Exploring and assessing sustainable flood mitigation strategies in response to rising sea levels in Boston

Elizavyeta Dmitrieva

*University of San Francisco*, elizavyeta.dmitrieva@gmail.com

Follow this and additional works at: https://repository.usfca.edu/capstone

Part of the *Environmental Studies Commons*

**Recommended Citation**


https://repository.usfca.edu/capstone/1710

This Project/Capstone - Global access is brought to you for free and open access by the All Theses, Dissertations, Capstones and Projects at USF Scholarship: a digital repository @ Gleeson Library | Geschke Center. It has been accepted for inclusion in Master's Projects and Capstones by an authorized administrator of USF Scholarship: a digital repository @ Gleeson Library | Geschke Center. For more information, please contact repository@usfca.edu.
This Master’s Project

Exploring and assessing sustainable flood mitigation strategies in response to rising sea levels in Boston

by

Elizavyeta Dmitrieva

is submitted in partial fulfillment of the requirements for the degree of:

Master of Science

in

Environmental Management

at the

University of San Francisco

Submitted: __________________________

Received: __________________________

Elizavyeta Dmitrieva   Date

Simon Scarpetta, Ph.D.   Date
Acknowledgment

I am extremely grateful to those who supported me during my time in the MSEM program. I am proud to be a part of this amazing cohort, and I am confident that great things await us. Most importantly, I would like to express my heartfelt gratitude to my parents for their unwavering encouragement, constant support, and belief in me. Despite being an ocean away, I could always feel your faith in me and my abilities. Мама и Папа, спасибо Вам за всё! Я Вас очень сильно люблю!
# Table of Contents

ACKNOWLEDGMENT ........................................................................................................... 2

TABLE OF CONTENTS ......................................................................................................... 3

LIST OF FIGURES ................................................................................................................. 5

ABSTRACT ............................................................................................................................. 7

1.0 INTRODUCTION ............................................................................................................. 8
  1.1 MOTIVATION FOR RESEARCH .................................................................................. 8
  1.2 RESEARCH QUESTIONS AND OBJECTIVES .............................................................. 10

2.0 LITERATURE REVIEW ................................................................................................ 11
  2.1 SEA-LEVEL RISE ......................................................................................................... 11
    2.1.1 Water Expansion .................................................................................................. 11
    2.1.2 The Melting of Greenland, Arctic and Antarctic Ice .......................................... 12
    2.1.3 Atlantic Meridional Overturning Circulation ....................................................... 13
    2.1.4 Unequal Sea Level Rise ....................................................................................... 14
  2.2 URBAN RESILIENCE .................................................................................................. 16
  2.3 FLOOD MITIGATION STRATEGIES .......................................................................... 17
    2.3.1 Nature-Based Solutions ....................................................................................... 20
  2.4 CITY OF BOSTON ....................................................................................................... 21
    2.4.1. Introduction to Boston History and Hazards ....................................................... 21
    2.4.2. Flooding Hazard and Sea Level Rise in Boston ............................................... 23
    2.4.3 Environmental Justice and Vulnerabilities ......................................................... 27

3.0 METHODS ...................................................................................................................... 30

4.0 ANALYSIS ...................................................................................................................... 32
  4.1 PLACES (CASE STUDY: COASTAL RESILIENCE SOLUTIONS FOR SOUTH BOSTON AND EAST BOSTON) ......................................................................................... 32
  4.2 PEOPLE (COMPARATIVE ANALYSIS) ....................................................................... 42
    4.2.1 Community Characteristics ............................................................................... 42
4.2.2 Equity Approaches (Outreach) ................................................................. 44
4.2.3 Equity Approaches (Green Gentrification) .............................................. 46

5.0 RECOMMENDATIONS ............................................................................. 48
5.1 Recommendation #1: Implement Hybrid Coastal Protection ......................... 48
5.2 Recommendation #2: Develop General Public Outreach Plan .......................... 49
5.3 Recommendation #3: Protect the Local Communities ................................. 51

6.0 CONCLUSION .......................................................................................... 52

7.0 LITERATURE CITED ............................................................................. 53
List of Figures

Figure 2.1: AOGCMs demonstrate sea level change (purple (left) is < 0 m and red (right) is > 0.8 m) over 21st century following the scenarios with different values for glacier and land ice mass change, global thermal expansion, atmospheric loading, ice sheet, groundwater, and glacial isostatic adjustment (GIA) contributions (Carson et al., 2016) ..................................................15

Figure 2.2: Sea level height change from 1992 to 2019. The blue (left) color indicates the negative change of 7 cm and the red (right) color indicates the positive change of 7 cm. (NASA 2024) ..................................................................................................................16

Figure 2.3: Image on the left visualizes the Boston coastline (in white) in the 17th century in comparison to the modern coastline (in darker orange). Image on the right visualizes the sinking the city might experience by 2050 due to SLR and soil compaction. (Rojanasakul and Hernandez 2024) ........................................................................................................................................22

Figure 2.4: Frequency of Flooding Along U.S. Coasts, 2013-2022 vs. 1950-1959. (NOAA 2023) ..................................................................................................................................................24

Figure 2.5: “Sea Level Will Continue to Rise” demonstrates the SLR in Boston under three emissions scenarios: Low Emissions - Major Emissions Reduction; Medium Emissions - Moderate Emissions Reduction; and High Emission - Business as Usual (BRAG 2016) ....................................25

Figure 2.6: Floods in Boston, Massachusetts, during a coastal flooding (2-1% annual flood) in January 2018 (Lombard et al., 2021)..................................................................................................................................................26

Figure 2.7: Environmental justice populations are identified within Census block groups across the Boston Metropolitan area based on one or more criteria (Commonwealth of Massachusetts 2022) ...........................................................................................................................................29

Figure 4.1: Projected Flood Progression in South Boston and East Boston throughout the 21st century: A. Near term (2030s with 23 cm SLR); B. Midterm (2050s with 53 cm SLR); and C. Long term (2070s with 91 cm SLR) (City of Boston 2016)..................................................................................34

Figure 4.2: Proposed coastal flood protection strategies for East Boston, including elevated parks, salt marshes, and berms, integrated with open space features (City of Boston, 2017)..................38

Figure 4.3: Border Street Area, a flood protection project integrating NBS through elevated parks, harbor walks, and salt marshes (City of Boston 2017)........................................................................................................39

Figure 4.4: Proposed flood protection strategies across South Boston (City of Boston 2018)……40
Figure 4.5: South Boston Waterfront flood extent through the 21st century (City of Boston 2018)
Abstract

With projections indicating up to a 30 cm rise in sea level along the US coastline by 2050, flooding emerges as a critical hazard for coastal communities. Boston, a pivotal urban center, anticipates experiencing 50-70 flood days per year by 2050. Addressing the inevitability of these events necessitates the implementation of robust and equitable flood mitigation strategies to alleviate stress on the city and its residents. This paper delves into the causes of sea level rise, flooding projections for Boston, and the City’s plans to mitigate these risks. Concentrating on the two neighborhoods most vulnerable to flooding—East Boston and South Boston—this study conducts a case study exploring how these plans incorporate nature-based solutions (NBS) into flood mitigation strategies. It also includes a comparative analysis examining how these plans promote equity and assess the risks posed by green gentrification to local communities. The analysis revealed that open spaces with permeable soil serve as the main NBS in the plans, complemented by increased outreach efforts targeting small businesses and building owners. Consequently, the recommendations are as follows: 1) hybrid coastal protection that combines vegetation with traditional methods can provide effective coastal defense while offering environmental benefits; 2) outreach to the general public is crucial for safeguarding communities against flood risks; and 3) it is essential for the City to monitor the social impacts of green infrastructure projects over time to ensure they meet community needs without unintended consequences.
1.0 Introduction

1.1 Motivation for Research

The natural beauty, abundant resources, and economic opportunities of coastal regions have attracted a significant portion of the global population to live in those areas, approximately 2.15 billion people (Reimann et al., 2023). Nearly 40% of Americans reside along coastlines (Trtanj et al., 2016). Many global hubs with thriving economic activity, growing industries, and governance centers are located in coastal regions, attracting a growing workforce each year. As these cities continue to expand, the human population density increases, exerting additional pressures such as habitat conversion and increasing pollutant loads on these regions. While human activities present one risk, coastal areas are susceptible to various natural hazards. Sea-level rise (SLR) poses a significant and escalating threat to coastal communities worldwide, primarily driven by anthropogenic climate change. Over the past four decades, the rate of SLR has accelerated, with sea level rising by 20 cm in the 20th century and the rate of increase doubling over the last 20 years (Nerem et al., 2018). Rapid SLR heightens the vulnerability of coastal communities to numerous hazards, including increased flooding events, coastal erosion, and storm surges. These hazards not only endanger infrastructure and livelihoods but also present long-term challenges to coastal ecosystems. For instance, saltwater intrusion into surface freshwater resources and infiltration into aquifers, which raises the groundwater table, alters the composition of freshwater by increasing salinity and decreasing pH levels, making water more acidic. This process also contributes to soil salinization, disrupting the nitrogen cycle and destabilizing the hydrating possibilities of soil, as well as its ability to sequester carbon. These changes can lead to a decline in vegetation species and organisms, including fish, birds, and animals, within coastal ecosystems, resulting in a loss of diversity in critical habitats (USGCRP 2017; Liu et al., 2023).

The primary driver of current SLR is increasing global temperature resulting from anthropogenic release of greenhouse gases, land use changes, and industry (USGCRP 2017). The ocean covers 71% of Earth's surface and acts as a primary heat reservoir, absorbing 90% of the atmospheric heat trapped by increased greenhouse gases concentrations over the last 50 years (Venegas et al., 2023). A result of rising ocean temperatures is thermal expansion—a phenomenon in which water density decreases and volume expands (Hall 2019). Between 1972 and 2008, it was
estimated that thermal expansion caused water levels to rise by approximately 0.8 mm annually (Mimura 2013). Additionally, rising temperatures contribute to the melting of glaciers and ice caps, particularly in regions such as Greenland and Antarctica, which collectively hold enough water to elevate sea levels by almost 70 meters. In the 1990s, Antarctica contributed approximately 0.14 mm of water per year to SLR. However, between 2012 and 2016, this contribution increased to 0.55 mm per year, but scientists anticipate this rate to escalate in the future (Oppenheimer et al., 2019). Another significant contributor to SLR is the decreasing rate of overturning of the Atlantic meridional overturning circulation (AMOC)—a system of ocean currents responsible for redistributing heat and freshwater across the globe (Wood et al., 1999).

For nearly four decades, it has been widely acknowledged that sea-level rise (SLR) is not just a future projection but a current reality of our changing environment (Oppenheimer et al., 2019; USGCRP 2017). The increase of a few millimeters in sea levels each year presents significant challenges to public health, security, economic activities, and environmental well-being (Hall 2019). With advancing SLR and the increased frequency of flooding events in recent years, we are confronted with another pressing issue: environmental justice. Numerous individuals within vulnerable low-income communities are disproportionately exposed to environmental hazards. This vulnerability arises from limited access to resources, primarily driven by systemic inequalities in social and economic factors such as income, education, and housing. Various factors, such as deteriorating infrastructure, higher-density housing, and inadequate access to transit services and healthcare, significantly impact the preparedness and resilience of vulnerable community members in coping with events like flooding, both during and after their occurrence (Douglas et al., 2012).

While sea levels are rising across North America, the East Coast, bordered by the Atlantic Ocean, is experiencing one of the highest rates of rise per year compared to other regions of the United States—second only to the Gulf Coast. The City of Boston, located along the coastline of Massachusetts, is among the areas facing more frequent and severe flooding events. According to the 2023 report by the National Oceanic and Atmospheric Administration (NOAA) Tides and Currents, Boston and its surrounding areas experienced up to 18 tidal flood days with no storms or excessive rain. By 2050, the average number of flood days per year in the Boston area is projected to range from 50 to 70 (NOAA 2023). Boston is one of the major economic, academic, political, and cultural hubs in the United States, and it has played a significant role in American history as the birthplace of the American Revolution.
The City is proactively preparing for projected SLR and tidal flooding by implementing flood mitigation plans and initiatives aimed at relieving pressure on infrastructure, roads, and communities (City of Boston 2016). These plans involve a combination of near- and long-term actions that encompass both nonstructural and structural approaches. The proposed actions vary in scale, ranging from individual measures that residents are encouraged to undertake themselves, such as home elevation above the projected floodplain and basement filling with sand and gravel, to citywide initiatives such as educational programs, carbon dioxide emission reduction efforts, and green infrastructure projects. As a city committed to sustainable development, Boston's Climate Resiliency Plan also includes initiatives that create recreational open spaces and promote environmental equity for local communities (City of Boston 2016).

This report begins with an overview of fundamental concepts surrounding sea-level rise induced by climate change. It subsequently transitions to the identification of flood mitigation strategies, with an emphasis on nature-based solutions. Following this, the report delves into the study areas, examining flood vulnerabilities and demographics. The analysis section explores nature-based flood mitigation approaches in Boston aimed at alleviating stress on the city and its communities by adapting to climate change and inevitable flooding events, rather than attempting to avoid them entirely.

1.2 Research Questions and Objectives

The overall objective of this research is to assess the flood mitigation strategies in the City of Boston with a focus on nature-based solutions (NBS) and green and blue-green infrastructure. The research aims to examine the effectiveness of the implemented strategies in addressing the increased frequency of flooding events caused by SLR. Specifically, the focus will be on evaluating physical adaptations to the impacts of SLR and assessing community preparedness and resilience. To achieve this objective, the main research question is:

*How effective are the nature-based solutions measures implemented in Boston in creating a resilient coastline and safeguarding communities from flood events?*

Equity in the public realm and the private sector is a fundamental goal of a well-functioning urban society (City of Boston 2017). Equitable development guarantees that individuals have fair access
to resources and benefits commensurate with their flood risk and existing adaptations. To assess how the implemented strategies uphold the health and safety of vulnerable communities, the following sub-questions address:

*How do the implemented flood mitigation strategies ensure that vulnerable communities are protected from flooding events caused by the sea-level rise?*

*What recommendations can be made to promote the equitable implementation of flood mitigation strategies that yield the most successful safeguard of people and infrastructure?*

### 2.0 Literature Review

This section serves as an overview of the report's key topics. It delves into the history of Pleistocene climate oscillations and human-caused climate change, considering both natural and anthropogenic influences such as water expansion and ice sheet and glacier melting and exploring their impact on global sea level rise. Additionally, it elaborates on the concept of sustainability and flood mitigation, specifically focusing on green and blue-green infrastructure. The section concludes by addressing the rationale behind selecting the City of Boston as the research location, highlighting its historical relationship with sea level rise and its community.

### 2.1 Sea-Level Rise

#### 2.1.1 Water Expansion

Climate change is a natural phenomenon that generally occurs cyclically and gradually on Earth. Over the past 800,000 years, Earth has undergone at least eight cycles of ice ages and interglacial warm periods, partly driven by slight variations in its rotational axis (Ussiri et al., 2017). Through chemical analysis of different forms of carbon in air bubbles trapped in ice cores, scientists have determined that warming is tied to an increase in carbon dioxide (CO₂) levels in the atmosphere—a key greenhouse gas in Earth's energy balance equation (Nakazawa 2020). However, the drastic increase in CO₂ levels in recent times cannot be solely attributed to natural factors. Since the onset of the industrial revolution in the 1700s, atmospheric CO₂ levels have
surged by more than 40% (National Academy of Sciences 2020). As CO₂ levels rise more heat becomes trapped in Earth's atmosphere. Since the 1970s, the Earth has experienced a temperature increase of 1°C. By comparison, it took approximately 7,000 years for the Earth to warm by 4 to 5°C following the most recent ice age around 18,000 years ago (National Academy of Sciences 2020).

Earth’s ocean cover the majority of the planet surface (71%), and absorbs most of the heat trapped in the atmosphere by greenhouse gases. This absorption results in an overall increase in the temperature of the water, causing a decrease in its density and an expansion of its volume (Hall 2019). Consequently, ocean thermal expansion leads to an increase in ocean volume at constant mass. Throughout the 20th century, the estimated rates of thermal expansion range from 0.7 to 1.1 mm/yr; however, rates have been accelerating, and from 2006 to 2015, the rate was estimated to be between 1.08 to 1.72 mm/yr (Church et al., 2001; Oppenheimer et al., 2019). Estimates in which CO₂ increases at a similar rate to that of today indicate that thermal expansion will cause substantial sea-level rise throughout the 21st century, with projected rates increasing to between 0.43 to 0.84 meters (430 mm to 840 mm) by 2100 (Oppenheimer et al., 2019).

2.1.2 The Melting of Greenland, Arctic and Antarctic Ice

Ice plays a crucial role in maintaining the balance of solar radiation absorbed and reflected by the Earth's surface due to its high reflectivity or albedo (Church et al., 2001). As the atmosphere warms, the melting of ice uncovers darker surfaces. For example, melting sea ice expands the ocean area, exposing the darker ocean water, while melting land ice reveals darker ground surfaces. These darker surfaces absorb more solar radiation (National Academy of Sciences 2020). Collectively glaciers and ice caps hold enough water to raise sea levels by nearly 70 meters (Church et al., 2001). While both the North and South Poles are predominantly covered by ice sheets and glaciers, the Arctic is more vulnerable to increased temperatures due to its geographical features and oceanic currents. The Arctic Ocean, partially enclosed by continents, has limited sea ice extent (Gregory and Huybrechts 2006). Satellite recordings since 1978 show a 40% decrease in Arctic ice surface area (Fetterer at el., 2017; Gregory and Huybrechts 2006). Greenland contributes to sea-level rise through an increased freshwater influx, resulting from a higher amount of precipitation and melting ice runoff, both of which are driven by climate change (Hawkins et al., 2011). Although Antarctica's ice sheets and sea ice have not yet significantly contributed to
sea-level rise due to the region's below-freezing temperatures on most days, making it colder than the Arctic, the area is still experiencing increased precipitation and freshwater accumulation (Gregory and Huybrechts 2006). In total Antarctic and Arctic regions contributed up to 0.5 mm/yr to sea-level rise over the 20th century (Church et al., 2001). While the contributions of Antarctica and Greenland's ice surfaces may seem minor over a century, it is crucial to note the significant impact over a longer period, especially compared to the 120 meters of SLR that occurred over approximately 20,000 years since the Last Glacial Maximum, the most recent period in Earth’s history when ice sheets reached their maximum extent (Church et al., 2001). Climate models project that as anthropogenic climate change intensifies, glaciers and ice caps are likely to surpass the contribution of ice sheets to SLR (Gregory and Huybrechts 2006).

2.1.3 Atlantic Meridional Overturning Circulation

The Atlantic Meridional Overturning Circulation (AMOC) is an important system of currents that circulate water northward and southward along the Atlantic Ocean. At higher latitudes, heat transported from the southern tropical regions via the Gulf Stream and North Atlantic Current is released into the atmosphere, significantly influencing the climates of Western Europe and North America (Wood et al., 1999). As water cools down, it densifies and sinks then transports back southwards, completing the circulation cycle. However, the influx of extra freshwater into the Atlantic Ocean from melting glaciers and ice caps, increased oceanic precipitation and river runoff disrupts this process by mixing with seawater, reducing its density, and limiting its ability to sink, thereby affecting the circulation overall (Hawkins et al., 2011). Observations since the mid-last century have indicated a slowdown in AMOC, which can potentially lead to severe impacts, including a future rapid collapse of the circulation (Hawkins et al., 2011; Wood et al., 1999). While certain models suggest the unlikelihood of AMOC collapse within the 21st century, other models that account for current emission rates, suggest a possibility of a collapse as soon as the mid-century (Wood et al., 1999). The consequences of a partial or full collapse of the AMOC can vary significantly leading to climate shifts, a decrease in ice volume and an increase in sea level by up to one meter (Bond et al., 1997; van Westen et al., 2024).
2.1.4 Unequal Sea Level Rise

Considering the combined effects of ocean-atmosphere dynamics, gravitational impacts from glacier and land ice mass changes, shifts in terrestrial water storage, alterations in atmospheric circulation and moisture content, significant spatial variations emerge in regional SLR (Kopp et al., 2015). Varying across regions, these factors cause some areas to experience SLR rates exceeding the global average, possibly doubling it, while others witness a decline in sea level (Church et al., 2001; Kopp et al., 2015). Figure 2.1 illustrates the non-uniform geographical distribution of SLR as projected by each atmosphere-ocean general circulation model (AOGCM) under various scenarios with differing greenhouse gas concentrations throughout the 21st century. Regions shaded in purple-blue represent a negative sea level change, indicating deviation from the average coastal sea level change, primarily affecting western Antarctica and Greenland due to gravitational drops from diminishing ice sheets and glaciers. Despite SLR being evident along most continental coastlines, areas experiencing the highest SLR, depicted in pink, are situated in open oceans away from most coastlines. Many small islands scattered across the Pacific and Indian Oceans are expected to undergo substantial changes in SLR (Carson et al., 2016).
A NASA research program initiated in 1992 launched the first satellite ocean altimetry missions, which continued until 2019. In this program NASA satellites from the TOPEX/Jason series captured records of ocean surface height. The compilation of satellite imagery spanning these years is depicted in Figure 2.2, illustrating sea level changes over a period of 27 years. The figure reveals variations in ocean height, with some areas experiencing a decrease of up to 10 cm, while others exhibit an increase of up to 15 cm. The global average change, as indicated by the data, is an increase of 7.6 cm (NASA 2024; USGCRP 2017).
Similar to the AOGCMs discussed in the 2016 study, NASA's ocean altimetry research demonstrates a decrease in sea level near the coasts of Greenland and Antarctica, accompanied by a notable increase in sea level height in the open ocean, particularly in the Pacific and Atlantic Oceans of the Southern Hemisphere.

In its global and regional SLR scenarios report, NOAA projects a SLR of 0.25-0.30 meters (10-12 inches) along the U.S. coastline by 2050. While the increase will affect the entire North American continent, the extent of rise will vary across regions: the East Coast is expected to experience a rise of 0.25-0.35 meters (10-14 inches), the West Coast an average rise of 0.1-0.2 meters (4-8 inches), the Gulf Coast a rise of 0.35-0.45 meters (14-18 inches), and Alaska a rise of 0.2-0.25 meters (8-10 inches) (Sweet et al., 2022).

### 2.2 Urban Resilience

Twenty-first-century cities, characterized by their interconnected infrastructure, institutions, and vibrant economic and cultural activities, face the risk of economic, social, and
physical collapse in the wake of cumulative shocks or disasters unless they are resilient (Arup 2015). The term “resilience” has gained increasing prominence across various fields, from psychology to ecology to engineering. A resilient system is one that can swiftly return to its normal state after stress, withstand significant stress without enduring permanent damage, and experience minimal disruption under any given level of stress. In the context of urban and climate resilience, stressors may include population growth, natural and artificial hazards, and socio-economic crises. Essentially, a resilient system maintains its functioning in the face of disturbances. Related terms such as vulnerability (the opposite of resilience), adaptation, and sustainability are often part of the discussion on resilience. Adaptation, or adaptive capacity, closely aligns with resilience, referring to a system's ability to effectively cope with stress. Sustainability, meanwhile, emphasizes the preservation of the system and its capacity to adapt to changes, ultimately fostering resilience over time. Achieving urban resilience is a gradual process that involves multiple components of the system, including infrastructure, transportation, utilities, the economy, and the community itself, encompassing politicians, planners, ecologists, workers, vulnerable populations, and other stakeholders. Collaborative efforts and innovative approaches are essential drivers of urban resilience. However, to achieve urban-ecological resilience, it is imperative to understand and leverage the resources provided by the local ecosystem (Martin-Breen and Andries 2011).

To understand what factors make a city resilient, Arup, a global engineering and sustainable development consultancy, developed a comprehensive City Resilience Framework. City resilience is complex, and this framework aims to help identify how to assess cities, their adaptations, and resilience to social, physical, and environmental stresses. In the framework, Arup identifies twelve goals in four categories: 1) People — the health and wellbeing of individuals; 2) Place — urban systems and services; 3) Organization — economy and society; and 4) Knowledge — leadership and strategy. These goals are focused on the performance and outcomes of actions to build resilience, rather than the actions themselves. The framework believes that these goals make a difference when comparing a resilient city with just a livable one (Arup 2015).

2.3 Flood Mitigation Strategies

In recent decades, the concept of flood mitigation has moved beyond traditional engineering-based approaches to embrace a holistic perspective that incorporates NBS. It is essential to adopt a strategic and inclusive approach, one that transcends mere response to flood
events and delves into understanding the multifaceted hazards and causes of floods, encompassing climate, geomorphological, and socio-economic factors. The overarching objectives of this approach is to minimize risks to people and coastal communities, safeguard the economy by reducing vulnerabilities, foster the resilience of ecosystems, and enhance societal well-being. This includes the protection of cultural and historical landscapes, as well as ensuring equity and fairness in flood risk management practices (Yuanyuan et al., 2013).

Flood mitigation strategies can be categorized into two main types: structural and nonstructural. Structural measures, also known as hard or flood control barriers, involve reshaping landscapes through the construction of floodwalls/seawalls, dams, dikes, floodgates, levees, reservoirs, tidal gates, diversion channels, and pumping stations to mitigate harm. This mitigation method reduces risks by redirecting water away from people and their communities. On the other hand, nonstructural approaches, also known as soft or flood damage reduction techniques, focus on reducing damage by keeping away or relocating people and property from high-risk areas. These measures include elevating structures to withstand floods, implementing buyouts or offering permanent relocation options, modifying laws and regulations (zoning and building codes), raising public awareness, implementing spatial and flood management plans and flood forecast-warning and evacuation routes systems (NYSDEC 2024; Meyer et al., 2012).

First introduced into discussions on conservation and environmentalism in 1979, the term 'sustainability' and its various iterations have become indispensable in modern conversations across nearly every area of life. Its direct translation from Latin, 'able to keep,' has evolved over time in response to historical trends. Today, within the environmental context, sustainable practices entail the prudent utilization of resources without their complete depletion, fostering resilience and balance (Khan et al., 2021). They facilitate the interconnectedness between society and the environment, ensuring diversity, health, and regeneration while committing to minimal disturbance to ecosystems and safeguarding the needs of future generations (Khan et al., 2021; Online Etymology Dictionary 2023).

Structural or hard measures demand significantly more resources, entailing higher costs for installation and maintenance, and often employing permanent building materials such as concrete. Concrete, known for its energy-intensive nature, is a major contributor to pollution and greenhouse gas emissions, accounting for approximately 8–9% of global carbon dioxide emissions, and resulting in significant waste generation (Cooke et al., 2020; Wang et al., 2022). Incorrect or
inadequate maintenance of hard infrastructure, or significant alterations to flood mitigation plans leading to removal of said structures, pose not only substantial financial losses but also heightened ecological impacts. Concrete structures can release fragments and dust into the air and water bodies, while aging concrete infrastructure may leach alkaline substances into soils and waterways. This can result in biodiversity loss by killing fish and invertebrates or damaging their outer surfaces, which reduces their fitness and survival (Cooke et al., 2020).

In contrast, nonstructural or soft measures can present a more cost-effective and sustainable alternative to structural approaches. These measures typically involve fewer structural components, offering greater flexibility and requiring less commitment, as they often entail non-engineering strategies primarily focused on planning (Kundzewicz 2002). It is essential to acknowledge that both types of measures are indispensable under certain circumstances. The decision regarding the choice of measure type should be based on multiple and complementary criteria, including hydrological information, risk factors (probability and consequences), and flood vulnerability (exposure, sensitivity, and adaptive capacity) (Wang et al., 2022).

While our society is currently striving for more sustainable alternatives, structural measures often remain preferred over nonstructural options due to the inherent complexity of evaluating the latter. The criteria used to assess the effectiveness, cost-effectiveness, and efficiency of flood mitigation measures typically include the following sub-criteria: 1) socio-economic considerations, including their influence on growth, resilience, and stability; 2) utilization of natural and environmental resources; 3) promotion and preservation of natural and environmental resources; 4) enhancement of public health, safety, and well-being; and 5) adaptability and sustainability of infrastructure projects and flexibility in response to changing circumstances (Kundzewicz 2002). It has been observed that there are challenges to applying these evaluation criteria to nonstructural measures, such as planning, warning systems, and resettlement options, making it difficult to ascertain their efficacy compared to more traditional structural options. Furthermore, decision-making difficulties may arise from a preference for time-tested, traditional measures, contingent upon organizational structures and the personal characteristics of decision-makers (Meyer et al., 2012).
2.3.1 Nature-Based Solutions

Despite the complexities involved in evaluation, an increasing number of areas, particularly densely populated urban regions, are opting for more sustainable and resilient nonstructural measures (Wang et al., 2022). One such subcategory of measures is nature-based solutions (NBS) or approaches (NBA). NBS represents a non-traditional and alternative approach to addressing environmental challenges, leveraging sustainable planning and engineering practices that utilize natural features and processes. These solutions contribute to green infrastructure by integrating green spaces (parks, gardens, etc.) and blue (rivers, lakes, coastlines, etc.) spaces in urban areas, while also preserving and enhancing biodiversity. Examples of NBS for flood mitigation, whether coastal or stemming from extreme precipitation, include sustainable urban drainage systems (SUDS), low-impact development (LID), water-sensitive urban design (WSUD), and Sponge City (SC) initiatives (Ferreira et al., 2021). These approaches involve creating more permeable surfaces, which help minimize the impacts of flooding by absorbing and storing excess water. In some cases, the water is directed to pipes, sewers, or other water storage locations such as lakes, ponds, or the sea. These methods are effective for flood mitigation once water has already reached the streets of the city (Ferreira et al., 2021; Kabisch et al., 2017).

To protect shorelines from coastal storms, powerful waves, and rising sea levels, various types of NBS are utilized. These include beach and dune nourishment, protection or restoration of islands, marshes, and mangroves, as well as the creation of coral and oyster reefs. These approaches can be employed individually or in conjunction with traditional gray infrastructure, such as burying cement walls within sand dunes. Unlike concrete-based structures, which are unable to adapt to and compensate for SLR, NBS approaches can reduce erosion and mitigate the impact of waves and storms, stabilizing the shoreline. They also help maintain or improve ecosystem health, biodiversity, and water quality, act as carbon dioxide storage, and require fewer resources such as concrete (Davis et al., 2015). Boston has been integrating NBS into its development plans, including artificial marshes, living shorelines, wetland terraces, sandy beaches, rocky shores, and floating wetlands (City of Boston 2018).
2.4 City of Boston

2.4.1. Introduction to Boston History and Hazards

In 1630, the Boston landscape looked vastly different from its present-day appearance. Figure 2.3 shows that at that time, the whole city, now the Boston Downtown area, occupied a peninsula connected to the mainland by a narrow neck that submerged during high tide. In the early days of Boston's establishment, surrounding neighborhoods like South Boston and East Boston had notably different configurations. South Boston, for instance, was a smaller peninsula compared to its current size. Similarly, what is now known as the East Boston neighborhood was originally composed of several separate islands. Much of the area near the shoreline consisted of tidal flats and marshes. However, significant transformations occurred through land reclamation or landfilling, resulting in much of the land along the coastline and riverbanks being filled to just above high tide (City of Boston 2016; Seasholes 2018). Inspired by similar projects in East England’s Fens and Holland, Bostonians opted for landfilling to address various historical needs, including harbor enhancement, waste disposal, urban expansion to accommodate a growing population, and the creation of public spaces and shipping facilities (Seasholes 2018). While some areas were filled with mud and refuse from flat fields, sand and gravel emerged as preferred materials for filling. The scale of land-making was substantial, resulting in the addition of approximately 5,250 square acres along the shores. The original Boston peninsula, initially covering 487 acres, was enveloped by an additional 500 acres. Similarly, East Boston's area expanded by 2.5 times, with the current site of Logan International Airport situated entirely on reclaimed land, effectively connecting all nearby islands. South Boston underwent a threefold increase in landmass through extensive filling efforts (Seasholes 2018; Mason 2017).
Figure 2.3: Image on the left visualizes the Boston coastline (in white) in the 17th century in comparison to the modern coastline (in darker orange). Image on the right visualizes the sinking the city might experience by 2050 due to SLR and soil compaction. (Rojanasakul and Hernandez 2024)

While land reclamation from the sea is often favored in developing areas to accommodate population growth, support infrastructure, and drive socio-economic development, it also brings significant environmental repercussions. These include degradation of natural coastlines, damage to coastal ecosystems, and heightened risk of geological disasters (Wu et al., 2021). Such areas are particularly vulnerable to storm tide-induced coastal flooding due to their low-lying elevation (Wu et al., 2021). Over time, the accumulated weight of sediment and heavy infrastructure, especially on reclaimed land, can trigger seismic activity and soil compaction (Alaoui et al., 2018). This compaction can result in decreased land elevation, exacerbating land sinking in coastal regions, which, combined with rising sea levels, amplifies the area's susceptibility to negative hazards. In Boston, the rate of land subsidence is approximately 2 mm per year (Ohenhenn et al., 2024).
Additionally, soil compaction leads to a low infiltration rate, affecting water removal during flooding events as the soil's ability to absorb water diminishes (Alaoui et al., 2018).

2.4.2. Flooding Hazard and Sea Level Rise in Boston

While sea levels are projected to rise along all shores of the United States, the East Coast is anticipated to bear the brunt of increased flooding events. Figure 2.4 illustrates a significant rise in coastal floods in the 21st century compared to the mid-20th century, with the national average of flooding events increasing from 3 days per year to 12 days per year (NOAA 2023). Consistent with this trend, the City of Boston has experienced one of the highest rates of increase in flood frequency among American cities. Between 1990 and 2009, the city averaged about 4 flooding events per year, whereas between 2010 and 2022, it experienced an average of 13 flooding days per year (NOAA 2018). However, this number is expected to increase up to 50 to 70 by 2050 (NOAA 2023).
Climate risks are not new to Boston. Over the 20th century, the sea level rose by 0.23 meters relative to the land. From 1923 to 2015, there was an average rise of 2.8 mm per year (BRAG 2016). Predictions based on various environmental factors, including the melting of land ice, water expansion, extreme precipitation, and changes in groundwater extraction or storage behind dams, suggest an increased rate of sea level rise in the area. It is projected that there will be an additional 0.20 meters increase by 2030 (City of Boston 2016). Although land subsidence in Boston is a minor change compared to sea level rise, the deepening of harbors due to increased water and lower land levels could expose the city to the possibility of higher, more powerful, and more damaging waves (BRAG 2016).
Coastal flooding and its increasing frequency will escalate the costs the City and Bostonians will bear to ensure the safety of public infrastructure, private housing, and residents. A severe flood event, such as the '1% annual chance flood,' also known as the '100-year flood,' would impact 2,100 buildings and 16,000 Boston residents, resulting in an estimated $2.3 billion in damages, including physical property damage and other economic losses such as relocation. It is important to note that the term '100-year flood' is somewhat misleading because it signifies that a flood of such severe magnitude statistically has a one percent chance of occurring in any given year (City of Boston 2016). The Federal Emergency Management Agency (FEMA) maps out flood zones, which are then used in their Flood Insurance Rate Maps (FIRMs) to assist the community during 1% chance flooding events. However, an analysis of flood claims received after a severe flood in March 2010 revealed that 27,000 people across seven counties near the Boston urban area
applied for disaster claims, yet only 4% of them were estimated to be in the FEMA-calculated 1% annual flood zone (Herbst et al., 2023).

Figure 2.6: Floods in Boston, Massachusetts, during a coastal flooding (2-1% annual flood) in January 2018 (Lombard et al. 2021).

One of the first notable floods occurred in the Boston area in 1978, with the coastal water level increasing by 3.03 meters from its original level. This event had less than a one percent chance of occurring (Lombard et al., 2021). In 2018, a nor’easter storm, caused by a large cyclone in the western North Atlantic Ocean, impacted the entire coastal area of New England. The water levels recorded in Boston Harbor during the storm were the highest measured there since modern records began. This observation is indicative of sea level rise, as one third of the top 20 peak water levels known since 1723 were observed since 2005 (Talke et al., 2018). Shown in Figure 2.6 are the flooded areas in the city during a January flood, during which the coastal water level rose by 2.94 meters above the original sea level, which is considered to be in an annual probability of 2-
1%. A few months later, in March of the same year, the coastal water elevation during the flood increased by 2.79 meters, which is a flood with an annual probability of 4-2% (Lombard et al., 2021).

While other climate hazards pose threats citywide, coastal and tidal flooding specifically poses risks to particular neighborhoods in Boston. The most vulnerable areas to coastal flooding are the low-lying waterfront neighborhoods: Downtown, Charlestown, East Boston, and South Boston (City of Boston 2016). Many of Boston’s systems are vulnerable to climate hazards, posing risks to people, buildings, infrastructure, and the economy. This includes systems that collect and distribute water during a flooding event, such as the sewer and storm drain systems, as well as systems that are vital for society to function, such as educational institutions, housing, transit, energy, and water. During and after flooding events, these systems can become compromised, leading to crises with power outages, disruptions in business and school operations, and road gridlock (City of Boston 2021).

Physical damages to infrastructure caused by flooding present the most significant portion of direct damage costs in urban areas. One of the costliest systems that could be significantly impacted by floods is the transit system, especially the underground components including stations, ventilation systems, tunnels, and low-lying sections of the system. The number of damages and costs of repairs has been increasing over time. In 2022, flood damages were estimated to cause a $24.4 million loss per year to the Massachusetts Bay Transportation Authority (MBTA). Under varying sea level rise scenarios, this number is expected to increase to up to $58 million per year by 2030 (Martello and Whittle 2023).

It is estimated that if a storm surge during a high tide adds an additional 1.5 meters in water level, it could lead to 212 kilometers of roadway being flooded. Such an event would leave the city paralyzed, with drivers, bicyclists, and pedestrians stranded or significantly affected, and emergency response efforts impacted (City of Boston 2021).

2.4.3 Environmental Justice and Vulnerabilities

While all residents of coastal communities are exposed to some risk of flooding events, studies across the United States indicate that residents of affordable housing units face significantly higher risks of flooding hazards. This heightened risk is often attributed to the age and poor quality of the housing, as well as their location in low-lying areas (Buchanan et al., 2020). Residents of
affordable housing units are often more socioeconomically vulnerable due to their income or background. These people encounter challenges in adapting themselves or their housing to climate hazards and find it difficult to recover from such events due to limited financial resources, reduced political influence, and a lack of awareness about hazard and the availability of financial aid programs. Often, these limitations stem from lifestyle choices that prioritize immediate wellbeing and safety over allocating resources toward disaster mitigation and preparedness (City of Boston 2016; Buchanan et al., 2020).

The number of affordable housing units exposed to floods is expected to triple by 2050 across the country. As of 2020, with a total of 3,042 affordable housing units in Boston, 407 of them were exposed to more than four flooding events per year, and 994 units were exposed to two floods per year. While the number of affordable housing units in Boston has increased since 2000, an additional 400 units have become exposed to floods (Buchanan et al., 2020).

Environmental justice is a movement aimed at combating environmental discrimination, a systemic issue that has historically disproportionately exposed people of color and those with lower socioeconomic status to high levels of pollutants and other hazards, thereby increasing risks to their health and well-being. Today, environmental justice communities primarily consist of ethnic minorities, indigenous individuals, people of color, and low-income populations who bear a disproportionate burden of air, water, and soil pollution (Mohai et al., 2009). In the State of Massachusetts, an area is designated as an environmental justice community if it meets one or more of the following criteria: the annual median household income is not greater than 65% of the statewide annual median household income (which was $89,212 in 2022); minorities constitute 40% or more of the population; 25% or more of households lack English language proficiency; or a specific geographic portion of a neighborhood is designated by the Secretary of Environmental Affairs as an environmental justice population in accordance with the law (Dimitri et al., 2023; USCB 2024).

Figure 2.7 focuses on the population of Boston by identifying areas where residents fall under environmental justice criteria. While there is no mixing of colors and a singular color is shown in some parts of the city, it is important to recognize that these criteria are often interrelated, meaning that residents can fall within several environmental justice categories (Commonwealth of Massachusetts 2022). In East Boston, with a total population of 40,500 (2016), the percentages are as follows: 10% are older adults, 63% are people of color, 43% have limited English proficiency,
and 34% are in the low-to-no income category. In South Boston, with 31,800 residents (2016), the percentages are: 10% are older adults, 22% are people of color, 8% have limited English proficiency, and 26% are in the low-to-income category (City of Boston 2016).

![Environmental Justice 2020 Populations](image)

*Figure 2.7: Environmental justice populations are identified within Census block groups across the Boston Metropolitan area based on one or more criteria (Commonwealth of Massachusetts 2022).*

In 2012, a series of workshops and outreach events were conducted in two environmental justice communities within the Boston metropolitan area: East Boston, a residential area, and Everett, a mostly industrial and commercial area. Residents in these areas expressed concerns about their lack of access to adaptations, such as the inability to afford infrastructural improvements for floodproofing or flood insurance, as well as their lack of knowledge about resources that could assist them during coastal flooding events. They also expressed feeling excluded from planning processes (Douglas et al., 2012). The inability to understand the risks posed by flooding hazards and the inability to safeguard their safety can further exacerbate the
impacts these communities might experience. These impacts include greater financial losses, health complications such as injuries and fatalities, and disruptions to livelihoods.

3.0 Methods

To study the approaches the City of Boston takes to mitigate flood risks and ensure environmental equity, case studies and comparative analyses were conducted on the two neighborhoods most vulnerable to flooding: East Boston and South Boston. The case study examines three reports: one general report for the city, Climate Ready Boston, and two neighborhood-specific reports—the 2017 Coastal Resilience Solutions for East Boston and Charlestown, and the 2018 Coastal Resilience Solutions for South Boston. The comparative analysis delves deeper into these reports, along with census data and a literature review, to understand the demographics of the communities, identify differences and similarities in their characteristics, and explore how the resilience plans address equity in their outreach efforts. Finally, as part of the comparative analysis, the criteria for equity are assessed to ensure that the plans propose methods to protect local communities, provide equitable access to new mitigation measures, and maintain affordable housing in these two distinct neighborhoods.

The Analysis section and the methods used are divided into Places (case study) and People (comparative analysis), aligned with the City Resilience Framework. Understanding the objectives of the Places and People categories within this framework is essential for addressing the research question. This structure facilitates a thorough comparison and assessment of NBS in East Boston and South Boston, as well as examining equity approaches to ensure the safety and well-being of all community members. The Places category focuses on environmental stewardship and the implementation of appropriate infrastructure. The three goals of the Places category are: 1) Reliable communications and mobility; 2) Effective provision of critical services; and 3) Reduced exposure and fragility. To fulfill this category of the framework, the city must maintain ecosystems and infrastructure, engage in effective land use planning, enforce planning regulations, and utilize diverse and affordable transportation and information/communication networks. The People category consists of the following goals: 1) Minimal human vulnerability; 2) Diverse livelihoods and employment; and 3) Effective safeguards for human health and life. These goals ensure that every community member's needs are met, there is access to financial and business support, as
well as skill training, and human health and safety is prioritized by integrating health facilities and emergency services (Arup 2015).

The City of Boston recognizes the threat posed by climate change and to address the ongoing impacts of hotter temperatures, stronger storms, and rising sea levels, Boston has undertaken proactive measures to protect its community and infrastructure. In 2016, the city released the *Climate Ready Boston* report, which includes updated climate projections for key climate factors: extreme temperatures, SLR, extreme precipitation, and storms. This comprehensive assessment evaluates climate hazards and their associated risks to people, buildings, infrastructure, and the economy. It particularly focuses on identifying vulnerable areas, especially those susceptible to coastal and ravine flooding. Furthermore, the report outlines a series of climate resilience initiatives encompassing policy development, urban planning, program implementation, and financial strategies to ensure effective plan execution. The overarching goal of the *Climate Ready Boston* report is to guide the City's adaptation efforts, providing a clear timeframe, delineating responsibilities, and highlighting key milestones (City of Boston 2016).

In line with the *City Resilience Framework*'s requirements, to ensure that all four categories with twelve goals are met in the 2016 *Climate Ready Boston* report, the City divides the report into five climate resilience initiatives, listed as layers, each covering some or all of the four categories — People, Place, Organization, and Knowledge. These initiatives assess vulnerability, identify and quantify future climate change impacts, and examine best practices to establish stronger neighborhoods with an improved quality of life. Each layer has its own objective: Layer 1 — Updated Climate Projections ensures that the Boston area is up-to-date with its flood maps, planning strategies, policies, and regulations; Layer 2 — Prepared and Connected Communities ensures that all Boston residents, business owners, organizations, and the City are engaged in an active and informative conversation about climate hazards, adaptations, preparedness steps, and economic development; Layer 3 — Protected Shores focuses on the major threat of flooding events and develops plans for a coastal protection system through three categories of coastal protection: 'gray', nature-based, and hybrid, focusing on the most hazard-prone areas; Layer 4 — Resilient Infrastructure focuses on a group of four major working groups: water and sewer, transportation, energy, and telecommunications; and lastly, Layer 5 — Adopted Buildings updates Boston zoning codes and building regulations (City of Boston 2016).
To provide more detailed climate change adaptation strategies as well as more accurate approaches that accommodate each community depending on their location in Boston, the report also has a Focus Areas section. Eight Boston areas are discussed individually and vulnerability assessment to illustrate what risks are posed to them particularly. These eight focus areas include: Charleston, Charles River, Dorchester, Downtown, Roxbury, South End, and the last two, East Boston and South Boston, are the focus areas discussed in this paper. The detailed coastal resilience initiatives for East Boston and South Boston are described in their own reports: 2017 *Coastal Resilience Solutions for East Boston and Charlestown* and the 2018 *Coastal Resilience Solutions for South Boston*.

Separated by Boston Harbor, the East Boston and South Boston neighborhoods are known for their distinct characteristics and lifestyles. The entire South Boston neighborhood is situated on a peninsula southeast of Downtown Boston and consists of smaller areas, including the South Boston Waterfront and Fort Point Channel, each with its own unique community and building stock. Over the past decade, there has been significant development interest in the South Boston Waterfront area, making it the fastest-growing urban area in the city (City of Boston 2016). Originally composed of five islands connected by landfill, East Boston is located across Boston Harbor from downtown Boston and South Boston. It is a neighborhood with a mix of residential and commercial areas, renowned for its multicultural atmosphere, diverse cuisine, and major transportation assets like Logan International Airport (City of Boston 2017).

### 4.0 Analysis

#### 4.1 Places (Case Study: Coastal Resilience Solutions for South Boston and East Boston)

South Boston is the Boston neighborhood most susceptible to various flooding events, including ravine, precipitation, and stormwater flooding, as well as SLR caused coastal and tidal flooding. The low-lying South Boston Waterfront, particularly along the Fort Point Channel and Boston Harbor, is the area most at risk within the neighborhood. In the near term, this region will face chronic exposure to high-tide flooding, with an anticipated increase in both frequency and severity of coastal flooding. According to the projected flood progression depicted in Figure 3.1,
by 2030, approximately 25% of the land is expected to be exposed to flooding, followed by 50% by 2050, and 60% by 2070 during 1% annual chance flooding events. Second only to Downtown Boston, South Boston boasts one of the most valuable real estate markets. However, by the end of the century, it is poised to become the most vulnerable neighborhood based on projected damage costs. Many of South Boston's assets, including transportation systems, emergency response facilities, and utilities, will face exposure to 1% annual flooding events beginning in the first half of the century. Towards the end of the century, nearly all assets will be vulnerable to high tides, compounded by 10% and 1% annual chance flooding events (City of Boston 2016; City of Boston 2018).

The East Boston neighborhood, situated northeast and across from South Boston, encompasses one of the largest land areas projected to experience coastal flooding throughout the 21st century. The neighborhood is susceptible primarily to high-tide flooding from Boston Harbor and ravine flooding from several creeks that flow through. By the 2070s, as illustrated in Figure 3.1, a 1% annual chance of flooding is expected to affect 50% of the neighborhood. Currently and in the near-term future, the most vulnerable parts of the neighborhood include the two low-lying inland points, East Boston Greenway and the area south of Bennington Street, which are susceptible to inland flooding. However, the likelihood of high-tide flooding and flooding from coastal storms is anticipated to increase throughout the century, exposing waterfront areas (City of Boston 2016; City of Boston 2017).
Figure 4.1: Projected Flood Progression in South Boston and East Boston throughout the 21st century: A. Near term (2030s with 23 cm SLR); B. Midterm (2050s with 53 cm SLR); and C. Long term (2070s with 91 cm SLR) (City of Boston 2016).

In comparison, while South Boston will incur higher annualized losses from floods, East Boston will face significantly greater losses in the private infrastructure sector. South Boston’s larger high-rise buildings typically experience smaller losses compared to low-height buildings, such as single-family housing units, which are more common in East Boston. Thus, South Boston
has a considerably lower number of buildings exposed to flooding, whereas East Boston is expected to have approximately three times more buildings exposed to low-probability flooding. By the 2070s, with one of the densest populations, about 50% of East Boston residents will be exposed to high-probability flooding, and more than half of the building stock, or 3,000 buildings in East Boston, will be exposed to low-probability flooding. Additionally, 41% of buildings will be exposed to 10% annual chance flooding, impacting approximately 18,500 people (City of Boston 2017; City of Boston 2018).

In the major coastal resilience plan for the City of Boston, the Climate Ready Boston report, the coastal resilience strategies are subdivided into four categories based on their intended purposes: Protected Shores, Prepared and Connected Communities, Resilient Infrastructure, and Adopted Buildings. The Protected Shores initiative is further divided into four categories, one of which focuses on developing a climate resilience plan for each neighborhood. These plans support district-scale climate adaptations, provide clarity on zoning codes, and propose ways to enhance zoning regulations that are adaptable to the changing climate and fast-paced reality. Lastly, they aim to ensure infrastructure protection in upcoming developments and identify areas of focus based on flood progression maps in neighborhoods around the city. This outline for developing a proper plan is then translated into individual plans for each neighborhood vulnerable to flood exposure (City of Boston 2016).

As part of the Climate Ready Boston initiative, the City released detailed plans for each neighborhood vulnerable to flood exposure. These include the 2018 Coastal Resilience Solutions for South Boston plan and the 2017 Coastal Resilience Solutions for East Boston and Charleston. These plans conduct vulnerability assessments, create flood models with flood pathways, identify critical locations requiring flood mitigation measures, and propose a variety of resilience initiatives. These initiatives vary in terms of the timeframes for completion, with some near-term actions to be implemented by 2025 and long-term actions to be completed between 2030 and 2070, with some extending beyond that timeframe. The scale of the projects also varies, ranging from building flood walls and raising harbor walkways or roads to increasing land area by filling the coastline.

Many of the proposed projects primarily involve gray infrastructure, utilizing engineering approaches with concrete and steel, such as vertical seawalls, water-tight buildings and structures, or raised harbor walks with amphitheater steps. Other approaches incorporate natural components,
such as permeable materials like sand and grass, utilization of plants in harbor walks that incorporate park elements, artificial marshes, and berms, making them nature-based solutions (NBS). The determination of which approach to use depends on several factors, including location, ownership (private, public, or Massport owned or released), flood risks and sea level rise projections, flexibility and adaptability over time, and aesthetic considerations.

The *Coastal Resilience Solutions for South Boston* plan offers a more detailed approach for each segment of the neighborhood by delineating projects focused on specific areas, whereas the *Coastal Resilience Solutions for East Boston and Charleston* appears to be broader in scope. This disparity is evident in the length and level of detail in the plans. While the East Boston plan does concentrate on critical areas and outline approaches, the South Boston plan provides multiple options for strategies. This discrepancy may stem from the bustling harbor activity in the South Boston area, which impacts the scale of the projects. Additionally, the predominance of near- or mid-term strategies in South Boston suggests a focus on immediate solutions rather than future-oriented ones. This is further reflected in the choice of strategies employed. In South Boston, there is a greater inclination toward gray solutions, such as vertical seawalls and raised harbor walkways, even though NBS and green infrastructure, such as living shorelines, dunes, and beaches, are still included. This preference may be attributed to potential losses the City could incur, particularly in cultural institutions and private offices, which carry higher costs compared to private infrastructure, more prevalent in East Boston.

As part of the plan's evaluation criteria, community and stakeholder engagement play a significant role in determining the most suitable approaches. In both neighborhoods, East Boston and South Boston, stakeholders including residents, business owners, and property owners expressed strong support for NBS approaches, citing their prioritization of public enjoyment, enhancement of the area, and community connection. In areas like South Boston Waterfront, there is a preference for approaches prioritizing building resilience and reducing flooding, while in other areas like East Boston shoreline, there is greater emphasis on creating open spaces that also act as recreational spaces, enhancing access to art and culture, and increasing vegetation.

To mitigate coastal flooding numerous nature-based strategies are proposed in both plans, especially in *Coastal Resilience Solutions for East Boston and Charleston*, and many of those strategies focus on flood protection systems integrated with open spaces. These flood protection strategies incorporate various in-water, shoreline, and upland features designed to increase the
amount of vegetated and permeable surfaces. This, in turn, enhances the waterfront's capacity to mitigate the impacts of flooding and other climate change hazards, such as extreme heat, potentially benefiting shoreline habitat. Emphasizing soft measures, these strategies include stormwater gardens, open lawns, and recreational fields. Moreover, by integrating ecological features with other developments, a mixed-use development model is created, prioritizing community and social spaces while emphasizing accessibility, public health, and aesthetics (City of Boston 2017).

The primary nature-based approach in the coastal resilience solutions for East Boston's shoreline along the Boston Harbor, excluding the shoreline along the Chelsea Creek, involves the implementation of berms. Out of the nineteen projects proposed by the plan, nine are berms, most of which are prioritized for execution within the near-term timeline by 2025 and 2030. Another significant category of flood mitigation projects is parks, comprising ten parks with varying completion timelines, primarily related to uncertainty surrounding neighborhood district zoning codes. These codes were established before flooding due to sea level rise was considered a significant threat, and issues regarding land ownership also contribute to the delays in park implementation. One of the main barriers to the development of parks is the active use of the harbor and its shoreline by water-dependent industries.

Why are berms a priority or the preferred strategy in East Boston? The low-lying nature of this neighborhood emphasizes the heightened threat of flooding due to SLR. Consequently, the City has proposed focusing on elevating waterfronts through various means, with berms being one of the preferred NBS along the East Boston shoreline. Berms, naturally occurring morphological features, develop at water's edge through the low-energy fractionation of waves and the deposition of sand, gravel, and other debris. They have a slope that steepens toward the land and can be artificially constructed using similar materials. However, a downside to this system is the potential for erosion, particularly during storms and exceptionally high tides, which are anticipated in East Boston, according to the Climate Ready Boston report (City of Boston 2016; Pontiki et al. 2023).
Clippership-Hodge Berm is one of the near-term projects underway in East Boston, expected to be completed by 2025 at a cost of $0.5-0.9 million. This berm is designed to elevate the harborwalk by approximately 6 meters, providing protection against the 1% annual chance of coastal flooding projected for 2070. It aims to safeguard thousands of residents and harbor-facing infrastructure, including newly built developments, long-standing structures, and nearby affordable housing. The berm has an expected lifespan of 50 years with maintenance, and it offers the advantage of being adjustable over time as projections for further SLR evolve. It is particularly suitable for the area because it does not require a wide space, making it ideal for well-developed areas. While berms effectively shield against storm surges and high tides by elevating the area and facilitating water drainage, the increased frequency of these events could lead to erosion, necessitating constant maintenance.
Another coastal flood protection system integrating open spaces in East Boston is the Border Street Area, shown in Figure 4.3. This project implements NBS through elevated parks, elevated harbor walks, and the restoration of salt marshes. It costs between $19.9 and $31.5 million and is on the near-term priority list. The project aligns with the Climate Ready Boston objective by providing the community with open space and equal waterfront access. In total, this project will create 44 thousand square meters of green infrastructure and open spaces. Combined, the green coastal resilience strategies in East Boston are estimated to protect over 10,800 residents and prevent approximately $620 million in flood-related losses.
Figure 4.4: Proposed flood protection strategies across South Boston (City of Boston 2018).

Diverse activities and lifestyles in different parts of South Boston necessitate varied flood protection strategies. Some areas emphasize open spaces, ecological features, recreation, views, and public waterfront access, while others prioritize strategies that optimize limited space for flood protection (Figure 4.4). Due to space constraints and the need for immediate solutions, the 2018 Coastal Resilience Solutions for South Boston plan recommends gray infrastructure, such as vertical seawalls, watertight structures, and tidal walls or flood gates (not depicted in Figure 4.4). However, the plan also includes green solutions, proposing three constructed ground projects (elevated parks and harbor walks), two living shorelines projects, and one extensive beach and dune restoration project. These strategies are primarily concentrated in areas like the South Boston Neighborhood, South Boston Waterfront, and Fort Point Channel.

One of the most vulnerable areas is First Point Channel, which is expected to experience flooding from average monthly high tides by the mid- to late-century, even without storm surges. Dominated by private land ownership, landmarks, and critical transportation routes and infrastructure, this area has already sustained flood damages for years and urgently requires a flood protection solution. Without immediate action, the 1% annual chance flood event is projected to
impact 101 structures and 1,120 people by the 2030s, causing an estimated $5.6 million in physical
damage and displacement (City of Boston 2018). In response to this urgent scenario, the plan
emphasizes the installation of gray infrastructure. However, it also incorporates several NBS, such
as various types of parks and other open floodable public spaces. These spaces are designed to
intentionally flood during extreme weather events without damaging the infrastructure, while also
providing recreational areas during dry periods, thus ensuring equitable access, community
partnership, and public benefit. Additionally, the strategy includes living shorelines with restored
salt marshes. Located in the foreshore area, these strategies have been demonstrated in other cases
to be more cost-effective than gray infrastructure due to lower investment and maintenance costs.
They also enhance habitat by improving water quality and sediment retention and reduce the height
and intensity of incoming waves (van Zelst et al., 2021).

Figure 4.5: South Boston Waterfront flood extent through the 21st century (City of Boston 2018).

The South Boston Waterfront, a mixed-use neighborhood featuring cultural sites, small
businesses, and new residential spaces, is currently under development following the 2018 release
of the climate resilience plan. Located directly on the waterfront and surrounded by water on three sides, this densely built area faces significant challenges in implementing flood protection due to limited space. Consequently, flood mitigation strategies are designed to develop vertically over time. A projected sea level rise (SLR) of 22 cm by the 2030s could expose the infrastructure to significant damage and potentially displace residents, with estimated costs reaching $200 million. Figure 4.5 illustrates the extent of flooding during current high tide events and with the projected SLR ranging from 22–101 cm. Given the neighborhood’s vulnerability, with multiple floodway flows posing hazards, the initial stages of flood mitigation strategy development must address these critical flows. While community engagement and stakeholder meetings have shown a preference for nature-based solutions, the urgent need for protection has led to a primary reliance on gray infrastructure solutions, including a floodwall and a tidal gate incorporated into a levee. These measures aim to prevent water from Boston Harbor and the marina floodway from reaching the neighborhood. One proposal within the Coastal Resilience Solutions for South Boston plan, which could be implemented in the mid-century if projections, costs, and benefits align, involves combining green and gray infrastructure by filling the marina to create a park with a permeable surface. This strategy of extending land into the water would provide effective drainage, increase the space between infrastructure and water, and offer social and economic benefits. However, it could negatively impact the environment by destroying aquatic and coastal habitats, disrupting sediment layers and increasing turbidity, and altering natural tidal patterns and water flows, potentially creating problems in adjacent areas (Afzal et al., 2022). Additionally, this strategy might face challenges in the permitting process, particularly because the marina is not publicly owned and involves in-water construction.

4.2 People (Comparative Analysis)

4.2.1 Community Characteristics

Located across Boston Harbor, the neighborhoods of East Boston and South Boston share a common susceptibility to flooding due to sea level rise, making them the two most affected areas in Boston according to projections (City of Boston 2016). By the 2030s, approximately 25% of the area in both neighborhoods is projected to be impacted by a 1% annual chance flooding event, with that number increasing to 60-70% by the 2070s (City of Boston 2017; City of Boston 2018).
Despite this commonality and their similar and significant population sizes, there are notable differences in average income and real estate costs between the two neighborhoods. Over the course of Boston's history, both neighborhoods have undergone considerable change and evolution, with new residents arriving and others departing. South Boston, in particular, has experienced significant gentrification attributed to its proximity to downtown, office spaces, academic institutions, and the harborwalk (City of Boston 2024; Global Boston 2024). There are concerns that East Boston could undergo a similar transformation, which would impact the local population, especially those living along the waterfront.

Between 2000 and 2015, the population in South Boston increased by 15%, exceeding the city's growth rate of 10% during that period (BPDA 2019). As of 2016, the population in South Boston was 31,800 people (City of Boston 2016). Originally recognized for its working-class Irish Catholic community that settled there in the mid-nineteenth and twentieth centuries, South Boston has undergone multiple waves of gentrification. With convenient access to public transportation and downtown offices, the area gradually became appealing to young professionals and families (Global Boston 2024). In 2017, adults aged 25-35 constituted the largest group of residents. Median household incomes varied throughout different parts of the neighborhood, ranging from $93,078 to $150,678 in South Boston Waterfront, compared to Boston's overall median income of $62,021 in the same year (BPDA 2019). In 2016, 26% of residents fell into the low-income to no-income category (City of Boston 2016). Approximately 61% of residents lived in rented housing, with median rents in South Boston ranging from $1,432 to $2,981, compared to the citywide median rent of $1,445 in 2017 (BPDA 2019). According to the 2020 US Census Bureau data, South Boston is home to 43,496 people, with 3,443 residents in the South Boston Waterfront and 36,212 in the rest of the neighborhood. Among all the residents, approximately 77% are white, 3.5% are Black or African American, 8% are Hispanic or Latino, and 7% are Asian (BPDA 2024). South Boston has a lower concentration of various categories of socially vulnerable people compared to the rest of Boston, with many of them being concentrated in public housing projects rather than dispersed across the entire area as in many other neighborhoods, including East Boston (City of Boston 2016).

Initially settled by Irish and Eastern European residents, East Boston's demographics evolved throughout the twentieth century, first with the arrival of Italian immigrants and later with an influx of Southeast Asians and Latin American immigrants (Global Boston 2024). Today, East
Boston has the highest percentage (50%) of foreign-born residents of any Boston neighborhood with 43% of residents having limited English proficiency (BPDA 2019; City of Boston 2016). Its total population stands at 43,066, with 37% identifying as white, 3.3% as Black or African American, 50% as Hispanic or Latino, and 4.5% as Asian residents (BPDA 2024). While East Boston has a higher percentage of children (0-17) compared to the Boston average, the most prevalent age group is between 35 and 64. In recent years, the area has been transforming with the development of more residential and recreational spaces due to an influx of young professionals. Some of the major development activity, including residential development as well as open spaces, has been along the waterfront (City of Boston 2016). The median household income in East Boston is $52,935 (2017), making it lower than Boston's median income by $9,086. East Boston has one of the highest percentages of low-income to no-income residents in Boston, with 34% of its residents falling into this category (City of Boston 2016). The median rent, at $1,249 (2017), is also below the citywide median by $196, with 71% of East Boston residents living in renter-occupied units (BPDA 2019). East Boston also has a high concentration of medical illnesses, with 13% of its residents living with disabilities. This can become a dangerous situation during flooding events, as tunnels and bridges leading out of East Boston, which serve as evacuation routes for many residents, can become blocked by flooding. This leaves people in an area with very few hospitals (City of Boston 2016).

4.2.2 Equity Approaches (Outreach)

In its 2016 *Climate Ready Boston* report, the City pledged to prepare its infrastructure and communities for climate change. To ensure the safety and well-being of all residents, the City committed to connecting community members through various methods, paying special attention to reaching socially vulnerable populations, including a large number of renters and students. This entails active communication aimed at sharing and receiving information among residents, businesses, institutions, and community partners. Additionally, the City promised to engage climate adaptation and planning experts to ensure the most efficient and equitable distribution of resilience investments. Recognizing that investments in transportation, open spaces, housing, and neighborhood services have the potential to enhance safety, economic opportunity, and livability for all residents, the City acknowledged that these adaptations may impact property values and
affordability. Therefore, it underscores the importance of developing a resilience and racial equity toolkit.

The Layer 2 — Prepared and Connected Communities objective of *Climate Ready Boston* underscores the vital importance of expanding community engagement and education regarding climate hazards and actions. Active participation by the public, alongside their understanding of how their neighborhoods might be affected by climate change, can help in understanding ways to mitigate risks to human health and infrastructure.

In both neighborhood-specific reports, the City’s strategy primarily focuses on conducting outreach in public spaces with high foot traffic, while also working closely with building owners, business owners, and vulnerable populations. Two key strategies aligned with Layer 2 of the resilience framework are proposed: 1) conduct an outreach campaign to private facilities that serve vulnerable populations to ensure that they engage in emergency preparedness and adaptation planning; and 2) expand Boston’s small business preparedness program. The first strategy includes outreach to managers of facilities serving vulnerable populations—such as affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, and small nonprofit offices—that are not currently required to have operational preparedness and evacuation plans. Additionally, in East Boston, there is a required action to partner with the Neighborhood of Affordable Housing (NOAH) on outreach initiatives. The second strategy involves assisting small businesses in developing continuity plans, evaluating insurance coverage, and identifying low-cost physical adaptations to manage risks from stormwater flooding in the short term or coastal flooding during a 1% annual chance event with 23 cm of sea level rise. In East Boston, this includes assisting efforts to owners of 83 commercial buildings and 133 mixed-use buildings; in South Boston, assistance will be offered to owners of 88 commercial buildings and 131 mixed-use buildings (City of Boston 2017; City of Boston 2018).

While the Layer 2 initiative for the entire City of Boston proposes the launch of education and engagement campaigns, as well as educational programs for building owners and users, these strategies were not explicitly mentioned and described in the specific sections for East Boston and South Boston. Additionally, they were not addressed in the updated materials for the 2018 *Coastal Resilience Solutions for South Boston* and the most recent update of the 2022 *Coastal Resilience Solutions for East Boston and Charleston*, leaving the rest of the general public engagement unaccomplished.
4.2.3 Equity Approaches (Green Gentrification)

Gentrification, characterized by redevelopment of under-resourced neighborhoods and an influx of affluent newcomers, often leads to increased housing prices and displacement of low-income residents, particularly renters unable to afford the rising costs in their evolving neighborhoods. This process has significantly impacted long-time residents and businesses, with marginalized communities experiencing a diminished sense of community and belonging (Jelks et al. 2021). Over the past decades, gentrification has had devastating effects on affordable housing in Boston, leading to the displacement of many community members from their neighborhoods. From 2010 to 2020, Black residents were particularly impacted by gentrification citywide, with the Black population declining by over 6% during that period (City of Boston 2022).

One of the key contributors to this phenomenon is the development of amenities such as entertainment venues, transportation systems, and office spaces, which elevate property values. While East Boston and South Boston exhibit some of these typical gentrification causes, their waterfront areas are also susceptible to a phenomenon known as green gentrification. This term refers to the integration of green infrastructure into urban sustainability and resilience plans, which, while aimed at mitigating climate change impacts, also attract sustainability-focused investors and developers, potentially displacing local and marginalized residents (Anguelovski et al., 2019).

The Climate Ready Boston initiative includes deploying green infrastructure along the 47-mile Boston Harbor coastline. Both the Coastal Resilience Solutions for South Boston and the Coastal Resilience Solutions for East Boston and Charlestown detail how they incorporate these measures. To align the plans with the overall agenda of the Climate Ready Boston initiative, these flood mitigation strategies are evaluated across seven categories: Effectiveness, Feasibility, Design Life and Adaptability, Environmental Benefits, Social Impact, Value Creation, and Equity. The criteria for the "Equity" category include: 1) New and Equitable Access to Waterfront; 2) Additional Benefits for Vulnerable Populations; 3) Community Partnerships; and 4) Protection of Affordable Housing over the Long Term.

The first criterion appears to be accomplished by both plans, as the proposed projects incorporating NBS provide public access to newly developed flood protections that integrate with recreational spaces, aiming to benefit the broader community rather than exclusively wealthier new residents. In the analysis of the plans, there were no identifications of privatization of land, except those already owned by other governmental entities, such as Massport. Despite these
intentions, surveys indicate that some long-standing community members feel socially and culturally excluded from the new green spaces, which are often situated near luxury developments (Anguelovski et al., 2019).

The second criterion, the addition of benefits to vulnerable populations through green infrastructure, has not been described in detail in either plan. Residents will benefit from the green infrastructure, which enhances protection from climate risks and impacts, including other hazards such as the heat island effect and poor air quality, in addition to flooding. However, the plans do not propose any benefits to vulnerable populations beyond the redeveloped waterfront, thus falling short of meeting this criterion.

The third criterion has been accomplished by both plans during the plan development process. Public feedback was an important part of the assessment and decision in both neighborhoods, East Boston and South Boston. Over 400 residents participated in the design process of the East Boston plan and over 650 residents participated in the design of the South Boston Plan. They provided feedback in online surveys, during open houses, and community meetings.

Lastly, the protection of affordable housing over the long term is a more complicated criterion because it not only involves the waterfront resilience plan, but it is based on the City’s policies and requirements for the developers. Many experts and residents believe that these requirements are minimal; thus it is sometimes hard to ensure that affordable housing is incorporated in the planning process (Stone Living Lab 2024). However, both plans put emphasis on racial and economic equity, but the current plans do not detail on how this could be achieved. While both plans work with multiple community stakeholders and partners, including the Boston Housing Authority in South Boston’s plan and the Neighborhood of Affordable Housing in East Boston, who helped to oversee the overall project and conduct community engagement between stakeholders and community members, there is no outlined strategy on how this equity and reduced possibility of green gentrification can be accomplished.

Green gentrification has been particularly evident in areas like East and South Boston where initiatives to mitigate climate risks of flooding through flood-resistant buildings and improved green spaces have simultaneously made these neighborhoods more desirable and expensive. South Boston has experienced one of the most significant levels of gentrification among all neighborhoods in the city, with its median household income increasing by 131% since 2000.
In contrast, the median household income across the country increased by approximately 77.62% during the same period (FRED St. Louis Fed 2024). The South Boston Waterfront underwent extensive redevelopment, transforming from a largely industrial area to a high-end residential and commercial hub. This shift brought in new residents and businesses, which significantly increased property values and living costs, pushing out many long-time, lower-income residents. In this part of the neighborhood, the median rent is $3,500 per month, which is significantly higher than the median range of $1,432 to $2,981 across South Boston (Ford Realty 2024).

In East Boston, right near the Clippership-Hodge Berm project, a new development has been built promising its residents easy access to the waterfront and park (ULI 2024). Clippership Wharf was redeveloped with a focus on green and sustainable features as part of its transformation of the East Boston waterfront. Despite that the redevelopment was recognized for its environmental sustainability efforts, such as raising the ground plane to protect against sea-level rise and incorporating green spaces that absorb rainwater, reducing flood risks, many believe it contributes to the green gentrification (Stone Living Lab 2024). This new apartment complex invites sustainability-class residents and offers apartments with rent starting at $2,300 per month, while the average rent in the neighborhood is $1,249, which is a drastic difference (Stone Living Lab 2024).

On a positive note, realizing its impact on the neighborhood, the company that is developing Clippership Wharf in a partnership with the Boston Housing Authority enabled the development of 22 affordable rental units and 30 mixed-income condominiums in the neighborhood (ULI 2024; Stone Living Lab 2024). However, these examples illustrate a trend where policy actions tend to favor higher-income groups and commercial interests, often at the expense of existing communities.

5.0 Recommendations

5.1 Recommendation #1: Implement Hybrid Coastal Protection

Analysis of the City of Boston's plans reveals a commitment to integrating strategies that offer environmental benefits and protect infrastructure and residents from flooding events.
Although gray infrastructure has historically proven effective in coastal protection, recent plans show a clear shift towards incorporating more green approaches. However, the city should further refine its strategy to adapt to coastal challenges, not merely by shielding itself from wave impacts but by adopting proven methods such as living shorelines and the restoration of local salt marshes (van Zelst et al., 2021). Given the heavy traffic in Boston Harbor, implementing vegetation requires a thorough analysis of both ecological impacts and human usage.

The focus should extend beyond mere land redevelopment to include restoring natural barriers. This could involve offshore areas where wetland restoration is feasible. Despite the significant decline of salt marsh areas by 81% since Boston's establishment, enhancing the remaining natural environments is crucial for bolstering the harbor's resilience against storms (Campbell et al., 2022). The strategy of vegetation restoration could also integrate into existing waterfront parks and pathways, especially as proposed in the East Boston plan. Increasing vegetation not only prevents erosion but also reinforces coastal defenses such as berms against wave wear and tear (Pontiki et al., 2023).

Incorporating vegetation into hybrid coastal protection strategies offers a sustainable and economically viable approach. Marshes, for example, provide numerous ecosystem services including carbon storage, habitats for wildlife, improved water quality, and sediment accumulation (Campbell et al., 2022). While small-scale restoration projects alone cannot shield Boston from sea-level rise, the combination of traditional flood defense measures with restored vegetation has not been thoroughly assessed and could prove effective (van Zelst et al., 2021). By implementing these strategies, Boston could pioneer a new way of thinking about flood mitigation that both protects and restores the environment while creating infrastructural resilience.

5.2 Recommendation #2: Develop General Public Outreach Plan

While the Climate Ready Boston plan and individual resilience plans for East Boston and South Boston do emphasize the importance of outreach, there does not seem to be a specific plan for general public outreach, which is crucial because one of the most important resilience strategies is to create resilient communities. As more and more people in Boston are exposed to floods, addressing heightened flood risks becomes increasingly important. Risk perception is the ability to subjectively judge the severity of risk. In the case of flooding, it involves assessing the probability of the hazard and its consequences. Flood risk perception and disaster preparedness in
flood-prone areas go together. By creating awareness of disaster risk and increasing flood preparedness, individuals deepen their knowledge of the hazard and its effects, subsequently building their and their community’s resilience to the hazard (Harlan et al., 2019).

Past events have demonstrated that without emergency planning at both urban and individual levels, significant physical losses, including damage to building stock and infrastructure, as well as declines in human health and loss of lives, can occur. The outreach events on flood hazards are designed to provide people with a framework of steps to take prior to, during, and post the flooding event, changing public attitudes and beliefs about flood hazards, and developing workable strategies to avoid and recover from them. Past events have shown major gaps in preparedness and risk perception, such as people feeling left behind during evacuation, especially those who rely on public transportation. Additionally, after a flooding event, residents often lack a plan that would help them to return to their normal lives, renovate their homes, or cover damages (Nick et al., 2009).

During flooding events, certain groups face significantly higher risks and barriers than the general population. These vulnerable groups include: the elderly, who may have mobility limitations and health issues that impede their ability to respond quickly; young children, who depend on adults for their safety and cannot independently seek help and are more susceptible to health complications; individuals with limited English proficiency, who may not fully understand emergency announcements or instructions if not provided in accessible languages; and those experiencing geographic or cultural isolation or addiction, who might be disconnected from traditional communication channels and support networks. These circumstances make it more challenging for these individuals to access, comprehend, and act on critical safety information, thus hindering their ability to react effectively during emergencies (Nick et al., 2009; Harlan et al., 2019).

The City of Boston should incorporate more outreach programs directed toward the general public. These outreach efforts should connect community members, forming a strong bond that could be helpful in emergency situations. Meetings or workshops dedicated to climate change and the hazards it poses, such as flooding or overheating due to extreme temperatures, should be held in Boston. During these sessions, participants can learn about specific hazards, identify flood zones if necessary, assess their personal risks, and receive information on safety strategies and available
support. This support could include flood assistance programs, FEMA flood insurance, and retrofitting options like home elevation or basement filling.

These meetings should be accessible to all attendees by providing information in multiple languages whenever possible. In East Boston, where 46% of residents have limited English proficiency, the most commonly spoken languages besides English are Spanish, Arabic, Portuguese, Chinese, Italian, and Vietnamese. In South Boston, 9% of residents who have limited English proficiency, predominantly speak Spanish, Chinese, and German (City of Boston 2016). While in-person meetings are preferable for fostering community connections, an online version should also be available for those who cannot attend in person due to medical reasons, work commitments, or childcare responsibilities. Additionally, during these meetings, people should be educated on basic safety tips, such as storing enough water and food at home and ways to obtain information during a disaster to ensure their overall preparedness.

5.3 Recommendation #3: Protect the Local Communities

Despite the planning process already incorporating public engagement, the City should conduct a comprehensive study to fully understand the factors beyond price changes that make local communities feel excluded once green infrastructure is implemented. This study would examine trends in green gentrification in Boston, identify who is moving to newly green-protected areas, who is being displaced, and pinpoint the specific implementations driving this process. Additionally, it should investigate whether these interventions increase the socio-ecological vulnerability of populations. The findings could then inform urban planning, public health, and other related professionals to collaborate and enhance the inclusivity and utility of green spaces for the residents.

To ensure that green infrastructure developments directly benefit local and vulnerable populations, the City should incorporate features like community gardens, which are designed to foster a sense of community ownership and inclusion. Engaging community members in the planning, design, and maintenance of these gardens can promote social interaction, enhance mental health, and raise ecological awareness among residents. Providing accessible, attractive, and well-maintained green spaces with ample room for socialization, where people feel safe, may increase their use (Kruize et al., 2019).
Furthermore, the City should reexamine its policies and planning processes to enhance affordable housing protections in waterfront areas targeted for green development. This could involve adopting inclusionary zoning, which mandates that a specific percentage of new housing be affordable. Such policies may require private developers to sell or rent some units at below-market rates, or contribute to a fund dedicated to developing affordable housing. Alternatively, utilizing public land for community land trusts can ensure permanent housing affordability. These measures would increase the availability of affordable housing units, helping to stabilize residents and promote mixed-income communities. Additionally, implementing anti-displacement regulations to protect existing residents from rising rents and property taxes associated with improved infrastructure and green spaces, such as rent control or stabilization policies, and property tax freezes for long-term residents, could also serve as effective tools.

Addressing these issues is complex and necessitates the expertise of policy professionals. As the City continues to develop nature-based programs to combat climate change, the effects of green gentrification may become more pronounced. Therefore, it is crucial that the City establishes mechanisms to monitor the social impacts of green infrastructure projects over time and adjusts policies as needed. This approach will help the city respond to unintended consequences and ensure ongoing community support for waterfront enhancements.

6.0 Conclusion

Implementing nature-based solutions into flood mitigation strategies offers extensive benefits beyond coastal flood protection. These benefits include enhancing ecosystems and local habitats to support biodiversity, improving the physical and mental health of residents through increased access to green spaces, and beautifying urban areas by reducing the prevalence of gray concrete. The City of Boston has demonstrated a commitment to sustainable and resilient development. The case study analysis indicates that the coastal resilience plans for East Boston and South Boston underscore an urgent need for flood protection. Although gray infrastructure is often favored for its immediate results, nature-based approaches may require time to integrate with the environment and are still being assessed for their effectiveness and feasibility.
However, with the inevitable and impending sea-level rise threatening significant impacts on parts of the city, Boston must enhance and diversify its flood mitigation strategies. East Boston and South Boston, the areas most vulnerable to coastal flooding, have seen the implementation of open spaces made from permeable materials. Another innovative strategy being considered is the creation of elevated parks and walkways, which could also be nature-based solutions depending on the materials used. A comparison of the plans reveals that East Boston is more actively exploring nature-based approaches than South Boston. It is recommended that overall Boston explore using more hybrid coastal protections that incorporate vegetation and restore its marshes, which are natural coastal defense mechanisms.

Ultimately, it is crucial that people’s lives are safeguarded, and that local communities feel prepared and equally served by policies and programs. The comparative analysis shows a desire to achieve equity within the community, but there is still room for improvement, especially in protecting and preparing the general public, not just local businesses. Developing public outreach plans and implementing policies that make local residents feel included and connected, and that provide access to systems offering additional support in their communities, should be a priority.

7.0 Literature Cited


Boston Planning and Development Agency (BPDA). 2024. 2020 U.S. Census Redistricting Data Release August 2021 Revised April 2024. 1-33. https://www.bostonplans.org/getattachment/c55502f3-3a70-4772-a894-0c51c325b216


Stone Living Lab. 2024. In Eastie, an early glimpse at Boston’s existential and expensive struggle to hold back the sea. Accessed April 25th, 2024. https://stonelivinglab.org/news-article/the-lab-in-


