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Boston's Open Space and Sea Level Rise

An Assessment of the Role of Open Spaces in Mitigating the Impacts of Climate Change-Related Sea Level Rise and Flooding

Working Paper WP18ED1

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Abstract

Boston, Massachusetts is vulnerable to a number of climate change impacts, the most certain of which are sea level rise (SLR) and the resultant coastal flooding. The feasibility of building a storm surge barrier across Boston Harbor to reduce this vulnerability was being evaluated at the time this project was beginning. The original motivation for the study reported herein was to evaluate the potential impacts of such a large construction project on open space in Boston. Instead, given the reported infeasibility of a harbor barrier, we found that open space has the potential to serve as a key component of Boston's resiliency to future climate change impacts, especially in mitigating the impacts of coastal flooding.

Keywords: Open space, coastal flooding, climate resilience, GIS, conservation benefits, ecosystem values.

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Executive Summary

As a densely populated city located on the Atlantic coast, Boston, Massachusetts is vulnerable to a number of climate change impacts, the most certain of which is sea level rise (SLR) and associated coastal flooding. Boston is ranked as the city with the 8th highest risk of damaging floods, according to the projected overall cost of damage.

The original motivation for our study, which we refer to here as the Boston Open Space and Sea Level Rise study, was to evaluate the potential impacts of a construction project as large as the proposed Harbor Barrier on open space in Boston. At the time our research project was beginning, the feasibility of building a storm surge barrier across Boston Harbor to reduce this vulnerability was being evaluated by another set of researchers at the University of Massachusetts Boston (UMass Boston). Over the course of the year in which our study was conducted, the researchers at UMass Boston reported that the Harbor Barrier concept was infeasible. Paul Kirschen, the lead investigator of that study and the academic director of the UMass Boston Sustainable Solutions Lab, summed up his conclusions in the spring of 2018 (Swasey, 2018):

> Right now, it doesn't make sense for the city to consider any kind of harbor-wide barrier system… Harbor barrier systems have been a helpful tool for certain other coastal cities, but in this case, Boston would be making a bet on a massive infrastructure project with limited benefits compared to the alternative.

The research conducted by the Boston Open Space and Sea Level Rise study is relevant not only to the Harbor Barrier concept, but also to alternative methods for addressing sea level rise in Boston harbor. As Kirschen goes on to explain, the preferred alternative strategy is based on:

> Shore-based solutions [that] would provide flood management more quickly at a lower cost, offer several key advantages over a harbor-wide barrier, and provide more flexibility in adapting and responding to changing conditions, technological innovations, and new information about global sea level rise.

Given the reported infeasibility of a harbor barrier, we find that currently existing open space, as well as open space that may be created in the future, has great potential to serve as a key component of 'shore-based solutions' that improve Boston's resilience to future climate change impacts, especially in mitigating the impacts of coastal flooding.

To better understand this potential, we first developed a comprehensive geospatial database of open space within the Boston Harbor domain and quantified the vulnerability of existing open space to flooding due to sea level rise and coastal storms. We surveyed the users of a sample of these open spaces to better understand the value and uses of Boston's open spaces. We then assessed the conservation benefits of these urban open spaces and investigated how other coastal cities are incorporating open space into climate resilience planning. Our key findings are summarized below:

- Green space (e.g., public parks, reserves) and undeveloped land together currently make up over 66% of the total open space within the domain of this study. Approximately 92% of these open spaces are protected from development; 73% of protected open spaces are protected by Article 97 of the Massachusetts Constitution.[1] Within the City of Boston proper, Chapter 7, Section 4.11 of the City of Boston Code of Ordinances (a.k.a., the '100 -foot rule') requires "the Commission [to] render its approval before construction begins on any development project within 100 feet of any park or parkway within the city", granting the city the right to review any project that could have "physical or visual effects on adjacent or nearby parkland" (Open Space Inventory 2002). Therefore, even if a harbor barrier were to be built in Boston Harbor (a strategy now *not* recommended by Paul Kirschen and his study team), it is unlikely that the open spaces evaluated in this study would be used as infrastructural staging areas during construction.

- Under present conditions, approximately 8% of the land area within the study domain is vulnerable to a 1% annual exceedance probability coastal flood event; approximately one-half of this vulnerable area is classified as open space as of 2018. By 2030, the extent of land area vulnerable to the 1% coastal flood nearly doubles, reducing the proportion of open space within this vulnerable area to between one-quarter and one-third. By 2070, approximately 25% of land area within the study domain is vulnerable to the 1% coastal flood event. Flood depths in about one-half of this vulnerable land area are projected to be between 1 and 4 feet and nearly one-third of this land area is vulnerable to flood depths exceeding 4 feet.[2]

- An evaluation of the literature on the ecosystem services afforded by open space reveals that the preservation and adaptation of urban open spaces will be essential elements in efforts to make cities climate resilient (Trust for Public Land, 2016) and that environmental planners, policy makers, and communities should consider current open spaces as important assets in flood mitigation. Haddad et al. (2015) proposed a framework for assessing the effectiveness of urban open spaces in attenuating storm surge. Brody et al. (2015) reported that open space protection is an important land use planning tool for flood mitigation; note, however, that Brody generally advocated for a managed retreat plan as an avoidance strategy, removing property and infrastructure from vulnerable areas. Pilkey et al. (2016) stated that some form of planned retreat will likely be inevitable for most coastal communities, despite the fact that managed retreat is currently not attractive to most coastal communities due to their heavy dependence on the economic and social value of waterfront property and access to marine resources.

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[1] Article 97 of the Massachusetts Constitution "prevents publicly owned lands held for park, recreation, and conservation purposes from being used or disposed of for other purposes without a majority vote of the Parks or Conservation Commissions and the City Council, the approval of the Mayor, and a two-thirds vote of both houses of the State Legislature" (Open Space Inventory 2002).

[2] This is particularly notable in Boston's Back Bay as well in the City of Cambridge, due to the fact that by 2070 rising sea levels may make it possible for storm surge to circumvent the protection afforded by the Charles River Dam. For example, the Boston Public Gardens, which rest on filled land that was a tidal flat prior to the damming of the Charles and Muddy River basins during the late 19th and early 20th centuries, could be vulnerable to flooding by 2070. In addition, many of the 52 institutions of higher education in the metro Boston area could be impacted by coastal flooding in the future including Harvard University, Massachusetts Institute of Technology, and Boston University.

- We surveyed the users of selected open spaces across the categories compiled within this study to better understand the values and uses of open spaces by urban residents. Most open space users surveyed were between the ages of 25 and 34 and most of those surveyed valued open spaces for their aesthetic and recreational benefits. A smaller proportion valued parks in particular for climate control. One of the participants interviewed at the Neponset River Reservation, for example, divulged that they value this space for climate control as they do not have air conditioning in their home and on hot days they come to sit by the water to enjoy the breeze. Not surprisingly, the majority of the survey participants at playgrounds were females with young children. These participants valued playgrounds most highly for recreation for their children as well as climate control. It is important to note that, in addition to the benefits most frequently cited by survey respondents, Boston's open spaces also serve to provide ecosystem services for adjacent and surrounding areas, acting as a buffer against climate change impacts such as extreme heat and reduced air quality.

- Boston should prioritize the protection of existing open space that is currently unprotected from development. In our study domain, there are approximately 2,417 acres of open space that are vulnerable to the 1% coastal flood by 2070. We estimate that 1,506 acres of that open space is legally protected from development. The remaining 911 acres is unprotected and therefore vulnerable to development pressure. Applying the $6,000 USD per acre of avoided flood damage cost for conserved urban open space (from Kousky et al, 2013, without adjustment for inflation or differences in land value), we estimated that the conservation benefit (as represented by avoided flood damage costs) of the existing protected open space inventory within the study domain is approximately $9 million annually by 2070. An additional $5.5 million in conservation benefit could be gained by protecting the 911 acres of existing open space that is currently unprotected from development. While this is a crude estimate, it highlights the potentially high economic value of urban open spaces within Boston's resilience framework. Boston should leverage the conservation benefits of preserving its existing open space, and consider a strategic expansion of its open space inventory, as part of a city climate resilience strategy, thereby embracing a "living with water" approach to land use planning.

- For Boston, the adaptive resilience approach would be most beneficial as a full retreat is not plausible under current governance, social structures, and perceptions of threat (Harman et al, 2015). This approach would include the construction of hard and soft shoreline infrastructure to protect vulnerable coastal areas. Hard infrastructure refers to heavily engineered protective structures such as dams, dikes, sea walls, and storm surge barriers while soft or "green" infrastructure uses or enhances natural ecological functions (e.g., beach nourishment and sand dune restoration) to reduce vulnerability to coastal flooding. In urban communities, a hybrid approach, in which green infrastructure compliments and augments hardened defenses, has been found to be the most effective. In order to understand the range of options that could be available to Boston, we reviewed the approaches of four coastal cities that are facing challenges and threats similar to Boston: New York City, Rotterdam, New Orleans, and San Francisco. While the individual characteristics and governance structures of the selected cities may differ, we identified common approaches that can be applied by Boston and its surrounding coastal communities to incorporate open space in flood mitigation and climate resilience strategies:

Approach 1: The use of existing federal initiatives and funding structures for resilience planning. From the U.S. Department of Housing and Urban Development (HUD) to state agencies to city programs, there are existing resources that can be leveraged as seed grants and pilot initiatives in resilience planning. New York City funneled some of the Hurricane Sandy disaster relief bill funding (an increase in the National Flood Insurance Program appropriations) into resilience initiatives to both restore and create natural features (e.g., saltmarshes, wetlands, beach dunes) in order to make hard-hit areas more resilient to future storm events. New Orleans leveraged funding from an HUD disaster relief program to develop and design resilient districting. These initiatives could lead to future appropriations for resilience efforts before disasters hit.

Approach 2: The development of innovative state agencies and local organizations dedicated to resilience. As a result of the destruction inflicted by natural disasters and the availability of federal resources, both New York City and New Orleans have created state and local agencies and organizations with missions to address reslience. The New York City Panel on Climate Change (NPCC)[3] was created to synthesize the lastest scientific research and create a report for direct use in resilience planning. OneNYC combines the long-term goals of reducing social inequity and increasing access to green space as part of its resilience strategy. Louisiana established the Coastal Protection Restoration Authority and approved a Coastal Master Plan, which will create structural and non-structural risk reduction projects and restore coastal ecosystems to increase the future resilience of New Orleans and other coastal cities.

Approach 3: The incorporation of multi-stakeholder engagement in design and planning. The cities of Rotterdam and San Francisco (as well as Boston) initiated design competitions that encouraged creative thinking and collaborative design for specific neighborhoods and vulnerable populations. Rather than viewing increased frequency of storm water flooding as a problem, Rotterdam redefined storm water runoff as a beneficial ecosystem service that can be channeled into increasing biodiversity and green space for its citizens. San Francisco enlisted resident stakeholder groups to develop innovative plans that meet the specific needs of their communities. The Boston Living with Water[4] design competition had a similar focus but engaged professional companies and universities to do the same.

Approach 4: The recognition that open/green spaces are valuable assets that have inherent social and natural resilience benefits within the urban landscape. Whether stated explicitly in resilience plans or inferred from the resulting initiatives, urban open spaces play an essential role in preserving and enhancing the resilience of urban communities. The preservation, restoration and creation of urban open spaces is an essential component of most (if not all) resilience plans and initiatives. This recognition is particularly meaningful in Boston, which is home to the Boston Common, the nation's first public park[5] and the Emerald Necklace[6], designed by Frederick Olmsted to connect parks and people within the city. Boston could

[3] http://www1.nyc.gov/site/orr/challenges/nyc-panel-on-climate-change.page
[4] http://www.bostonlivingwithwater.org/
[5] https://www.boston.gov/parks/public-garden
[6] https://www.emeraldnecklace.org/

enhance its existing resilience planning by continuing to preserve, protect and expand its inventory of open/green spaces for the purpose of social and natural resilience. Such an approach may include the creation or repurposing of open spaces, similar to those contemplated in resilience plans in such cities as New York, New Orleans, San Francisco and Rotterdam. These new open spaces may be used as playing fields, walking paths, vegetative berms, or for other purposes. They might be established on: existing land forms that are now unprotected; existing landforms that will be opened due to planned retreats from the existing shorefront; created landforms on newly-made land built with relatively high elevations along the existing shoreline; or created islands in Boston Harbor kept open for recreational and ecosystem service purposes, or for other purposes, in strategically sited locations.

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Boston's Open Space and Sea Level Rise: An assessment of the role of open spaces in mitigating the impacts of climate change-related sea level rise and flooding

Introduction

As a densely populated city located on the Atlantic coast, Boston, Massachusetts is vulnerable to a number of climate change impacts, including sea level rise (SLR) and resulting coastal flooding. One means to protect Boston is to build a flood barrier around Boston Harbor; the Sustainable Solutions Lab at the University of Massachusetts Boston has recently evaluated the feasibility of this approach. The Lincoln Institute of Land Policy (LILP) has contracted the School for the Environment to address this vulnerability by evaluating the potential for open spaces within Boston to play a role in flood mitigation, as well as to evaluate the potential impacts of a Boston Harbor Flood Barrier on these open spaces. We first developed a comprehensive geospatial database of open space within the Boston Harbor domain and then surveyed the users of a sample of these open spaces to better understand the value and uses of Boston's open spaces. Maps using the open space database have been created to depict the extent and depth of open space flooding for the years 2013, 2030, and 2070.

The objective of this report is to summarize our analysis of the following research questions:

1. What is the extent of open space (terrestrial and intertidal) which exists within the Boston Harbor domain?

2. How is this open/green space used by people and what level of zoning and/or regulatory protection currently exists for these open spaces?

3. Based on the answers to 1 and 2, how much of this open space could be considered as staging area for the Boston Harbor Barrier construction

4. What are the conservation benefits of existing open space and how can we best maximize the conservation benefits of existing and potentially new open space during the design, construction and management of the Boston Harbor Barrier, if such a harbor barrier is adopted?

5. How much of this open space is vulnerable to coastal flooding in the 21st century?

6. How much open space could potentially be created by the Boston Harbor Barrier, if such a harbor barrier is adopted?

We outline the results of this research by addressing Tasks 1 through 4 of the scope of work provided to LILP (contract dated August 14, 2017). This report summarizes research and analysis performed from June 1, 2017 through May 31, 2018, and in subsequent discussions of the results of this study.

Task 1: Create a comprehensive GIS database of open space within Boston Harbor domain

1.1 Defining the Boston Harbor domain

The Boston Harbor domain was defined in accordance to the domain for the Boston Harbor Flood Risk Model (BH-FRM) Raster Datasets provided by the Massachusetts Department of Transportation (MassDOT). These datasets were developed to assess the vulnerability of the Central Artery/Tunnel system to coastal flooding. Details of this project can be found in Bosma et al. (2015). The datasets were used with the permission of MassDOT. The extent of the Boston Harbor domain defined for this project includes metro Boston and the surrounding coastline from Nahant to Hull.

1.2 Compiling the open space data

A comprehensive database of open spaces within the Boston Harbor domain was created using geospatial data using Environmental Systems Research Institute's (Esri's) Geographic Information Systems (GIS) software. The available geospatial datasets of open space were compiled; these datasets and their sources are shown in Table 1.

MassGIS provided the geospatial data for 'Protected and Open Spaces,' which served as the primary reference for analysis. Due to the coarseness of this dataset, Analyze Boston, a City of Boston-funded entity, was also utilized to provide further open space locations in the study domain. To yield the most complete geodatabase of open spaces within the domain, the two datasets were joined together. All duplicate open spaces were eliminated and when two datasets had the same open space listed, the most current information was utilized for the open space attribute.

Another geodatabase, the National Wetlands Inventory (NWI) from MassGIS, was evaluated for suitability in the open space analysis process and found to be too arduous to incorporate into the analysis. This geodatabase provides detailed boundaries for wetlands within the study domain; however, the shapes themselves are categorized differently than in the other geodatabases, which would have complicated the process and potentially compromised the rigor of the data analysis.

Table 1: Geodatabases and their Sources

Geodatabase	Source
Protected and Open Spaces	MassGIS: www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/osp.html
Open Space	Analyze Boston/City of Boston: http://bostonopendata-boston.opendata.arcgis.com/datasets/2868d370c55d4d458d4ae2224ef8cddd_7
National Wetlands Inventory	MassGIS: http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application- serv/office-of-geographic-information-massgis/datalayers/nwi.html

1.3 Defining and categorizing open spaces

For this project, we have adopted the United States Environmental Protection Agency's (EPA) definition of open space ("What Is Open Space/Green Space?" 2017):

"Open space is any open piece of land that is undeveloped (has no buildings or other built structures) and is accessible to the public. Open space can include green space (land that is partly or completely covered with grass, trees, shrubs, or other vegetation). Green space includes parks, community gardens, and cemeteries, schoolyards, playgrounds, public seating areas, public plazas, vacant lots. Open space provides recreational areas for residents and helps to enhance the beauty and environmental quality of neighborhoods."

Table 2. Open space categories and descriptions used in this study

Open Space Category	Description
Green Space	Land that is partly or completely covered with grass, trees, shrubs, or other vegetation. Includes parks, community gardens, and cemeteries/ burial grounds, fields (527 spaces)*
Playgrounds and Recreation	Includes school yards, skating rink, tennis courts, water tower, swimming pools, and dog parks. (210 spaces)
Public Plazas	Includes squares, public seating, mall, monument, Harbor Walk, Museum of Science, forts, wharf, cruise terminal, pier, senior center, bathrooms, and mill. (204 spaces)
Conservation Land	Includes beaches, greenways, access areas, parkways, overloops, arboretums, lakes, estates, lanes, and parking lots. (221 spaces)
Wetland	Includes estuary parks, estuarine and marine wetland, freshwater emergent wetland, and freshwater forested/shrub wetland. (39 spaces)
Other/Miscellaneous**	Includes yacht clubs, marinas, boat yards, a chocolate factory, boat ramps, fishing piers, boat landings, golf courses, water supplies, dams, and country clubs. (19 spaces)

*A few of the open space categorization 'spaces' are included more than once in the geodatabase, as some of the open spaces have different land use protections and ownerships that we wanted to preserve these attributes.
**Other/Miscellaneous was included in the list as to not eliminate any locations that the MassGIS's Protected and Open Space shapefile included in their geodatabase.

From this definition, six categories were created to differentiate primary uses of open space: green space, playgrounds and recreation, public plazas, undeveloped land, wetland, and other/miscellaneous. These categories and their descriptions are listed in Table 2. The open space features often fell within multiple categories and the decision to choose a particular category was based on prior knowledge of the open space use, in-person visits to these locations, geodatabase descriptions, and aerial imagery. For example, the Boston Harbor Islands were categorized as 'Undeveloped Land' because there are minimal structures on the Islands, and they serve more as a wilderness reserve than as a groomed and manicured park.

1.4: Create maps of open spaces within the Boston Harbor domain

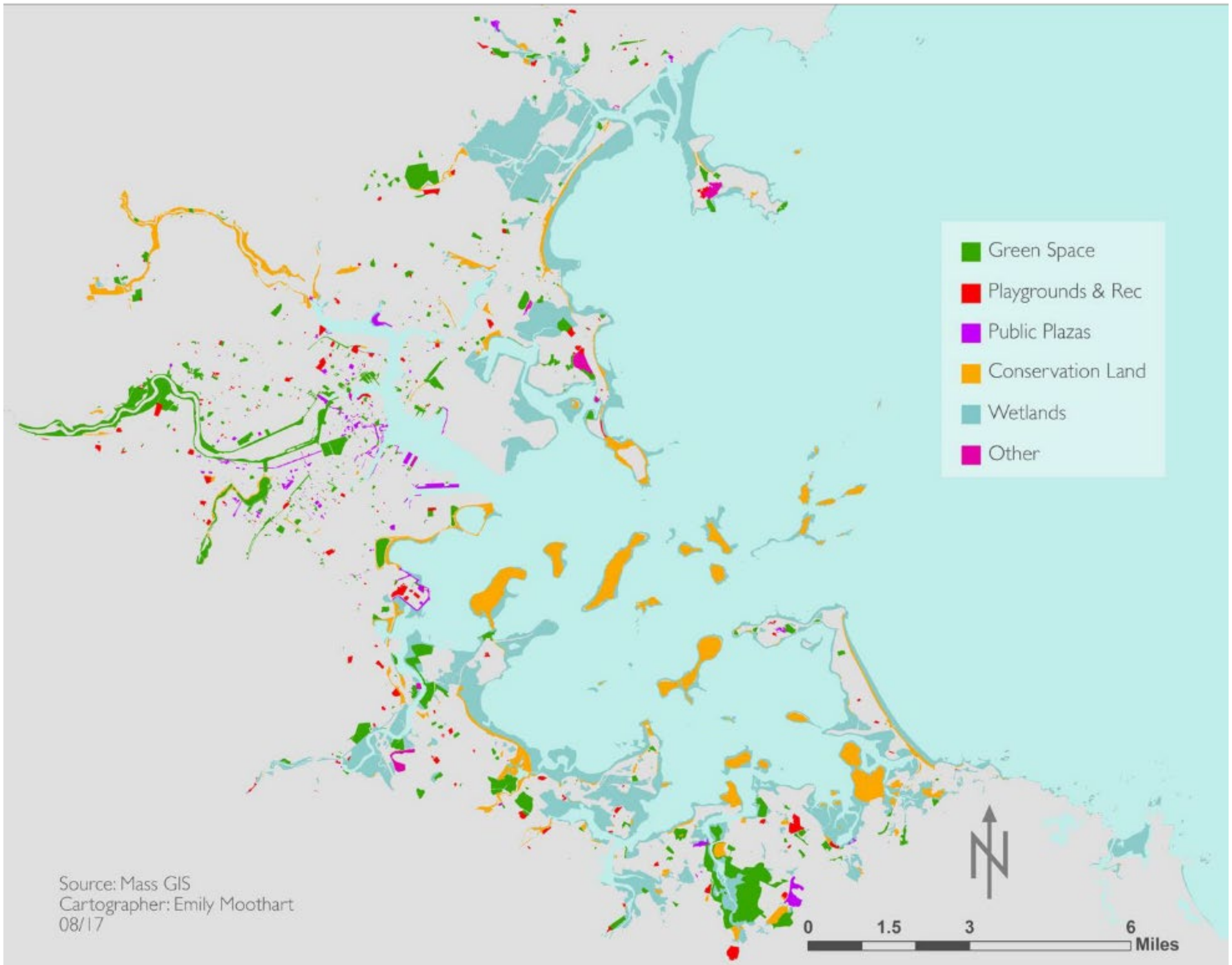
After the open spaces geodatabases were compiled into the Boston Harbor Open Space Database (BH-OSD), a map was created to display the spatial distribution open spaces in the six categorizaties shown in Table 2. Each open space location and area was checked for accuracy based on Esri's basemaps within ArcGIS and Google Earth. The shapes were manually modified if there was an inconsistency in its representation on the map. Table 3 lists the areal proportions of the six open space categories after the editing was complete. Green space and undeveloped land together make up over 66% of total open space.

Table 3: Area and percentage of total open space covered by the six open space categories described in Table 2.

Open Space Category	Area (mi^2)	% of Total Open Space
Green Space	4.85	33.8%
Playgrounds and Recreation	0.79	5.5%
Public Plazas	0.56	3.9%
Conservation Land	4.66	32.4%
Wetland	3.26	22.7%
Other/Miscellaneous	0.25	1.7%
Total	14.37	100%

Figure 1 represents the spatial distribution of BH-OSD features as described in Tasks 1.1 through 1.3. In general, the wetlands are located closest to the ocean and other open water sources and conservation land is primarily adjacent to wetlands. The largest concentration of public plazas is in downtown Boston. Green space and playgrounds and recreation are typically located near one another in residential areas. The 'Other' category tends to be close to the water, as many of the spaces are marine-based as defined in Table 2.

Figure 1: Boston Open Spaces Map



The open space geodatabases provided attribute information regarding land policy protections for each plot of open space land. Table 4 highlights the diverse land protections that exist in this study area. These protections prevent or delay further development on this land. Many of these open spaces have multiple protections, thus adding another level of defense against the alteration of the land's use. Although all of the protections listed in Table 4 are important, arguably the most important land policy is the Article 97 restriction which states that the Massachusetts Executive Office of Energy and Environmental Affairs "and its agencies shall not sell, transfer, lease, relinquish, release, alienate, or change the control or use of any right or interest of the Commonwealth in and to Article 97 land" (EEA, 2017). The City of Boston also has another unique protection, Chapter 7, Section 4.11 of the City of Boston Code of Ordinances, otherwise known as the '100 -foot rule'. This ordinance requires "the Commission [to] render its approval before construction begins on any development project within 100 feet of any park or parkway within the city" (Open Space Inventory 2002). This grants the city the right to review any project that could have "physical or visual effects on adjacent or nearby parkland" (Open Space Inventory 2002).

Table 4: Land Protections on Open Spaces in the Study Area

Protection	Description
Article 97	Amendments to Massachusetts Constitution
Ch 91	Protects Public Use of Tidelands & Waterways
ACEC	Area of Critical Environmental Concern
WPA	Wetlands Protection Act
LWCF	Land and Water Conservation Fund
NHL	National Historic Landmarks
MPPF	Mass. Preservation Projects Fund
NRHP	National Registry of Historic Places
PR	Historic Preservation
BL	Boston Historical Landmarks
NPS	National Parks Survey
Airport Mitigation	Logan International Airport Mitigation Program
Browne Fund	Edmund Ingersoll Browne Fund, City of Boston Trust
Ch 114s17	Cemetery Preservation
Easement	A Right of Use Over the Property of Another
Sewer Easement	Rights to Have Sewer Pass Through Private Property
License	Non-Proprietary Permit for Use of Land
Lease	Owner of Land Determines Protections
Land Trust	Land Trust Ownership
100	Boston Parks & Recreation Commission “100 Foot Rule”
BPRD License	Issued by BPRD for Use of Parcel
GPOD	Greenway Protection Overlay District
CAT Mitigation	Mitigation of the Big Dig
CAT Mitigation/RFK	Rose Kennedy Greenway Mitigation

Source: BH-OSD and Open Spaces Inventory 2002.

Figure 2 is a map indicating areas within BH-OSD that are protected by some level of policy. Many of these open spaces have multiple land protections hence the map is categorized into Protected and Unprotected/ Unknown open space. The National Wetlands Inventory (NWI) features are also shown in Figure 3, however, these areas were not explicitly added to the BH-OSD. This is due to difficulties in separating NWI features from those in the BH-OSD. Many of the wetlands depicted in the NWI may also be protected under Wetlands Protection Act; however, this information was not readily available and so we chose to display NWI features as a separate category.

Figure 2: Spatial distribution of open spaces that are protected and unprotected under current land policy.

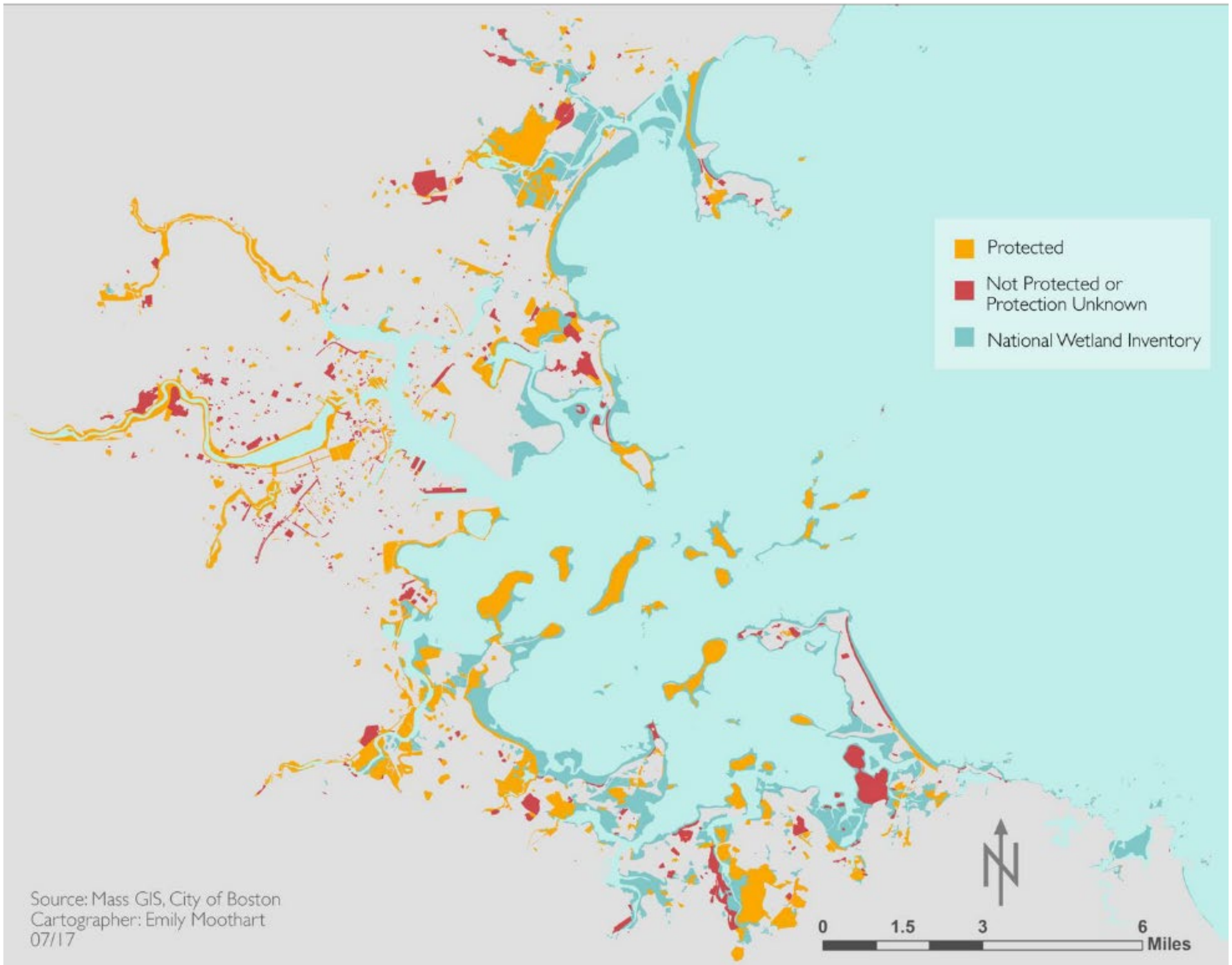
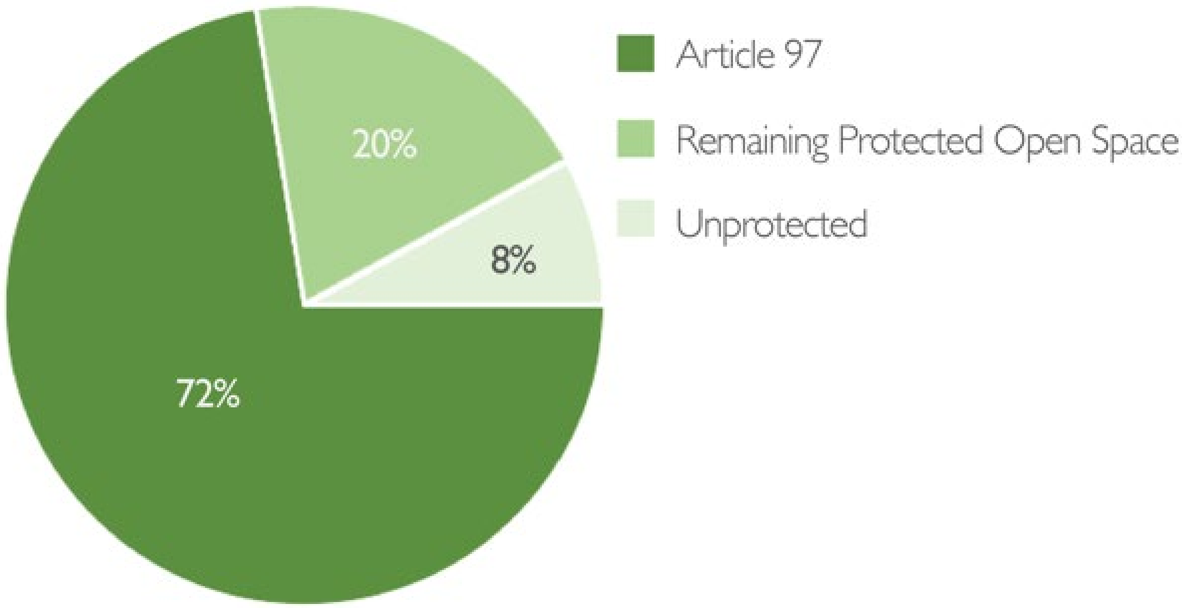


Figure 3 shows that over 90% of open space within the BH-OSD domain is protected from development; 73% of this open space is protected under Article 97, which "prevents publicly owned lands held for park, recreation, and conservation purposes from being used or disposed of for other purposes without a majority vote of the Parks or Conservation Commissions and the City Council, the approval of the Mayor, and a two-thirds vote of both houses of the State Legislature" (Open Space Inventory 2002). This makes it extremely challenging for designated Article 97 land to be used for a non-conservation purpose. Less than 10% of open space is categorized as unprotected, meaning that this land area may be available for other non-conservation land uses.

Figure 3: Distribution of open space protection in the Boston Harbor Study Area



Task 2: Assess the vulnerability of open space within the Boston Harbor domain to coastal flooding in the 21st century

2.1 Assess the vulnerability of open space to coastal flooding

Coastal flood depths and probabilities were extracted from the BH-FRM Raster Datasets provided by MassDOT. These datasets were developed to assess the vulnerability of the Central Artery/Tunnel (CA/T) system to coastal flooding. Details of CA/T vulnerability study can be found in Bosma et al. (2015). A summary of the project is included in Appendix A.

The BH-FRM Raster datasets include modeled flood depth for the years 2013, 2030, and 2070. For each of these years, the flood depths are associated with an estimated 1% coastal flood exceedance probability (CFEP), meaning flood depths that have a 1% chance of being equaled or exceeded in any year. It should be noted that the BH-FRM model domain was smaller than our Boston Harbor domain and did not include coastal areas north and south of Boston proper. These areas are also likely to be susceptible to coastal flooding. Figures 4 through 6 represent the spatial distribution of total land area and open space area vulnerable to the 1% CFEP event for 2013, 2030 and 2070, respectively. The far north and south coasts are currently outside of the BH-FRM domain, therefore flooding in these areas is not shown. The dark blue in Figures 4 through 6 flooded open spaces; the lighter blue indicates the extent of the total flooded area.

Much of the flooded open spaces shown in Figure 4 are wetlands and beaches which have land protections preventing further modifications to the landscapes. Figure 5 shows approximately 40% more land area and 10% more open space flooded by 2030 relative to 2013. The majority of this vulnerable area is projected to be flooded at depths of less than 1 foot. By 2070, the total land area vulnerable to flooding is approximately 50% greater than in 2030, and approximately 30% more open space will be flooded in 2070 than 2030 (Figure 6). Although not shown in the Figure 6, approximately half of the vulnerable area is projected to be flooded to depths between 1 and 4 feet and nearly one-third could be flooded to depths greater than 4 feet. Figure 7 aggregates the results shown in Figures 4 through 6 and highlights the increasing extent of the 1% CFEP flood extents over the 21st century. By 2070, there is a significant increase in land area that could be flooded during an extreme coastal storm event. This is particularly notable in Boston' Back Bay as well in the City of Cambridge because by this time, rising sea levels may make it possible for storm surge heights to circumvent the protection afforded by the Charles River dam.

Figure 4: Extent of 1% flooding in 2013

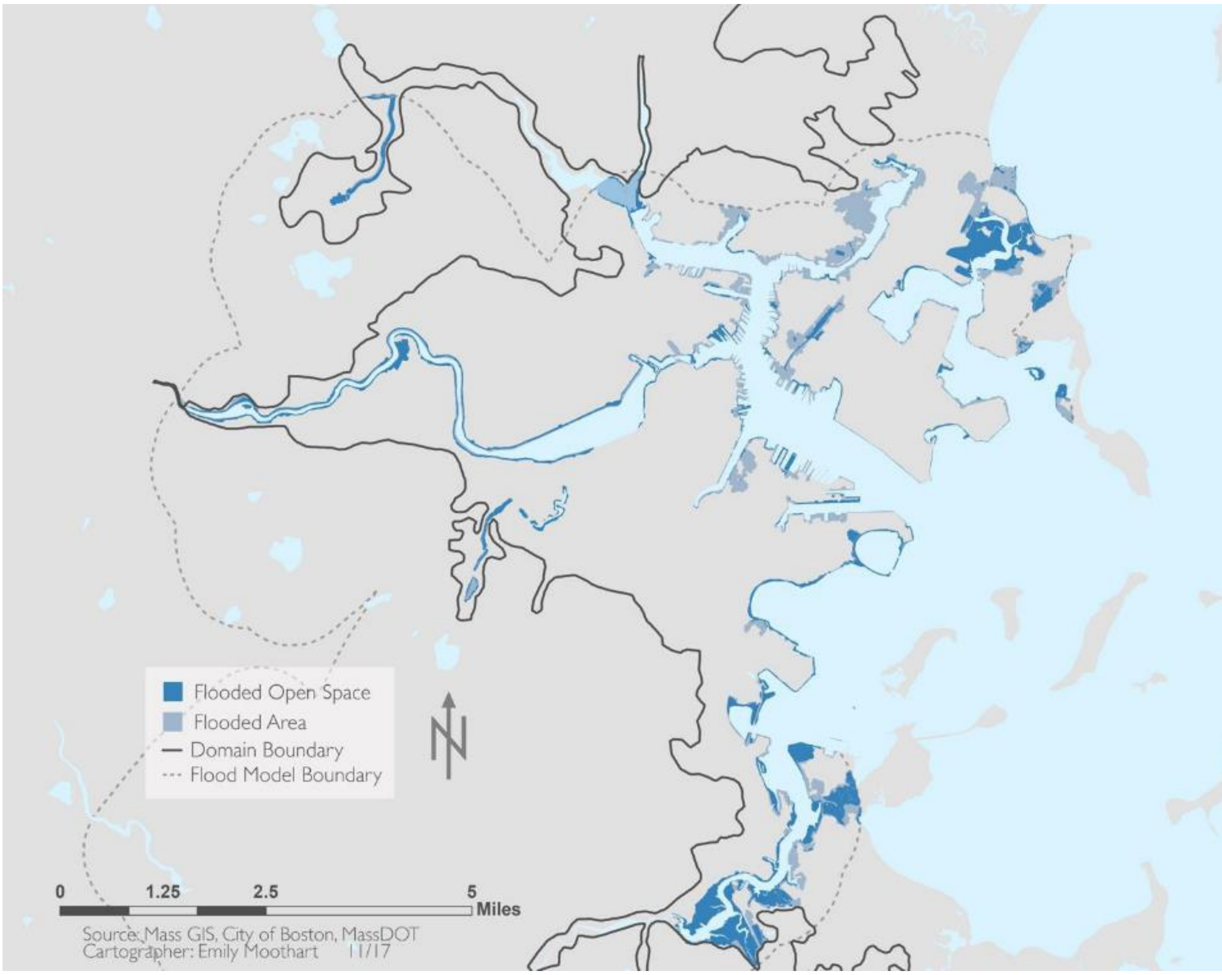


Figure 5: Extent of 1% CFEP flooding in 2030

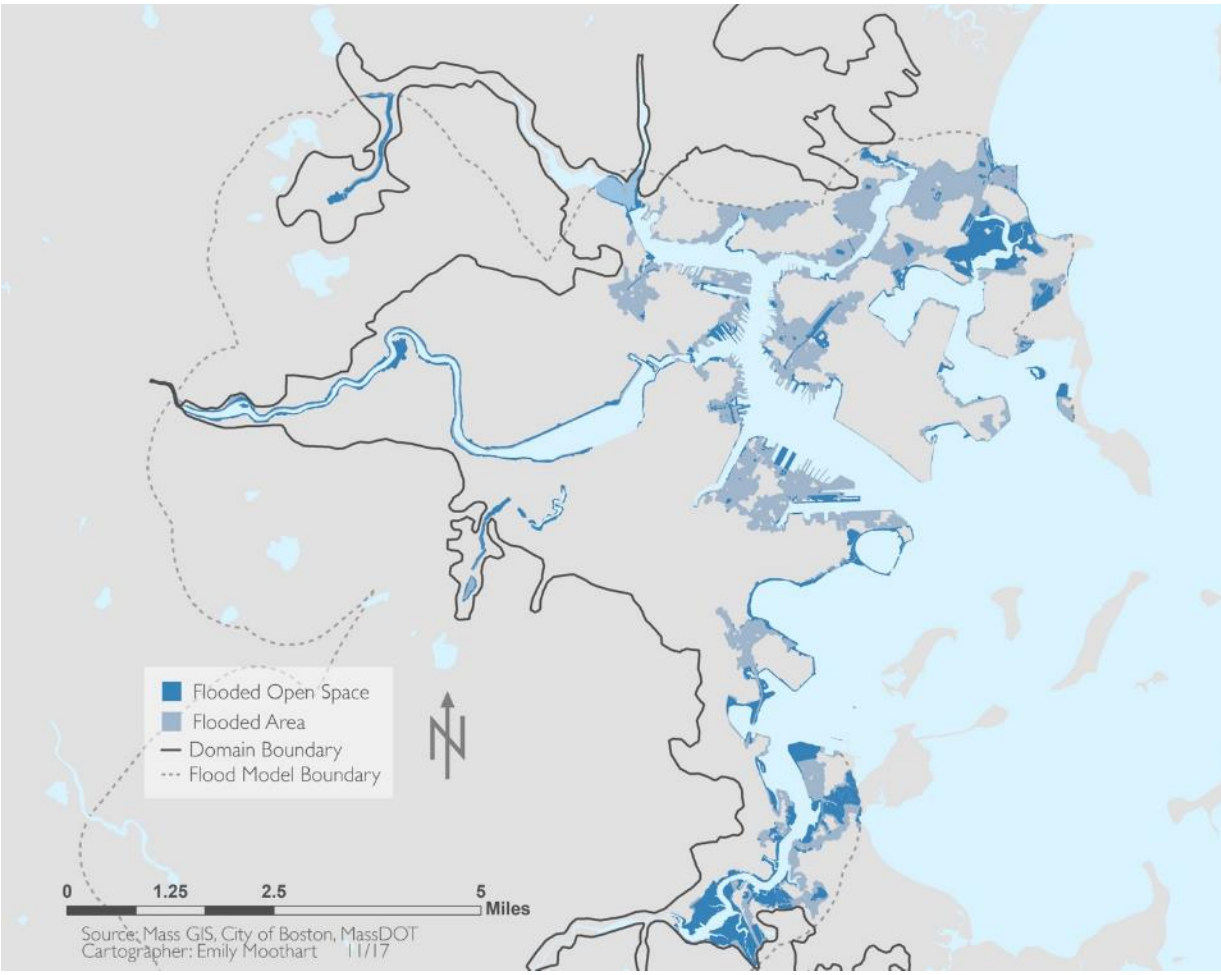


Figure 6: Extent of 1% CFEP flooding in 2070

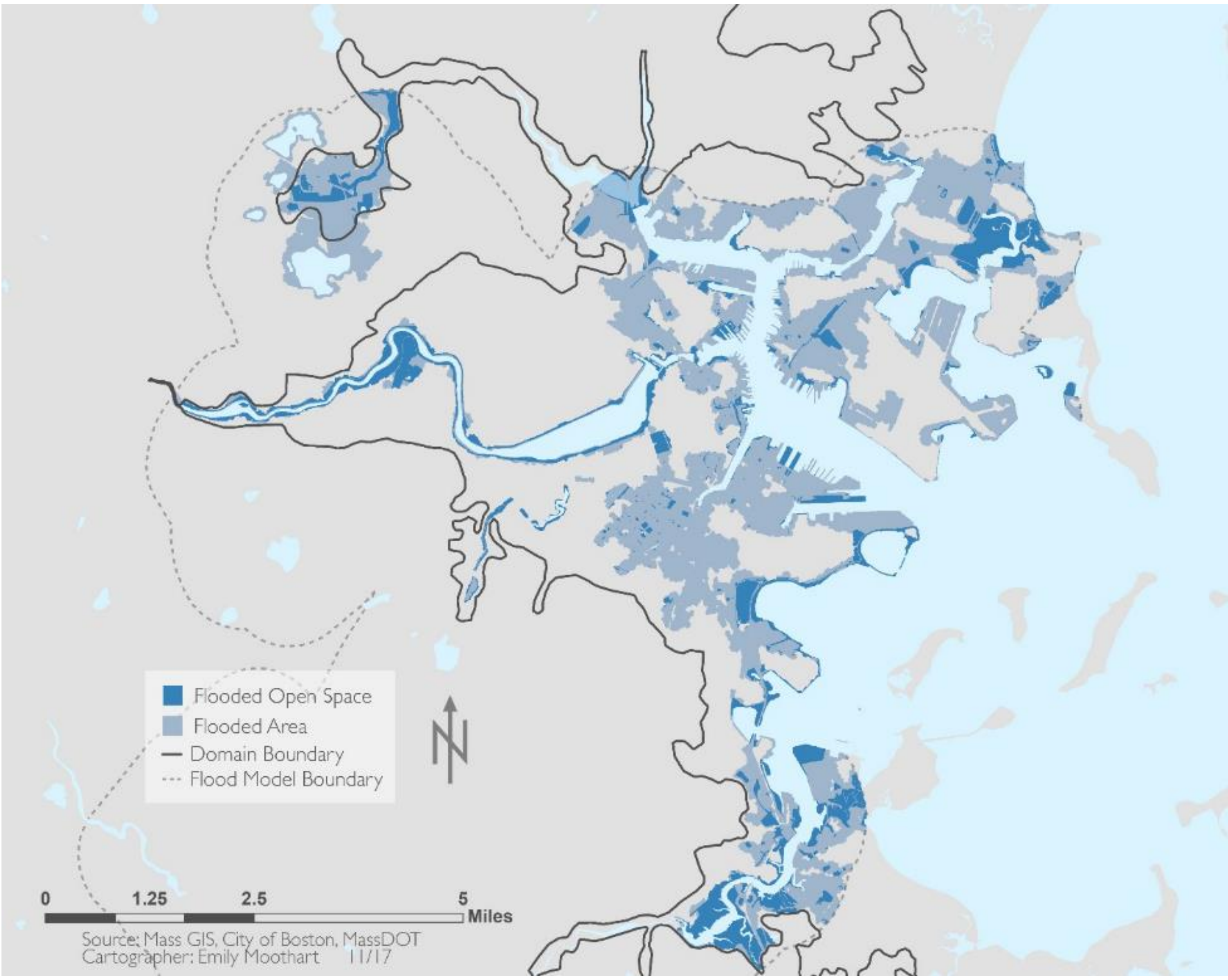


Figure 7. Increasing extent of the area vulnerable to 1% CFEP flooding over the 21st century.

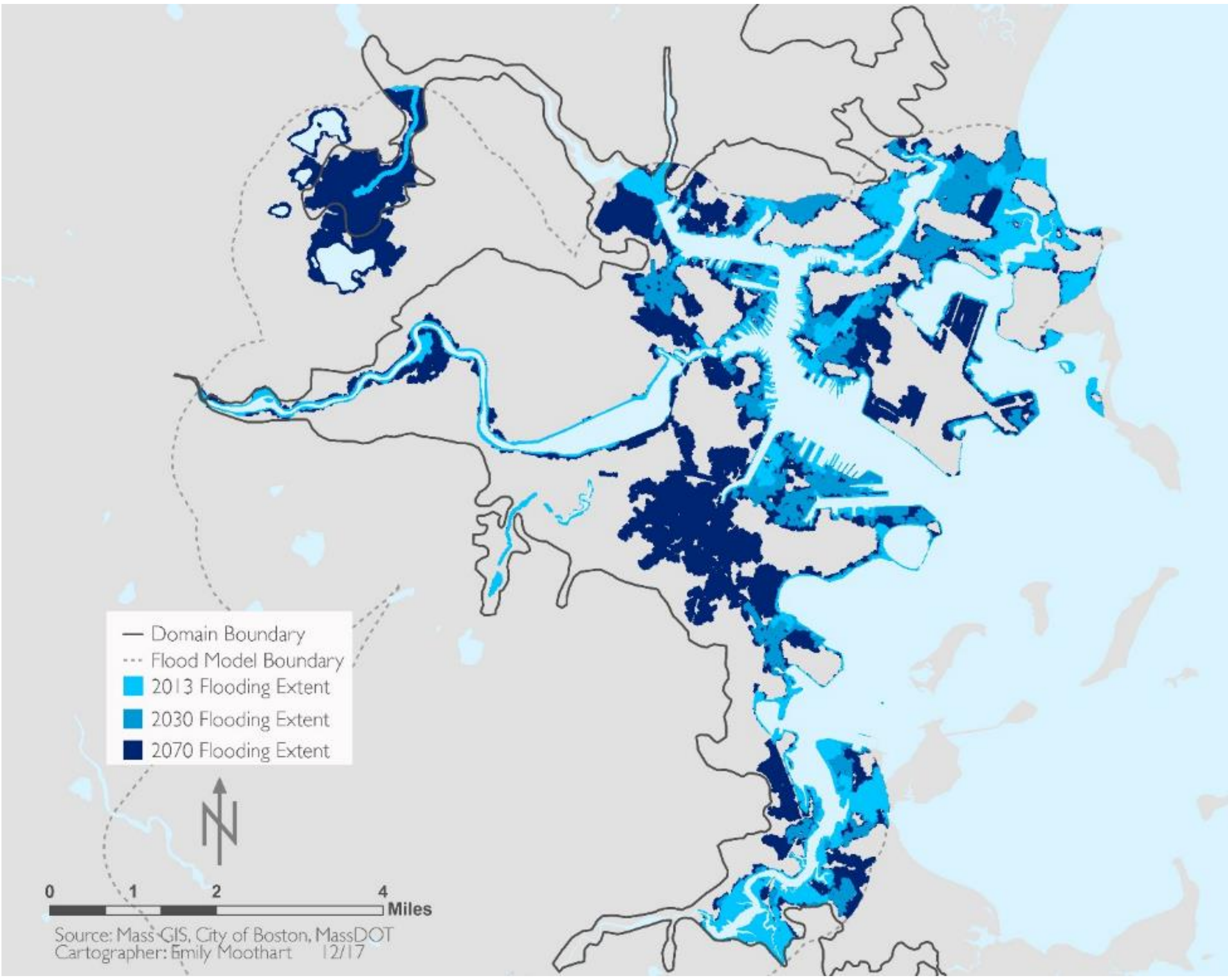
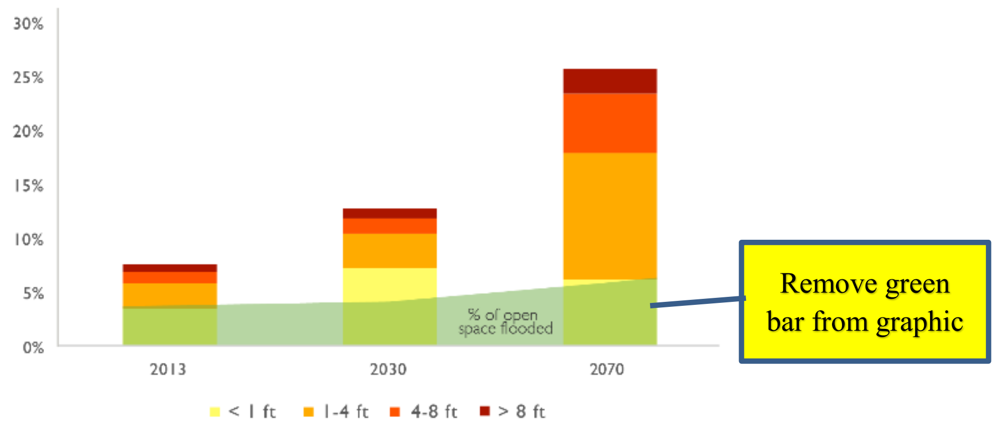


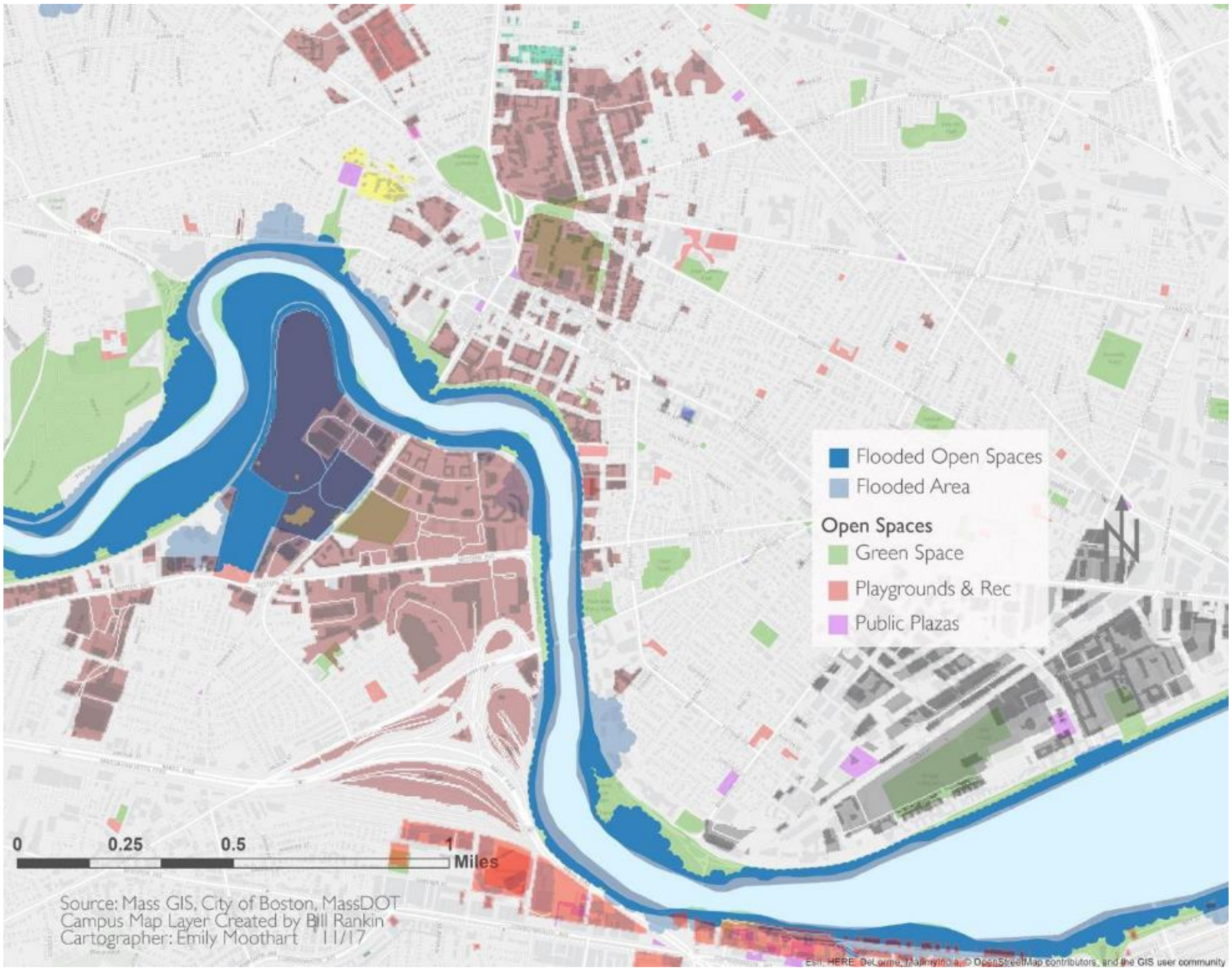
Figure 8 aggregated the results shown in Figures 4 through 7 and compares the percentages of flooded total land area and flooded open space area within the study domain due to the 1% CFEP event for the years 2013, 2030, and 2070. Figure 8 also delineates the proportions of total land area vulnerable to flood depths of less than 1 foot, 1 to 4 feet, 4 to 8 feet and greater than 8 feet. These depth delineations were not quantified for flooded open space area. In 2013, only 7.6% of total land area and 3.6% of the open space area are vulnerable to the 1% CFEP event flooding, which means that approximately one-half of the potentially flooded land area is occupied by open space. In 2030, the total land area vulnerable to coastal flooding from the 1% CFEP event nearly doubles to 12.7%, while flooded open space area increases to 4%, hence the proportion of the total land area flood by 2030 that is occupied by open space, drops to one-third. By 2070, 25.8% of the total land area and 5.7% of the open space area within the study domain is vulnerable to flooding from the 1% CFEP event, meaning that less than one-quarter of the flooded land will be occupied by open space, assuming the existing open space distribution. This suggests that the existing open spaces in the Boston Harbor domain have the potential for use in flood mitigation in the near term (through 2030), but that substantially more open space would need to be added to mitigate flooding impacts over the long term (by 2070 and beyond).

Figure 8: Percentage of total land area (colored bars) vulnerable to flooding as a result of the 1% coastal flood exceedance probability flood event. Yellow, mustard, orange and red colors delineate the proportions of area vulnerable to flood depths of less than 1 foot, 1 to 4 feet, 4 to 8 feet and greater than 8 feet, respectively. The green shaded polygon represents the percentage of open space area that is flooded from the same event (flood depth delineations for open space is not shown).



Another aspect to consider is the effects that flooding could have on universities in Boston. There are 52 institutions for higher education in the metro Boston area ("Roster of Institutions" 2017). Many of these could be impacted by coastal flooding in the future. One such area is Cambridge and Allston, which are home to three large research universities: Harvard University, Massachusetts Institute of Technology, and Boston University. These three institutions alone house over 64,000 students or 29% of Boston's higher education population ("National Center for Education Statistics" 2017). Coastal flooding could inhibit many routes of public transportation which is essential for students to travel to their home institutions.

Figure 9: Example of the impact of the 1% flood on Higher Education Campuses in 2070



In addition to the overview of the Boston flood maps (Figures 4 through 7), a series of maps (Figure 10 through 13) illustrates the higher resolution flood vulnerability by 2070 in the areas of Cambridge/Allston, East Boston, Downtown Boston, and South Boston/Dorchester. In these maps, darker blue represents flooded open spaces and lighter blue represents the entirety of flooded areas. These maps illustrate that every area will be more vulnerable to flooding as we near the end of the century. Similar fine resolution flood maps of flood vulnerability in these areas for 2013 and 2030 can be found in Appendix C.

Figure 10. 1% CFEP Flood Extent of Cambridge/Allston in 2070

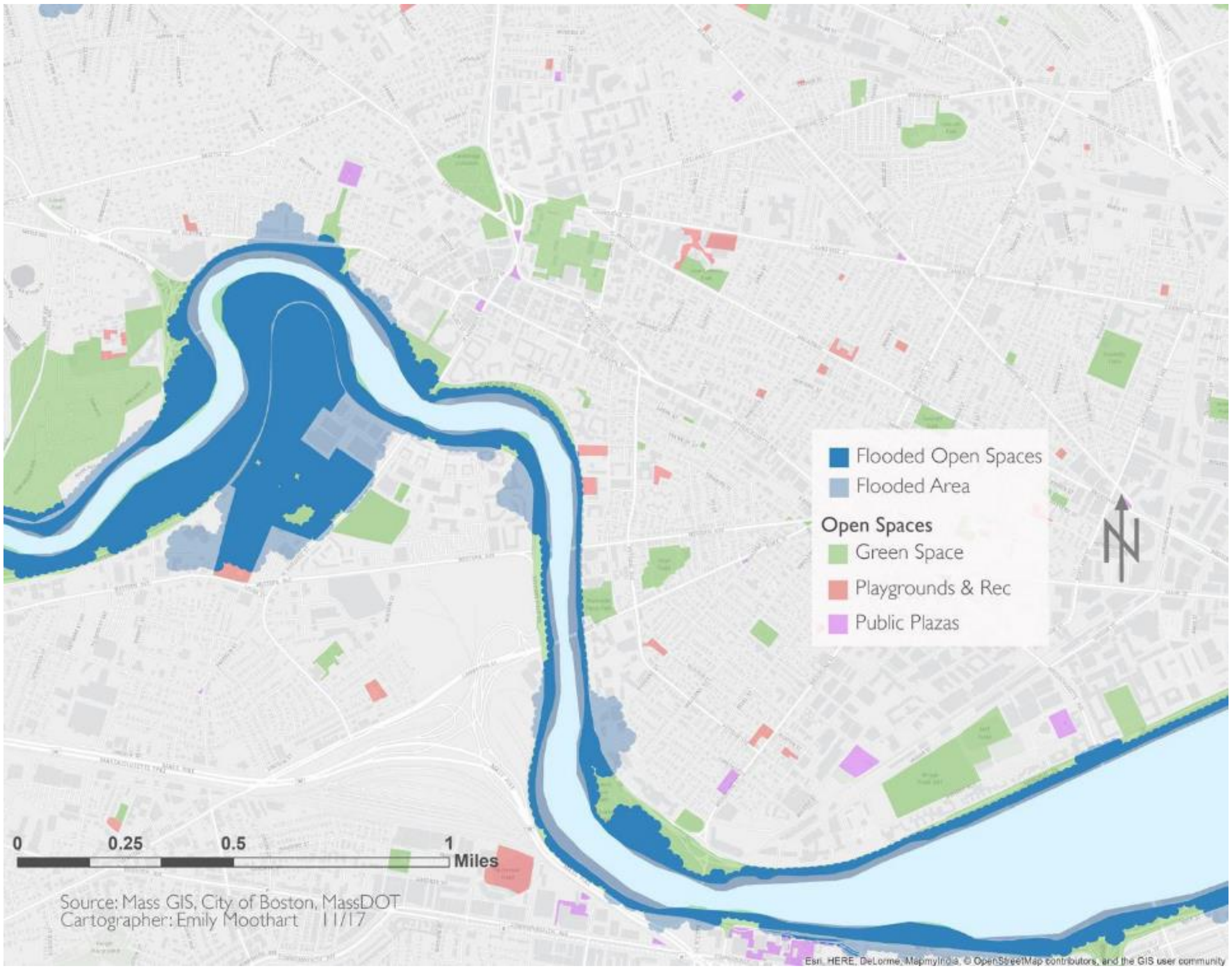


Figure 11. 1% CFEP Flood Extent of East Boston in 2070

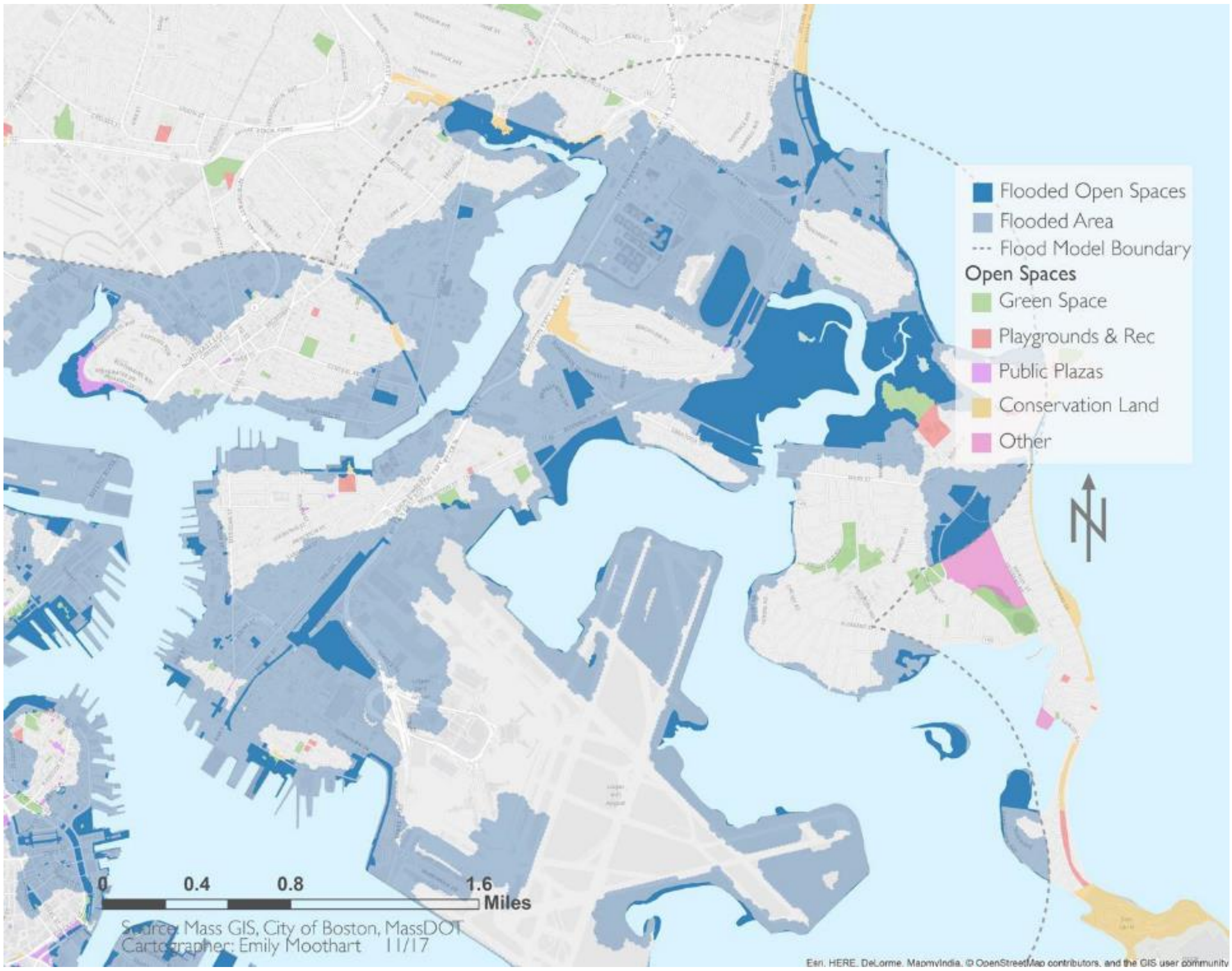


Figure 12. 1% CFEP Flood Extent of Downtown Boston in 2070

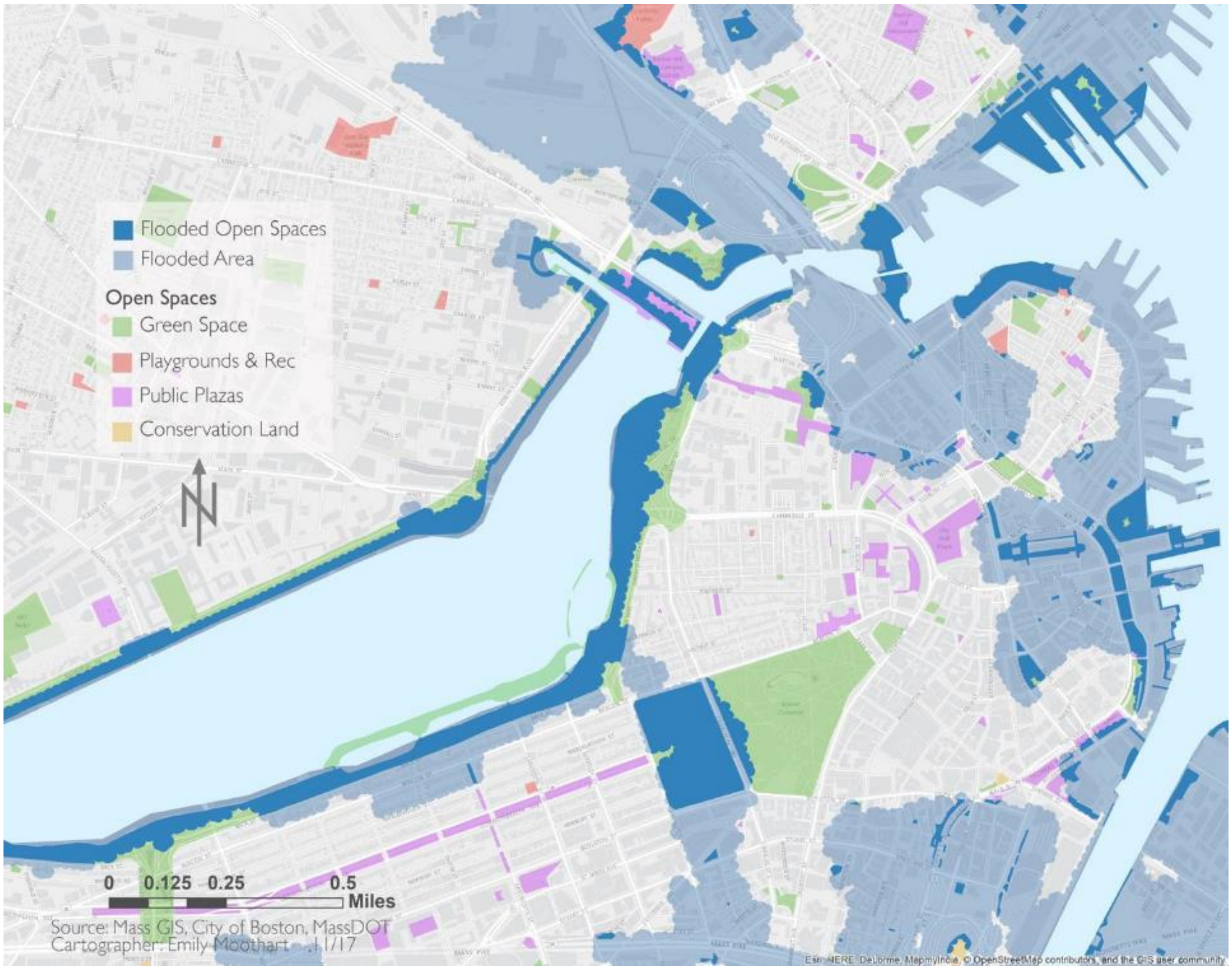
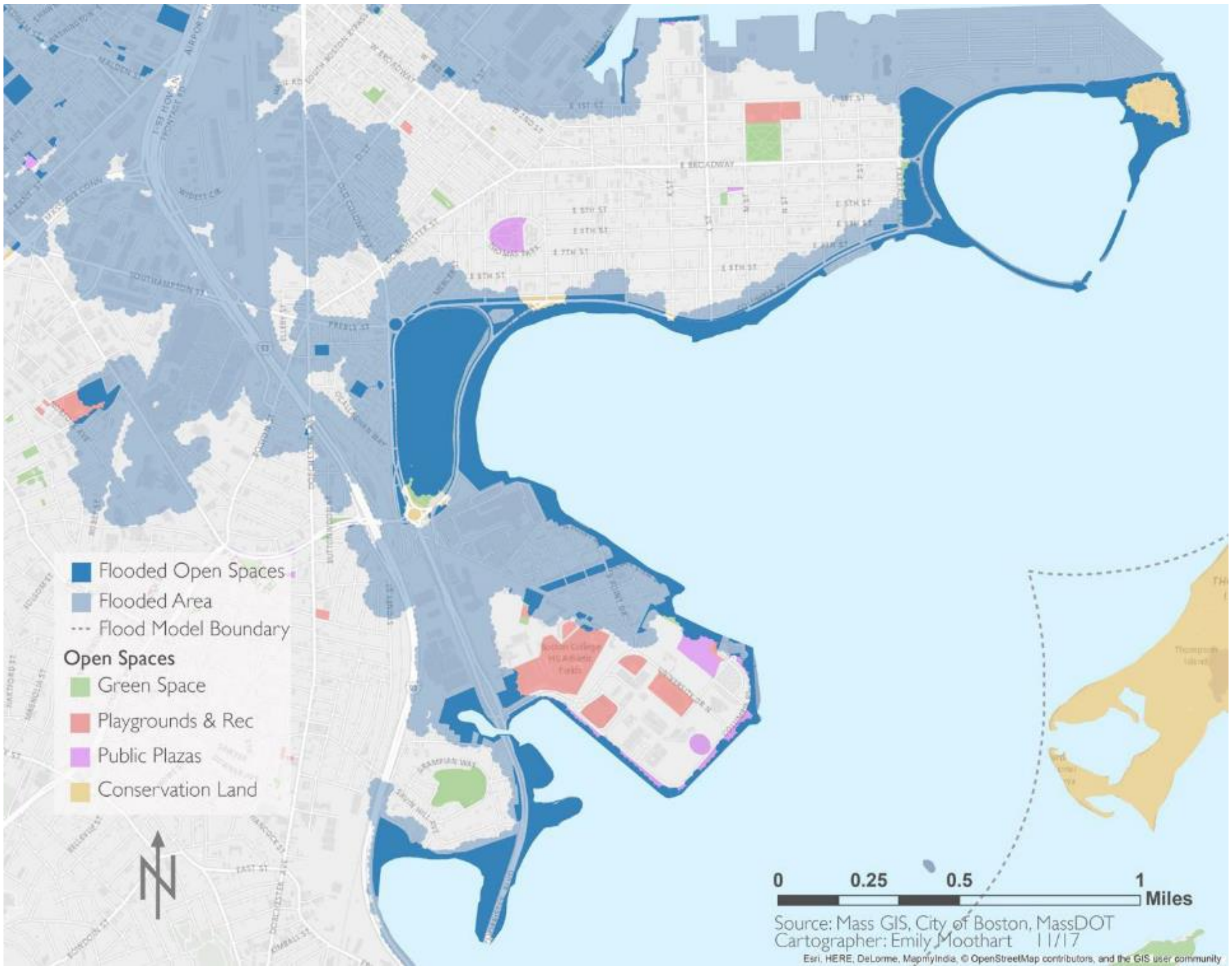


Figure 13. 1% CFEP Flood Extent in South Boston/Dorchester in 2070



Task 3: Assess the ecosystem service values and conservation benefits of open spaces in Boston

3.1 Overview of ecosystem values and urban open spaces

To guide our understanding of the ecosystem values provided by urban open spaces and to help us define potential conservation benefits, we reviewed the scientific literature. The following is a summary of the most relevant articles to open space conservation as a flood mitigation strategy.

In "Open Space Protection and Flood Mitigation: A National Study (Brody et al. 2015) the authors attempt to evaluate the effectiveness of open space protection as a flood mitigation strategy at the local level. There is little evidence or research on the effectiveness of this strategy in actually reducing the damage caused by floods. They measured the amount of open space protection under FEMA's Community Rating System (CRS) as a representative national sample to test the efficacy during the period of 1999 to 2009. Their results indicated that the protection of open space is an important land use planning tool for flood mitigation. In general, the authors advocate for a managed retreat plan as an avoidance strategy, removing property and infrastructure from vulnerable areas. The idea of a planned retreat is not attractive to most coastal communities as their economies are heavily dependent on the value of waterfront property and access to marine resources.

Haddad et al. (2015) states that environmental planners, policy makers, and communities should consider current open space as important asset in flood mitigation. Their study proposes a framework for geospatial characterizations of the interactions between storm surge and wetlands to assess their effectiveness in attenuating storm surge. The authors apply this framework to Virginia's Chesapeake Bay region. Using nationally available datasets, maps of maximum storm tides for four historical storms were generated based on a coupled hydrodynamic wave model (ADCIRC-SWAN). This framework 'demonstrates that effective storm surge protection from wetlands and marshes is related to a combination of the incidence of storm surge inundation, proximity to coastal communities, and the relationship of sufficient spatial scales for surge attenuation'. In the case of Boston, wetlands and marshes should not be left out of considerable options for flood mitigation, "green infrastructure" strategies. Although wetlands and marshes are considered effective wave attenuators, it is unclear how effective they will be as sea level rise accelerates over the next century.

Pilkey et al. (2016) reports that some form of planned retreat will likely be inevitable for most coastal communities. Their study describes the driving forces and mechanics of global sea level rise and provides an overview of national and global policy related to coastal development. As advocates for a managed retreat of coastal communities, the authors criticize the long- established subsidy of development of valuable property along a coastline. Using New Orleans and Miami as worst-practice examples of development along a receding shoreline, the authors argue for the elimination of federally subsidized flood insurance in order to encourage a retreat from the coast. They suggest that national burden from disaster relief expenditure has reached a level far beyond what is sustainable given that storms are likely to increase in number and intensity over the next century. Federally subsidized flood insurance provided by the National Flood Insurance Program (NFIP) uses taxpayer dollars to subsidize the flood insurance of individuals and communities that occupy areas prone to flooding. In some instances, entire developments are rebuilt repeatedly after disasters, regardless of the likelihood that another disaster will occur. Another flaw of the program is that many of its beneficiaries are secondary homeowners whose properties sit on precarious and particularly vulnerable seaside property.

Ultimately, the author suggests that the current mentality of "retreat is not an option" will continue to drive the construction of hard structures (i.e., sea walls) to mitigate flooding. This approach will likely make the impact of a disaster greater in scale as development is encouraged within a protected coastal area. Inevitably, cities along coasts all over the world will be forced to retreat leaving millions of people stranded as environmental refugees. This concept of retreat is more pertinent than ever as the United States was battered by Hurricanes Harvey and Irma during the writing of this report.

3.2 Ecosystem service values of open spaces in Boston

Boston has a long history of publicly owned land and universal access to open space within city limits. Boston Common was the first public park in the United States. Established in 1634, it remains a central attraction to city visitors and residents of the area. According to the projections outlined earlier in this report, Boston Common is not predicted to be affected by storm surge through 2070; however, the adjacent Boston Public Gardens could be vulnerable to inundation by 2070 or earlier depending on localized effects of sea level rise and carbon emissions scenarios (Figure 13) (IPCC, 2016). It is important to note that the Public Gardens rest on filled land that was a tidal flat prior to the damming of the Charles and Muddy River basins during the late 19th and early 20th centuries. By filling land, Boston was able to expand economically and geographically, providing amenities such as green space and waterfront open space to serve city residents and create a cleaner, healthier urban environment. However, with the threat of sea level rise and coastal flooding events, Boston must now consider options for protecting valuable property, assets and ecosystems that are located on these filled lands. One prevailing concept is the construction of a harbor barrier to protect the metro region from storm surge inundation caused by hurricanes and other extreme weather events in the next century.

Within the context of preserving amenities and ecological value of the city in the face of climate change, the preservation and adaptation of urban open spaces will be essential to urban climate resilience (Trust for Public Land, 2016). Urban parks provide many benefits to their human users that are beyond perception but which should be evaluated to inform environmental policy and resilience adaptation. Storm surge inundation can damage delicate urban ecosystems and damage infrastructure and can restrict access to open spaces post disaster. In order to inform policy and design of flood mitigation strategies in Boston, it is important to conduct a broad evaluation of citizen perceptions of open spaces and the ecosystem services in areas that are risk of inundation as soon as 2030.

As most ecosystem services are not perceived by the average citizen (Buschel and Frantzeskiaki 2015), it is important to understand the subjectivity of services provided by urban parks and open spaces. For this study, an interceptor interview was developed to assess the perceived value of ecosystem services in a sample of ten open spaces within the study domain. A copy of the questionnaire used for this survey is included in Appendix B. Two parcels each were randomly selected from five of the six open space categories described in Table 2 (we did not sample the miscellaneous category) to ensure a broad range of open space users and values. Surveyed open spaces are listed in Table 5. The interviewer asked open space visitors questions regarding their typical use of the space (i.e. frequency, duration, modes of transportation and general demographics) and deployed a scoring exercise to assess the user's perceptions of climate change in the form of extreme weather and sea level rise, as well as their personal valuation of specific ecosystem services. The ecosystems included in the valuation exercise were recreation, aesthetic appreciation, climate control, protection from extreme weather, and production of food or raw materials from plants or animals. The services included in the survey were adapted from Buchel and Frantzeskiaki's (2015) concept of cultural ecosystem services, which are more subjective than other ecosystem services. Each selected open space was surveyed three times over the course of the summer at different preselected time intervals. Surveys were taken once at mid-day on a weekday, once in the evening on a weekday and once at mid-day on a weekend.

Table 5: Open Spaces Surveyed during Summer 2017

Open Space Category*	**Open Spaces Sampled**	
Green Space	Boston Common & Public Gardens	Neponset River Reservation
Playgrounds and Recreation	Hooker-Sorrento Playground	Cambridge Public Library Playground
Public Plazas	Copley Square	Long Wharf
Conservation Land	Mystic Lakes	L Street Beach
Wetland	Rumney Marsh Reservation	Broad Meadows

* For category descriptions please see Table 2.

For this study, we adapted the methods outlined in Buchel and Frantzeskiaki (2015) in assessing the importance of urban open space. As park users will not usually be able to perceive all services such as flood mitigation, it was important to translate services into simple and objective terms. This study developed a method to a guided translation of the concept of ecosystem services to citizens to assess the values of park users. They developed a methodology to present value statements to park users in Rotterdam which resulted in three main user profiles including, ‘love of nature’, ‘recreation and connection’, and ‘social setting and relaxation’. Using this framework, ecosystem services were translated into generalizing and universally understood concepts.

As the sampled open spaces spanned a variety of uses and densities of pedestrian traffic, the sample size for each open space varied respectively. In parks that fell under the green space category, pedestrian foot traffic was most dense and therefore there were more interview participants available during each sampling, while in other categories such as undeveloped lands or wetlands the presence of interview participants was considerably less. Another sampling limitation was that cyclists and runners were not greatly represented in interviews, as the interviewer was on foot and could not always intercept those engaged in such activities. For the purposes of this report, survey results will be summarized with statistics regarding the entire sample or by land use category described above. This broad understanding of how open space users perceive their ecological importance adds a social element to the debate over flood prevention strategies for the Boston metro region. The perceived importance of open spaces in urban environments could create the political will to protect access for generations to come.

3.4 Open spaces surveyed

3.4.1 Example Green Space: Neponset River Reservation

The Neponset River Reservation is a system of riverine parks and restored wetlands that extends along the Neponset River from Milton, Massachusetts until it feeds into the Quincy Bay connecting it to the Boston Harbor. Areas within the reservation that were surveyed include Pope John Paul II Park and Hallett Park, which are closest to the mouth of the river. This space overlays a former landfill, which was later, reclaimed as a Drive-in movie theatre sometime in the 1990's. Currently the space is a restored wetland developed into an urban park equipped with water play features, gazebos and pedestrian pathways. Interview participants value this space most highly for its aesthetic value and recreational uses such as cycling, walking, team sports, boating, kite flying. A smaller proportion of the users interviewed also valued the space for climate control. One of the participants divulged that they value this space for climate control as they do not have air conditioning in their home and on hot days they come to sit by the water to enjoy the breeze.

Figures 14 & 15: Images of the Neponset River Reservation


3.4.2 Example Playgrounds and Recreation: Hooker-Sorrento Playground

Hooker-Sorrento Playground is a playground in the Lower Allston neighborhood of Boston. This space was observed to be used primarily by families with young children and as a walkthrough for pedestrian traffic. The majority of the survey participants were female and had brought young children to the space for use of the waterplay features and jungle-gym structures. Participants valued this space most highly for recreation for their children as well as climate control. While no one in this space mentioned a lack of air conditioning in their home, there was a perceived lack of places to swim and interact with water in the summer months. Many participants stated that the Charles River Reservation was one of the other parks in the area they liked to visit but that swimming was not allowed so it is not a viable climate control option.

Figures 16 & 17: Images of the Hooker-Sorrento Playground


3.4.3 Example Green Space: Boston Common

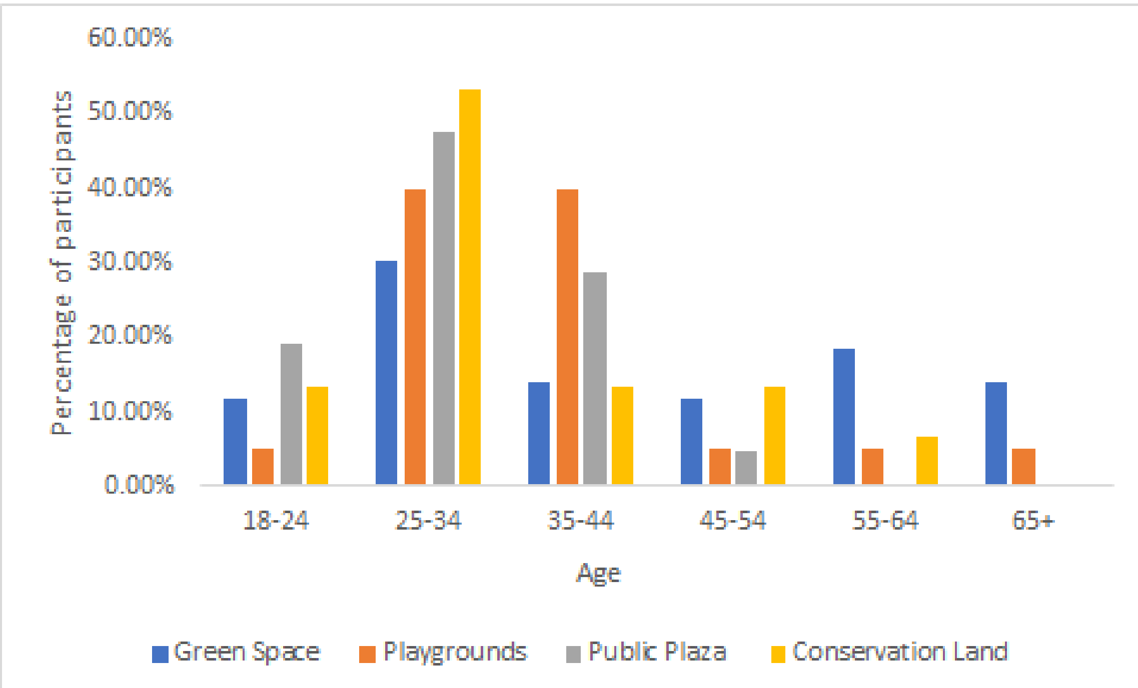
Boston Common was the first public park in the United States established in 1634, it remains a central attraction to city visitors and residents of the area. According to the projections above, Boston Common is not predicted to be affected by storm surge through 2070, however, the adjacent Boston Public Gardens could be vulnerable to inundation by 2070 (see figure 12) or earlier depending on localized effects of sea level rise and carbon emissions scenarios (IPCC, 2016). It is important to note that the Public Gardens rest on filled land that was once a tidal flat prior to the various manipulations of the Charles and Muddy River basins completed throughout the late 19th and early 20th centuries.

Figures 18 & 19: Images of the Boston Common


3.5 User survey results

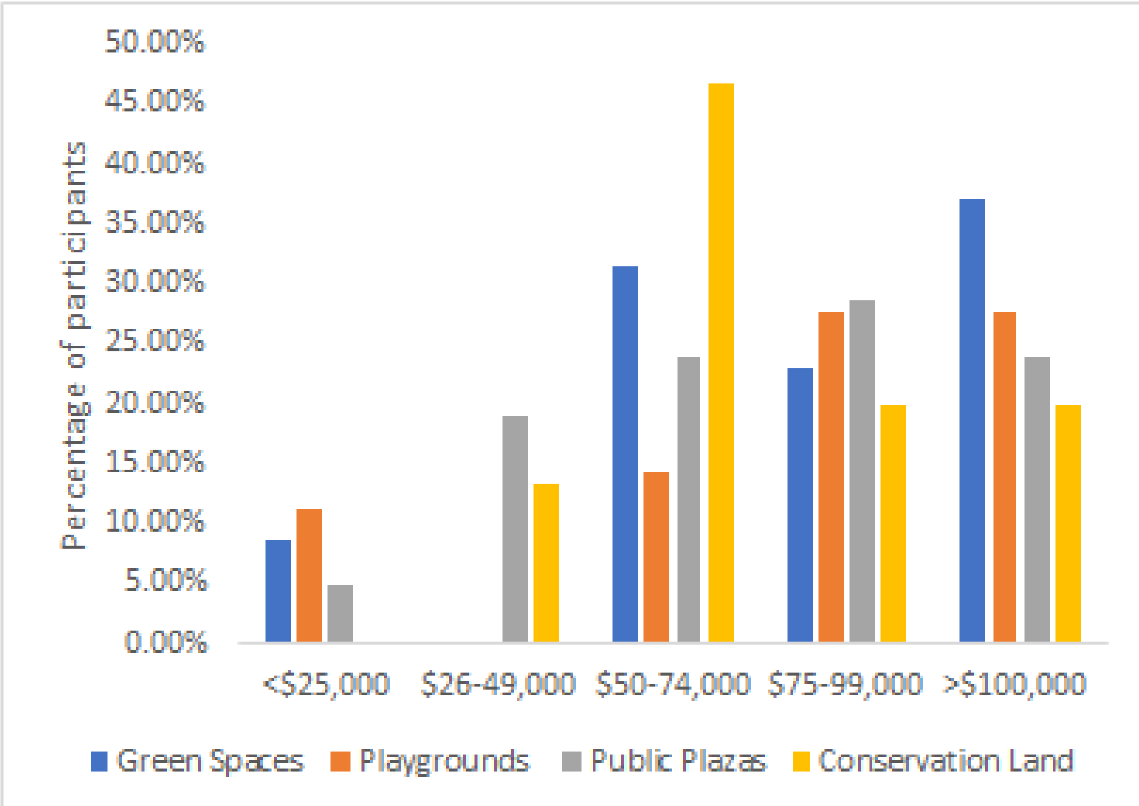
Figure 20 shows the age distribution of those surveyed within each open space category (as described in Table 5). Most open space users were between the ages of 25 and 34. There is a possible relationship between age and use of certain spaces. For instance, the green spaces sampled were much more wooded than the public plazas and conservation land. If these areas are prone to the urban heat island and are lacking in canopy cover, older people who are more vulnerable to heat may not spend time in these spaces at the time of the survey collection.

Figure 20: Age Distribution of Survey Participants by Open Space Category



The income distribution of the survey participants (shown in Figure 21) suggests that most parks are accessible to all income levels, a result which is supported by the Trust for Public Land's (TPL) Park Score data base. According to the TPL database, 98 percent of residents in the city of Boston live within a ten minute walk of a city park or playground, however the quality of these spaces varies greatly. It is not the purpose of this survey to presume a correlation between income and access to open space in the Boston area but it is relevant to issues of equity when planning for resilience to flooding. If adaptive strategies are employed issues of social equity should be address as lower income people are often housed in more vulnerable areas (Pilkey et al., 2016; Nicholls, 2011).

Figure 21: Income Distribution of Survey Participants by Open Space Category



The results of our park user survey suggest that the majority of users value the open spaces for their aesthetic and recreational benefits. Figure 22 represents the valuation of ecosystems for each of the open space categories (as described in Table 5). Despite differences in park size and location, park users valued aesthetics consistently the highest of the ecosystem values afforded by these open spaces. The aesthetic and climate control services decrease as the type of open space changes from a more natural to a more human designed space (green space to conservation land to public plazas). Gathering food and raw materials was not highly valued at any of the spaces surveyed, which is not an unexpected result in an urban setting. The reason that climate and protection from extreme weather were valued the least in the public plaza category could be because one of the sample spaces was Copley square which can become extreme hot in the summer months as the area is densely development and has limited tree cover.

Figure 23 shows the aggregated ecosystem value results from the ten surveyed open spaces (a total of 100 surveyed users) which confirms aesthetics and climate control as the most valued ecosystem services for open spaces in the Boston Harbor domain.

Figure 22: Broad Ecosystem Service Valuation by Open Space Category

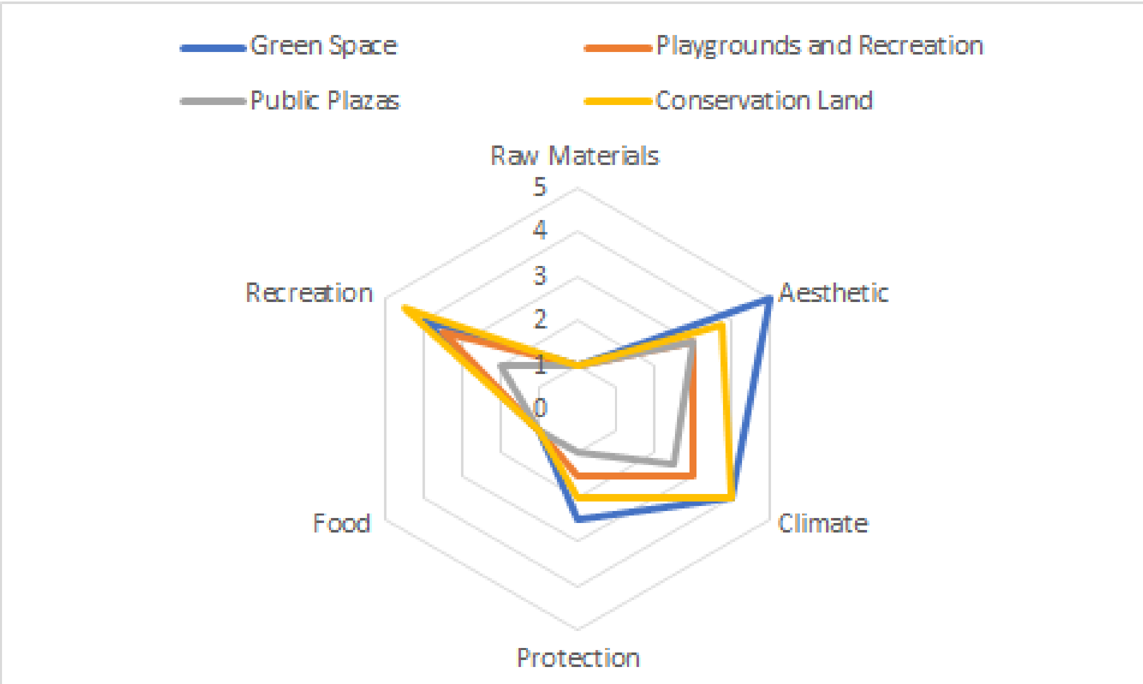
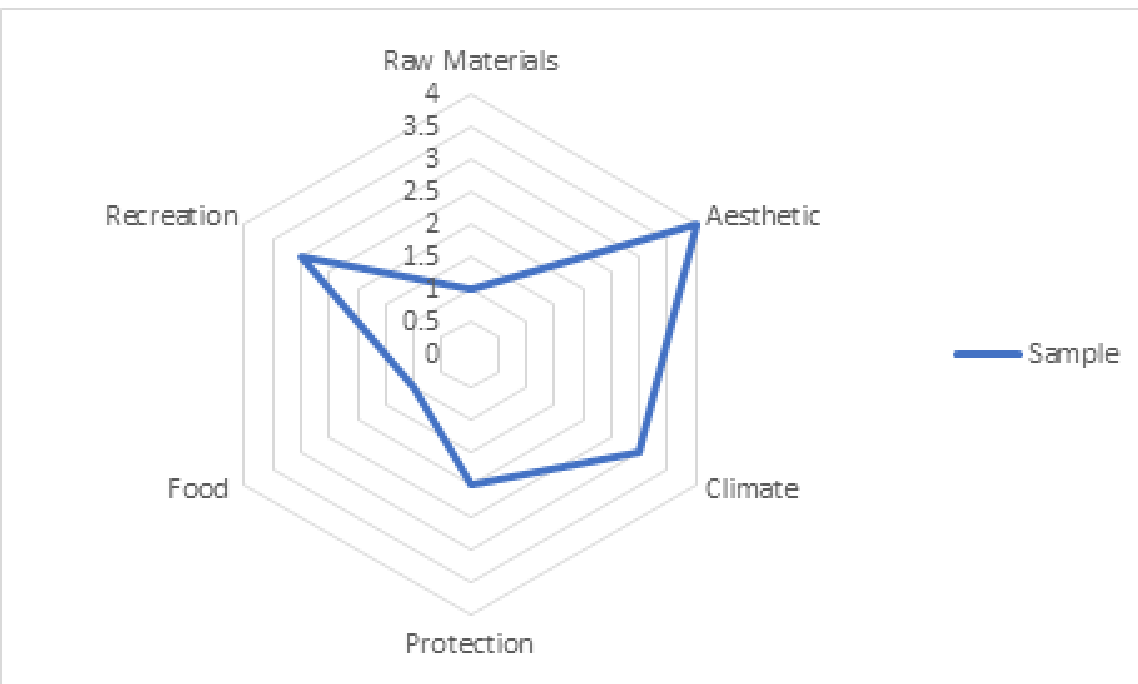


Figure 23: Broad Ecosystem Service Valuation of Entire Sample (N=100)



3.6 How can Boston leverage the value and conservation benefits of open space?

As Boston is projected to experience unprecedented storm surges and coastal flooding over the next century, the City and the Commonwealth have been evaluating options for hard infrastructure such as sea walls and harbor barriers that would protect the City from SLR and storm surge. However, given the distinct geography and history of filling tidal lands, hardened infrastructure alone is not likely to be the most efficacious or feasible solution. Similar to the approaches highlighted in the case study cities, Boston should leverage the conservation benefits of preserving its existing open space, and consider a strategic expansion of its open space inventory, as part of a resilience strategy, thereby embracing a "living with water" approach to land use planning.

Boston's open spaces not only provide recreational and aesthetic benefits to their users, they also serve as a buffer against climate change impacts, such as the extreme heat and reduced air quality. Not only are the ecosystem services provided by open spaces critical to quality of life for residents and visitors in the City (as discussed in Section 3), but they are also key components in climate resilience. But is it possible to adapt the current network of open spaces to address the issues of microclimate daily, and accommodate flood waters? We offer a few lessons from the scientific literature on the subject.

First, the objective should be to protect as much of the unprotected spaces as possible and promote infill development away from the projected flood pathways. This would prevent a loss of open spaces that would benefit a future system of floodable parks and open spaces. The economic benefits of such a system was evaluated by Brody et al (2017) who assessed the benefits resulting from the spatial configuration of open spaces in the Gulf Coast. The authors found that larger continuous patches of naturally occurring open spaces most effectively reduce losses from floods. While the scale of the study area is different from that of the Boston metro region, it remains relevant as Boston has lost or removed many of its natural defenses to coastal flooding over the course of its history (Seasholes, 2003). Beyond the ecosystem services provided by conserved open space, there are direct economic benefits of the avoided flood damages (Kousky et al, 2013), who reported that, on average, an avoided cost of $6,000 per acre could be anticipated from protected land in the 500-year flood plain of the Merac Greenway in St. Louis County, Missouri.

In our study domain, **there are approximately 2,417 acres of open space that is vulnerable to the 1% flood by 2070**, 62% (1,506 acres) of that open space is legally protected from development (as discussed in Section 1). The remaining 911 acres (38%) is unprotected and hence, vulnerable to development pressure. If we apply the $6,000 USD per acre of avoided flood cost for conserved urban open space (from Kousky et al, 2013, without adjustment for inflation or differences in land value), we estimate that the conservation benefit (as represented by avoided damage costs) of the existing protected open space inventory within the study domain is approximately $9 million annually by 2070. An additional $5.5 million in conservation benefit would be gained by protecting the 911 acres of existing open space that is currently unprotected from development. While this is a crude estimate, it highlights the enormous economic potential value of urban open spaces within Boston's resilience framework.

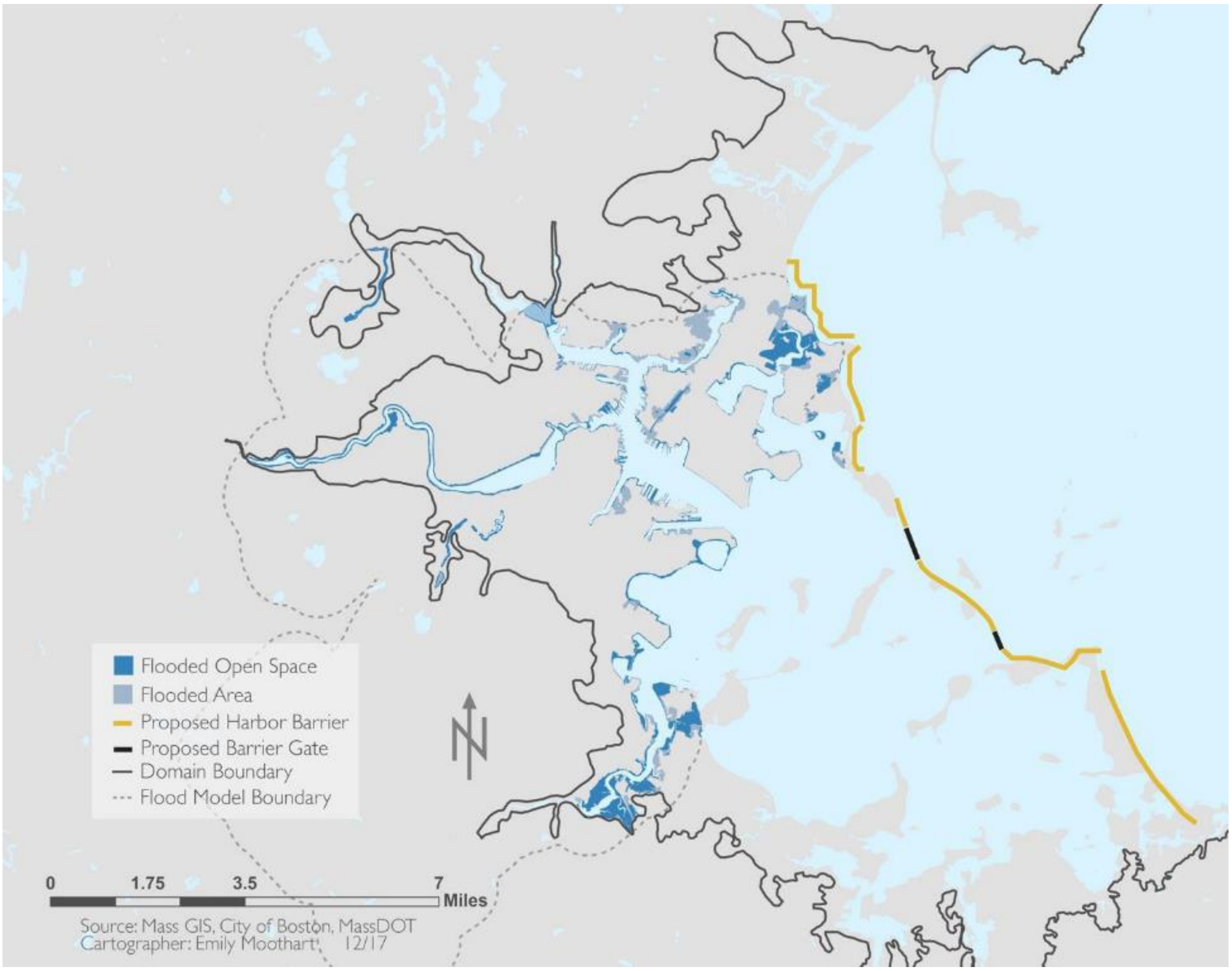
3.7 The potential impacts of a Boston Harbor Flood Barrier

3.7.1 Description and analysis of the Boston Harbor Flood Barrier

Some large coastal cities have installed or are considering storm surge barriers as a protective strategy against coastal flooding impacts. Rotterdam, for instance, is protected from storm surge by an extensive system of locks, dykes, canals and a large storm surge barrier dispersed throughout the surrounding river delta. The Dutch are global leaders in climate resilience design related to flood mitigation and prevention. The Maeslantkering storm barrier in Rotterdam protects the city from damaging storm surges but allows the harbor essential to the city's economy to remain open between weather events. A design concept to protect lower Manhattan was proposed after New York City was devastated by storm surges caused by Hurricane Sandy. The design proposal called the "Big U" was conceived as 10 continuous miles of protection tailored to respond to individual neighborhood typology as well as community-desired amenities. The proposal breaks the area into compartments: East River Park; Two Bridges and Chinatown; and Brooklyn Bridge to The Battery. Like the hull of a ship, each can provide a flood-protection zone, providing separate opportunities for integrated social and community planning processes for each. Each compartment comprises a physically separate flood-protection zone, isolated from flooding in the other zones, but each equally a field for integrated social and community planning. The compartments work in concert to protect and enhance the city, but each compartment's proposal is designed to stand on its own. The proposal utilizes some of each of the types of protective strategies while each flood prevention strategy can function in concert or isolated from the overall system.

A multidisciplinary team at the University of Massachusetts Boston has studied the potential ecological, social and economic impacts of constructing a flood protection barrier across Boston Harbor, similar in design to the Maeslantkering Barrier in Rotterdam (Kirshen et al, 2018). According to the proposed design (shown in Figure 24), the barrier would extend from the end of Deer Island, across the harbor, connect to Lovell's Island to the Hull Peninsula, which is another heavily armored land mass. The proposed design includes two different gates that would remain open under normal operating conditions and could be closed in the event of an extreme coastal storm. One gate would be wider to accommodate larger commercial ships and recreation cruise ships which frequent the harbor. The other smaller gate would allow small commercial and recreational ships to pass into the harbor. An area that has the potential to increase open space would be the buildup of Lovell's Island, which is part of the US National Park System, to accommodate the foundation of the proposed barrier. This process of expanding the island could increase the availability of open space to residents of the area, however, this method of connecting the segments of the barrier are not yet determined. The Boston harbor barrier would be designed to prevent the extent and depth of flooding projected for 1% coastal storm in 2070. However, this would not alleviate the steady encroachment of tidal flooding due to projected sea level rise over the 21st century. Figure 24 depicts the 1% coastal flood extent under current climate conditions, which under the highest projections of future sea level rise, could represent flooding at the astronomically high tide by 2100 (Douglas et al., 2013).

Figure 24: Proposed Harbor Barrier Design with 2013 Flood Extent



3.7.2 The feasibility of the Boston Harbor system

The feasibility study that evaluated various designs for a storm surge barrier (Kirshen et al., 2018) focused on barrier designs and configurations that would offer protection from coastal flooding while minimizing interference with shipping and the on harbor water quality. It also examined potential conflicts with various harbor uses, and conducted a preliminary comparison with shore-based protective solutions. The two most reasonable options for a barrier system are an Outer Harbor Barrier (OHB) from Winthrop to Hull (as shown in Figure 24) and an Inner Harbor Barrier (IHB) between Logan Airport and the Seaport area of South Boston. Each configuration would be a gated barrier system that would only be closed during flood conditions caused by storm surge. The key findings from this study are that the construction of a harbor barrier system to protect Boston Harbor communities would likely be infeasible and shore-based actions should be pursued for the following reasons:

- Because of the large gate openings necessary for shipping, neither barrier system would reduce the tidal range in the harbor and therefore, would not decrease tidal flooding that is projected to increase as sea levels rise.

- While in the early years of operation, the frequency of closure of a barrier would be no more than a few times per years, in later years, the frequency of closure would exceed the design capability of the barrier, thereby rendering it ineffective.

- A preliminary benefit to cost ratio analysis indicated that neither barrier system would be cost-effective. Benefit to cost ratios were generally well below 1.0, which is very unfavorable when compared to benefit to cost ratios of recently designed shore-based systems in Boston of 3.22 to 5.3.

- A barrier will require a very large investment all at once that cannot be adjusted over time as we learn more about future sea level rise. Hence, there is a risk of over or under investment depending on the actual trajectory of future sea levels. An alternative of shore-based solutions offers the possibility of incrementally investment over time and provides many co-benefits to local communities.

- The increased water velocities through the barrier gate openings could cause navigational and safety issues for both recreational and commercial vessels. The OHB configuration could also impact the abundance, distribution, and behavior of fish populations, which would in turn impact both commercial and recreational fisheries.

The details of the analysis and results can be found in Kirshen et al. (2018).

3.7.3 Would construction of a harbor barrier impinge on Boston's existing open spaces?

If a harbor barrier were to be constructed, large amounts of open space would be needed for the manufacture and assemblage of its parts. Similarly, the development of the components for off shore wind energy requires large amounts of open space. According to a recent report published by Massachusetts Clean Energy Center (MassCEC) and the Urban Harbors Institute (MassCEC, 2017), infrastructural staging for wind energy production would not impede on existing public open spaces or conservation land as staging and construction would occur offsite using commercial sites. In fact, Article 97 of the Commonwealth of Massachusetts prohibits the sale, transfer, relinquishment, release, alienation, or change of the control or use of any right or interest of the Commonwealth in land that falls within this statute. The majority of open space within the study domain (~90%) is protected from development and land transfer, most of it by Article 97, hence it is unlikely that these lands would be used as infrastructural staging areas during construction of a harbor barrier.

Task 4: What role can urban open spaces play in mitigating the impacts of coastal flooding?

<u>4.1 Overview of coastal resilience approaches</u>

More than 2.5 million people globally live within 60 miles of the coastline (Barbier 2015). As a result, coastal cities around the world are facing increasing impacts from sea level rise and coastal flooding. Environmental planners, policy makers, and communities should consider current open spaces as important assets in flood mitigation strategies. Protecting existing open spaces from development and land acquisition in flood plains can be a very effective flood mitigation strategy. Brody et al (2015) evaluated the effectiveness of open space protection as a flood mitigation strategy on the local level in the Gulf Coast. They measured the amount of open space protection under FEMA's Community Rating System (CRS) for a representative national sample to test the efficacy during the period of 1999 to 2009. The results indicated that open space protection is an important land use planning tool for flood mitigation, however, the authors generally advocate for a managed retreat plan as an avoidance strategy, removing property and infrastructure from vulnerable areas. The idea of a planned retreat is not attractive to most coastal communities as their economies are heavily dependent on the value of their waterfront property and access to marine resources.

Adaptive resilience theory emphasizes a "living with water" approach to land use planning in the face of rising seas (Nicholls, 2011). In the case of Boston, the adaptive resilience approach would be most beneficial as a full retreat is not plausible under current governance and social structure and perceptions of threat (Harman et al, 2015). In order to preserve the current urban fabric that supports a robust system of open public spaces and amenities, Boston should consider a robust approach based on the framework of protect, accommodate, and retreat. Harman et al (2015) designed this framework originally in the context of the Australian Gold Coast, but also discussed this approach in the United States context. The emphasis in this framework pertains to the construction of hard and soft infrastructures to protect vulnerable coastal areas from inundation. Hard infrastructure refers to the construction of heavily engineered structures such as dams, levees, dikes, and storm barriers which are currently the most implemented flood protecting strategies in developed nations (Harman et al, 2015; Nicholls, 2011). Soft or "green" infrastructure uses or enhances natural ecological functions (e.g., beach nourishment and sand dune restoration) to prevent damage from coastal inundation. In urban communities, green infrastructure often compliments seawalls and other hardened defenses. Beach nourishment has been one of the preferred methods of erosion and inundation control along coastal parts of the United States, particularly in the Atlantic and Gulf Coast states (Trembanis, Pilkey, and Valverde, 1999).

Living shorelines are another type of coastal defense approach which is described by Scyphers et al. (2011) as "a suite of bank stabilization and habitat restoration techniques to reinforce the shoreline, minimize coastal erosion, and maintain coastal processes while protecting, restoring, enhancing and creating natural habitat". A living shoreline can provide a more flexible adaptable alternative to hard defenses and can create additional amenities such as new open spaces. One example of this strategy being implemented in the United States is the GreenShores project in Florida, which created a living shoreline of more than 30 acres of oyster reefs, salt marsh, and sea grass habitat along 2 miles of urban waterfront (Harman et al., 2015).

Some cities are taking a changing climate and rising seas as an opportunity to create new parks and enhance others to mitigate flooding and storm surge inundation. Figure 4 suggests that later in the 21st century, less than a quarter of all flooded area in the Boston Harbor domain is open space, suggesting that creating more open space as part of a larger resilience strategy should be considered here as well.

4.2 Resilience approaches that incorporate open space that could be used in Boston.

Boston is ranked as the 8th most at risk city according to the overall cost of damage (Hallegatte et al. 2013), but has only just begun the process of preparing for future flooding impacts. Figure 4 suggests that open spaces represent about half of the land area currently vulnerable to the 1% coastal flood, hence open space could play an important role. In order to understand the range of options that could be available to Boston, we investigated the approaches of four other coastal cities that are facing challenges and threats similar to Boston. These cities were selected using criteria derived from 100 Resilient Cities Initiative of the Rockefeller Foundation (https://www.100resilientcities.org/). Because the construction of a harbor barrier system to protect Boston and the surrounding communities is likely to be infeasible, we focused on evaluating how urban open spaces can be utilized as part of an on-shore flood mitigation strategy.

The 100 Resilient Cities initiative provided a standardized framework for our selection of case study cities. Four categories of 'Shocks and Stresses' were specifically chosen as selection criteria: 1) coastal/tidal flooding 2) sea level rise/coastal erosion 3) climate change 4) severe storms. In addition to these criteria, the case study cities were chosen based on similarities in city infrastructure and urban form. The cities selected based on these criteria are New York City, Rotterdam, New Orleans, and San Francisco. For more details on the selections process and comparison, see Moothart (2018). A brief description of each case study city is given below.

4.2.1 New York City, New York

New York City is the largest city in the United States, with over 8.5 million residents and is approximately 400-year-old city. On average, NYC hosts 60 million visitors per year. In 2015, New York City released its resilience strategy, OneNYC (The City of New York 2015). This report is not the first of its kind in New York City. There have been previous sustainability strategies produced by PlaNYC in 2007, 2011, and 2013 which focused on growth, sustainability, and resilience. While these goals are still fundamental in the OneNYC program, three new approaches have been added: 1) a focus on inequality 2) a regional perspective 3) leading the change we need. The timeline to achieve the goals in the report ranges from 2030-2050. Additionally, focus areas include community strengthening, new climate projections, focus on heat, land use policy, as well as an updated federal agenda (The City of New York 2015). The table below addresses OneNYC's primary visions for the 2015 report (see Table 6).

Table 6: OneNYC's Vision's for Resilience

Vision	Description
Our Growing, Thriving City	New York City will continue to be the world's most dynamic urban economy where families, businesses, and neighborhoods thrive.
Our Just and Equitable City	New York City will have an inclusive, equitable economy that offers well-paying jobs and opportunity for all to live with dignity and security
Our Sustainable City	New York City will be the most sustainable big city in the world and a global leader in the fight against climate change.
Our Resilient City	Our neighborhoods, economy, and public services are ready to withstand and emerge stronger from the impacts of climate change and other 21st century threats.

Source: OneNYC, 2015 (The City of New York 2015).

The OneNYC 'Visions' are backed by specific initiatives. While there are 94 initiates in the OneNYC 2015 report, the 'Vision 4: Our Resilient City' is the most relevant for this project. Specific initiatives related to improving the resilience of neighborhoods, buildings, infrastructure and coastal defense are outlined in the report along with the agencies responsible for each initiative and funding sources. While, the OneNYC 2015 report does not specifically examine the vulnerability of coastal open spaces in NYC as we have done for Boston, it does provide some insights as to how the city is thinking about open spaces. Two of the main concerns are **access to open spaces and the maintenance and enhancement of existing public open spaces**. *Parks Without Borders*[7] is a $50 million effort created in response to these concerns. The organization's purpose is to redesign and create parks to be more accessible by reducing barriers such as fences and by better utilizing spaces with more gathering areas and seating (see examples in The City of New York 2015).

Below are additional organizations formed to aid in the NYC resilience effort:

- **East Side Coastal Resiliency Project**: The East Side Coastal Resiliency (ESCR) Project[8] seeks to strengthen the projection of 2.2 miles of coastline through the creation of a system of berms. These berms provide protection during storm surge and SLR while providing a community-friendly open space accessible to the waterfront for all to enjoy. The ESCR Project[6] report shows conceptual designs for this system of berms.

- **Waterfront Revitalization Program**: In addition to the OneNYC, the Waterfront Revitalization Program (WRP)[9] serves as the city's primary coastal zone management tool. They establish policies 'for the development and use of the waterfront and provides a framework for evaluating the consistency of activities in the Coastal Zone with those policies" ("The New York City Waterfront Revitalization Program" 2016). In 2017, the WRP

[7] https://www.nycgovparks.org/planning-and-building/planning/parks-without-borders
[8] http://www.nyc.gov/html/planyc/downloads/pdf/150319_ESCR_FINAL.pdf
[9] http://www1.nyc.gov/site/planning/applicants/wrp/wrp.page

released the 'Climate Change Adaptation Guidance' which specifically addresses how agencies should adhere to the WRP's Policy 6.2 (Program 2017). **This specific policy's purpose is to plan and design the city's coastal zone according to the New York City Panel on Climate Change's projections for climate change and SLR in NYC.** It further requires that "projects should consider potential risks related to coastal flooding to features specific to each project, including, but not limited to, critical electrical and mechanical systems, residential living areas, and public access areas" ("The New York City Waterfront Revitalization Program" 2016. pg. 22). This policy, as well as the guide itself, increases accountability to agencies to adhere to the goals of the OneNYC reports and make more progressive strides to a more resilient waterfront.

- **NY Rising Community Reconstruction**: In response to Hurricane Sandy, the NY Rising Community Reconstruction (NYRCR) Program[10] was developed, using federal funding, to "support the planning and implantation of community-developed recovery and resiliency projects" ("NY Rising Community Reconstruction Program" 2018). **A component of this program included voluntary buy-outs for properties severely affected by Sandy**. In place of these properties, coastal floodplains were restored, thus lessening the effects storm surge and SLR on the community and infrastructure as well as creating open spaces for New Yorkers to enjoy ("Challenges and Solutions for Coastal Resiliency in New York" 2018).

4.2.2 New Orleans, Louisiana

New Orleans is a neighbor to the Mississippi River delta as well as the Gulf of Mexico. With a population of approximately 350,000, the poster-child city for hurricane destruction is now thriving and eager to come back stronger and more resilient than ever before. Hurricane Katrina flooded portions of New Orleans in 2005 and displaced 1.2 million people, resulting in approximately $110 billion dollars in damage and 1,800 deaths (Barbier 2015). The state of Louisiana established the Coastal Protection Restoration Authority (CPRA) in response to Katrina's damage on the coast. In 2017, the state legislature approved the Coastal Master Plan which will cost an estimated $50 billion dollars over the next 50 years. In this plan, the state will create marshes, divert sediment, and construct restoration projects, structural protection projects, and nonstructural risk reduction projects (Louisiana's 2017). The CPRA is mandated to implement and enforce the Master Plan while working with local, state, and federal agencies.

In addition to the state-level Coastal Master Plan, the City of New Orleans established the Office of Resilience and Sustainability. In 2015, the city released a report entitled Resilient New Orleans (Hebert 2015) outlining three main visions for the city's future (see Table 8).

Table 7: New Orleans' Visions for Resilience

Vision	**Description**
Adapt to Thrive	We are a city that embraces our changing environment.
Connect to Opportunity	We are an equitable city.
Transform City Systems	We are a dynamic and prepared city.

Source: Resilient New Orleans, 2015. (Hebert 2015)

[10] https://stormrecovery.ny.gov/community-reconstruction-program

As with OneNYC 2015, Hebert (2015) outlines the featured resilience actions, lead organization and current status. Specific to open/green space initiatives, New Orleans is piloting a 'Resilience District' in the Gentilly neighborhood that was funded through a $141 million grant from the US Department of Housing and Urban Development's National Disaster Resilience Competition[11]. The goal of this project is to "reduce flood risk, slow land subsidence, and encourage neighborhood revitalization" (Office of Resilience and Sustainability 2018). This effort will include creating a water garden, stormwater network, blue and green corridors, green streets, wetlands, and an adaptation program for the neighborhood residents. Conceptual designs for these solutions can be found in Office of Resilience and Sustainability (2018).

4.2.3 Rotterdam, Netherlands

The city of Rotterdam, Netherlands, is over 700 years old and is home to 600,000 residents. Not only is Rotterdam the second largest city in the Netherlands, but it is also the largest port city in Europe (Gupta 2013). The city is almost 80% below sea level, and has an ambitious goal to be 100% 'climate-proof' by 2025 ("100 Resilient Cities," n.d.).

Rotterdam released its resilience strategy in 2016. A unique aspect of this strategy is that, rather than relying on government-led resilience efforts, the city is encouraging many small projects led by citizens and businesses in addition to 'effective large-scale projects' (Gemeente Rotterdam 2016). The focus of this strategy is on *rainwater as an ecosystem service that can be utilized for the good of the people rather than a threat*. Table 10 lists Rotterdam's resilience goals that are included in resilience strategy report.

Table 8: Rotterdam's Resilience Goals

Resilience Goals for Rotterdam
1) Rotterdam: A balanced society
2) World port city built on clean and reliable energy
3) Rotterdam Cyber Port City
4) Climate resilient Rotterdam to the next level
5) Infrastructure ready for the 21st century
6) Rotterdam Networkcity—truly our city
7) Anchoring resilience in the city

Prior to Rotterdam's 2016 resilience strategy, the city had developed the Rotterdam Climate Change Adaptation Strategy in 2013. The strategy aimed to: "a) strengthen a robust system of flood, storm water surge and sea-level rise defenses; b) adapt the urban space to combine its three functions: 'sponge' (water squares, infiltration zones and green spaces), protection (dykes and coastal protection) and damage control (evacuation routes, water resistant buildings and floating structures); c) increase city resilience through integrated planning; d) foster the opportunities that climate change brings, such as strengthening the economy, improving the

[11] https://nola.gov/resilience/national-disaster-resilience-competition/. Other winners of this grant include New York City (awarded $176,000,000), and the states of New York ($35,800,000) Connecticut ($54,277,359) and New Jersey ($15,000,000), which are also places that had the highest storm surge during Hurricane Sandy in 2012.

quality of life, and increasing biodiversity" (C40 Cities Climate Leadership Group 2016). Since the 2013 report was released, many 'climate-proof' ideas have taken shape, including the ones below:

- **Water Squares:** Rotterdam is developing water squares in open spaces such as playground or plaza areas. These water squares are able to sequester excess rainwater via pumps during storm events. The water passes through a filter before filling up the water square where it can be retained until the water levels are back to normal. More details about water squares and design renderings can be found in "Water Squares: Playgrounds Doubling as Water Storage," (n.d.).

- **Tidal Parks:** Another innovative resilience development in Rotterdam is the concept of the Tidal Park. This park is intentionally created in the tidal zone along the coast. A gradually sloping bank serves as a breakwater during storm surge events. The construction of these parks will also increase public access to the waterfront and could serve as an urban wetland ("Tidal Park," n.d.). In Boston in particular, a tidal park would be beneficial in the estuaries of the Mystic, Charles, and Neponset Rivers.

- **Floating Pavilions:** In addition to retrofitting existing infrastructure, Rotterdam is testing 'climate-proof' technology, such as the floating pavilion, a three-dome floating island of sorts that can be used for large group functions up to 400 people (see images in Floating Pavilion 2015). The building is powered with solar energy, every 'wall' is a window, and toilet water is cleaned on the structure. There are limited waves where the pavilion is stationed, and very little shipping traffic. This pavilion is the first of Rotterdam's climate-proof efforts as a part of the Rotterdam Climate Initiative ("Floating Pavilion" 2015).

4.2.4 San Francisco, California

Located on the western coast of the United States, San Francisco has suffered a variety of disasters from drought, earthquakes over its history, and now must also face sea level rise (SLR). Current projections indicate approximately 66 inches (5.5 feet) of SLR will be impacting the coastline by 2100. Table 11 outlines San Francisco's resilience goals that were a part of their Resilience Strategy that was released in 2016 (City and County of San Francisco 2016).

Table 9: San Francisco's Resilience Goals

Resilience Goals for San Francisco
1) Plan and prepare for tomorrow
2) Mitigate, Adapt and Retrofit
3) Ensure Housing for San Franciscans Today and After a Disaster
4) Empower Neighbor and Neighborhoods through Improved Connections

The Bay Area: Resilient By Design Challenge[12] recently released its nine finalist projects that can now be actively supported by local agencies. All selected projects included the utilization of existing and/or new open spaces as part of their resilience strategies. One of the projects, the Resilient South City[13], **seeks to create a network of public open space while reducing flooding risks to the city and restoring native vegetation**. This design incorporates terraced bank which serve as seating and recreational space for walkers and bicyclists, but then will be able to serve as flood protection during severe storms (see design renderings "Bay Area Resilient By Design Challenge" 2018).

Another project, ouR-HOME[14] proposes to bring the 'Marsh to Main Street' by creating a horizontal levee. This space will function as a transition zone for the marsh to move as the seas become higher. This also provides residents with access to open space as well as safe bike lanes (City and County of San Francisco, 2016).

In San Francisco's resilience plan, they also outline SLR planning options for accomodating, protection, and retreat. One such option incorporates a planned retreat from the coast while emplacing a berm, coastal recreational trail, and a seasonal wetland that would be critical in protecting infrastructure from storm surge and coastal flooding events [see before and after design renderings in City and County of San Francisco (2016)]. In addition to the Ocean Beach Master Plan, the city also suggests stepped terraces and strategic site grading to coastal open spaces. This naturally allows the landscape and the water to meet, while serving as waterfront recreational space for residents (City and County of San Francisco 2016).

4.3 Summary of approaches for incorporating open/green spaces into resilience planning.

While the individual characteristics and governance structures of the selected cities noted above may differ, there are common approaches that can be applied by Boston and the surrounding coastal communities for incorporating open space in flood mitigation and climate resilience strategies.

Approach 1: The use of existing federal initiatives and funding structures for resilience planning.

From the U.S. Department of Housing and Urban Development (HUD) to state agencies to city programs, there are existing resources that can be leveraged as seed grants and pilot initiatives in resilience planning. NYC funneled some of the Hurricane Sandy disaster relief bill funding (an increase in the National Flood Insurance Program appropriations) into resilience initiatives to both restore and create natural features (e.g., saltmarshes, wetlands, beach dunes) to make hard-hit areas more resilient to future storm events. New Orleans leveraged funding from a HUD disaster relief program to develop and design resilient districting. Admittedly, both cities were devastated by recent storms, but the success of these initiatives could lead to future appropriations for resilience efforts before disasters hit.

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[12] http://www.resilientbayarea.org/

[13] http://www.resilientbayarea.org/south-san-francisco/

[14] http://www.resilientbayarea.org/north-richmond/

Approach 2: The development of innovative state agencies and local organizations dedicated to resilience.

In addition to, or perhaps as a result of, the destruction from natural disasters and the availability of federal resources, both NYC and New Orleans have created state and local agencies and organizations with missions to address resliency. The *New York City Panel on Climate Change* (NPCC)[15] was created to synthesize the lastest scientific research and create a report for direct use in resilience planning. *OneNYC* combines the long-term goals of reducing social inequity and increasing access to green space as part of its resilience strategy. Louisiana established the *Coastal Protection Restoration Authority* and approved the Coastal Master Plan, which will create structural and nonstructural risk reduction projects and restore coastal ecosystems to increase the future resilience of New Orleans and other coastal cities.

Approach 3: The engagement of multi-level stakeholder communities in design and planning.

The Cities of Rotterdam and San Francisco (as well as Boston) initiated design competitions that encouraged creative thinking and collaborative design for specific neighborhoods and vulnerable populations. Rather than viewing increased frequency of stormwater flooding as a problem, Rotterdam redefined stormwater runoff as a beneficial ecosystem service that can be channeled into increasing biodiversity and green space for its citizens. San Francisco enlisted resident stakeholder groups to develop innovative plans that meet the specific needs of their communities. The Boston Living with Water[16] design competition had a similar focus but engaged mostly professional companies and universities to do the same.

Approach 4: The recognition that open/green spaces are valuable assets that have inherent social and natural resilience benefits within the urban landscape.

Whether stated explicitly in the resilience plans or inferred from the resulting initiatives, urban open spaces play an essential role in preserving and enhancing the resilience of urban communities. The preservation, restoration and creation of urban open spaces is an essential component of most (if not all) resilience plans and initiatives. This recognition is particularly meaningful in Boston, which is home to the Boston Common, the nation's first public park[17] and the Emerald Necklace[18], designed by Frederick Olmsted to connect parks and people within Boston. Boston could enhance its existing resilience planning by continuing to preserve, protect and expand its inventory of open/green spaces for the purpose of social and natural resilience.

[15] http://www1.nyc.gov/site/orr/challenges/nyc-panel-on-climate-change.page
[16] http://www.bostonlivingwithwater.org/
[17] https://www.boston.gov/parks/public-garden
[18] https://www.emeraldnecklace.org/

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Appendix A: Description of Boston Harbor Flood Risk Model Raster Data

Boston Harbor Flood Risk Model Raster Datasets

These raster datasets are derived from output of Version 3 of the Boston Harbor Flood Risk Model (BH-FRM) for 2013, 2030, 2070/2100 sea level rise and coastal storm simulations as described in the report MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability and Adaptation Options for the Central Artery/Tunnel System (Pilot Project Report).

Details of the project and model are described in the Pilot Project Report which is available for download here:

https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_Report_MassDOT_FHWA.pdf (PDF 16mb).

For each of these three simulations, the model output is provided as three separate raster datasets: (1) estimated coastal flood exceedance probabilities (CFEP), (2) estimated flood depths for 1% CFEP, and (3) estimated flood depths for 0.1% CFEP. Each dataset has been spatially interpolated to facilitate visual interpretation. Locations located near boundaries of a probability zone may or may not be within the probability zone due to mapping inaccuracies and interpolation between model nodes. Due to the nature of the project and BH-FRM development, nodal spacing varies. The rasters will interpolate the values between model nodes and create probabilities that may be inaccurate between model nodes. Therefore, care should be taken when using the raster data to evaluate site-specific properties or locations. By accessing these data, the user agrees with the terms herein and understands the limitations of the data provided.

These raster datasets represent Version 3 of the BH-FRM model results and are being provided as nine individual BH-FRM zip files (*.zip), the BH-FRM Frequently Asked Questions (FAQ), this ReadMe file, and two additional zip files: (1) the associated metadata and (2) a shapefile that represents the BH-FRM Study Area Buffer as described in the metadata. The extent of these datasets is limited to the Central Artery and Tunnel (CA/T) project domain including the Cities of Boston and Cambridge, Massachusetts. Version 3 of the BH-FRM model output includes updates in four specific areas: Allston, Morrissey Boulevard, Prudential Tunnel (I-90/MassPike) and Muddy River. Additionally, data quality checks were performed throughout the domain resulting in minor changes from Version 2.

These datasets are provided without any guarantees or warranty. In association with the product, MassDOT makes no warranties of any kind, either express or implied, including but not limited to warranties of merchantability, fitness for a particular purpose, of title, or of noninfringement of third party rights. Use of these datasets by a user is at the user's risk. This information cannot be used for the purpose of boundary resolution or location. This information is not intended for use as a flood insurance determination, nor should it be directly related to FEMA FIRM maps or data since these data and FEMA data are for different purposes.

Each BH-FRM v3 zip file listed below contains one raster dataset in Esri GRID format and an associated ArcGIS 10.1 layer file to facilitate the recommended symbology. For ArcMap users, we recommend first adding the layer file to your MXD and then setting the data source to the associated raster dataset. The symbology in these layer files also provides the conversion between raster values and the CFEP as %, or the depth as feet (see the metadata for additional details on the raster values). For other users, the recommended symbology is described in the metadata.

These datasets are provided for discussion and research purposes only. It is not appropriate to use these datasets for detailed analysis (i.e., at the community or parcel level). Users should be aware that this dataset is interpolated from detailed results and are best used for planning and visualization purposes only. Users should not use these data for critical applications without a full awareness of its limitations. Please see full Pilot Project Report for additional information on methodology and limitations.

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BH-FRM zip file names below

File Name
    Description

MassDOT_CAT_BH-FRM_Raster_metadata.zip
    BH-FRM Raster metadata

BH-FRM_StudyAreaBuffer.zip
    BH-FRM Study Area Extent (shapefile)

BH-FRM_FAQ_Rev11-14-2014.pdf
    BH-FRM Frequently Asked Questions

BH-FRM_2013_Probability_v3.zip
    BH-FRM Coastal Flood Exceedance Probabilities (CFEP) for 2013

BH-FRM_2013_Depth_1percent_v3.zip
    BH-FRM Flood Depths for 2013 at 1% CFEP

BH-FRM_2013_Depth_0.1percent_v3.zip
    BH-FRM Flood Depths for 2013 at 0.1% CFEP

BH-FRM_2030_Probability_v3.zip
    BH-FRM Coastal Flood Exceedance Probabilities (CFEP) for 2030

BH-FRM_2030_Depth_1percent_v3.zip
    BH-FRM Flood Depths for 2030 at 1% CFEP

BH-FRM_2030_Depth_0.1percent_v3.zip
    BH-FRM Flood Depths for 2030 at 0.1% CFEP

BH-FRM_2070_Probability_v3.zip
    BH-FRM Coastal Flood Exceedance Probabilities (CFEP) for 2070/2100

BH-FRM_2070_Depth_1percent_v3.zip
    BH-FRM Flood Depths for 2070/2100 at 1% CFEP

BH-FRM_2070_Depth_0.1percent_v3.zip
BH-FRM Flood Depths for 2070/2100 at 0.1% CFEP

Appendix B: Open Space User Survey Summer 2017

Interviewer: _________________________
Location: _________________________
Date: _________________________

Introduction

My name is _______________________ and I am a student with the University of Massachusetts Boston, we are working with the Lincoln Institute of Land Policy in Cambridge studying open spaces in the Boston metro area that are vulnerable to future climate events such as coastal flooding and storm surges due to extreme weather events.

Would you be willing to take a few minutes to answer a few questions on this topic?

This survey will take about ten minutes and is completely voluntary, your responses will be kept completely confidential and you may refrain from answering any question that makes you feel uncomfortable. You may end your participation in the survey at any time.

Part I: General Information about your park use

1. How often do you visit this park?
   a. Rarely
   b. Sometimes
   c. Often (more than a few times a week)
   d. First time visiting

2. Do you visit other parks in the Boston Metro Area?
   a. Yes
   b. No

3. If yes, which parks:

4. How much time do you usually spend here on an average visit?
   a. A few minutes
   b. About an hour
   c. More than an hour
   d. Several hours

5. On a scale of 1-5, how much do you value having this park/open space? ___________

5- essential 4- very important 3- important 2- somewhat unimportant 1- unimportant

6. On a scale of 1-5, how important are the following services this park provides:

5- essential 4- very important 3- important 2- somewhat unimportant 1- unimportant
   a. Recreation (eg. exercise, team sports, boating) _____
   b. Aesthetic appreciation ______
   c. Climate control _____
   d. Protection from extreme weather_____

e. Food from animals/plants _____
f. Raw materials from animals/ plants _____

7. If you couldn't access the park, would you be able to get these services in another place?
   a. Yes
   b. No

8. If yes, Where?
   a.____
   ____

9. How do you usually travel to the park?
   a. Walk
   b. Bicycle
   c. Automobile
   d. Bus or train

10. Where are you traveling from?
   a. Home
   b. Work
   c. Out of town (tourism)

11. On a scale of 1-5, how concerned are you that sea level rise or extreme weather will prevent your use of this park/open space?
   1. Never thought about it
   2. Not concerned
   3. Unsure
   4. Somewhat Concerned
   5. Very Concerned

Part II: Demographic information:
12. Gender?
   a. Male
   b. Female
   c. Other ______________________

13. What neighborhood/town do you live in?
a. ______________________________

14. Which age group do you belong to?
   a. 18-24
   b. 25-34
   c. 35-44
   d. 45-54
   e. 55-64
   f. 65+

15. Which category best describes your ethnicity?
   a. Native American
   b. Black/ African American
   c. Asian/ Pacific Islander
   d. Hispanic/ Latin American
   e. Caucasian/ White
   f. Other: ______________________________

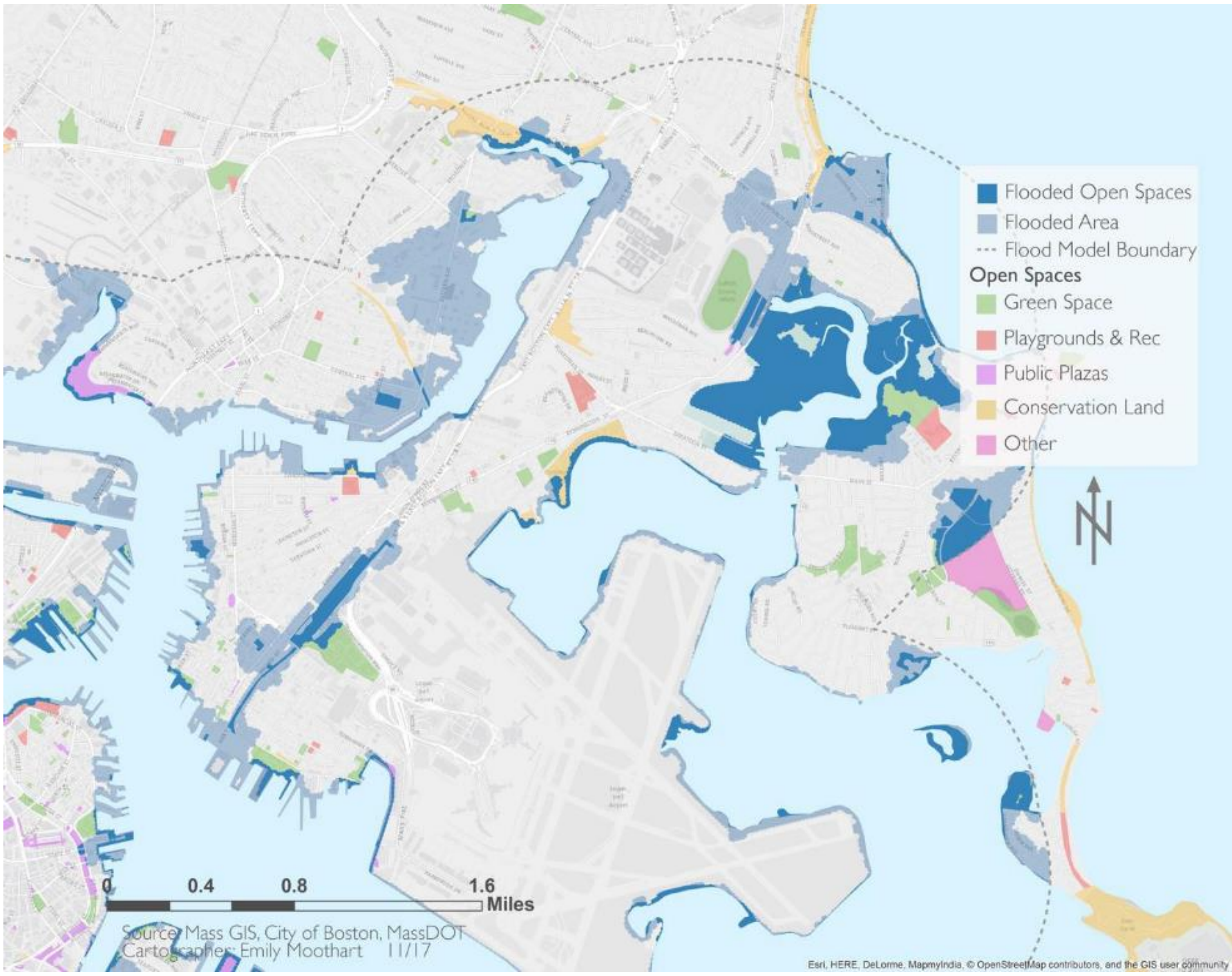
16. Which category best describes your household income?
   a. Less than $25,000
   b. Between $26,000 and $49,000
   c. Between $50,000 and $74,000
   d. Between $75,000 and $99,000
   e. More than $100,000

17. Are there any other ways this park is important to you?

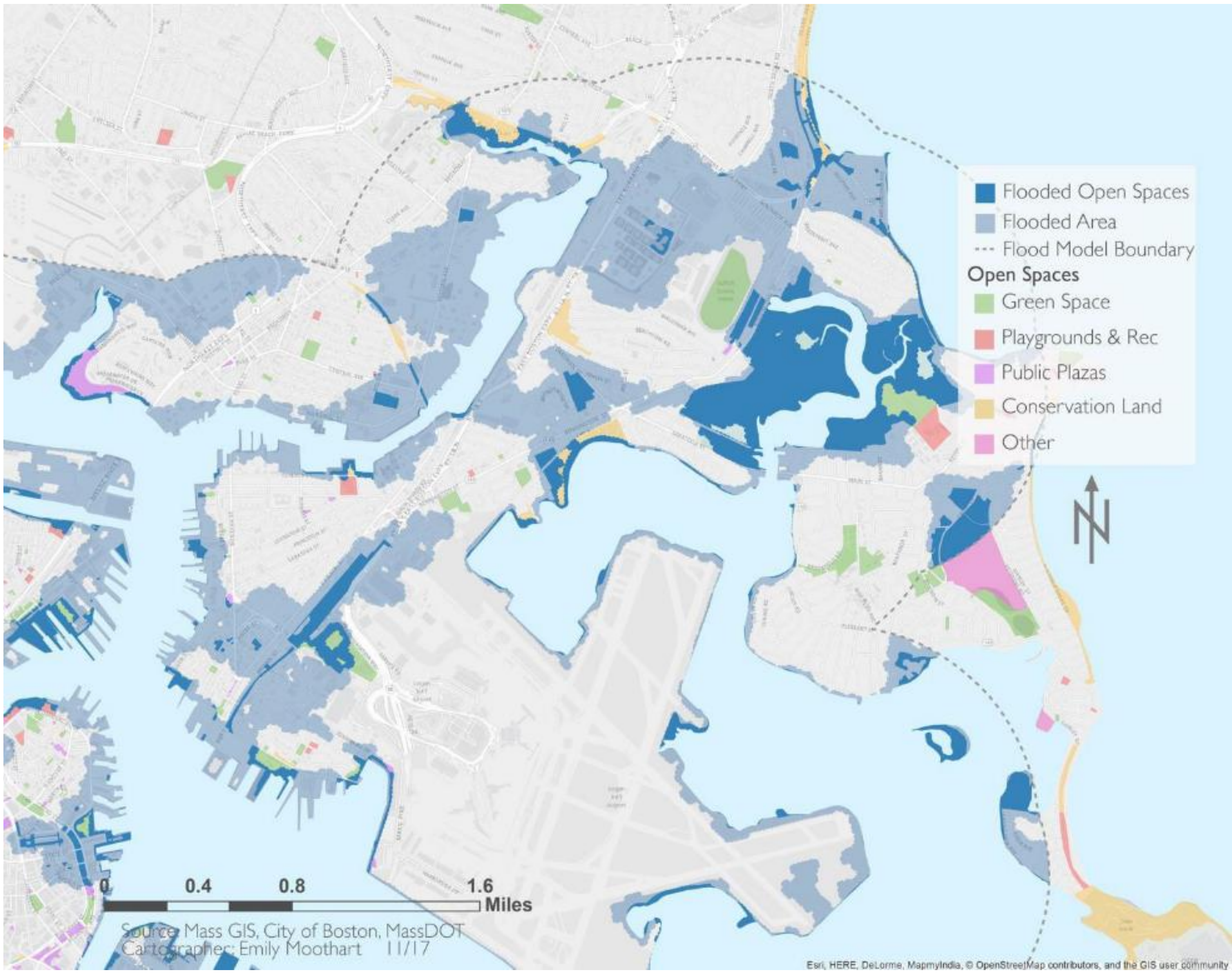
____
____
____
____
____

Appendix C: Inset Flood Maps for Cambridge, East Boston, Downtown Boston, and UMass-Boston in 2013 and 2030

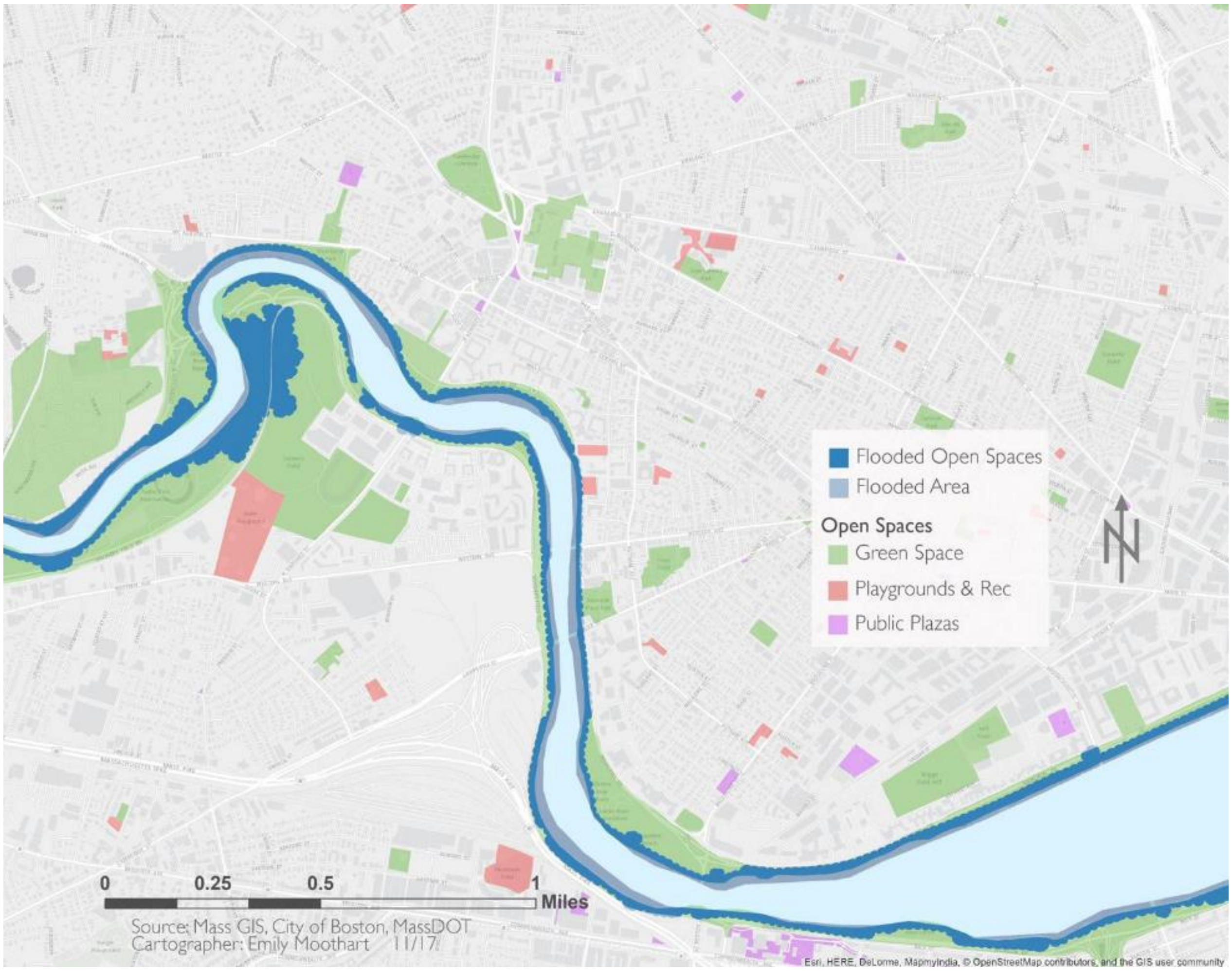
1% CFEP Flood Extent of East Boston in 2013:



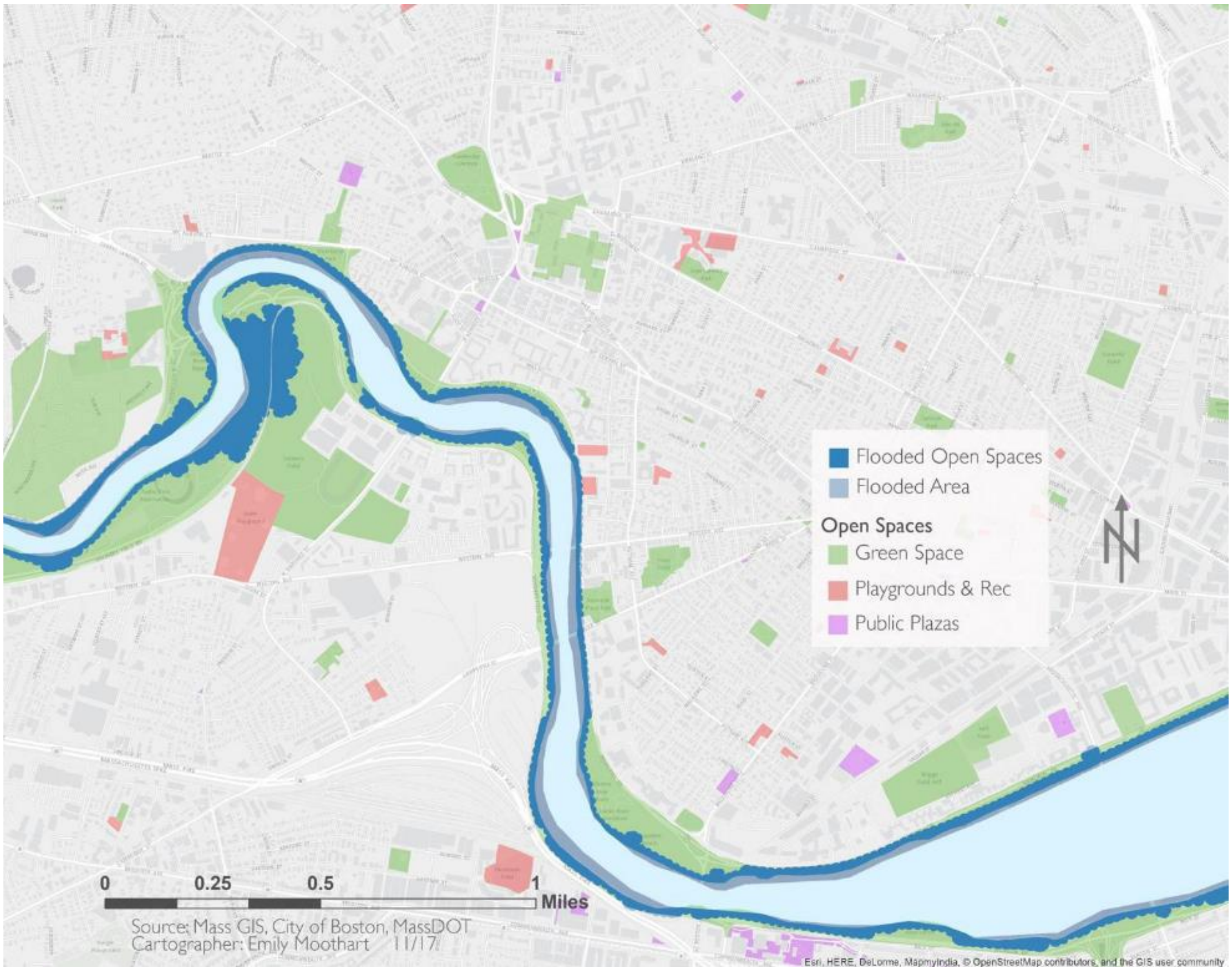
1% CFEP Flood Extent of East Boston in 2030:



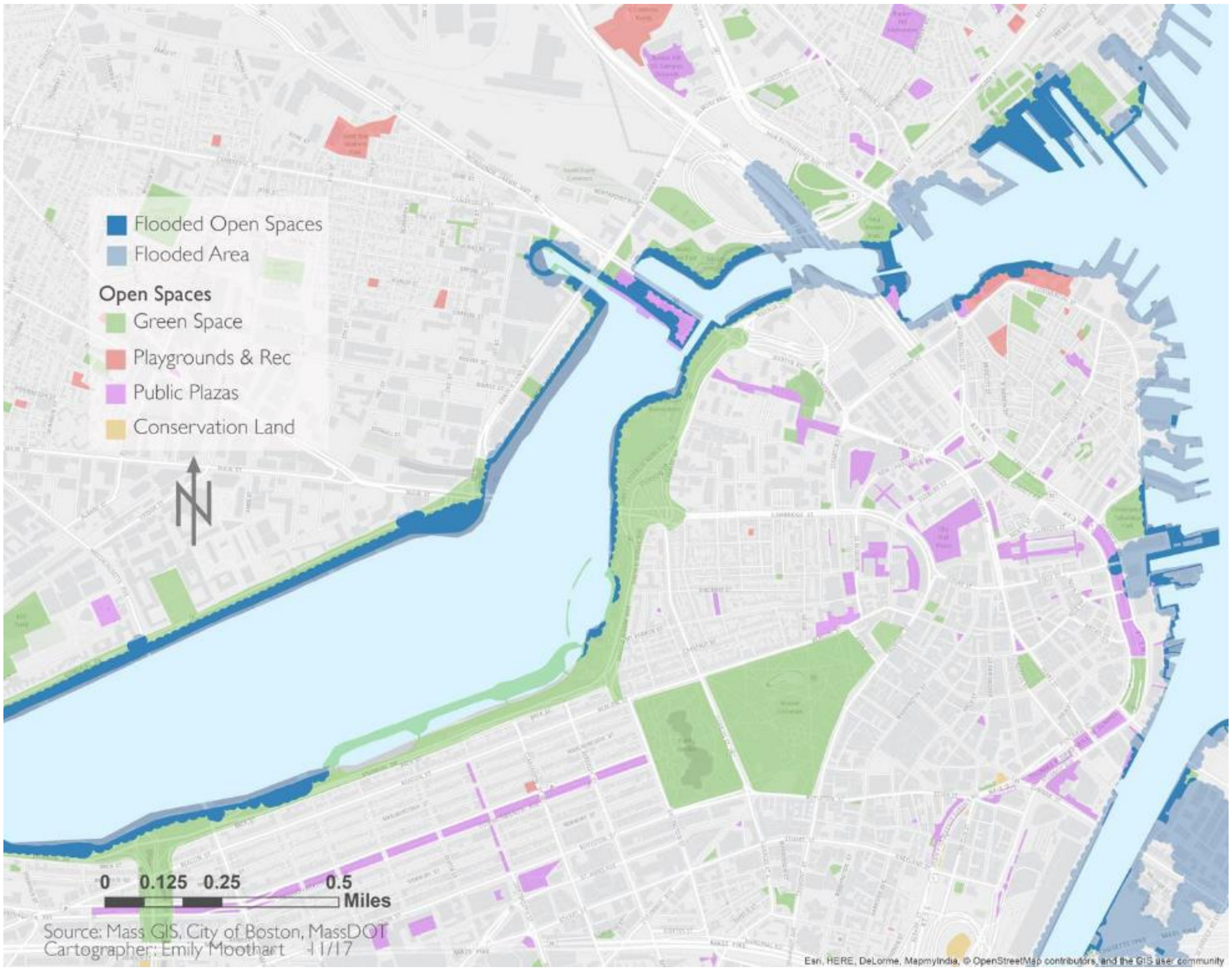
1% CFEP Flood Extent of Cambridge/Allston in 2013:



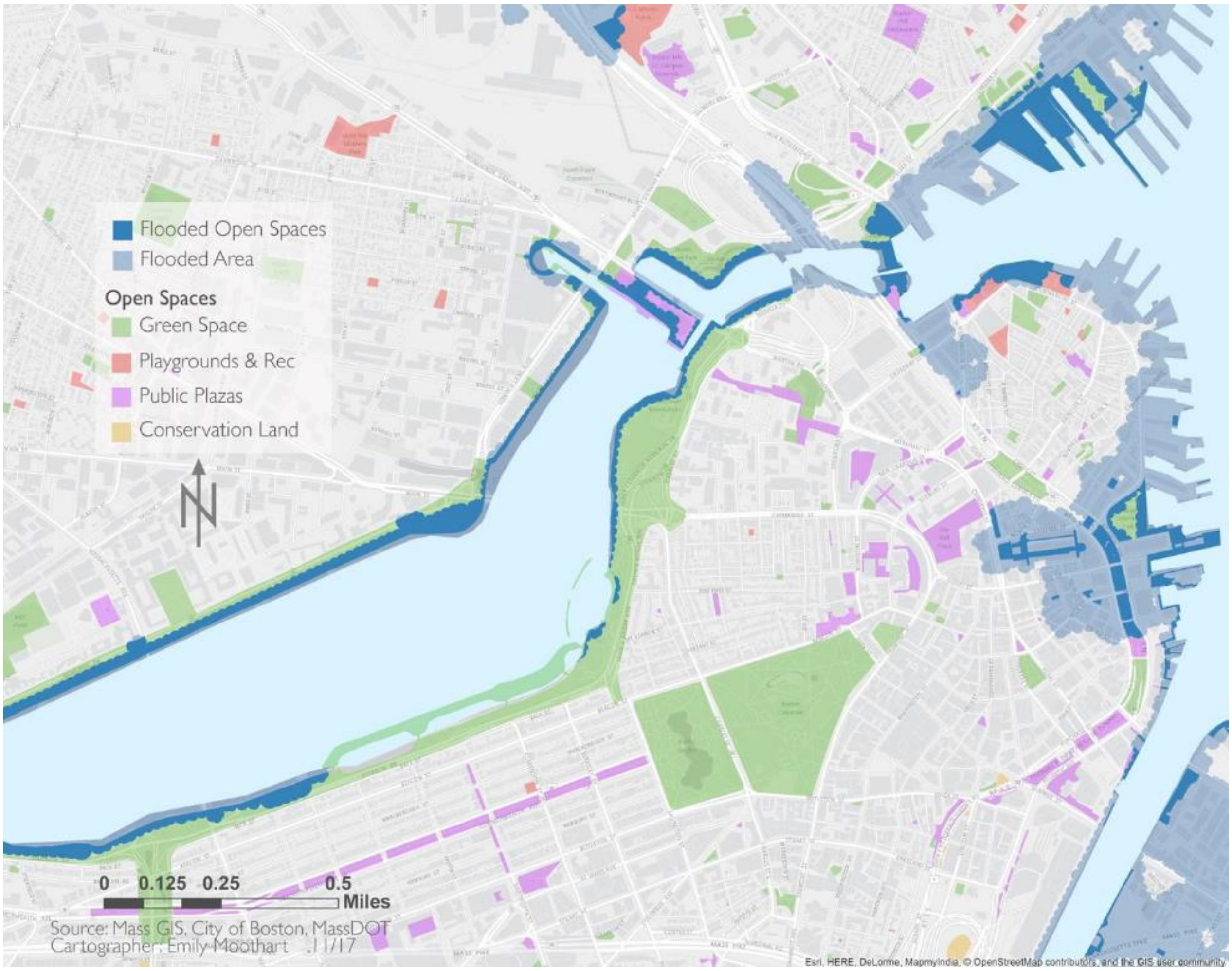
1% CFEP Flood Extent of Cambridge/Allston in 2030



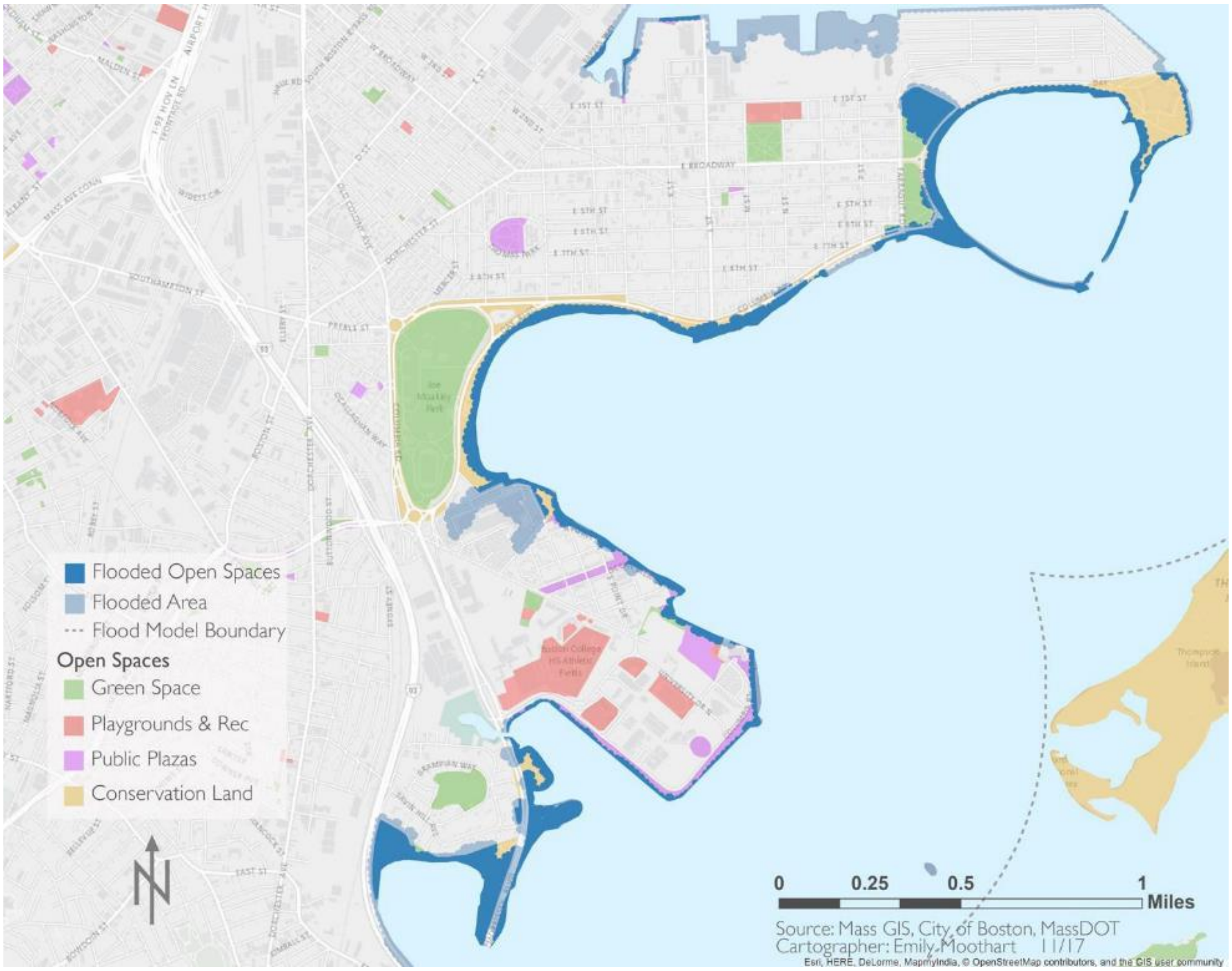
1% CFEP Flood Extent of Downtown Boston in 2013:



1% CFEP Flood Extent of Downtown Boston in 2030:



1% CFEP Flood Extent of South Boston/Dorchester in 2013



1% CFEP Flood Extent of South Boston/Dorchester in 2030