on citizens of Boston and surrounding areas.



Figure 13: JFK/UMass MBTA Station (original photo)

3. Double Tree Hilton Hotel

The Double Tree Hilton is a commercial building that provides leisure and temporary housing. According to the MassDOT hydrodynamic model the flood exceedance is 1.0% but of negligible flooding depth in the year 2030, but in the year 2070, these values will rise to 50% and 4 feet respectively. The hotel contains windows, doorways, vents, and electrical equipment all on ground level, which is considered highly vulnerable to flooding. If flooding were to occur, water could infiltrate the building through the ground level features. Consequences of flood damage can include loss of economic viability to the owners of the Hilton, loss of employment if the hotel were to shut down, loss of temporary shelter for nearby residents (potentially displaced by the same flood)



Figure 14: Double Tree Hilton Hotel with vulnerable features located on ground level (original photo)

4. Bayside Expo Center

The Bayside Expo Center is a private commercial venue owned by UMass Boston that hosts shows and events (Forrey, 2010). Using the MassDOT model, we saw that the Bayside Expo Center demonstrated a 1.0% probability of flooding. This is a high likelihood, and previously considered to be at the level of intolerable risk (FEMA, 2015). A brief investigation of the outside of the building (Figure 15) revealed ground level entrances and assets vulnerable to flooding at ground level. Flooding could cause the owners of the facility lose funding to repairing damages, and possibly a loss of business if use is halted. An approximation of the relative impact of its inundation to the population of Boston, however, lists it lower on a scale of consequence because of its questionable importance to a smaller number of people.



Figure 15: Ground level doors at the Bayside Expo Center (Original Photo)

5. First Community Health Center

Our field study also showed that this asset had architecture located at ground level such as doorways and windows, making the property highly vulnerable to inundation of water. According to the MassDOT hydrodynamic model, the health center will experience a 1% exceedance probability to a depth of 0.5 feet by the year 2030. By the year 2070, the flood exceedance will rise to 50% and the depth will to 5 feet. This asset has potential to experience critical flooding conditions. Considering that a medical center is crucial to the health of its patients, interruption of care could have dire consequences. The medical center could also lose important documents and equipment, such as crucial lab equipment and materials. These factors result in high consequences for the asset.



Figure 16: Vulnerable features at the First Community Health Center (original photo)

6. Harbor Point Luxury Apartments

The Harbor Point Luxury Apartments are residential buildings for the public and are located on the shoreline of Columbia Point. The MassDOT hydrodynamic model shows for year 2030 a flood exceedance probability of 0.5% and a flood depth ranging between 0.5-1.5 feet. In the year 2070, the values will rise to an exceedance probability of 20% and a flood depth of 2.5 feet. Many of the apartment buildings have doorways on the ground level, as well as windows on the first floor, making these residential properties vulnerable to flood waters. Flood damage to these properties can cause consequences such as financial loss to families for repairs to infrastructure and replacing furniture. Some may even lose shelter need to relocate. These consequences could prove disastrous for a family or student living in this area.



Figure 17: Ground level doorways on the Harbor Point Luxury Apartments (original photo)

7. John W. McCormack School

The John W. McCormack School, a commercial building, is a local middle school in the Columbia Point area. Models show flooding in 2030 poses little threat to the school, as there is 0.2% flood exceedance and negligible flood depth. In the year 2070, the school can expect a flood exceedance of 50% and flooding depths of 2.5 feet. The school possesses ventilation systems 1 foot above ground level, raised doorways, and windows on the second floor. Flood damage imposed on the school can cause damages to books, employment loss for faculty and staff members. If the school were to shut down because of severe damage, classes could be delayed or the school could be rendered unusable, which can lead to overcrowding at other schools.



Figure 18: The John W. McCormack School with raised doorways and windows (original photo)

8. Paul A. Dever School

Neighboring the John W. McCormack School is the Paul A. Dever School, a local elementary school located along the Columbia Point. The hydrodynamic model shows that the school will experience a 0.2% flood exceedance and a 0.5-foot flood depth in the year 2030, while in the year 2070, it will experience a flood exceedance rate of 50% and flood depth of 2.5 feet. Ventilation systems appear to be located 1 foot above ground level, windows are located on the second floor, and doorways are located slightly above ground level. The features of the school seem protected for the year 2030, but the year 2070 might see infiltration of floodwaters through the vulnerable features. This infers that the school is not immediately vulnerable to flood damage. Flood damage deems similar consequences to those of the John W. McCormack School (above).



Figure 19: Paul A. Dever Elementary School in Columbia Point (original photo)

9. Peninsula Luxury Apartments

The Peninsula Luxury Apartments are another group of residential buildings in Columbia Point, but are located further inland than the Harbor Point housing. In comparison to the Harbor Point Luxury Apartments, these properties possess fewer vulnerable features, with vents 6 inches above the ground, windows on the second floor, raised doorways, but still have exposed electrical equipment on ground levels. They will also experience less of an impact with flooding according to the information provided by the hydrodynamic model. In the year 2030, the asset will experience a flood exceedance of 0.2% with negligible flooding depth. The year 2070 shows that the flood exceedance will 20% and the flood depth will be 2.5 feet. Flood damage to these properties poses the same consequences as the Harbor Point Apartments.



Figure 20: Luxury Point Apartments with raised windows and doorways (original photo)

10. Star Market

The Star Market is a commercial property that serves as the local supermarket in the district. The property has elevated doorways, electrical equipment on ground level, but possesses no windows. The MassDOT hydrodynamic model illustrates that in the year 2030, the property could experience a flood exceedance likelihood of 0.7% and an insignificant flood depth. By the year 2070, the flood exceedance will rise to 50% and the flooding depth will rise to 4 feet, causing a higher impact of flooding. Due to the locations of doorways and lack of windows, flood inundation would be difficult in the year 2030. But there is potential for damage to the vulnerable electrical equipment on the ground level. The owners of the store will likely experience a financial loss due to the damage to infrastructure, produce, and replacement of inventory. The consequences of a grocer closing on the local community could be large, possibly amplified by a flooding event, where provisions are needed by nearby residents. Other stores in the surrounding area, however, mitigate the regional impact of closure.

11. Santander Bank

The Santander Bank is a branch of the large commercially owned retail bank based in Boston, Massachusetts. The flood exceedance is predicted to be 1% without any flooding depth. The year 2070 will pose a higher risk with a 20% exceedance of flooding and a flooding depth of 4 feet. The bank contains windows and doorways on the ground level, making the building susceptible to flooding in both the years 2030 and 2070. No risk is posed on the electrical equipment since it is located on the rooftops. Damage to this asset would inconvenience residents of the surrounding area. Santander bank will have to compensate for damage to infrastructure and equipment. The community will have to suffer from a lack of means to obtain and deposit capital.



Figure 21: Santander Bank

12. State Police Community Action Team

The hydrodynamic model shows that in the year 2030, the exceedance is considered to be low at 0.2% as well as negligible flooding. By 2070, the exceedance rises to 2% and the potential flood depth increases to 2.5 feet. The features of the building are all low lying, such as the vents and doorways, which are located at ground level. There were also windows on the first floor, but the electrical equipment was located on the rooftops. With the building's current location, it will not be impacted in the year 2030, but will experience flooding inundation in the years 2070. Flood damage could reduce the effectiveness of the state police in the Columbia Point area, or move the offices to a different location. The State Police Community Action Team is specially assigned State troopers who specifically enforce vehicle laws and regulations. These consequences are likely immediately remedied because of the State Police's strong network of assets and offices.



Figure 22: State Police Community Action Team (original photo)

13. St. Christopher's Church

This property contains windows located at basement level but raised doorways. The hydrodynamic model reveals that St. Christopher's Church will experience a 0.3% likelihood of flooding but it will not have much impact due to negligible flooding depth by the year 2030. The exceedance will not rise by much in 2070 compared to flooding depth. The flood exceedance will reach 2% while the flood depth will reach 4 feet. This makes the building susceptible to flooding inundation in the year 2070. This damage to the church but can have effects on members of the church by losing a place to worship, financial loss for the church due to infrastructure damage.



Figure 23: St. Christopher's Church (original photo)

14. Greater Media Inc.

Greater Media is a radio station and considered a commercial building in the neighborhood. The property has doorways located on the ground level with ventilation systems located right above the doors. Windows are located about 4 feet above ground level. Determined by the MassDOT model, the flood exceedance in 2030 is predicted to be 0.75% and the flooding depth 0.5 feet. The flood exceedance and flood depth will rise to 50% and 4 feet, respectively. The property will experience some flood damage due to the low-lying windows, and at a much higher impact in 2070. The consequences of flood damage to this property can cause loss of emergency communication to listeners and possibly financial loss if radio equipment were to become harmed.



Figure 24: Local radio station, Greater Media Inc. (original photo)

15. Columbia Park

Through our fieldwork and flood model analysis we found that Columbia Park was at a low risk to the effects of flooding. We categorized this asset as “individual risk” because few people are affected by the inundation of this area. There are no jobs affected and day-to-day activities are not altered if the park is flooded. It can still impose a financial impact to the district if repairs were needed or if natural features, such as trees, grass, and plants, require replacement. The park also has a very low annual likelihood of flooding through the year 2030, 0.2% probability as well as a 1.5-foot flood depth. By 2070 the annual likelihood of flooding will rise to about 50% for the area and flood depths will reach about 4ft. Although the likelihood and flood depths increase from 2030 to 2070, impacts to the community and consequences of flooding in this area remain relatively the same. The park is not a necessity to the case study area and is not vital to the lives and well beings of the citizens surrounding.



Figure 25: Open field at Columbia Point (original photo)

4.4 The Columbia Point Community is Vulnerable

4.4.1 Finding #2: A risk-consequence prioritization framework can be applied to assets.

Many assets within the Columbia Point neighborhood are likely to experience damage in the event that a serious flood occurs. The damage that does occur will have a different impact on different communities based on the asset affected. We charted the assets we investigated into a plot of their likelihood of flooding and the relative approximate population impacted by them. The plot in Figure 26 is an estimation of a possible risk-consequence prioritization.

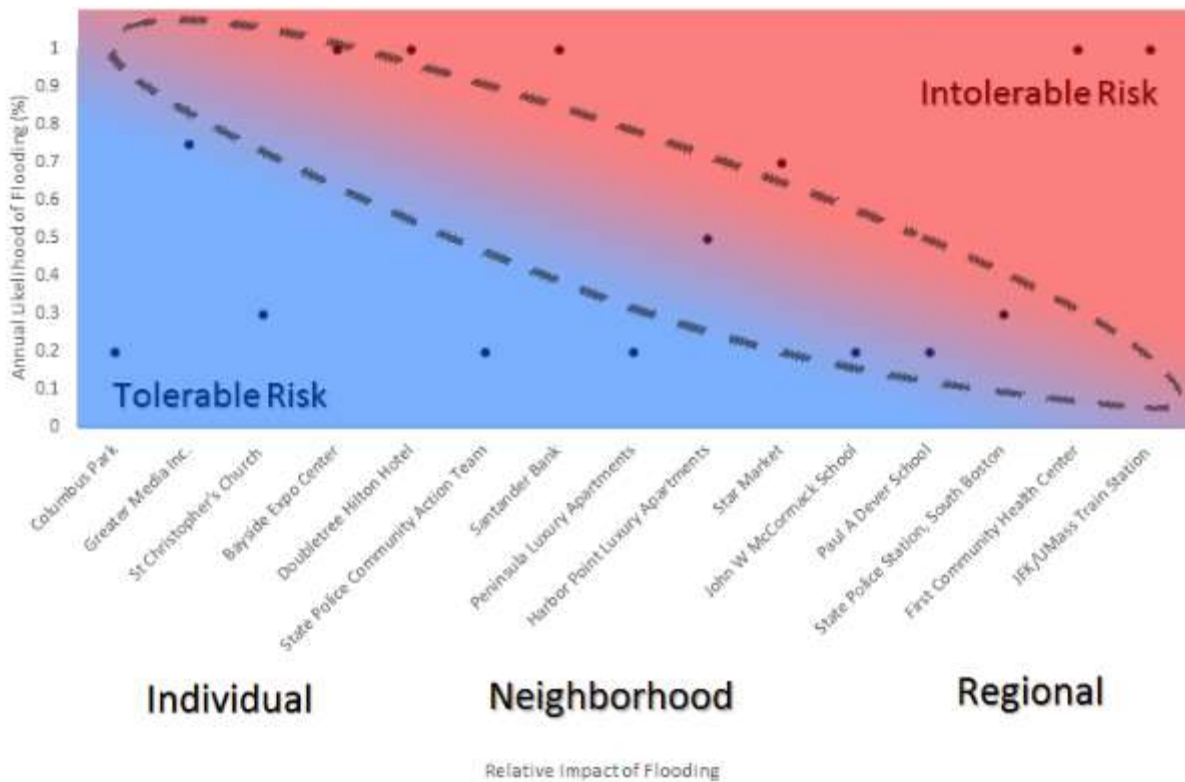


Figure 26: Risk-Consequence Prioritization Framework for 2030 exceedance probability

The graph can be interpreted as an illustration of risk-consequence prioritization, developed from Dow et. al's 2013 *Risk Tolerance*. From this graph, we can suggest the tolerability of risk to 15 assets in the UMass/JFK area according to 2030 predictions. Assets are plotted by the likelihood of flooding (using data from the MassDOT hydrodynamic model due to their quantitative nature) on the y-axis against the approximate impact of flooding ordered relative to each other (MassDOT-FHWA, 2013). The impact, gauged from the approximate population affected by damage, could also be determined by other measures (examples discussed in chapter 5).

The chart includes a gradation along a diagonal line to indicate the varying level of tolerable risk. In this example, the line of tolerable risk is illustrative of how one might use this conceptual framework in analysis and is not a definitive analysis of the assets in our case study. The actual demarcation of tolerable and intolerable risk will have to be determined appropriately by any group using this strategy.

Our representation of these assets shows a relationship of tolerance to the risk and consequence of each asset. Those assets that are both likely to flood and are of high value or significance to the community face an intolerable level of risk without appropriate mitigation. Those that fall below the tolerable demarcation appear to face a tolerable risk in the community. This method of representing the risk and consequence attempts to make clear the

often vague relationship between the probability of a disaster and how much that matters for different assets. This prioritization relationship can be used to direct efforts to mitigate risk, attempting to protect those assets of highest priority to a given community.

4.5 Resilience Strategies and Mitigation Efforts

Efforts to mitigate flood risk can reduce the damage caused by flooding in the event of a major event. In this section we'll discuss various risk mitigation strategies that are commercial, residential, or considered part of the transportation network of a city. Deployed appropriately in conjunction with a prioritization framework, strategies like these could protect a community from damage to critical assets in the short and long term.

4.5.1 Flood Resilience through Policy

Coastal cities around the world have very different landscapes and factors to consider, resulting in unique mitigation strategies being implemented. New Orleans, for example, contains system of large levees surrounding the city. These levee systems provide protection for many parts of the city and have been in place for decades. The levees stand well above sea level and provide ground on which buildings can be built. Their purpose is to block the ocean water from flooding parts of New Orleans that are below sea level (Dale Morris, Personal Communication, 2015). Although it is beneficial to understand the approaches taken by a city working effortlessly for flood resilience, Boston is not faced with the same issues as New Orleans because of their different landscapes. In Boston, properties have been built right up to the harbor, posing a concern for their safety with future storms and sea level rise, while the City of New Orleans is well below sea level in many areas, resulting in a bathtub flooding effect. The Boston Harbor is also very different from the Gulf Coast that faces New Orleans because multiple islands are present in the harbor, which serve to break any energy buildup of water (Dale Morris, Personal Communication, 2015).

The United States includes various cities where the federal government has made deliberate contributions in aiding with issues surrounding flooding. New York City, for example, established numerous flood resiliency programs such as the Hudson River Estuary Program and The Local Waterfront Revitalization Program, which provides technical assistance, matching grants, to villages, towns, cities, and counties located along New York's coasts or designated inland waterways, to prepare or implement strategies for community and waterfront revitalization (HREP, 2013).

An international example is located in Hamburg, Germany. The government collaborated with city developers to create a large 80-mile dike along the waterfront of the Elbe and Weser River to fortify against flooding. This dike has a system of flood compartments to propagate floodwaters into sewers, flood pipes, and waterways. The Government has taken

action to raise the dike twice after it has been destroyed due to flooding, with the most destructive flood being in 1962 where the dike was breached and 300 people died. The government continues to have plans to reinforce the current dike, as well as raising it higher and adapting the environment around it to better suit flood disasters (Goltermann, 2008).

The cities mentioned in this section possess a common feature that allowed them to implement solutions for flood vulnerability. They benefited from the aid of government action and funding. The adoption of risk mitigation strategies by vulnerable cities will be challenging without proper motivation and assistance from the city and state governments. The government has been successful in encouraging mitigation and reducing required federal disaster aid by providing incentives through insurance policies. They can offer underpriced flood insurance to create an incentive to build up flood resilience (Brannon, 2011). According to our interview with Trevor Johnson, the development of his *Resilient Neighborhoods* Project was extremely effective in encouraging the community to help establish a more prepared community with a development plan (Trevor Johnson, personal communication, 2015). There has to be incentive and reason for not only city planners, but for residents to adopt these policies, whether that be through making the policies voluntary action, such as an emergency brochure or flood shelters; or mandatory policies such as building codes being linked to having insurance. Barriers must be removed in order for new policies to be developed.

Once those barriers to resilience are removed, reducing the risk to property through mitigation can be accomplished. Strategies to mitigate risk can be developed with and without the aid of government bodies, and can protect property in different ways.

4.5.2 Flood Resilience through Risk Mitigation

Short term and long term strategies for residents and government organizations have been identified to mitigate these impacts (Knopp, 2013). Based on our literature review and interviews, we were able to compile some examples of resilience strategies. Short-term strategies can be implemented quickly in already existing buildings and infrastructure; while long-term strategies are built into assets from their inception.

As a brief example of risk mitigation strategies, below are listed some potential short term and long term options that are discussed in greater detail in this section:

Short term:

- Emergency Preparedness Plans
- Flood sealants and shields
- Backflow valve for sewage management

Long term:

- Raised roads
- Retention ponds
- Drainage system and permeable pavement
- Living shorelines

In this section we will discuss flood resiliency in commercial, residential, and transportation property sectors, as well as provide examples from international cities.

4.5.3 Flood Resiliency in Commercial, Residential, and Transportation

Given the varying types of assets located in Columbia Point, we were able to classify assets into three categories: commercial, residential, and transportation. We found that the different properties implement specific strategies to assess flood resiliency. We researched the different methods adopted by the distinct assets within each category. In this section we discuss general as well as specific strategies implemented for assets within each category.

Commercial:

Commercial properties are essential to communities as they can provide resources in retail, hotels, and restaurants, health care in hospitals and medical centers, job opportunities in office buildings. Important commercial assets are located along the Boston waterfront that needs to be protected from flood damage.

Although there are already some resilience strategies in place, hospitals are one of the most critical commercial assets in need protection. They use large concrete walls to fortify against flood damage to the walls and insulation. They also implement slab-on-grade tiled flooring to resist water damage. Additionally, there are safety regulations in place to protect equipment from water damage. For instance, permanently installed equipment is located on a non-floodable floor level (TBHA 2013). Electrical equipment and appliances located in floodable areas must be moved to safe, elevated locations or covered and tethered down. Elevators also should not reach basement level. Hospitals contain many crucial items that must be preserved such as medical supplies, specialized pipes used to deliver medical gas, emergency communication infrastructure, medical records and files, electrical systems and components (heating, ventilation, and air conditioning), as well as laboratory equipment. All these essential utilities are at risk of being destroyed if a flood were to happen near a hospital (FEMA, 2014).

Some businesses have implemented flood resilient methods to better protect against floodwaters. In cities that are highly vulnerable to flood damage, such as Hamburg, Germany, large businesses use strategies such as thick aquarium glass to seal the ground floor of the

buildings. A number of businesses sit behind thick concrete walls and have large watertight storm doors (Goltermann, 2008).

Residential:

Civic governments have also been known to play a role in directing risk mitigation efforts for residential districts. An important aspect of developing residential resilience is to engage the members of the community. For instance, Norfolk, Virginia engaged citizens to restore wetlands and national shorelines to preserve flood buffers (City of Norfolk, 2014). Norfolk adapted the environment to better absorb flood and rain waters. For example, more trees are planted, rain barrels are installed, and rain gardens are developed. Residents prepare their homes for flooding by elevating any important utilities out of the basement flood of their homes, such as furnaces, water heaters, and electrical panels.

Homes in highly floodable residential areas could also set physical barriers around their homes to protect from flood damage. Some homeowners in New Brunswick, Canada, for example, implement sandbag dikes around their homes to defend against incoming flood waters. These are built by stacking sandbags to form a protective barricade (New Brunswick, 1989).



Figure 27: Residential installation of sandbag dike (New Brunswick, 1989)

Commercial production flood protection devices are also marketed for protection against varying amounts of water (Flood Panel, 2015). Professionally made solutions to rising water are designed to protect property to varying depths, with varying installation requirements. These solutions are designed with varying degrees of installation and protection; the implementation having associated costs and challenges.

Transportation:

Means of transportation can be severely impacted due to flooding. In some areas, highways, subway systems, walkways, and train systems are found to be vulnerable to sea level rise and increased storms, in most cases being brought to a complete standstill.

Highways and roadways are susceptible to stripping due to water damage. Stripping is defined as “a physiochemical process that is influenced by the nature and condition of the aggregates and the chemistry and thickness of the binder film” (Baldachin et al., 2008). Exposure to warm and moist conditions lead to an acceleration of this process, especially if the asphalt is made up of loose particles in which water can squeeze into the base layer (U.S. DOT-FHWA, 2015). Stripping without the presence of water is usually limited to small sections and rarely spread but with water trapped between layers of asphalt, pressure of vehicles traveling above it result in widespread damage to the roadway. Highways can be protected from stripping and seawater corrosion by using a stable aggregate of fully compacted material and a surface level of asphalt that is water resistant. This combined with proper drainage systems around the highways and regular maintenance of the surface asphalt can be very effective in protecting its integrity as flooding becomes more frequent (U.S. DOT-FHWA, 2015).

Covers for subway stairwells and street vents are being implemented in subway systems and walkways to prevent floodwater from penetrating the highly vulnerable underground transport systems (Floodbreak, 2010). The stairwell covers are useful for storm preparedness alone and are not designed for everyday protection as they completely shut off access to the subway underground. Street vent shaft protectors are designed to be permanent, passive solutions with minimal maintenance required. Floodbreak RFC is a company that specializes in passive designs for flood mitigation. They have developed gates for both pedestrian walkways and residential/commercial driveways, capable of blending in with surroundings when not in use, and rising when needed simply by the force of increasing floodwaters (Floodbreak, 2010). Following the aftermath of Hurricane Sandy in New York, many solutions have been developed within the flood mitigation field, especially to their subway systems.

New York is highly reliant on their subway systems for transportation. When Super storm Sandy hit, 9 of the 14 subway tunnels below the city were flooded and the subway was shut down for days. The Metropolitan Transit Authority (MTA) was able to save the subways of New York from further damage to flooding due to their work. They were able to move the trains out of flood-prone areas and took electrical signals out of the tunnel. After the flood, they were able to pump water out and replace the electrical signals. Within a week, 80 percent of the subway service had been restored. This action saved the city significant time and money (Lewis, 2013).

4.6 Potential Mandatory and Voluntary Actions

We categorized our recommendations into mandatory and voluntary actions. Mandatory actions are those required by an authority (e.g. government organization or insurance company) to be implemented by a property owner, while voluntary actions are designed to be implemented at the discretion of the property owner or resident. From the information we obtained from our interviews as well as the research we performed with The Boston Harbor Association, our team developed Table 7 below that outlines our findings for potential mandatory and voluntary actions.

Table 7: Potential Mandatory and Voluntary Actions Tied to Government or Community Involvement

Category	Specific Example
Potential Mandatory Actions	
Tie Insurance Premiums to Resilience	Increased premiums for buildings that do not submit plan for retrofitting building by X date
	If building owners do not comply with retrofitting, they cannot be insured or aided by government
	Decrease premiums and provide funding for buildings that develop plan for retrofitting that adheres to all new standards and can be complete within X years
Tie Property Taxes to Resilience	Create resilience funding pool/loan (“Green Bank”)
	Provide tax breaks for investments in resilience
	Taxes increase if building and property owners do not comply with implementing flood resilience strategies
	Interest free loans to protect homes
	Build a seawall along coastline in areas of high risk
	Protective dikes under Harbor walk
	Ensure subway stations and routes are protected from water
	Fortify the Central Artery and Tunnel system
Tie Building Codes to Environmental Conditions	Require buildings to be resilient for entire lifespan of structure
	Require specific improvements (e.g. mechanicals, entry points) above flood zone
	Measure building relative to height of flood at end of lifespan, not absolute elevation; allow increased height of building/space for mechanicals to be safely stored
	Immediate requirement for new buildings, before 2030 for existing buildings
	Instill new department that ensures flood resilience safety standards are upheld annually similarly to fire inspections/codes
	Receive government benefits if buildings are retrofit to minimum resilience code
	Abandon first floor and convert to floodable space that is usable by the public
	Important utilities raised from basement or first floor level to a level above flood level
	Point of entry must be above floodable height (i.e. second floor)
	Important assets are not to be permitted to be built in flood zones (i.e. hospitals)

Voluntary Actions	
Tie Community to Resilient Redevelopment	Provide vulnerability checklist framework to community leaders to assess their own vulnerability
	Community leaders can submit findings along with their own recommendations for community to government to analyze and decide to fund
	Brochures to explain possible resilience strategies
	Inform residents of likelihood and consequences of flooding in their area (i.e. climate preparedness kits, programs, workshops)
Tie Community to Emergency Preparedness	Establish shelters for Emergency Flood Situations
	Develop action plan in place similar to emergency practices for blizzards

The implementation of mandatory actions is thought to be an effective method to incentivize flood resilience in the community. Through interviews as well as background research, we were able to identify specific actions to be taken by government offices, insurance organizations, and individuals. Encouraging and enforcing these actions reduces the load on potential government and insurance intervention after the event of a flood.

Voluntary actions are also expected to be beneficial for building flood resilience. These actions include the presentation of information to individuals who are unaware of climate change, and involving the community in adaptation. Our interviews revealed that community members were better prepared when they were presented with a development plan for their neighborhood (Britta Restemeyer, personal communication, 2015).

4.7 Summary

Our team was able to develop a risk prioritization method using the data from the MassDOT hydrodynamic model and analyzing the vulnerability of assets located in Columbia Point. After examining the flood exceedance and flood depths, we determined the level of vulnerability for the properties along the Columbia Point and found that there are buildings unprepared for a flooding event that can cause critical consequences not only to the building itself, but also to the community.

A limitation on our study was the use of only a single method of prioritization. Other measures of consequence are viable options to prioritize the importance of assets examples of those measures may include:

- Vulnerability of the people affected
- Price of assets affected (FEMA, 2013)
- Ownership of asset at risk (Muller, 2013)

Our findings can be beneficial in providing the information needed to prepare properties for future flooding. We identified flood resilience strategies that can be implemented to residential, commercial, and transportation systems with the information provided in our conducted interviews with global experts and background research. These strategies were then implemented into our policy recommendations, which will be explained in detail in the next chapter.

Chapter 5: Recommendations and Conclusion

In this chapter, we present policy recommendations for the City of Boston in an effort to reduce the vulnerability of Boston's waterfront due to flood risk. This includes our risk consequence prioritization framework and potential resilience strategies to implement in the city. Finally, we conclude our document with a review of our work and possible implications.

5.1 Recommendations

By combining results from our case study and considering approaches used in other cities through interviews and research, we developed a set of recommendations to address vulnerability. **The first recommendation that we developed was for communities to take action in assessing their own level of vulnerability.** To aid in this, we created a Vulnerability Checklist Template. Using this template, community members and property owners can assess their vulnerability based on various factors we determined significant through our case study findings (see description of TapForms in Section 3.1.1 Document Assets in Case Study, deliverable provided in Appendix 5). We utilized the Vulnerability Checklist Template, as well as the data gathered through our field work, to create a memorandum for the Imagine Boston 2030 project team. The memorandum document includes policy recommendations as well as a graph assessing tolerable and intolerable risk based on the consequences of flood damage (provided in Appendix 6).

5.1.1 Assessment of Risk

Our definition of risk assigned two dimensions, likelihood of flooding, and the vulnerability of the asset involved (Turner et al., 2003). The model developed by the MassDOT provides data for the assessment of future likelihood of flooding for the Boston area. Determining the probability of flooding using this model can establish the vulnerability of a location well into the future. By using this model to build resilience for the entire lifecycle of a building, property owners can prevent assets from being unprepared for future risks.

Our field study analysis of risk required the team to determine the vulnerability of each asset. We developed a checklist for the assessment of vulnerability in an area likely to flood. The checklist accounts for the likelihood of flooding based on the data provided in the MassDOT's hydrodynamic model, impact determined by the number of people affected, and location of vents, windows, and doors, and the presence of ground level electrical equipment. There are many ways to determine vulnerability and numerous factors to consider but we decided to focus on this matrix given the limited time frame. The Vulnerability Checklist Template, as well as our completed checklist for the assets along Columbia Point can be found in Appendix 5 and Table 6, respectively.

5.1.2 Risk Consequence Prioritization

Current policy does not involve a risk-consequence analysis to determine the actions required for the mitigation of risk of an asset (Julie Wormser, personal communication, 2015). **We recommend that communities prioritize and invest in assets appropriately according to risk of flooding.** For our study and recommendations, we used an approximation of number of people who are dependent on the asset to gauge its individual, neighborhood, and regional consequence.

The best method of prioritization can be determined by those drafting the policy at hand to best suit the constituents and political environment of the city, perhaps collaboratively. By focusing risk-mitigation efforts on assets determined to have greater consequence, the effects of damage from a major flooding event could be reduced. This consequence-based management of risk is designed to build resilience into the assets deemed critical to the population.

5.1.3 Policy recommendations to implement in Boston

Based on our literature review, the investigation of our case study, and information from our interviews, we were able to generate flood policy recommendations. We developed our recommendations specifically for the city, but recognize that other entities and levels of government will likely play important roles in crafting strategies to promote resilience to future floods (Britta Restemeyer, personal communication, 2015). Specific recommendations are listed in the memorandum (deliverable can be found in Appendix 6) of this report as well as Table 7 in Chapter 4. We also provide further detail in section 4.6 of the Findings chapter.

A. Potential Mandatory Actions

Our team developed policy recommendations, incorporating possible mandatory actions to incentivize the community to build resiliency. The policies tie together potential mandatory resiliency practices with insurance premiums and property taxes, as well as tying building codes with the environmental conditions. Further detail on voluntary actions can be found in section 4.6 of the Findings chapter.

a. Mobilizing Community Action through Policy Change

One potential action is to use insurance premiums to incentivize the community. For instance, insurance companies can raise and lower premiums depending on if a building has submitted a plan for retrofitting to fortify against flood water damage. Also, taxes can play a role in incentivizing, such as providing tax breaks and interest free loans for individuals that invest in flood resilience, while also raising taxes for the properties that do not comply with the implementation of flood resilience strategies.

b. Update Building codes to enforce geographic flood resilience

Building codes must be reviewed and updated as a response to the increasing likelihood of flooding. There should be no new buildings erected in flood zones. For properties that are already in place, the buildings must be retrofitted so that they are resilient for the remainder of their lifespan. As seen in the assets we analyzed in the Columbia Point neighborhood, there are numerous building conditions that need to be addressed to further the lifespan of said building. The federal government could require property owners to fortify their homes and businesses to better protect against flood damage. To accomplish this, we recommend policies that require the implementation of mechanical improvements to their homes. This can consist of abandoning ground level floors, raising entranceways as well as important utilities (i.e. electrical equipment) above floodable heights. Damage to utilities can cause serious hazards to the building and its residents. It will also cost more to replace than the utilities than it will to relocate them. Buildings can increase their lifespan by fortifying all vulnerable aspects including but not limited to: windows, doorways, and vents. These should be fortified against the inundation of water by possibly installing flood sealants to the foundation of properties, implementing flood shields on low-lying doors and windows, or even elevating them wherever possible. The property owners who retrofit their buildings to these codes can then receive government benefit and aid.

B. Potential Voluntary Actions

While mandatory action is highly effective, it is not always easy to put into place, as different political parties may have conflicting views on certain actions and their funding. But some voluntary actions can be enacted that will allow communities as well as the individual to assess their own vulnerability and have a voice in what is implemented to protect it. Further detail on voluntary actions can be found in section 4.6 of the Findings chapter.

a. Proactive risk mitigation requires community involvement in preparing for inevitable circumstances.

Resilience efforts are meant to prepare communities for future action of fortifying their properties, and are considered voluntary actions. It involves tying the community to resilient redevelopment and emergency preparedness. These policies address communities that are relatively unaware of the future risk of flooding or are reluctant to take action. We recommend a policy that suggests communities should make the effort to assemble an action plan in the case a heavy storm or flooding event occurs in the area. An action plan can consist of an evacuation plan or a recovery plan where the neighborhood can drain floodwaters. Communities can also take action by constructing a flood shelter for emergency flooding situation.

b. Incentivizing the Community

To encourage the community to be more proactive towards mitigating potential flood damage to their neighborhood, we recommend that communities work collaboratively to build resilience in their district instead of taking individual efforts. We recommend a policy that calls for the government to establish resilience committees who develop programs and community based projects to not only inform the community on the risk of flooding, but also provides enticement to work towards preservation of their properties. These committees can mobilize communities into assigning community leaders to be their voice in analyzing their respective neighborhoods for possible vulnerabilities with our Vulnerability Checklist and providing that data to the government committee with their own developed policy recommendations that can be implemented for their respective neighborhoods. In this way, communities can get the assistance that they need from the government in making their neighborhoods resilient while still having their concerns and needs represented.

5.1.2 Delivering Recommendations

As a means of input on the Imagine Boston 2030 Citywide Project, we drafted a memorandum to the planning team with our findings and recommendations. Imagine Boston 2030 will define a vision for Boston as Boston's first citywide plan in 50 years. The plan for Boston is to create positive physical change, promote prosperity, coordinate public investments, and a healthy city overall. It is clear that Boston has transformed significantly over the recent years and is still changing under constant construction. The current challenge is to preserve the city and grow to enhance the lives of the citizens.

Designed to communicate the findings of our research in concise and precise terms, the memorandum outlines both our work in the MassDOT model and our recommendations for future policy decisions. In this memo we outline the relationships between flood likelihood, consequence, and the tolerance of this risk, and tie these relationships to government and community actions in both mandatory and voluntary.

5.2 Conclusion

Through our literature review and the utilization of MassDOT's flood model data as a map overlay onto the case study area, it was clear that assets in the case study area and, by extension, Boston, are becoming increasingly susceptible to flooding. The city must implement strategies to mitigate the future cost of damage should projected flooding occur.

Our research and interviews with global experts both provided us with information regarding resilience strategies utilized in cities around the world, as well as some of the policies that were installed to ensure widespread adaptation. Through these we have adapted a risk-

based framework for application in Boston. Assets at either extreme of our risk tolerance spectrum should have more obvious courses of action required for their protection. Those in between tolerable and intolerable will be more challenging to protect appropriately.

Our project scope did not include developing building codes for flood resilience, but that is a logical step in the government's planning for flooding process. Proper application of these strategies could benefit the greater Boston community as well as the Imagine Boston 2030 citywide planning project as they plan to improve the prosperity and living conditions of the city.

Bibliography:

Baldachin, L., McHale, M., Harding, M., Nunn, M., Reeves, S., Willway, T. (2008, October). "The effects of climate change on highway pavements and how to minimise them." Retrieved from: <http://www.ukroadsliaisongroup.org/en/guidance/climate-change-highways-guidance.cfm>

Baldachin, L., McHale, M., Harding, M., Nunn, M., Reeves, S., Willway, T. October 2008. "The effects of climate change on highway pavements and how to minimise them." Retrieved from: <http://www.ukroadsliaisongroup.org/en/guidance/climate-change-highways-guidance.cfm>

Biesbroek, G.R., Kabat, P., Klostermann, J.E.M., Termeer, C.J.A.M. Institutional governance barriers for the development and implementation of climate adaptation strategies. 2009. Retrieved September 27, 2015, from <http://earthsystemgovernance.org/ac2009/papers/AC2009-0044.pdf>

Binder, K. (1986). Introduction: Theory and "Technical" Aspects of Monte Carlo Simulations. In K. Binder (Ed.), *Monte Carlo Methods in Statistical Physics* (Vol. 7, pp. 1-45): Springer Berlin Heidelberg.

Bosma, K., Douglas, E., Paul Kirshen, P. D., McArthur, K., Chris Watson, M. S., & Miller, S. (2015). *MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments And Adaptation Options for the Central Artery*. Retrieved from Boston, MA.

Brannon, I., & Lowell, E. (2011). *American Action Forum*. Retrieved September 10, 2015, from http://americanactionforum.org/uploads/files/research/National_Flood_Insurance_AA F.pdf

Brunswick, C. o. N. (1989). *Flood Barriers - Sandbag Dykes. Floodproofing: Protect Your Home against Flooding*.

Busch, Chris (2015, September 23). Personal interview.

Castella, Tom. (2014). How Does the Thames Barrier stop London Flooding? British Broadcast Corporation. Retrieved from <http://www.bbc.com/news/magazine-26133660>

City of Boston. 2014. Climate Action Leadership Committee. Retrieved from:<http://www.cityofboston.gov/climate/bostonsplan/CALC.asp>

City of Norfolk. (2014). Resilience: the Capacity to Adapt to Stress and Change. Retrieved from <http://www.norfolk.gov/DocumentCenter/View/16292>

Cockerham, Sean. (2012). 7 years after Katrina, New Orleans homeless twice pre-storm level. The Standard Times. Retrieved from <http://www.seattletimes.com/nation-world/7-years-after-katrina-new-orleans-homeless-twice-pre-storm-level/>

Doyle, S. (2013). How to Write a Policy Recommendation. Eng 302, Writing for Government. Retrieved from Web.UVic.CA website: <http://web.uvic.ca/~sdoyle/E302/Notes/Policy%20Recommendation.html>

Emergency Measures Organization (EMO). (n.d.) Flood Barriers - Sandbag Dikes. The Government of New Brunswick. Retrieved from http://www2.gnb.ca/content/gnb/en/departments/public_safety/emo/flood_barriers_sandbagdikes.html

Federal Emergency Management Agency (FEMA). (2013). Adjustments Claims Manual. Online Retrieved from http://www.fema.gov/media-library-data/264f7e03c5b3ad5852808636f55efce7/adjclaimsmanual_part3_508rev_20sep13.pdf.

Federal Emergency Management Agency (FEMA). (2014). Making Hospitals Safe From Flooding. Retrieved from http://www.fema.gov/media-library-data/20130726-1609-20490-5010/577_ch3.pdf

Federal Emergency Management Agency (FEMA). (2015). Flood Zones. Online Retrieved from <http://www.fema.gov/flood-zones>.

Flood Insurance | Flood Maps | Flood Risk | FloodSmart. (2015, September 3). Retrieved September 10, 2015, from https://www.floodsmart.gov/floodsmart/pages/crs/community_rating_system.jsp

Flood Panel (2015). Flood Log. Online.

FloodBreak Revolutionary Flood Control. (2010). Roadway Gate Drawings. Retrieved September 12, 2015 from <http://floodbreak.com/wp-content/uploads/2012/09/FBRoadwayDrawings.pdf>

Goltermann, D., Ujeyl, G., Pasche, E. (2008). Making Coastal Cities Flood Resilient In the Era of Climate Change. Retrieved from http://gfzpublic.gfz-potsdam.de/pubman/item/escidoc:6080:6/component/escidoc:6081/148_Goltermann.pdf

Halcrow. (2012). City of London Strategic Flood Risk Assessment. Retrieved from <http://www.cityoflondon.gov.uk/services/environment-and-planning/planning/design/Documents/strategic-flood-risk-assessment-2012.pdf>

Herman, Karl. Scarlett, Lynn. (2011). Social and Cultural Incentives and Obstacles to Adaptation to Increased Coastal Flooding in East Boston, MA USA. Online: Restoring Lands-Coordinating Science, Politics, and Actions

Holland, & Business, P. i. (2015). Delta Technology. Retrieved from <http://waterandthedutch.com/delta/>

Holmes, R.R., Jr., Dinicola, K., 2010, 100-Year flood—it's all about chance: U.S. Geological Survey General Information Product 106, 1 p.

Hudson River Estuary Program (HREP). (2013) Financing Flood Resilience: State and Federal resources for communities. Retrieved from http://www.dec.ny.gov/docs/remediation_hudson_pdf/financefr2.pdf

Hydro Response LTD. (2006). Product Catalog. Retrieved from <http://www.hydroresponse.com/>

IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA

Johnson, Trevor (2015, September 21). Telephone interview.

Katrina Impacts. (2012). Hurricanes: Science and Society. Retrieved from <http://www.hurricanescience.org/history/studies/katrinacase/impacts/>

Lewis, Tanya. (2013). The Scientist Who Helped Save New York's Subway from Sandy. livescience. Retrieved from <http://www.livescience.com/40736-scientist-who-saved-new-york-subway-from-sandy.html>

MassDOT-FHWA Climate Resilience Pilot Project. (2014): 1-4. Print.

Morris, Dale (2015, September 23). Telephone interview.

Moser, Susne C. Tribbia, John. (2008). More than information: what coastal managers need to plan for climate change. Environmental Science & Policy (2nd ed.) ScienceDirect

Muller, J. (2013). Integrated Concepts for Coastal Flooding Safety and Urban Development in Hamburg. Retrieved September 4, 2015, from <http://www.lansstyrelsen.se/skane/SiteCollectionDocuments/Sv/miljo-och-klimat/klimat-och-energi/klimatanpassning/Studieresa Nederländerna 2013/4 Integrated concepts for coastal flooding Müller.pdf>

National Climate Assessment (2014). Climate Change in the Northeast. Retrieved April 15, 2015, from <http://nca2014.globalchange.gov/report/regions/northeast>

National Geographic (NatGeo). (2013). Floods. Retrieved from <http://environment.nationalgeographic.com/environment/natural-disasters/floods-profile/>

National Oceanic and Atmospheric Administration (2014). What percentage of the American population lives near the coast? (2014, February 7). Retrieved September 24, 2015, from <http://oceanservice.noaa.gov/facts/population.html>

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe(2007): Coastal systems and low-lying areas. *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Eds., Cambridge University Press, Cambridge, UK, 315-356.

NYC Planning. (2015). Resilient Neighborhood Initiative. Retrieved from http://www.nyc.gov/html/dcp/pdf/resilient_neighborhoods/rn_overview_handout.pdf

Restemeyer, Britta (2015, September 28). Personal interview.

Rice, D. (2015). S.C. Flood is 6th 1,000-Year Rain Since 2010. *USA Today*. Retrieved from <http://www.usatoday.com/story/weather/2015/10/05/south-carolina-flooding-climate-change/73385778/>

Rom, Joe. (2011). Thailand Suffers Most Expensive Flood in History, Destroying More Than 10% of Rice Farms in World's Top Exporter. *Climate Progress*. Retrieved from <http://thinkprogress.org/climate/2011/10/14/344749/thailand-most-expensive-flood-in-history-damaging-10-of-rice-crop-top-exporter/>

Schworm, Peter (2013): Hurricane Sandy slams Massachusetts, hundreds of thousands lose power. Retrieved on April 29, 2015 from <http://www.boston.com/metrodesk/2012/10/29/outer-edges-hurricane-sandy-are-bringing-high-winds-and-rains-today-but-worse-still-come/Q9xxjXy0lsXcVzUKT49CkJ/story.html>

SHARE YOUR VISION. SHAPE OUR CITY. (n.d.). Retrieved September 1, 2015, from <http://imagine.boston.gov/>

Smith, J., Lee, A., & Bierbaum, R. (2014). Adaptation. Retrieved from Online: <http://nca2014.globalchange.gov/report/response-strategies/adaptation>

The Boston Harbor Association. (2013). Preparing for the Rising Tide. http://www.tbha.org/sites/tbha.org/files/documents/preparing_for_the_rising_tide_final.pdf

Tips for Prioritizing Using the Traffic Light Method. (n.d.). Retrieved August 30, 2015, from <http://www.swinglineblog.com/06/tips-prioritizing-traffic-light-method/>

Turner, Et al. (2003). Vulnerability. In A Framework for Vulnerability Analysis in Sustainability Science (14th ed., Vol. 100, pp. 8074-8079). PNAS.

U.S. Department of Transportation Federal Highway Administration. August 27, 2015. "U.S. DOT Gulf Coast Study Phase 2." Retrieved from: http://www.fhwa.dot.gov/environment/climate_change/adaptation/case_studies/gulf_coast_study/gcsph2.pdf

USGCRP (2009). Global Climate Change Impacts in the United States . Karl, T.R., J.M. Melillo, and T.C. Peterson (eds.). United States Global Change Research Program. Cambridge University Press, New York, NY, USA.

Wormser, J. (2012). A Tale of Two Cities: Boston, New York, and Hurricane Sandy. Online: The Boston Harbor Association.

Wormser, Julie. The Boston Harbor Association. (2015, October 1). Personal Interview.

Zimmerman, Kim Ann. (2015). Hurricane Katrina: Facts, Damage & Aftermath. Live Science. Retrieved from <http://www.livescience.com/22522-hurricane-katrina-facts.html>

Appendix:

Appendix 1: Columbia Point Satellite Imagery



Appendix 2: MassDOT-FHWA model prediction overlays







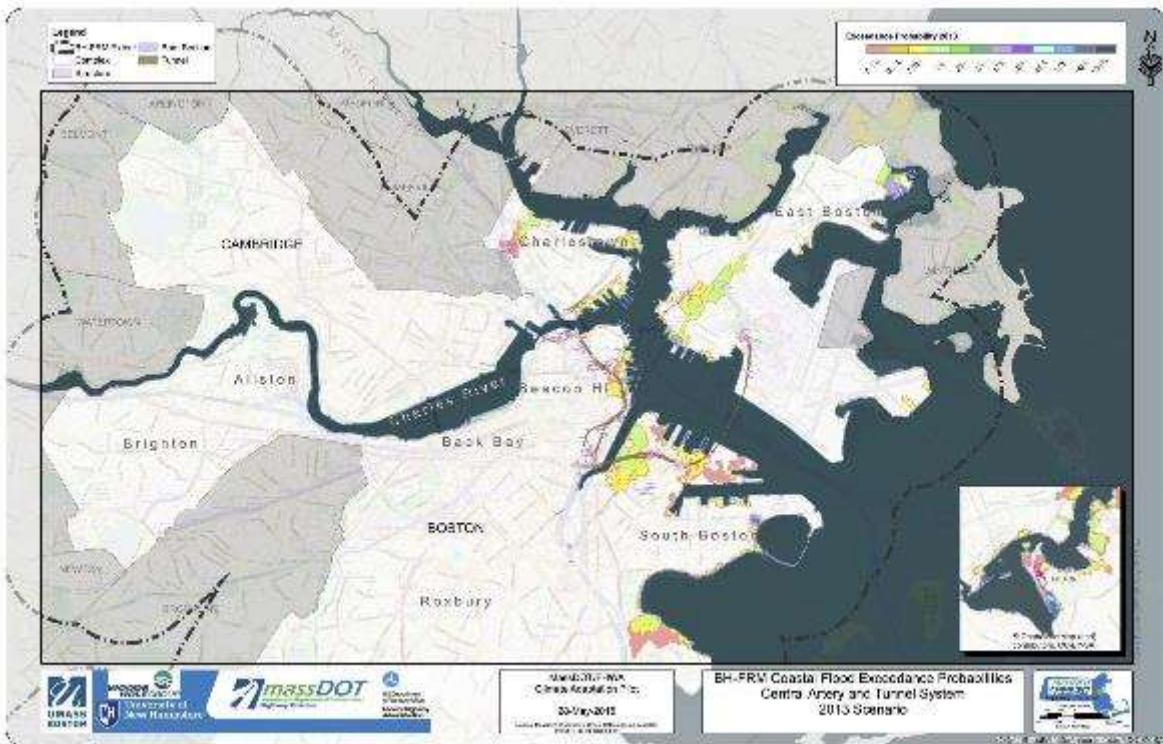
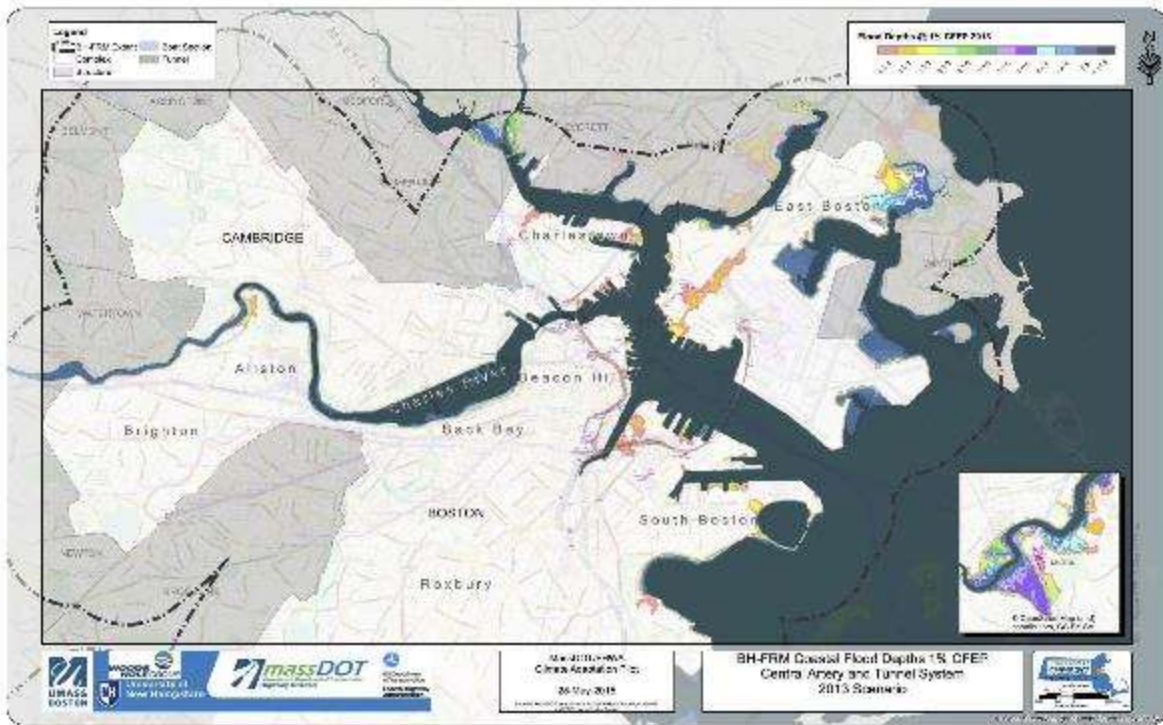
Appendix 3: Interview Data

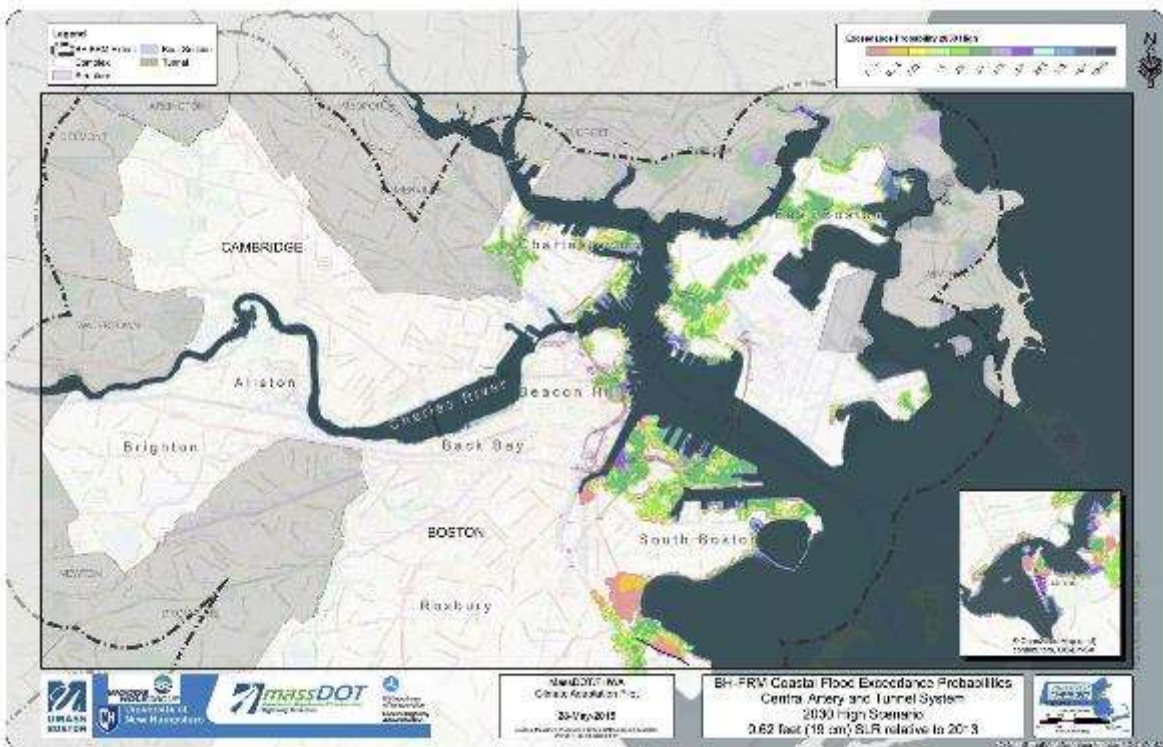
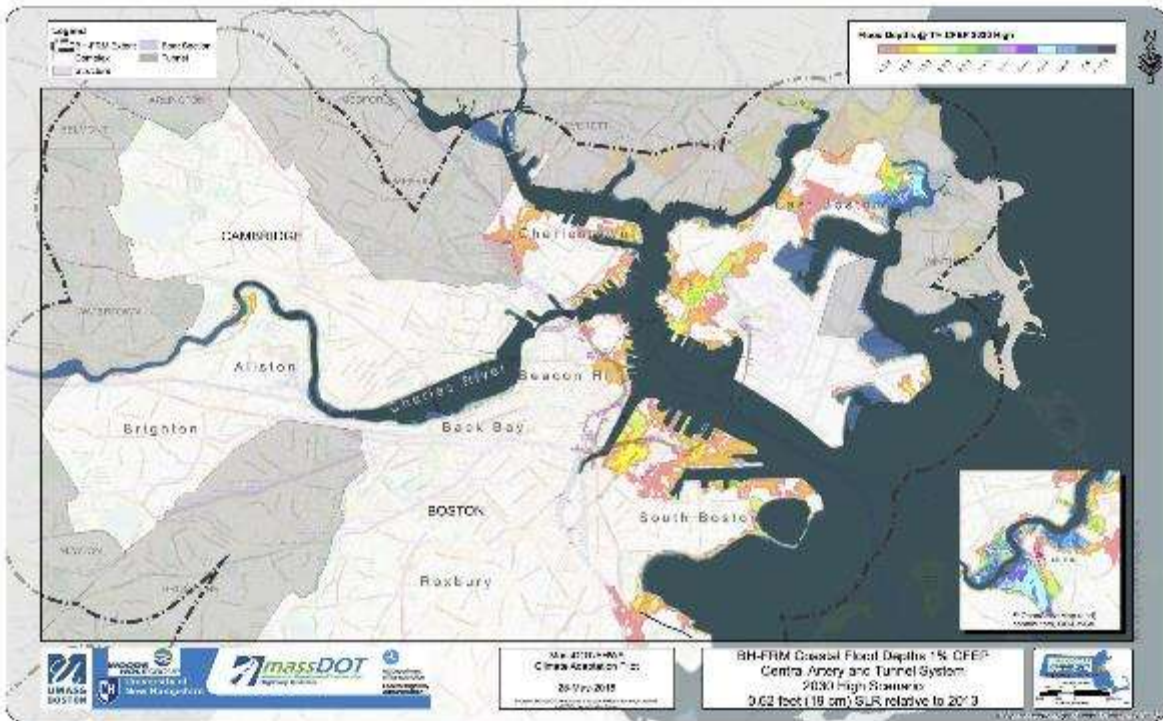
Interview subject	Location	Highlights of Interview
Chris Busch	Boston, MA	<ul style="list-style-type: none"> ● Works in the Economic and Planning Agency at BRA <ul style="list-style-type: none"> ○ Planning for city and ownership interest ● “I am involved with the development of harbor municipal harbor plans” ● Individual communities can develop own plan ● Flood plans for Boston developed over the past 25 years ● “Climate change has become a clear and present issue given sea level rise and storm events and precipitation and what not” ● “Challenge of risk is based on various property interests involved.” ● “Imposing threat at some point in future that is not really present yet” <ul style="list-style-type: none"> ○ people don’t respond to this ○ need an event similar to Sandy to get people on board pan <ul style="list-style-type: none"> ■ “We need a minor flood to allow people to understand what affects of flooding could be if worse event were to take place” ● Funded by own real estate assets <ul style="list-style-type: none"> ○ not a part of city budget ○ acts as part of city agency ○ mayor is major client ● “From a zoning standpoint we have a preparedness and resiliency checklist” ● article 37 code building and checklist <ul style="list-style-type: none"> ○ “building code is really where resiliency standards come into play” <ul style="list-style-type: none"> ■ elevating base floor elevation ■ sacrificial elevation of first floor ■ flood proofing standards ● harbor walk <ul style="list-style-type: none"> ○ “constructed and designed to be utilized after flood” ○ mitigates wave action
Dale Morris	New Orleans, LA Netherlands	<ul style="list-style-type: none"> ● “In Boston you have many areas with a lot of fill which increases vulnerability, but you don’t have a lot of areas that are subsiding, like many other US coastal cities: New York, Hoboken, Norfolk, Houston, Miami etc.” ● “Boston Harbor, though, already has a lot of structures that reduce wave energy and wave height. Bostonians, however, need to prepare for overtopping and wave height when mean sea level increases.” ● “Designers, politicians and engineers the world over are facing questions and uncertainties about what kind of storm they should design for. The complexity of uncertain future weather means that there could be overinvestment, which is wasteful, or under investment, which is worse.” ● “When you look at those fill areas in Boston you’ll have to look at soil compaction rates which will increase flood risk. And you must also take into account how those areas are used, now and in the future.”

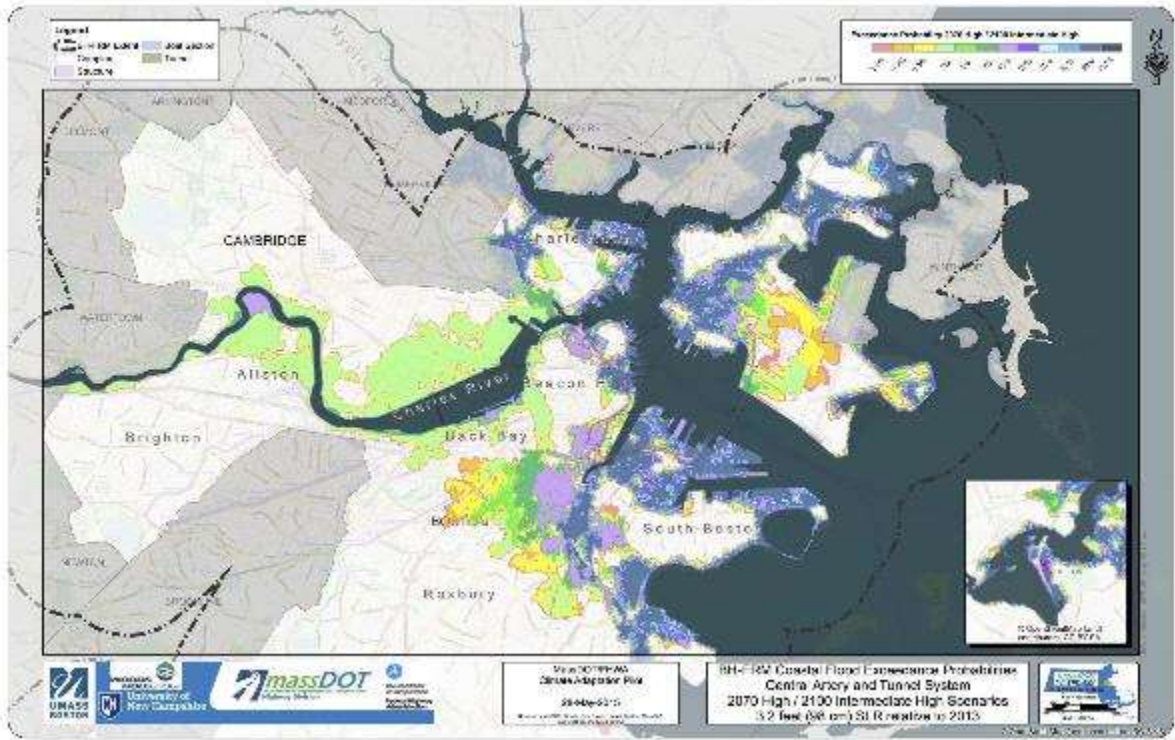
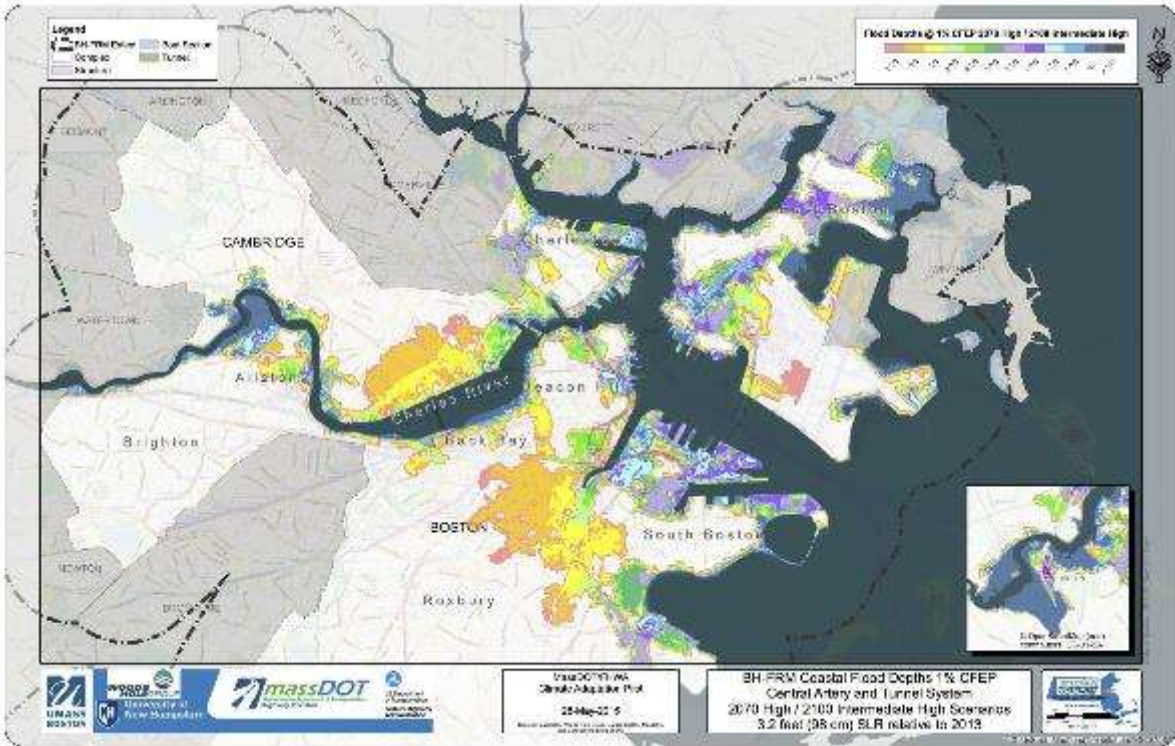
		<ul style="list-style-type: none"> ● “You can set a policy that says that if and when interventions in infrastructure are made within, say, 100m of the waterfront, landowners need to elevate by x amount in order to get the permit.” ● “You could incentivize land owners to take certain actions by giving them a preferential rate on their property tax when they’ve worked to mitigate to help offset the costs of their mitigation actions.” ● “Without the state government involvement, though, it’s still an open question how local governments are going to fund and finance landscape interventions and infrastructure improvements. Policy can play a huge role here.” ● “For Instance, a private or commercial landowner might have, say, in years to make improvements to mitigate risks and if they don’t they can be disqualified for post-disaster bailout.” ● “Insurance markets have a large role to play in this. Higher premiums will also work to incentivize the actions you’re looking for.” ● “If the NFIP isn’t charging the full premiums to the coastal communities, then the rest of the United States is subsidizing the insurance policies of those living on the coast. By forcing a full premium you see the real cost of insurance, and thus people armor their homes and properties, or they retreat because they are unwilling or unable to make that investment. Either way, the overall impact is to reduce risk to life and property, as well as the cost of recovery.”
<p>Britta Restemeyer</p>	<p>Hamburg, Germany</p>	<ul style="list-style-type: none"> ● “I worked for the water management authority after completing my studies determining how citizens would like to be informed about flood risk and getting citizens to participate.” ● “I worked on a case study in Lower Saxony, Germany. The public generally liked usual means of media communication as well as workshops. This was more effective in areas that have already experienced flooding. About 50% wanted better information and 30% wanted to engage actively on flood management development” ● “Hamburg was very lucky that land was owned by city allowing them to properly plan and shape the area. Think there will be similar projects in cities with similar issues. Certainly easier in areas that city owns land.” <ul style="list-style-type: none"> ○ Citizens played minimal role. ○ City was allowed to plan out everything before citizens came into area. ○ Streets were elevated to flood proof level by city. ● “Flood protection communities works well and keeps people involved but I expected more involvement.” ● “Residents say living with water view is so nice, increases productivity of employees up to 25%. Consider it a positive rather than a negative.”
<p>Trevor Johnson</p>	<p>New York, New York</p>	<ul style="list-style-type: none"> ● Vision 2020 Comprehensive Waterfront Plan involved stakeholder input. While it did not directly alter private ownership of waterfront land, it did make recommendations that influenced the future development of private land. ● Zoning changes help to mitigate flooding by adjusting heights that a building is measured from

		<ul style="list-style-type: none">● Buildings need to have a good relationship to the streets surrounding it● Once a building is elevated to a certain level to comply with flood resilient construction standards, you then need to provide certain architectural elements to mitigate adverse streetscape impacts These ideas are ways to avoid ruining streetscape view while also fortifying buildings.● Engaged the community during “Resilient Neighborhoods”<ul style="list-style-type: none">○ Developed community advisory groups made up of local people that care a lot about the neighborhood● “We, as in the U.S., are not good at always planning proactively, especially when it comes to coping with the effects of climate change”● Removing barriers within zoning, such as building heights and floor area restrictions, that make disincentivize retrofits to existing buildings.● Insurance Incentives at the federal level, such as lower annual premiums for buildings that complied with standards● There is a potential affordability crisis for buildings that can’t be retrofitted for flood resilience and may be charged a higher premium because of it
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Appendix 4: MassDOT-FHWA model output maps







Vulnerability Checklist

Asset Name		
Flood Depth*		
Exceedance Probability**		
Ground Level Vents		
Door locations		
Window locations		
Electrical Equipment?		
Picture 1		
Reference:	*Computational flood depth for a flood with 1% occurrence rate; also known as the 100 year flood.	
	**Likelihood that an area will flood in a given year according to SWAN+ADCIRC computational models	

Notes:



To: Imagine Boston 2030 project team
CC: Julie Wormser, TBHA
From: WPI Climate Research Team
Date: October 6th, 2015
Re: Methods and recommendations to
prioritize and manage coastal flood
risks

Introduction

We are a team of engineering majors from Worcester Polytechnic Institute working with The Boston Harbor Association on a research project designed to identify, prioritize and reduce the risk of coastal flood damage along Boston's waterfront.

We used the results of the MassDOT hydrodynamic model to identify buildings at risk of coastal flooding in the Columbia Point neighborhood of Dorchester. We came up with a method of assessing and prioritizing risk based on both the likelihood of flooding and the severity of consequences if a property does flood. Finally, we interviewed experts from New York, New Orleans, The Netherlands and Germany to develop policy recommendations that could be incorporated into Imagine Boston 2030 to reduce Boston's risk of coastal flood damage. Our results are summarized below. We would be glad to provide you with greater detail.

Identifying and prioritizing community assets at risk of coastal flooding

Scientists from UMass Boston and the Woods Hole Group developed a hydrodynamic model of the likelihood of coastal flooding based on the interactions of predicted extreme weather events, sea level rise and tides. They developed projected flood risk maps (both depth and probability of flooding) for the years 2013, 2030, 2070, and 2100. Future maps included predictions of both higher and lower increases in sea level.

We used the 2030 maps that predicted higher increases in sea level for our research (see Figure 1). We conducted site visits to visually inspect properties and assets in the area identified in the MassDOT study as being at risk of flooding in 2030. We found that that multiple structures in the current and future flood zones are currently at risk of flood damage due to the location of windows, doorways, electrical equipment, gas tanks and ventilation systems below the height of projected flooding.

Figure 2 compares the likelihood of flooding in 2030 to a simple ranking of consequences of flooding for the assets we surveyed in the Columbia Point neighborhood. In this case, we based "consequences" on the relative number of people that would be affected by flood damage. An actual assessment would likely use a more sophisticated measure of consequence.

The National Flood Insurance Program (NFIP) does not currently differentiate the risk of flood damage based on either flood depths or the severity of consequences of flooding. All structures—from warehouses to schools, hospitals and nursing homes—are required to prepare for a current annual flood risk of 1% (the “100-year flood”). The MassDOT model data allow decision makers to prioritize vulnerable assets based on consequences, either to require higher preparedness standards for critical regional resources or vulnerable populations, or to prioritize structures for public investment.

Figure 2 shows how one can create a measure of “tolerable” versus “intolerable” risk and require assets within “intolerable” risk levels to prepare at higher levels. We believe that Boston can and should require assets with greater consequences (e.g., number of vulnerable people at risk, number of people using a public asset, residences vs. other building types) to be prepared for more extreme flooding than assets with lower consequences.

Because our measure of consequence is simple and subjective, the line in this graphic is for illustrative purposes only. Even in our simple example, however, two resources jump out as being at intolerable risk: the First Community Health Center and the JFK/UMass MBTA station. Both are at higher risk of flooding, and both are critical public resources. As mentioned before, this simple exercise can readily identify critical resources needing additional resources and/or stricter codes to decrease their—and Boston’s—risk of crippling flood damage

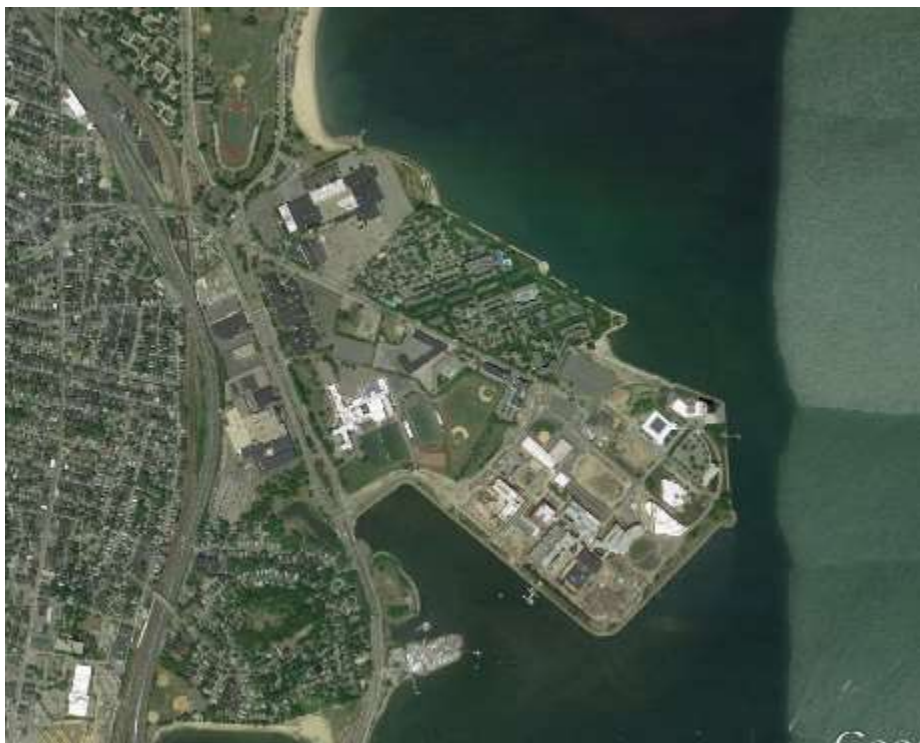


Figure 1: Satellite Overview of Case Study Area.

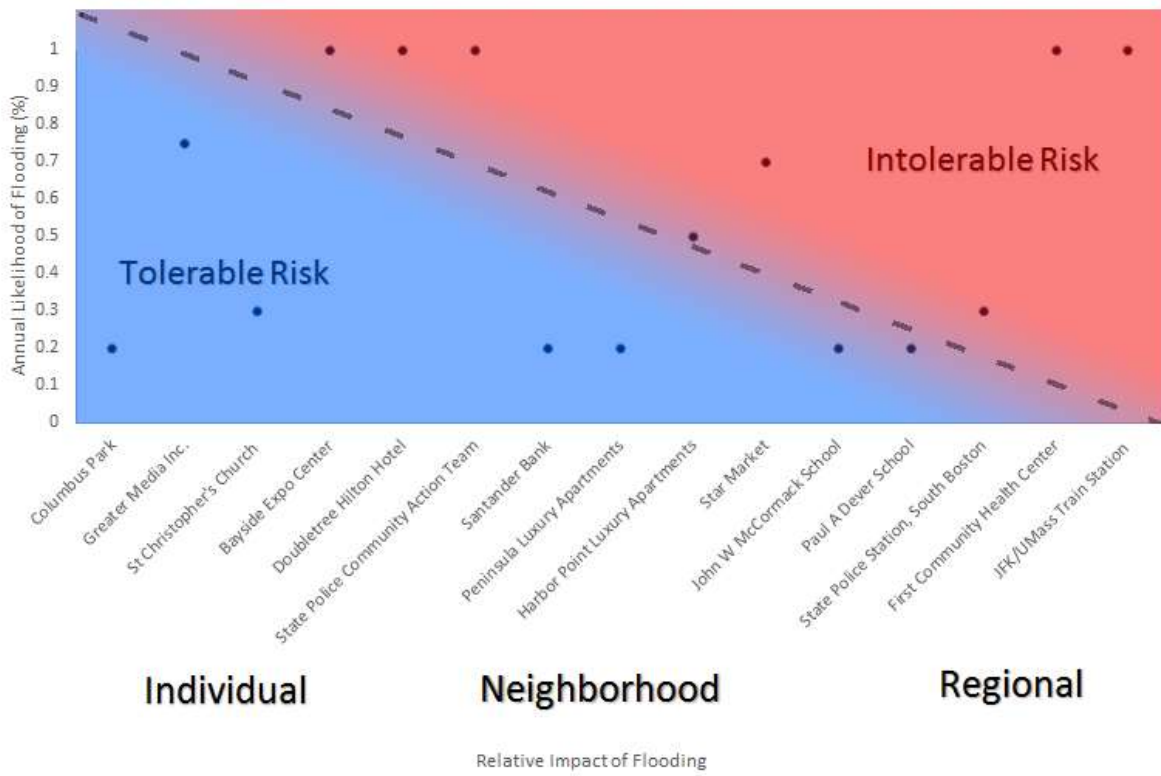


Figure 2: Likelihood versus Consequence of Coastal Flooding

Possible Policy Solutions to Reduce Vulnerability:

Our literature review and interviews led to a collection of insights from flood resilience around the world. We collected possible actions the government could take to create a resilient city. The results of our findings are summarized in the table below:

Category	Specific Example
Mandatory Actions	
Tie Insurance Premiums to Resilience	Increased premiums for buildings that do not submit plan for retrofitting building by a given date
	If building owners do not comply with retrofitting, they cannot be insured or aided by government
	Decrease premiums and provide funding for buildings that develop plan for retrofitting that adheres to all new standards and can be complete within a number of years
Tie Property Taxes to Resilience	Create resilience funding pool/loan ("Green Bank")
	Provide tax breaks for investments in resilience
	Taxes increase if building and property owners do not comply with implementing flood resilience strategies
	Interest free loans to protect homes
	Build a seawall along coastline in areas of high risk
	Protective dikes under Harbor Walk
	Ensure subway stations and routes are protected from water
	Fortify the Central Artery and Tunnel system
Tie Building Codes to Environmental Conditions	Require buildings to be resilient for entire lifespan of structure
	Require specific improvements (e.g. mechanicals, entry points) above flood zone
	Measure building relative to height of flood at end of lifespan, not absolute elevation; allow increased height of building/space for mechanicals to be safely stored
	Immediate requirement for new buildings, before 2030 for existing buildings
	Instill new department that ensures flood resilience safety standards are upheld annually similarly to fire inspections/codes
	Receive government benefits if buildings are retrofit to minimum resilience code
	Abandon first floor and convert to floodable space that is usable by the public
	Important utilities raised from basement or first floor level to a level above flood level
	Point of entry must be above floodable height (i.e. second floor)
	Important assets are not to be permitted to be built in flood zones (i.e. hospitals)

Voluntary Actions	
Tie Community to Resilient Redevelopment	Provide vulnerability checklist framework to community leaders to assess their own vulnerability
	Community leaders can submit findings along with their own recommendations for community to government to analyze and decide to fund
	Brochures to explain possible resilience strategies
	Inform residents of likelihood and consequences of flooding in their area (i.e. climate preparedness kits, programs, workshops)
Tie Community to Emergency Preparedness	Establish shelters for Emergency Flood Situations
	Develop action plan in place similar to emergency practices for blizzards

Conclusion

Coastal flooding will play an increasingly important role in the development of Boston’s waterfront property. The recent 1000 year flooding event in South Carolina demonstrated that climate change may have wider reaching effects than previously thought (USA Today, 2015). It is important to recognize that policies and resilience strategies should be implemented as preventative measures before the floodwaters inundate properties and cause damage. New York was not prepared for Hurricane Sandy, resulting in a considerable amount of damage and a rush to take reactive measures that proved to be very costly. Considering how narrowly Boston avoided similar damages from Sandy, we propose the city implements preventative measures and resilience strategies.

Thank you for considering our input. We hope our research is helpful. It was a pleasure to work on this analysis.

Best Regards,

- WPI Climate Change Team
- Jacquelyn Nassar, Chemical Engineer
- Josh Ledee, Electrical and Computer Engineer
- Josh Graff, Robotics Engineer
- Elie Karam, Biomedical Engineer

Summative Assessment

<p>Teamwork Monitoring:</p>	<p>Our team conducts all documentation work through Google Drive. This allows us to collaborate on all materials and review each other's work as well as monitor team participation. We regularly ask for opinions about ideas and often brainstorm as a group. Our entire report was written in a collaborative manner through Google Docs. We wrote each section together and edited the document together. This method was effective for us because we were able to ask each other questions about the work as well as bounce ideas off of each other in real time as we were writing. In the event that the group felt that an individual was not working or wasn't working on the same material, we would have a discussion to ensure that everyone was on track and working towards the same goal.</p>
<p>Team critique and conflict identification:</p>	<p>Over the course of this term, we have spent a lot of time together, constantly working on our project five days per week. This forced us to establish effective means of communication to work productively together, as well as form a closer bond as a team. During group discussions on team assessments as well as general meetings, we would take opportunities to politely critique each other on matters we felt were impacting the group negatively.</p> <p>At the beginning of the term, we tended to alternate between heavily communicating with either the advisors or the sponsor. However, as we settled into the topic of our project and working in Worcester/Boston, we never hesitated to contact the advisors or sponsor for any questions or concerns that we had. We designated a sufficient portion of time prior to any advisor/sponsor meetings to ensure that we were well prepared.</p>