Storm Smart Planning for Adaptation to Sea Level Rise: Addressing Coastal Flood Risk in East Boston

By

Victoria H. Wolff

B.A. Art History and Practice
Williams College, 2004

Submitted to the Department of Urban Studies and Planning in partial fulfillment of the requirements for the degree of

MASTER IN CITY PLANNING

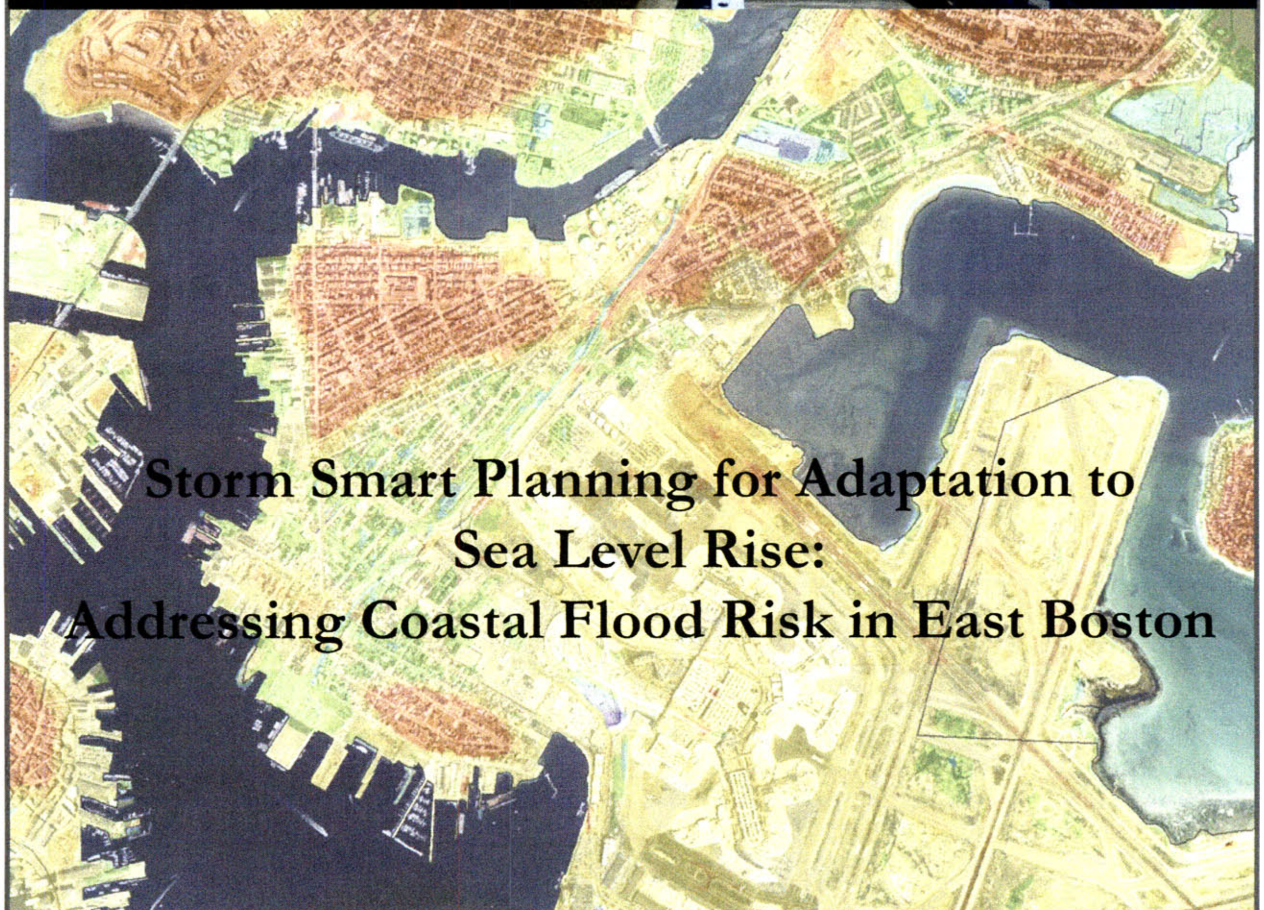
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2009

Signature of Author: ....
Department of Urban Studies and Planning
May, 2009

Certified by: ....
Professor James Wescoat
Aga Khan Professor of Architecture
Thesis Supervisor

Accepted by: ....
Professor Joseph Ferreira
Chair, M.C.P. Committee
Department of Urban Studies and Planning



Storm Smart Planning for Adaptation to Sea Level Rise: Addressing Coastal Flood Risk in East Boston

ABSTRACT

Regardless of how well we implement sustainability plans, now and in the future, the weight of scientific evidence indicates that mean sea level will continue to rise at an increasing rate over the next century. Thus, coastal lands and development lie in a precarious position, increasingly vulnerable to flood damage brought by storm surges and extreme weather events.

In order to avoid disastrous losses of property, life, ecological health and social wellbeing, our cities and regions must quickly implement adaptation plans that consider plausible climate models. Coastal risk can be managed through rigid protections, soft landscape solutions, and land use decisions and regulations. In developing and implementing adaptation plans, it is important to understand the options and their applicability to different site contexts.

Experts warn that today's once-in-a century flood will likely occur every two or three years by 2050![1] However, Boston, like many other U.S. coastal cities, is in the early stages of devising adaptation plans that seek to reduce coastal flood risk from sea level rise. As implementation of adaptation plans may take several years or decades, Boston should act quickly to strategically consider its options.

This thesis examines the effectiveness of different planning approaches to hazard mitigation in urban coastal areas and applies them to at-risk sites in East Boston under coastal flood scenarios for the years 2050 and 2100. Two sites in East Boston, one with a soft edge and one with a hard edge, create two distinct urban landscapes for design solutions. A menu of planning solutions that has been collected from a review of the literature and best practices is then used to inform design solutions to these problems.

By applying contemporary predictions for sea level rise and the problem-specific expertise of coastal management to the site-specific realm of land use planning, I hope to provide a precedent and method for planners, particularly in the Boston area, to seriously incorporate sea level rise predictions into community discussions, regulations, and comprehensive plan making.

<?> *Confronting Climate Change in the U.S. Northeast: Massachusetts.*

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor James Wescoat for his constant, support, creative direction, and eagerness to teach throughout my writing of this thesis. I would also like to thank my reader Sam Bass Warner for his imaginative insight and encouragement.

Thank you to my mother and father whose selfless support throughout my education has been unwavering and to my partner Noah who has helped me to keep perspective while encouraging me to make this thesis even better.

Also, I would like to thank the many experts and professionals who shared their knowledge insight, time, and advice to make this thesis possible. Among them are: Carolyn Bennett, Te-Ming Chang, Julie Conroy, Andrea Cooper, Antonio Di Mambro Ellen Douglas, Valerie Gingrich, Rebecca Haney, Herman Karl, Paul Kirshen, Julia Knisel, Tunney Lee, Hubert Murray, Julia O'Brien, Carl Spector, Juan Carlos Vargas-Moreno, Brad Washburn, Chris Watson, and Richard Zingarelli. I hope that you find the result both interesting and useful.

TABLE OF CONTENTS

CHAPTER 1: PROBLEM STATEMENT AND METHOD

Research Problem

In the face of scientific consensus that sea level rise will notably increase the risk of flooding in coastal cities over the next century, Boston, like most US cities, is in the early stages of significantly addressing how to plan for these conditions.

Planners attend to a plethora of issues related to their region, city, or neighborhood. Unable to master new trends and findings for every issue, many planners are unaware of some of the best information available concerning sea level rise, coastal flood risks, and coastal zone management.

While the city develops a better understanding of the risks and vulnerabilities of its coast, stakeholders and leaders must explore and develop smart planning options that will address the range of risks. This thesis presents a menu of relevant options and explores how these interventions might best apply to urbanized conditions like those in East Boston.

Planners and other stakeholders can learn a good deal about the flood risks associated with sea level rise and related best practices through local coastal hazard experts, scientists, and examples of innovative developments around the world. Such understanding will fuel the development of smart site-specific solutions that fit within the physical, social, and economic context of a neighborhood.

East Boston Sea Level Rise Adaptation Planning

Sections of the East Boston waterfront are at increasing risk for future floods. However, development plans for these areas move forward with little explicit consideration of flooding. Neighborhood and waterfront plans for the area also avoid mention of sea level rise and the impact it may have on the future development landscape of East Boston. The Massachusetts Office of Coastal Zone Management (Mass CZM) offers a wealth of knowledge and resources concerning traditional coastal hazard mitigation, the changing landscape of flood hazards for the area, and best practices in managing risk from policy and land use perspectives. Actors need to utilize and expand on these tools more rigorously.

Confounding Challenges

Time Scale of Plans

Developers and planners tend to plan ahead for five, ten, or twenty years where as the more severe impacts of sea level rise are predicted to occur in the years following. However, the planning and development decisions we make now and in the next five to twenty years will have a tremendous impact on how coastal lands respond to sea level rise. In essence, there is a dangerous disconnect between short-term development and planning and long-term consideration of flood risk.

Focus on Mitigation

Planners, designers and political leaders have begun to recognize and act on climate mitigation through climate action plans and other measures, but very few of these plans have begun to seriously address how cities and regions should adapt to unavoidable changes such as sea level rise. While designers and planners have recently worked to minimize carbon production, their research and practice to date has been largely remote from the climate geography of how change will impact particular landscapes and places.

Uncertainty

Uncertainty also leads to planners' hesitation in dealing with sea level rise. At the most basic level there has been uncertainty within the scientific community about the rate at which sea level rise will increase. Scientists are conservative by nature and, as a group, are unwilling to offer predictions without high statistical certainty. Thus the range of possible climate futures is large and difficult to plan for. Fortunately, scientific research is rapidly addressing the issue of sea level rise and creating more precise models all the time. In addition to sea level rise, several other climate and coastal development factors contribute to uncertainty about the future physical state of coastal lands. These include changes in coastal storm, sediment transport, erosion and marine biological systems as well as coastal urbanization and new types of human demand for coastal lands. Despite the acknowledged uncertainty, change is certain, and planners can move ahead with flexible plans considering the best scenarios available.

Research Question

How might planners, coastal landowners, and communities address the increasing risk of coastal flood hazards due to sea level rise at the site scale in East Boston?

This thesis considers current and exploratory techniques for dealing with coastal flooding and land use and identifies those practices well suited for East Boston development. Using recent projections for global sea level rise and resulting local coastal floods projections as well as appropriate best practices, this thesis offers design solutions for specific sites along the East Boston waterfront.

Conceptual Framework and Method

Literature Review

The literature on sea level rise, coastal zone management, and land use planning is reviewed individually and as the topics relate to each other. The review includes grey literature from local to federal levels, scientific and planning reports, and academic literature.

Design Menu

Existing and exploratory flood hazard mitigation measures from the literature and contemporary practice provide a menu of options for interventions in East Boston.

Hazard Scenarios

Local flood risk projections consider sea level rise in East Boston in 2005, 2050 and 2100. The future

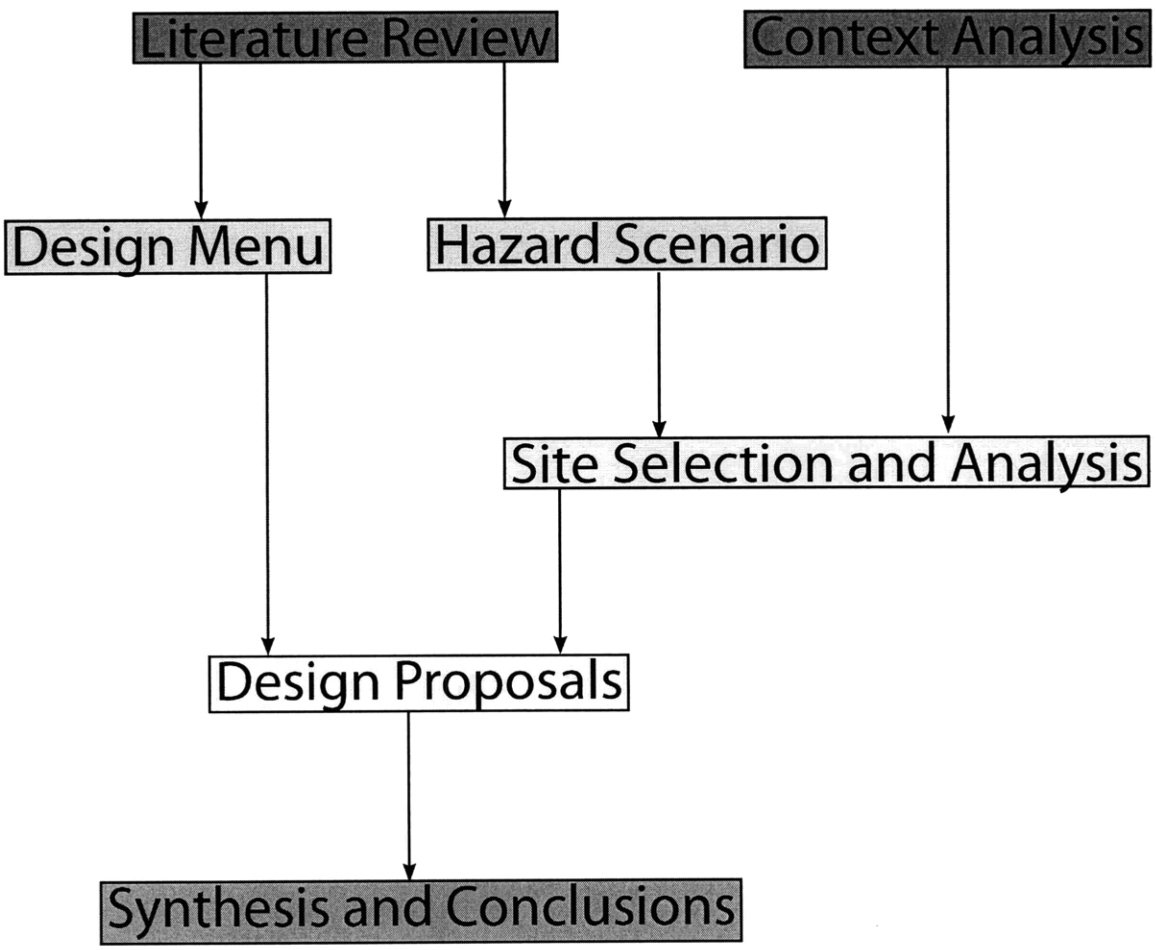


Figure 1. Conceptual Framework and Method

scenarios are based on the sea level rise projections of Stephan Rahmstorf and the subsequent coastal flood projections of the Northeastern Climate Impact Assessment coastal team headed by Paul Kirshen. [1]

Context Analysis

The policy context for addressing coastal flooding, land use, and sea level rise in Boston is summarized. Also, the social and physical landscape and context of East Boston are explored to frame an understanding of the sites.

Site Selection and Analysis

Two sites are chosen in East Boston based on their separate and important urban contexts. The Proposed Boston East development site provides an example for how to consider a site of modest depth on structural bulkheads along the port area. The Constitution Beach site provides an example of how a more natural shoreline and a greater depth of undeveloped land can respond to a variety of solutions that allow for landscape-scale interventions. These sites are analyzed through the lens of protecting against sea level rise while considering the current needs of surrounding communities.

Synthesis – Design proposals

Drawing from the design menu and responding to the coastal flood projections for 2050 and 2100, two design proposals are offered for each site. These proposals aim to minimize risk while still effectively utilizing the parcels. The main categories of interventions considered will are hard engineered barriers, landscape flood mitigation, flood-resistant building design, and land use planning and policy solutions.

A Note on Prioritization

Sea level rise, as well as solutions to mitigate it, will impact people and their land on many dimensions. The direct societal cost of coastal flooding alone includes relocation, job loss for coastal industries, disruption of daily life, inequitable distribution of impacts, visual scarring of the landscape, and development pressure due to future growth. This thesis will focus on loss of property and life due to coastal flooding. Given the flood scenarios, solutions will aim to ensure that buildings will continue to operate during flood events and that flooding will occur only in those areas expected to receive minimal damage.

Purpose

These design solutions will provide East Boston planners and residents with options for addressing sea level rise. More broadly, it should encourage communities to critically address sea level rise and offer examples for how to adapt through structural, landscape, land use planning and policy solutions.

Outline of Argument

Chapter 1 – Problem Statement and Method

This chapter is responsible for introducing the problem statement, method, and outline of the thesis paper.

Chapter 2 – Literature Review

This chapter reviews the most relevant literature on sea level rise, coastal zone hazard management, and land use planning. It refers to work developed by experts such as IPCC scientists, Timothy Beatley, and Ian McHarg as well as contemporary Dutch practitioners.

Chapter 3 – Design Menu

This chapter explores common, popular and best practices being implemented or proposed for managing coastal flooding with consideration for sea level rise. Options are drawn from current practices in the Boston area, cases from Maine to the Netherlands, academic theories, and government synthesis. Hard engineered barriers, flood-resistant building design, landscape flood mitigation, land use planning and related policy tools provide the building blocks for subsequent design analysis.

Chapter 4 – East Boston Context

This chapter begins by mapping institutions, from federal to local, that are most involved in coastal flooding, sea level rise adaptation, and planning as it relates to Boston. It briefly describes the physical and social geography of the East Boston neighborhood. Following this, it explains the sea level rise scenario used and presents a map showing the extent of future

---

1 Kirshen et al., *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions: Appendix: NECIA Coastal Impacts Analysis.* Rahmstorf, "A Semi-Empirical Approach to Projecting Future Sea-Level Rise."

flood risk with sea level rise in 2050 and 2100. Finally, it introduces the two sites selected for further analysis.

Chapter 5 – Boston East Site Design Adjustments

This chapter begins by explaining the details of the Boston East site design proposals as it relates to flood hazards with future sea level rise. After identifying the areas of vulnerability and opportunity, options from the design menu are applied using visual designs and explanatory text. The chapter concludes by summarizing how different methods address the problem.

Chapter 6 – Constitution Beach Site Design Proposals

This chapter begins with a site analysis of the Constitution Beach site related to flood vulnerabilities and opportunities. Options from the design menu are applied using visual designs and explanatory text. The chapter concludes by summarizing how different methods address the problem.

Chapter 7 – Synthesis and Conclusion

This chapter synthesizes the findings from the design exploration and discusses how different options might best apply to different site contexts in Boston. It also discusses next steps, complementary actions, and further research required.

CHAPTER 2: LITERATURE REVIEW

Human civilization is facing an unprecedented rate of change in climate and sea level that will require ingenuity and an unprecedented scale of solutions. However, while the rate and scale of impact might be unprecedented, the nature of these impacts are familiar. Communities have long dealt with development suitability through land use planning and and flood hazards through coastal zone management. Solutions from land use planning and coastal zone management can and should inform the issues of coastal flooding due to Sea Level Rise. This chapter will introduce the issues of Sea Level Rise, Coastal Zone Management, and Land Use Planning as they relate to the problem of increasing flood hazards on our coasts. It will then review literature dealing with the intersection of two or more of these fields in the search to understand how they can work together to address the problem in this thesis.

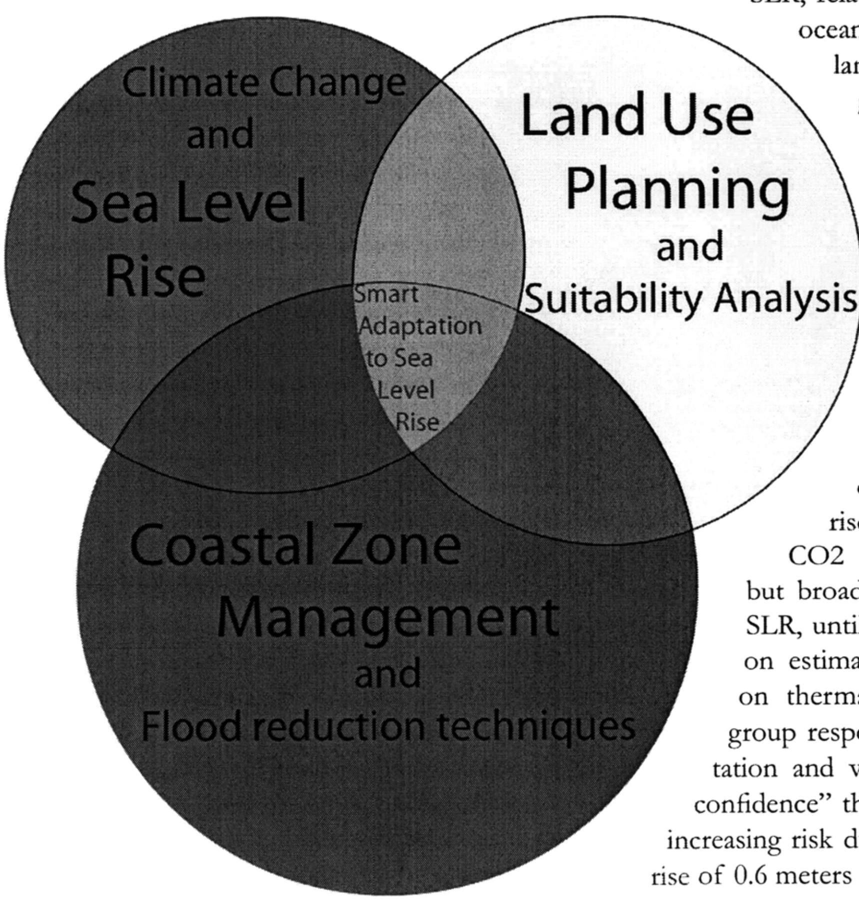


Figure 2. Literature Review Diagram

Sea Level Rise

The quantity and confidence of scientific data predicting notable sea level rise over the next century is increasing, and, while some uncertainty remains over the rate of change, there is near consensus that sea level rise (herein referred to as SLR) will significantly impact our coastal communities

In 2007, the Intergovernmental Panel on Climate Change (IPCC), a respected panel of top climate change researchers from around the world, came out with their fourth, and most extreme, assessment report. While many researchers speculated that international politics and the need for consensus led to overly conservative predictions, the picture is, nonetheless, startling. Because the report represents consensus, it has appealed to the general population and helped to raise public and political awareness of climate change.[2]

Process and Predictions

Relative SLR is a function of eustatic or global SLR, related to the volume of water in the oceans, and isostatic SLR related to local land subsidence and erosion. While global isostatic SLR is expected to approximate historical trends, climate change is contributing to a troublesome increase in eustatic SLR.

Two distinct processes contribute to the accelerating rate of eustatic SLR. Thermal expansion, the more predictable of the two, involves an actual expansion in the volume of ocean water as ocean temperatures rise due to causes such as increased CO2 in the atmosphere. Conservative, but broadly excepted predictions of global SLR, until the recent past, have relied solely on estimates of thermal expansion. Based on thermal expansion, the IPCC working group responsible for studying impacts, adaptation and vulnerability, expressed "very high confidence" that coastal zones will be subject to increasing risk due to climate change and sea level rise of 0.6 meters or more on the higher end by 2100

2 Intergovernmental, *Climate Change 2007.*

and impacts are "virtually certain" to be overwhelmingly negative.[3]

However, there is another major contributor to eustatic SLR, the timing of which is more difficult to predict. Rising temperatures and other changes in climate patterns are also contributing to ice melt including small but numerous ice caps and the breakdown of ice sheets sitting on land in Greenland and Antarctica. Such a breakdown would significantly increase long term SLR. As scientists began to measure and predict the rate of ice melt with more confidence, it became clear that the estimates agreed to by the IPCC were incomplete[4], and consequently too low.

At the March 2009 International Scientific Conference on Climate Change in Copenhagen, researchers revealed that sea level has been rising much faster than had been predicted by the UN only two years before.[5] Experts tended to agree, "the upper range of sea level rise by 2100 could be in the range of one meter, or possibly more. In the lower end of the spectrum, it looks increasingly unlikely that sea level rise will by much less than 50 cm by 2100."[6] As this scientific conference is a precursor to the big political conference in Copenhagen in December 2009, the agreed upon findings are extremely relevant for decision-making.

Estimates made by Stephan Rahmstorf in 2007 were met with initial skepticism but as new data has proved his predictive methods robust, many scientists and decision makers are referring to his work for best current estimates of eustatic SLR. Using a "semi-empirical" method, he found that "When applied to future warming scenarios of the Intergovernmental Panel on Climate Change, this relationship results in a projected sea-level rise in 2100 of .5 to 1.4 meters above the 1990 level.[7] This paper will rely on predictions for local coastal flooding that incorporate Rahmstorf's projections.

Given the time scales of these processes, the warming of the oceans over the next century is largely related to CO2 that has already been released into the

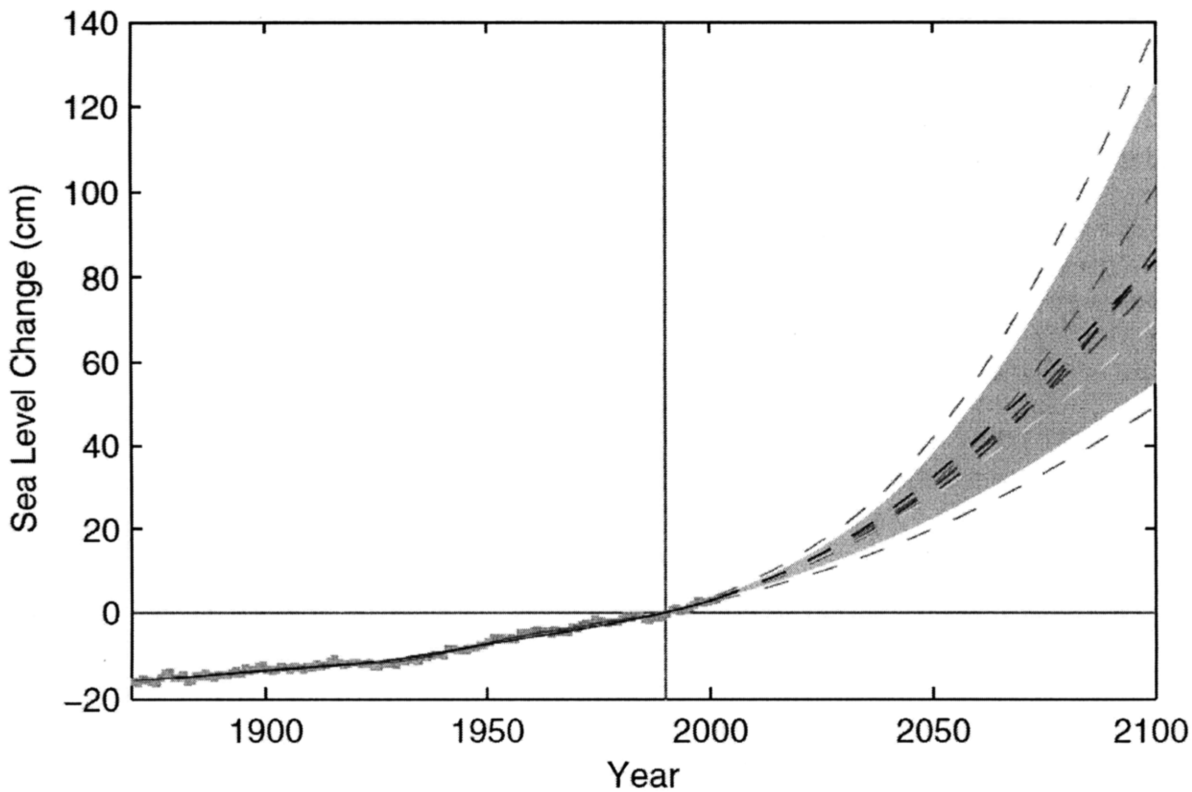


Figure 3. Prediction of Sea Level Rise to 2100. Source: Stephan Rahmstorf. "A Semi-Impoerical Approach to Projecting Future Sea Level Rise" in Science

3 Ibid.

4 Meier et al., "Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century."

5 "A sinking feeling: Climate change."

6 Charlotte Brix Andersen, "Rising sea levels."

7 Rahmstorf, "A Semi-Empirical Approach to Projecting Future Sea-Level Rise," 368.

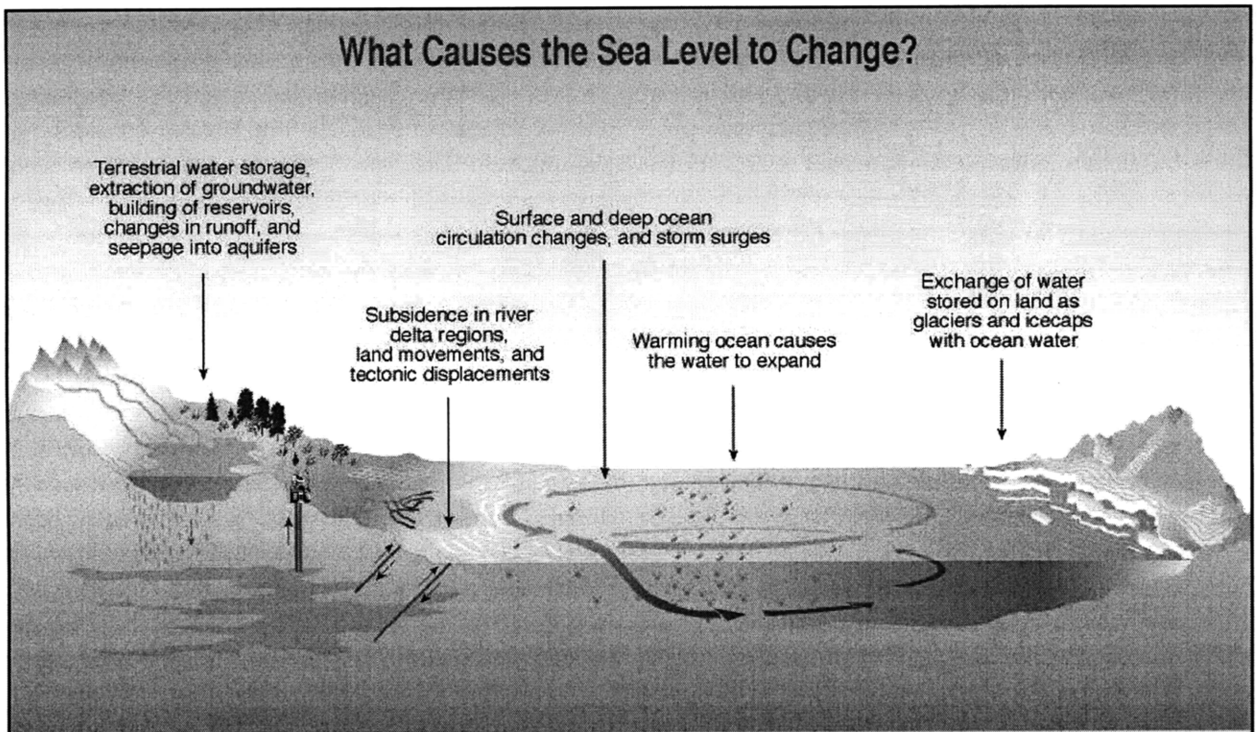


Figure 4. Causes of Sea Level Change Source: David Griggs in Climate Change 2001, Synthesis report, Contributions of working groups i,ii and iii to the Third Assessment Report of the Intergovernmental Panel on Climate Change

atmosphere. Thus, even heroic CO2 mitigation measures in the present and future will not allow us to avoid notable SLR by 2100. In fact, there is very little variation among 2050 SLR predictions based on different emissions scenarios between now and then.[8]

Eustatic SLR, related to the volume of water in the oceans, is only one component of relative SLR. The other component, isostatic SLR, reflects the change in sea level due to land subsidence and erosion. Natural processes have always contributed to subsidence and uplift. Land masses shift, soft soils compact, and shorelines change. Development pressures also contribute to subsidence and erosion whether through extracting water from soft soils along the coast, building on unstable coastal edges, or erecting flood defenses that increase impacts on neighboring lands. Climate change may also affect local erosion through amplification of storm activity in some places and changes in wave patterns. Recent research has found that, due to global temperature's impact on ocean currents, sea level rise in the northeastern United States is likely to exceed mean global sea level rise by about 8 inches.[9][10] While Eustatic SLR is the biggest global concern, any consideration of local impacts needs to carefully look at isostatic changes as well.

Impacts

Particularly low lying areas of the world are at risk of having large swaths of currently developed land permanently inundated by higher sea levels over the next 90 years. Many coastal areas will have to deal with eroding shorelines, increased salinity of estuaries and aquifers, impaired water quality, altered tidal ranges in rivers and bays, increased wave height, decreased light for corals and other marine life living closer to the floor, and threatened wetland ecosystems. However, coastal storm activity added to higher sea levels will account for the most common and pervasive flood risks. [11] Such storms and flooding can inflict loss of life, damage to property, loss of habitat, damage to

8 Frumhoff et al., *Confronting Climate Change in the US Northeast.*

9 Yin, Schlesinger, and Stouffer, "Model projections of rapid sea-level rise on the northeast coast of the United States."

10 Bornstein, "Northeast US could suffer most from sea rise: Add 8 inches for the region, new study says."

11 Gornitz et. al, 2002 in Intergovernmental, *Climate Change 2007.*

infrastructure such as coastal protection works, loss of subsistence resources, loss of tourism, recreation, and transportation functions, business interruption, family interruption.

In order to minimize the impacts, it is crucial that we prepare for adaptation to future climate realities. The vulnerability of a community to SLR is a factor of exposure (how hard it will be hit), sensitivity (how resilient the land use is to flooding) and adaptive capacity (the degree to which a community can evolve or change to cope with a situation).[12] Drawing largely from coastal zone management and land use practices, this paper will address how to minimize exposure and land use sensitivity to minimize impacts.

Coastal Zone Management

Coastal storms can significantly damage development and landscapes through storm surges, heightened wave action, torrential rains, and high winds. The effects are particularly pronounced when combined with SLR.

In order to enjoy the economic, cultural, and natural advantages of coasts, societies have had to learn to defend themselves against these forces by resisting the flood waters or building in resilience to them. Technological advances over the past several centuries have leaned towards relying on hard engineered barriers to keep the water out, but recent developments and increased risk have led communities to reevaluate the tools used to keep themselves safe from the ocean.

The Coastal Zone Management Act of 1972 established the Coastal Zone Management Program to protect, develop, and, where possible, restore the nations coastal communities. Further legislation in 1990 incorporated the Coastal Hazards Enhancement Program which more explicitly addresses coastal hazards. [13] This federal-state partnership offers federal funding to the states, which develop policies and solutions that fit their particular needs. Many of the physical and policy solutions applied to coasts today derive from these state coastal zone management programs. The following sections will explore the methods used.

Hard Engineered Barriers

Hard Engineered barriers are developed to keep water out of built areas, even during storm conditions. These may include revetments, seawalls, groins, jetties, offshore breakwaters and other shore-armoring devices. However, engineered structures that harden the coast may negatively impact the environment significantly. They can exacerbate erosion in adjacent areas alter sand circulation patterns, block landward migration of barrier islands and create eventual loss of beach.[14] Additionally, unplanned overtopping or breaching during the most extreme events leaves areas with structural interventions at even higher risk. When building hard structures, it is important to plan in flexibility. As environmental planner Ian McHarg notes about the world's leaders in water management, "In their long dialogue with the sea, the Dutch have learned that it cannot be stopped but merely directed or tempered, and so they have always selected flexible construction."[15]

Landscape Flood Mitigation

Landscape flood mitigation defenses such as wetland retention areas or the berms and dunes of beaches tend to accommodate the environment and natural processes better than hard barriers. Dunes, unlike rigid engineered structures, can accept the waves while reducing their velocity, absorbing their force, and holding back waters. They also tend not to mar the vista of a coast as seawalls often do. However, even natural defenses can negatively impact coastal systems. For example, foredune construction and beach nourishment, where sand is dredged and pumped onto beaches, can alter natural systems and their restorative properties.[16] At the same time, they can be relatively short-lived compared to hard structures and maintenance costs can be comparable. Still, many prefer landscape mitigation techniques to hard structures where both are feasible solutions. Unfortunately, such landscapes require more space, which comes at a premium in dense urban settings.

Flood-Resilient Building Design

A generally smaller-scale alternative to resisting flooding is to accommodate the waters or build resilience into flood-prone areas. This can involve raising buildings on pilings (referred to in federal flood programs as freeboard) or using floodproofing

12 Ibid.

13 *National Coastal Zone Management Program.*

14 Beatley, *An Introduction to Coastal Zone Management.*

15 McHarg, *Design with Nature*, 7.

16 Nordstrom, 2000, Hamm and Stive, 2002 in Intergovernmental, *Climate Change 2007.*

materials and sealants around the base of a building. While retrofitting structures can prove costly, raising or rethinking the materials on new buildings, particularly smaller ones, requires relatively little investment. However, when raising a structure, it is important to critically consider the stability of piling foundations in repeated storm conditions and the treatment of a streetscape where the ground may lie several feet below building entrances. Owners of existing buildings subject to unexpected floods in the short term, can quickly retrofit their structures by reprogramming the interiors to move important and basic functions above the first floor while relegating the ground floor to non-valuable storage use and opening it up to flood flows

Land Use Planning

Land use planning, a major field of theory and practice in all regions, proves particularly important when applied to sensitive areas such as coastal zones. A development's risk of exposure and sensitivity to flooding derives from the fact that the development exists in a flood-prone area, as is the case for much coastal development. One way for a community to minimize its exposure and sensitivity to coastal flooding is through thoughtful land use planning that fully analyzes the suitability of uses for a given area.

In his book Design with Nature, Ian McHarg points out that certain areas in the landscape, such as floodplains, are generally inhospitable to development. "Let us accept the proposition that nature is process, that it is interacting, that it responds to laws, representing values and opportunities for human use with certain limitations and even prohibitions to certain of these."17 Relative to coastal areas, he notes "In principle, only land uses that are inseparable from waterfront locations should occupy them"[18] This may include ports, harbors, marinas, and water-related industry. He also grants the option of waterfront development for non-diminishing, water-resilient uses such as recreational open space.

When communities ignore these suggestions, they take on a great risk. Speaking about hazards from coastal storm events like hurricanes, Timothy Beatley, a prominent coastal zone expert, asks, "But why do these disasters occur? Because people have put themselves in the way of a natural force that cannot be diverted or stopped. The coastal zone is hazardous because humans have made it so"[19] Beaches are not only the land most vulnerable to coastal flood events, they are also the first line of defense against winds, waves, currents, and coastal storms. By building on them, communities are notably increasing the hazards.

Following Beatley's logic, and McHarg's principles of suitability analysis for ecologically-informed planning would help to avoid the impacts of floods without substantial investments to keep the water out or build extra resilience into buildings. However, what may work for the theoretical planning of a clear landscape can not be so simply applied to land already developed and occupied by a coastal community. Coastal geographer Rutherford Platt also recognizes the risk of developing permanent structures on ever changing and exposed beaches, while acknowledging that coastal communities have and, in some capacity, will continue to develop these areas. "Cities on the beach are a fait accompli." He says, "We must find ways to optimize the pleasures of visiting or residing in them while minimizing the social and environmental costs of overbuilding them."[20]

Nonetheless, hazard zone avoidance and even retreat are legitimate alternatives to investing in resistance or resilience. These options do not require a complete lack of development in coastal areas vulnerable to current or future flooding. They may involve replacement of existing land uses that are subject to high loss from flooding with land uses such as recreation and agriculture that can better accommodate flooding.

Hazard zones can be fully or partially avoided through the use of coastal setbacks, limited land use in an area, or density restrictions. For previously developed areas, authorities may choose to place restrictions on rebuilding after notable storm damage. Alternatively, programs and policies can promote landward relocation by compensating coastal landowners. Additionally, to allow for flexibility, authorities can prevent building immovable structures in high erosion zones.[21] Such measures can be applied after a storm to damaged or new development; before a storm, but only to new development; or before a storm to all new and existing development.

17 McHarg, *Design with Nature*, 7.

18 Ibid., 58.

19 Beatley, *An Introduction to Coastal Zone Management*, 7.

20 Platt, *Cities on the Beach*, 13.

21 Beatley, *An Introduction to Coastal Zone Management.*

Intersection of Land Use Planning and Coastal Zone Management

Effective consideration and application of any of these options requires strategic spatial planning that is responsive to SLR for coastal zone management. Speaking of one of planners' greatest tools, Burby notes, "Land use plans enable local governments to gather and analyze information about the suitability of land for development, so that the limitations of hazard prone developments are understood by policy makers, investors and community residents."[22] He describes the importance of planning for hazard mitigation to ensure that damages to existing at-risk properties is minimized, hazard potential from development is minimized, and the rights of both the community and individual landowners are taken into consideration.

Planners can draw from a number of tools, related to community land use plans to direct or redirect suitable growth. Land uses can be regulated through overlay zoning, subdivision regulation, building codes (including floodproof retrofitting requirements), design standards, floodplain regulations related to location, building elevation, and materials, and environmental impact assessments. Local governments can also direct spending for infrastructure to guide growth and encourage low impact / low risk land uses in coastal flood areas through preferential assessment of these uses in the tax system. Land acquisition can be a powerful tool if used strategically. In addition to direct purchase, a local government can purchase development rights, transfer development rights, accept dedication of conservation easements, relocate buildings, acquire damaged buildings or even use its power of eminent domain. By acquiring these properties in one fashion or another, local governments can either use this property in defense against floods, or ensure that the type of use is resilient. Finally, disseminating information will help the market to function more accurately. This may include educating professionals as to the risks and options, requiring hazard disclosures for real estate transactions, or simply distributing information to the greater public. [23]

Municipalities may hesitate to assume some of these powers for fear of legal action and takings suits. However, the courts have found that government has not only a right, but also a responsibility to manage coastal and inland floodplains to protect people and property. Experts suggest that, to avoid a takings claim, local officials should show both that regulations serve an important public interest and that the actions show a rational relationship to the interest they purport to serve. Furthermore, they should avoid actions that render land valueless. [24] The coastal zone management community offers broad suggestions as well for how communities can avoid legal challenges while addressing their responsibility to manage coastal floodplains. The "No Adverse Impact" principles suggest avoiding the taking of property rights, preventing one person from harming another's property, and basing standards on performance rather than "arbitrary or inflexible" construction restrictions.[25]

Land Use Powers for Hazard Mitigation

- Zoning
- Building Codes
- Capital Investment
- Land Acquisition

Integrated Flood Management

The best responses to projected coastal flooding derive from the integration of principles and tools used in coastal zone management with those used in land-use planning. The European Commission on Integrated Coastal Zone Management has summarized several good principles for coastal zones including taking wide-ranging perspectives, understanding the specific conditions of the particular area of interest, working with natural processes, ensuring that multiple options remain open for the future, planning in a participatory way that will help to develop consensus, involving and garnering support from all relevant administrative bodies, and drawing from a combination of instruments.[26] In the spirit of working with natural processes, the Dutch have been exploring ways to accommodate water and profoundly integrate

22 Burby, Burby, *Cooperating with Nature*, 1-2.

23 Goldshalk et al. in Burby, *Cooperating with Nature.*

24 Olshanky and Cartez, Ibid.

25 Shaw, "StormSmart Coasts: No Adverse Impact and the Legal Framework of Coastal Management."

26 Vermaat et al., *Managing European Coasts.*

consideration of water planning with land use planning. "The essence of this principle (of integrated coastal policy) is: flexible integration of land in sea and of water in land, making use of materials and forces present in nature."[27] This thesis explores methods for practicing the theory in an urban context.

Synthesis: Using Coastal Zone Management and Land Use Planning to Address Sea Level Rise

The threat of SLR will heighten the imperative to protect coastal areas through a combination of traditional costal zone management methods of resistance and resilience, as well as land use planning regulations. However, the situation presents tougher challenges than coastal communities may have dealt with in the past. Particularly in urban coastal areas, land that has been developed to appropriate historical flood standards will have to adapt to increased projections. Furthermore, current developers and planners will have to reframe their approach to hazards identification, replacing predictions based on historical trends with those considering differnt climate change scenarios. Old and new tools should address both magnified future flood conditions and a greater range of uncertainty. These tools and methods need to be shared widely between coastal communities, while the final decisions for how to apply them will need to take place at local levels.

27 Waterman, "Impact of Sea Level Rise on Cities and Regions," 64.

CHAPTER 3: DESIGN MENU

Most of the options and best practices from traditional coastal zone management and land use planning and from cutting edge practices for adapting to SLR fit into one or more of four categories: Hard Engineered Barriers, Landscape Flood Mitigation, Flood-Resistant Building Design, and Land Use Planning and Policy. Each category encompasses an array of physical change options with policy tools for implementation. This chapter will lay out the various options appropriate for coastal cities with a focus on the types of interventions most relevant and promising for East Boston.

Hard Engineered Barriers

Coastal zone managers recognize a variety of engineered physical barriers that can be used to protect coastal shorelines. These include sea walls, sea dikes, revetments, bulkheads, groins, jetties, breakwaters, storm surge barriers, pile structures or piers, floodgates and water retention basins, among others. While there is some overlap in the naming of these barriers, they do have somewhat distinct forms and purposes.

The primary purpose of a sea wall is to protect landward structures from flooding during storm surge. This hard surface structure of concrete, steel or stone, when functioning properly, has the most definitive ability to keep water off of land, and thus can provide a great sense of security. However, beyond construction costs, there are challenges to this approach. Seawalls tend to take the full brunt of wave during storms and redirect some of that energy to the base increasing the likelihood of erosion of the seabed in front of the wall. The resulting toe scour can then weaken the stability of the wall. Also while sea walls can be quite effective if stable, they rarely include backup measures. Failure, often characterized by a breach or overtopping, can actually increase the damage that would have otherwise occurred. Another drawback of sea walls is that natural systems and cycles are disturbed. This not only negatively impacts the ecosystems of the water's edge, but may also contribute greatly to diminishing beaches on the seaward side of the structure.[28] Despite these drawbacks, however, sea walls are often considered one of the more desirable options to be used in high-density and high-value urbanized coastal areas where a great deal of investment has already been made over a short span of coast. The benefits of strategically placing a wall in a city such as Manhattan may outweigh the costs.

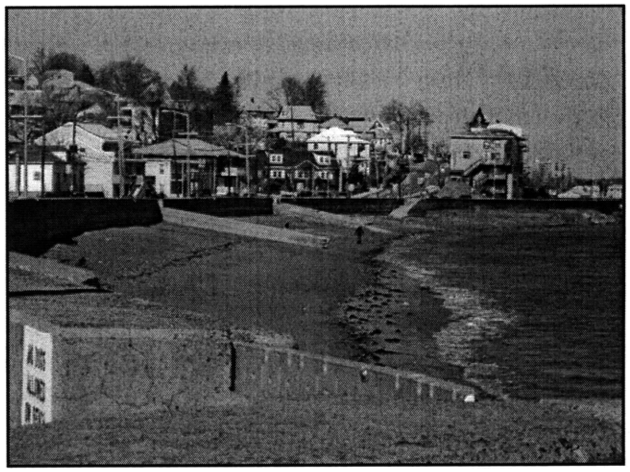


Figure 5. A Sea Wall in Winthrop, MA

The term revetment, though sometimes used interchangeably with sea wall, generally indicates a different form. Where as seawalls are usually vertical, revetments are placed on an existing slope or embankment. They also protect the land from strong waves and currents, but tend to deal as much with minimizing erosion of the land as with keeping the water out. The typical revetment impacts natural processes less than large vertical seawalls do; for example, they tend to absorb energy along a rough surface rather than deflect it, potentially to other vulnerable areas. They are generally less massive and used on a smaller scale than seawalls.[29]

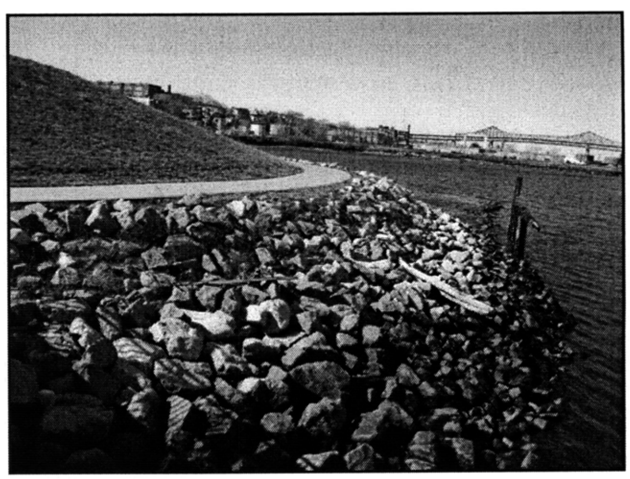


Figure 6. A Revetment in East Boston

28 Basco, *Coastal Engineering Manual - Part V*.

29 "CHL - Types of Coastal Structures."

Structures more commonly used on the bayside land of East Boston are bulkheads, and piers. Bulkheads are vertical walls, generally anchored to the land, that hold back soils. The primary function of a bulkhead is to reduce erosion of land into the sea, while mitigating wave action and flooding are only secondary objectives.[30] Piers are concrete or wood pile supported structures with decks that jut out into the waters. They serve well as areas for mooring vessels or recreational land, though they are sometimes used to support heavier structures. Given their extension from the shore, they are exposed to loads from waves and currents.[31] Many of the functions programmed for piers are resistant to coastal flooding. Other piers can be built high enough to avoid coastal flooding, though buildings would still be subject to wind and spray from storms.

Figure 7. Piers Park on a Reconstructed Pier in East Boston

Hard structures, creating hard edges are used along a good portion of urbanized coastal areas. While replete with disadvantages, they can also effectively allow coastal areas, otherwise too wet or vulnerable to coastal storms, to function smoothly and manage large scale changes in the environment. For example, the Dutch, exemplary leaders in the field of water management, have built and benefitted greatly from hard engineered barriers. In the early 1930's they completed the Afsluitdijk, an approximately 20-mile massive dike that closed off a sizable inlet to the North Sea that became a freshwater body (the Ijsselmeer) from which parts were dredged and pumped to create polders, or new bodies of land.

30 Basco, *Coastal Engineering Manual - Part V.*

31 Ibid.

Landscape Flood Mitigation

While the Dutch will continue to maintain much of their $2.5 trillion dollars worth of existing infrastructure, they have begun to change their approach, relying less on engineering marvels and more on natural barriers such as wetlands and salt marshes or the sand dunes and berms of beaches to ease the force of storms and retain floodwaters. [32] Many of the flood mitigating landscapes exist naturally and need little more than to be maintained to stabilize shorelines. Other measures call for enhancement of the natural landscape.

Beach nourishment is a common landscape intervention that helps to counteract erosion (caused by natural events, climate change, or development pressures) and to protect against flooding.[33] Methods include directly depositing sand on the beach, beach scraping, building artificial dunes as storm buffers or reservoirs, laying pipes that suck in the water and trap sand, and building groin fields to trap the sand. Of particular importance for coastal flood mitigation is use of sediment to expand, restore, or construct berms and dunes. Dunes provide a barrier parallel to the coast that protects inland structures while allowing for natural beach formation and direct access to the water on the shore side. Made up of sand and other fine particulate, dunes in formation are subject to wind scatter. Thus it is imperative, in creation or maintenance of dunes, to establish a vegetated cover. Effective dunescapes are generally made of two or more layers. The foredune, the one closest to the water's edge, supports sea grasses with deep roots that can flourish despite salt spray while stabilizing the dune. However, trampling by humans and other

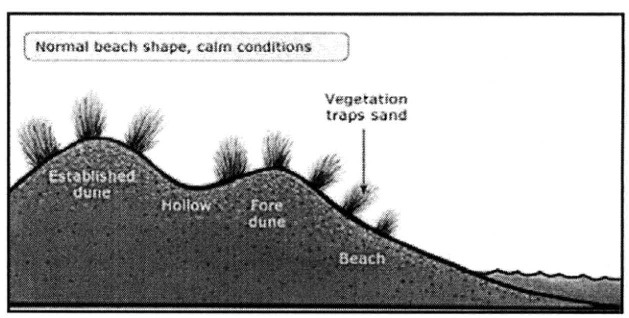


Figure 8. Section of a typical beach dune.
Source: www.teara.govt.nz

32 Nickerson, "Holland goes beyond holding back the tide."

33 Basco, *Coastal Engineering Manual - Part V.*

forces needs to be minimized. The backdune, while supporting larger and slightly less sensitive vegetation, should be protected from trampling as well.[34]

Urban municipalities can also choose to add not sand, but rather land fill, and raise the entire elevation of coastal properties to make them less subject to coastal flooding. Boston, Massachusetts has, as noted, used fill to extend most of its urban core and the land we know as East Boston. This simply shifts the process toward building higher rather than out farther. For better or worse, despite advances in heavy machinery, filling land should prove more complex today than a century ago. Our attention to environmental remediation for the health of our ecosystems and ourselves limits the ease with which we might find plentiful waste material or nearby ocean dredgings to use as fill. Furthermore, such fill would either have to extend the shoreline, disrupting the current maritime uses, or disrupt current building along the shoreline. In places where the shoreline is in transition, however, this might prove a viable solution.

Natural landscapes can also mitigate coastal flood impacts due to their absorptive qualities. Flat landscapes, as well as berms and dunes, can both absorb floodwaters and slow the speeds at which water flows across the land, unlike paved surfaces which can increase the velocity of floodwaters onto neighboring properties. Impermeable surfaces not only mitigate the impact of coastal floodwaters rising from the sea; they also minimize the quantity of storm-generated inland flood waters. This is particularly important during a coastal storm as drains to the sea may be blocked by rising storm surges.

Policies for Smart Development of Barriers

Developers may bear the burden of the cost of structural solutions at the site scale while local authorities will need to draw on taxes to support the costs of larger infrastructure projects. If local governments invest in large-scale flood barriers, they should explicitly communicate the remaining risk to ensure that property owners do not assume complete protection. If property owners feel that the government has fully addressed the problem, they lack incentive to otherwise mitigate risk on their own property. If encouraging private investment in flood protection, local governments should offer technical assistance and recommendations while implementing restrictions that limit the visual and flooding impact of such barriers on neighboring properties, and ecologically sensitive areas.

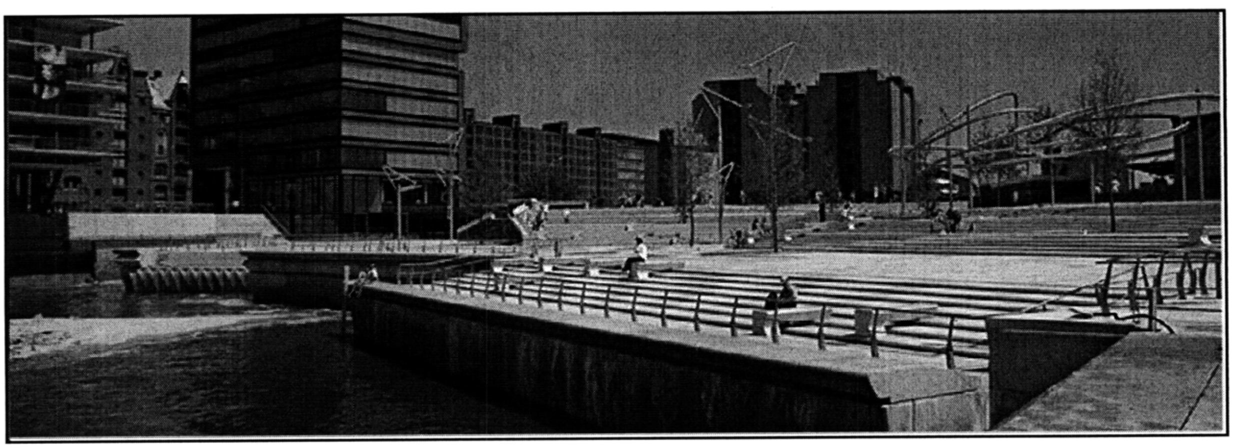


Figure 9. Public space along the water's edge in Hafencity, Hamburg, a city raised above flood levels. Source: Hafencity.com

Flood-Resilient Building Design

A rather different approach to holding back the waters is learning to let them in. The Dutch, with most of their inhabitants living on water reclaimed from the sea, are nonetheless leading the charge to accommodate floodwaters and accept them in the built landscape. They have begun to suggest that, "the range of dunes be opened here and there so that water from the sea can penetrate and form creeks between the dunes. The realization is setting in that larger pumping-stations and higher dikes might not turn the tide for a bit, but that ultimately this rigorous tech-

34 McHarg, *Design with Nature.*

nique will prove to have nothing but a negative effect on the resilience of the coastal zone."[35]

To coexist with floodwaters, buildings must be resilient to the impacts. Lifting buildings on piles or "freeboard", a method widely used from the Netherlands to the Gulf Coast, should raise the occupied spaces in vulnerable buildings above harm's way. Builders can either raise the lowest horizontal structural member just above the projected 100-year flood level for the lifespan of the building, or they can raise the structure high enough to create less vulnerable programmable space beneath the building such as parking and gardens. The later option has the added benefit of improved access for maintenance, but poses urban design challenges in connecting the floor level of elevated buildings with the streetscape. Lifting buildings is relatively simple for small, new construction, while retrofitting and building of much larger structures adds cost. On the Silodam Causeway in the Netherlands, a 157 unit apartment building is actually raised on piles above standing water. Rather than use the ground floor for car parking, residents use it as a marina for mooring their boats. Projects such as this one indicate that the scale of building on piles and the ability to effectively accept water into the built environment are increasing.

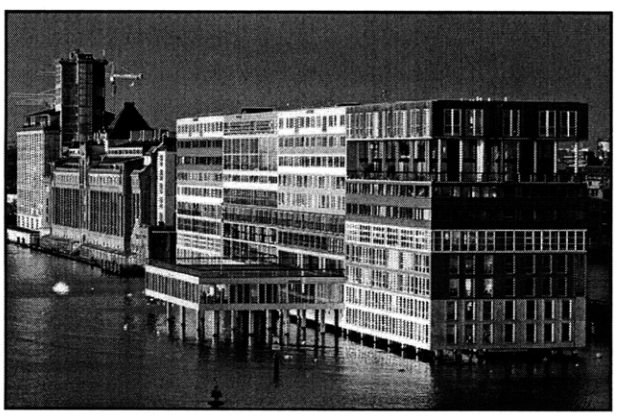


Figure 10. Silodam apartment building in the Netherlands. Source: Flickr contributor CruiseAir

Owners of existing moderate- to large-scale urban structures might choose to waterproof and seal their buildings on lower floors to the extent possible. Floodproofing materials, while more easily incorporated into new buildings, can be appended to existing structures with some success and with less investment than required to raise the building or build structural barriers. In addition to minimizing the water that enters buildings, owners can move particularly sensitive possessions and equipment (such as furnaces) to higher ground. Thus, while the building is more likely to experience some flooding, the impact is minimized.

Floating buildings more directly approach the concept of integrating land developments with water. The earliest examples of this included ships that were houses followed by houseboat-type structures that float on hollow concrete boxes. Later came the modern water villa with full-fledged stable floating foundations , the kind of foundations that have been scaled up to support the density of urban villas and terrace houses. [36] Today's construction involves special EPS elements to provide stiffness and buoyancy with open spaces filled by a concrete mesh/shell for the base of the foundation. [37] Floating utility units with protected integrated piping can help to maintain services to floating structures irrespective of the water level. Cost aside, large floating foundations can be provided at pretty much any scale which suggests that water sheet might be considered as a building plot. Well-designed floating buildings, unlike buildings on piles, offer the advantage of not only accommodating water, but accommodating steady fluctuations in water. However, in a high energy coastal environment, these buildings remain vulnerable to the force of winds and waves that can penetrate above the floating foundation. Their use is much more appropriate in a low-energy environment.

Amphibious structures offer some of the advantages of land-bound buildings with the water level flexibility of floating structures. These buildings, set on hull-like floating concrete bodies with coupling construction, rest on concrete foundations during normal water conditions. During floods, they rise with the water level while staying anchored to flexible mooring posts that "cushion" the swell of water.[38]

In communities supported by Federal Emergency Management Flood Plain Insurance, landowners within the "official" 100 year floodplain are offered rate incentives to raise there buildings up to 3 feet above ground level. While the extent of the official floodplains and the recommended heights do not consider SLR, the concept of using minimum eleva-

35 Graaf, *Europe, coast wise*, 138.

36 Olthuis, "Building Floating Constructions."

37 "DeltaSync: Floating Foundation."

38 Kengen, "Bouyant Bases."

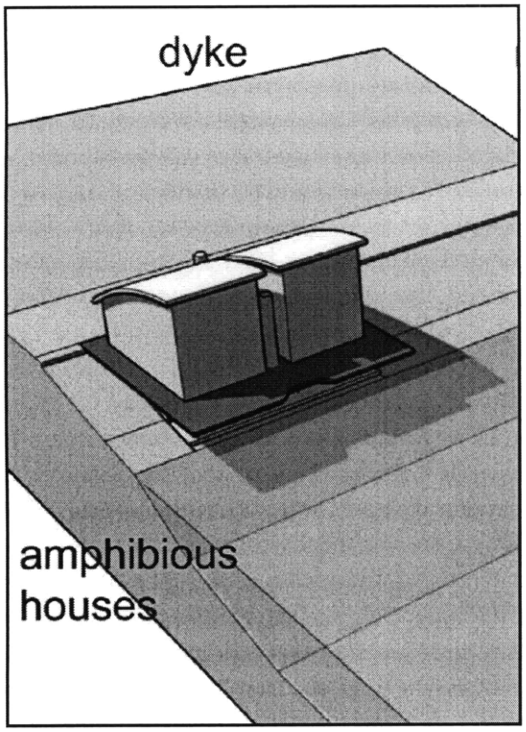


Figure 11. Amphibiuos houses sit at ground level during normal conditions. Source: Presentation by A.L Kengen

tion standards to ensure appropriate heights above flood levels is robust.

Land Use Planning and Policy Tools

A city's resilience to coastal flooding is largely dependent on the suitability of sensitive land uses along coastal areas subject to current or future flooding. Any suitability consideration should start with a broad assessment of which lands and land uses are subject to hazards. Incorporating this into a master plan or a land use overlay plan of SLR and future flood risk will improve the overall affect of individual actions.

Such plans may find areas where development should be entirely restricted now or in the future, but many coastal areas will call for an intermediate solution. Cities and landowners can continue to capitalize on coastal edges that lie above even future mean high water levels but are, or will be, subject to rare coastal floods by limiting these areas to resilient or low-loss uses and/or those uses that are water dependent. These include public beaches, ball fields, tracks, urban gardening, public parks, open plazas, temporary performance or event spaces, industrial ports, water transportation landings, and marinas. Following a suitability analysis, planners can limit or direct land uses in a variety of ways to minimize a community's vulnerability.

Acquisitions allow local governments to directly determine whether and what kind of development occurs on exposed coastal areas. Methods include: direct purchase, eminent domain, purchase of development rights, transfer of development rights, dedications of conservation easements, and funded relocation of buildings. Once the planning body can exert more control over these sensitive areas, it can plan flexibly for land uses. Economic or, in the case of eminent domain, political costs present the greatest challenges to this course of action.

Flood-hazard-specific zoning, preferably following from a master planning process, may include: floodplain regulations, density restrictions, coastal setback rules, rolling easements, hazard overlay districts, and presumed mobility rules. These regulations can be applied to all development or to new or rebuilt development. The state of Maine has pioneered presumed mobility and rolling easements, newer zoning regulations that respond directly to foreseen changes in the landscape due to SLR. Relative to presumed mobility, they have limited the size of structures in some coastal areas to 35ft and 2,500 sf (a movable size) if the applicant cannot demonstrate that the site will remain stable over the next 100 years.[39] Relative to moving easements, and related to presumed mobility, Maine has required that if shoreline change due to SLR erosion and other coastal processes results in the foundation of an already permitted structure being located in the intertidal zone for six months, then the structure must be removed from the site. This particular regulation is appended to the property deed.[40]

Considering a phased retreat in response to SLR, Maine has required that "A project may not be permitted if, within 100 years, the property may reasonably be expected to be eroded as a result of changes in the shoreline such that the project is likely to be severely damaged after allowing for a two-foot rise in sea level over 100 years. Beach nourishment and dune restoration projects are excluded from this requirement."[41]

39 Rubinoff, Vinhateiro, and Piecuch, *Summary of Coastal Program Initiatives That Address Sea Level Rise as a Result of Global Climate Change.*

40 Ibid.

41 Ibid., 7.

These policies place some onus on the developer and landowner to seriously consider future conditions in making decisions about land development today. The regulations explicitly respond to future conditions and projections of SLR ensuring that the market has the information it needs to respond accordingly. It will be interesting to see how Maine lawmakers factor future refinements of sea level projections into the existing regulations.

No–rebuild rules offer a more conservative approach to retreat that responds to changing flood and sea level conditions. Cities with already built up areas that are likely to be exposed to future storms, may chose to phase building out of these areas as conditions change by requiring that properties sustaining significant damage (to be determined by percent value calculations) can not be rebuilt. Such a rule ensures that coastal cities are not responsible for repeated damage to increasingly exposed areas. Furthermore, it avoids the problem of uncertain projections of storm risk or the cost of abolishing development while the land remains viable for building assets. Such a policy, however, does not avoid the cost, economic and otherwise, of the impacts of that first substantial storm. Furthermore, any use of this policy needs to incorporate strong public outreach efforts concerning the projected risk of the area and the implications of the policies, including an altered role for flood insurance.

Combined Strategies

Several innovative techniques for responding to future coastal flood situations rely on combining strategies. Oftentimes strategies are layered to offer backups and minimize the magnitude of robustness needed for each. For example, a seawall that could block nearly all possible storms without overtopping, given future SLR flood scenarios, could prove prohibitively costly as well as unsightly. If floodwaters overtopped such a structure, with no protection behind it, the effect could be devastating. However, if the rare case of overtopping were accommodated, say by an absorbent landscape buffer behind the wall, the impacts would be greatly minimized. Consequently, the wall could be built less tall and less costly and obtrusively since the impacts of "failure" could be tolerated.

A combination of approaches also responds to the risk posed by successive large storms in which a dune may be compromised by the first. Instead of being composed entirely of fine-grain sediment a dune can encompass an underlying rock sea wall or revetment. This solution provides some of the aesthetic, maintenance, and ecological advantages of a landscape solution while offering a secondary protection. In the case of two large storms in rapid succession in which the first might deplete the sand dune, the wall remains to protect development from the succeeding one. [42]

Taking Action

In places such as Maine and Maryland, states have taken the lead in forming policies that will encourage adaptation to SLR and flood conditions. Land use planning, however, needs to be studied and largely implemented at the local level. At this level, more detailed disaster assessments can be made, building permissions can be structured to require minimum elevations or prohibition of basements, land use designations can be restricted or protected, zoning ordinances can be reconsidered, and local residents can be consulted.[43]

The next chapter focuses on the context of East Boston in Massachusetts to describe the frame within which these physical, land use planning, and policy options would be applied.

42 Faludi, *European Spatial Research and Planning.*

43 OAR US EPA et al., "US Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region."

CHAPTER 4: BOSTON AND EAST BOSTON CONTEXT

Institutions, Organizations, and Initiatives

Government institutions and other organizations have the responsibility of actually applying best management practices for protecting coastal communities from SLR and coastal flooding. To understand how change and action might occur in the Boston context, we need to understand the role and progress of players from the federal to local arenas.

Federal Institutions and Initiatives

The Federal agencies currently most involved in coastal flood hazard mitigation and/or adaptation for the impacts of SLR are the US Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA), the National Oceanographic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the United States Geologic Survey (USGS) and the US Climate Change Science Program (CCSP). At times, theses agencies work together, and the numerous initiatives, studies, reports, and projects implemented complement each other. [44] At other times, the organizations would do better to coordinate efforts, and more readily incorporate the findings of other agencies into their analyses. In either case, each of these federal agencies plays an important role in shaping our policies, programs, and understanding of the issues

The USACE, through their mandate to protect the nation's navigable waterways, runs a laboratory to understand and a program to reduce flood and coastal storm damage. In addition to providing coastal zone mapping and imaging, they offer expertise in coastal structures, coastlines, erosion control and flood control. Much of this information is culled and provided in the Coastal Engineering Manual freely available to the public.[45] Given the technical detail of the document, coastal zone managers may benefit more from this manual than would the average landowner. While the amount of information is laudable, the Corps does not seem to have yet incorporated SLR projections of any amount into its publications.

FEMA's role in coastal zone management is to reduce loss of life and property from floods through disaster preparation, response and recovery. The agency creates Flood Insurance Rate Maps (FIRMS) that provide a foundation for insurance and hazard zone mapping in many areas. It also runs the National Flood Insurance Program (NFIP), which offers flood insurance to homeowners in coastal areas where private insurers have dropped out of the market but localities have adopted a minimum of flood and safety standards. It provides a coastal construction manual as well. FEMA has been criticized for failing to incorporate SLR projections into its much-needed map updates and for providing incentives, through its flood insurance program, for people to continue building in flood hazard zones.

NOAA makes its major contributions to issues of coasts and climate change through the Office of Ocean and Coastal Resources Management and the Climate Program Office. The former is responsible for seeing through the Coastal Zone Management Program, a partnership in which the federal government supports states in developing programs to support wise use of land and water resources with consideration for ecological, cultural, historic, aesthetic, and economic values. The Coastal Zone Management Act, which established the program, actually requires that coastal states anticipate and plan for SLR due to global warming. The climate service development program, run by the Climate Program Office, aims "to assess impacts of climate variability and change, support regional adaptation strategies, and develop climate information products and tools appropriate for evolving user needs" [46]. NOAA is developing a National Climate Service analogous to the National Weather Service, for consolidating government climate records, climate forecasts, and related information. Practitioners should welcome a more centralized location for useful information.

The EPA hosts the "Coastal Zones and Sea Level" website which, in addition to clearly explaining the major issues relevant to SLR, also provides links to a wealth of scientific reports on the subject. Many, though not all, of the reports are supported by the EPA.

The USGS provides expertise in collecting geographic data used to map SLR and its effects on

44 Basco, *Coastal Engineering Manual - Part V*.

45 "Climate Program Office (CPO)." http://www.climate.noaa.gov/index.jsp?pg=./cp_pp/description.html.

46 Thieler, Williams, and Hammar-Klose, "National Assessment of Coastal Vulnerability To Sea-Level Rise."

coastal populations. They are currently working with Woods Hole Science Center on a "National Assessment of Coastal Vulnerability to Sea-Level Rise."[47]

The US Climate Change Science Program, composed of NOAA, EPA, USGS, and ten other federal agencies, works to develop a comprehensive view of climate change and its potential significance. Through the Coastal Elevation and Sea Level Rise Advisory Committee, they recently released an important report entitled "Coastal Sensitivity to Sea-level Rise: A focus on the Mid-Atlantic Region." [48]

State Institutions and Initiatives

While the federal government provides research, some general policies and regulations, and funding to address coastal flooding from SLR, the states have more responsibility for developing strategies to mitigate adverse impacts on their lands and territorial waters.

Massachusetts's lawmakers are in the early stages of addressing issues related to SLR or other impacts of climate change. The Global Warming Solutions Act of 2008 focused almost entirely on greenhouse gas reductions, but also initiated concern for adaptation. Section nine states "the Secretary shall convene an advisory committee to analyze strategies for adapting to the predicted impacts of climate change in the Commonwealth".[49] The committee should file a report of findings and recommendations on strategies for adapting to climate change by the end of 2009.

Meanwhile, the state has much experience in dealing with coastal waters. The Department of Environmental Protection, through its responsibility to create and enforce regulations such as the Massachusetts Public Waterfront Act (Chapter 91), has significant influence over the state's coastal waterways. It protects public right of ways and areas of environmental concern while reviewing projects in the municipal harbor plan districts (largely flowed tidelands).[50]

However, the Massachusetts office of Coastal Zone Management (Mass CZM), under the Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA) has played the key role to date in protecting Massachusetts shores from storm hazards and considering the influence of SLR on coastal flooding. Mass CZM provides policy assistance, technical assistance and guidance to coastal communities for dealing with storms, floods, and SLR. Recently, they led the Coastal Hazards Commission to develop a report "Preparing for the Storm: Recommendations for Management of Risk from Coastal Hazards in Massachusetts". This report, released in 2007, offers 29 recommendations for improving flood hazards. While few of these recommendations specifically address sea level rise scenarios, the report does acknowledge that SLR "will result in greater erosion and flood impacts over time".[51]

Recommendations relate to one of four categories with a priority recommendation for each category. With respect to hazards information, the report recommends that Massachusetts DCR assist FEMA to update federal insurance rate maps (FIRMs). Unfortunately, while FEMA, with the input of local agencies, has recently updated the Boston area flood maps (FIRMS), the new digitized version still uses a good deal of forty year old data, and does not consider SLR. With respect to policy, the report recommends that the EOEA establish a storm-resilient communities program with case studies for "effective coastal smart growth planning and implementation".[52] With respect to planning and regulations, the report recommends that state environmental agencies and regional planning agencies develop, update, and mitigate hazard mitigation plans. With respect to protection, the report recommends implementation of a program of regional sand management promoting beach nourishment as a coastal hazard protection. Of additional significance are recommendations to map and model climate change and SLR data related to coastal hazards in Massachusetts, incentivize retrofitting homes for floods in coastal areas, acquire storm-prone properties through payment or conservation restrictions in order to conserve coastal land and minimize loss, consider creating a best management practices docu-

47 OAR US EPA et al., "US Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region."

48 *An Act Establishing the Global Warming Solutions Act.*

49 *Mass. Gen. Laws ch. 91. The Massachusetts Public Waterfront Act.*

50 Coastal Hazards Comission, *Preparing for the Storm: Recommendations for Management of Risk from Coastal Hazards in Massachusetts*, 3.

51 Coastal Hazards Comission, *Preparing for the Storm: Recommendations for Management of Risk from Coastal Hazards in Massachusetts.*

52 *Climate: Change: The City of Boston's Climate Action Plan.*

ment for land subject to coastal storm flowage, and develop a standardized benefit-cost analysis model for shoreline protection projects (or related alternatives) that considers capital, societal, and natural resource benefits and costs.

StormSmart Coasts, an award winning new initiative of Mass CZM, offers information to help communities better prepare for and protect themselves from coastal storms. The StormSmart Coasts website distills an enormous amount of information such as that being produced by the federal agencies mentioned above, into a simplified and easily accessible framework. While summarizing the most relevant points of outside information, it also offers links to the source documents and relevant organizations. The program also produces fact sheets, successful case studies, and regional workshops. The site still skirts around the issues of what to expect from and how specifically to address the added hazards attributable to SLR, but the program is beginning to institute pilot projects in a handful of coastal communities, including Boston, some of which address SLR as a significant consideration in coastal hazards management.

City Institutions and Initiatives

In 2007, Mayor Menino of the City of Boston issued an executive order on Climate change. The order, which focused on mitigation, mentioned the need to adapt, but offered no specific recommendations or actions at the time. Similarly the city's Climate Action Plan focuses almost entirely on green house gas emissions while mentioning the need to consider adaptation. "The City shall prepare an integrated plan that outlines actions to reduce the risks from the likely effects of climate change, and coordinates those actions with the City's plans for emergency response, homeland security, natural hazard mitigation, neighborhood planning and economic development."[53]

The Boston Harbor Association, a non-profit public interest organization, supports use of the harbor for public access, liveliness, a commercial port, a clean asset, to the city. While the association has no regulatory powers, the policy positions that its members develop carry weight in the city. Furthermore those developing large waterfront projects will generally consult the well-regarded experts at the Boston Harbor Association during the planning and development process.

The BRA plays an extremely important role in guiding land use and development decisions that minimize the impact of coastal flooding from SLR. As the planning and development agency for Boston, it creates and maintains citywide land use plans, and community master plans, while drafting zoning plans and bylaws for the zoning commission. It maintains a vision of the city as a whole while maintaining an on-the-ground presence understanding the local social, cultural, and landscape issues. The agency is also responsible for developing, though not approving, municipal harbor plans, such as the East Boston Municipal Harbor Plan and Amendment. All large projects and other significant projects are subject to Article 80 review, a more rigorous review that introduces greater oversight into development.[54]

The BRA addresses coastal flood issues through Article 25, a statute that regulates development with respect to flood hazards.[55] Regulations require that any new residential structure in the 100 year floodplain has its lowest floor, including basement, elevated above base flood heights. Similarly, new non-residential structures must submit to the same guidelines or sufficient floodproofing below the base elevation. The Boston Redevelopment Authority has many tools at its disposal to regulate and direct the form of development in coastal areas and its resiliency to increased coastal flooding due to SLR. The organization appears to be engaged in figuring out the best course of action, but is not yet poised to roll out fully vetted regulations and guidelines.

Neighborhood Organizations and Efforts

While few if any neighborhood organizations in Boston have formed around adapting to climate change, there is an awareness budding at the community level, particularly in environmental justice (EJ) communities that have historically endured a disproportionate share of environmental hazards. The Neighborhood of Affordable Housing (NOAH), a non-profit multi-service community organization in East Boston, has partnered with a team of environmental researchers to evaluate strategies for EJ com-

53 *The Boston Zoning Code: Article 80 Development Review and Approval*; "Boston Redevelopment Authority." www.bostonredevelopmentauthority.gov.

54 *The Boston Zoning Code: Article 25 Flood Hazard Districts.*

55 Douglas et al., "Coastal Flooding and Environmental Justice: Developing Strategies for Adapting to Climate Change ." (Proposal/Overview)

munities to increased coastal flooding due to SLR. The research project "Coastal Flooding and Environmental Justice: Developing Strategies for Adapting to Climate Change", funded by NOAA's sectoral Analysis Research Program, should directly serve this East Boston Neighborhood while providing insights for related communities, and, perhaps, even wealthier communities with greater adaptive capacities.[56]

Multi-jurisdictional Organizations and Initiatives

Many organizations and knowledge communities that deal with coastal zone management and climate change cross jurisdictional boundaries. The Coastal States Organization, of which Massachusetts is a member, has looked at the role of coastal zone management programs in adaptation to climate change. The Association of State Floodplain Managers, an association of professionals involved in floodplain hazard management, aims to limit the losses and suffering of flooding by using principles of "no adverse impact" (NAI) The premise of this widely cited concept is that the actions of one property owner can not negatively affect the rights of another. Where actions follow this philosophy, legal and political challenges are minimal.

The Union of Concerned Scientists and Metropolitan Area Planning Council (MAPC) have organized efforts to respond to climate change and SLR at a regional level. MAPC has partnered with a core group of researchers to develop a series of CLIMB (Climate's Long-term Impacts on Metro Boston) reports. The Union of Concerned Scientists has partnered with several climate change experts in developing the North East Climate Impact Assessment (NECIA) reports, "Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions". Paul Kirshen, environmental engineer at Tufts University, participated in both studies

Coordination of findings at all levels and players at the local level is imperative for quickly, thoughtfully, and comprehensively addressing the problem. In particular, understanding the context and tools at hand up front, will make such a discussion more productive. This paper aims to provide a starting point for that aspect of the discussion, and a sense for how the tools might apply

56 Kirshen, Knee, and Ruth, "Climate change and coastal flooding in Metro Boston," 453.

The Economic Case for Adaptation to Sea Level Rise in Boston

As mentioned above, two major projects have addressed SLR in Boston from a scientific and policy point of view. The CLIMB study offers a quantitative analysis of the net cost to the Boston metro region of generalized adaptation scenarios. The significance of this study derives from the finding that, "Risk-based analysis shows that the cumulative 100 year economic impacts on developed areas from increased storm surge flooding depend heavily upon the adaptation response, location, and estimated sea level rise."[57] The study considers two SLR scenarios (.45 meters eustatic SLR for a total of .6 meters SLR and .85 meters eustatic SLR for a total of 1 meter SLR), and tests four adaptation scenarios against them. It also varies the number of successive flood events that would occur.

The RIO (Ride it Out) scenario, something of a business as usual scenario, assumes that all structures would be repaired to current conditions after each flood and that floodproofing would take place only for new development in the current 100 year floodplain. The GREEN scenario assumes that all buildings would be flood proofed upon building or sale of structure. It does not suggest any sort of natural solution; the name suggests only that it likely has fewer negative environmental impacts than the BYWO scenario. The BYWO (Build Your Way Out) scenario assumes that after two 100 year flood events, protective structures would be built to meet or exceed the 500 year flood level. For the purpose of this scenario, these protective structures are assumed to be traditional hard engineered barriers. The RETREAT scenario assumes that no new development would occur in the floodplain and that after a large storm and flood event caused damage to a property, it could not be rebuilt. The scenario does not assume a partial retreat, or replacement of highly sensitive development uses with more resilient development uses such as ball fields or parks. None of these scenarios assume changes in the officially designated flood plain area or nuanced intermediate interventions.

The caveats used in describing the scenarios are not meant to undermine the importance of this work,

57 Kirshen et al., "Integrated Impacts of Climate Change-Induced Sea Level Rise in Metro Boston and Adaptation Strategies," 6.

but rather to distinguish how it compares to options offered throughout this thesis. Few of the options considered in the thesis, and, indeed none of the final design proposals, fit neatly into any of these scenarios. However, the damage and adaptation costs for all but the RIO scenario very roughly approximate the scale of costs expected for many of the options considered in this paper. The reports resulting from the study make some of the limitations clear. For instance, they note that certain maintenance costs and environmental impacts are not included and that cost estimates are necessarily general.

Cost of Sea Level Rise Scenarios in Millions of Dollars						
Model run		Residential	Commercial/ Industrial	Emergency	Adaptation	**Total**
13	Ride-It-Out—1 m SLR, one event	6,131	25,014	5,295	0	36,440
14	Build-Your-Way-Out—1 m SLR, one event	969	3,613	779	3,462	[redacted]
15	Green—1 m SLR, one event	1,268	4,959	1,059	2,897	**10,183**
16	Retreat—1 m SLR, one event	5,564	9,632	2,583	546	**18,325**
17	Ride-It-Out—1 m SLR, three events	16,140	64,250	13,666	0	94,056
18	Build-Your-Way-Out—1 m SLR, three events	1,820	6,703	1,449	3,462	[redacted]
19	Green—1 m SLR, three events	3,272	12,760	2,726	6,798	**25,556**
20	Retreat—1 m SLR, three events	5,651	9,632	2,598	558	**18,439**

Figure 12. Cost of Sea Level Rise Scenarios.
Source: Adapted from chart 5 in "Climate Change and Coastal Flooding in Metro Boston

Using simplified estimates for implementation costs of the 4 adaptation measures, and modeling the damage costs of repetitive flood events under each scenario, the study compares the net cost of taking different courses of action.

Boston: impacts and adaptation strategies

As seen in the figure above, the RIO scenario, in which damaged buildings are rebuilt as before in the same area, proves the most expensive. The BYWO scenario proves least expensive despite high upfront costs required to build the storm barriers. This and other findings, leave the investigators to conclude that, "While uncertainty in the expected rate of sea level rise and damages makes planning difficult, the results also show that no matter what the climate change scenario or the location, not taking action is the worst response as in our Ride It Out scenario." In their 2003 report, investigators reach a little further to comment on the role of land use. "Present and future land use greatly affects the magnitude of the impacts"[58], they find, and land use regulations can both decrease property damage by flooding and improve hydrological conditions to decrease the severity of flooding.[59]

Projecting Flood Frequency and Extent in East Boston due to Sea Level Rise

The NECIA research, as it relates to SLR in Boston, focuses on the scientific findings of SLR and how they translate to local SLR impacts. Its findings, and the way they are framed, are astonishing! The research team projected that, "by 2005, the 100-year storm surge will exceed the elevation of the 2005 1,000 year storm surge"[60] Furthermore, "What is now considered a once-in-a-century coastal flood in Boston is expected to occur, on average, as frequently as every two to three years by mid-century and once every other year by late century under either (high or low) emissions scenarios"[61] To clarify, the higher and lower SLR scenarios that they analyze are, by there own admittance, rather conservative. "A more recent

58 Kirshen et al., "Integrated Impacts of Climate Change-Induced Sea Level Rise in Metro Boston and Adaptation Strategies."

59 Kirshen et al., "Coastal flooding in the Northeastern United States due to climate change," 446.

60 *Confronting Climate Change in the U.S. Northeast: Massachusetts*, 3.

61 Kirshen et al., *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions: Appendix: NECIA Coastal Impacts Analysis.*

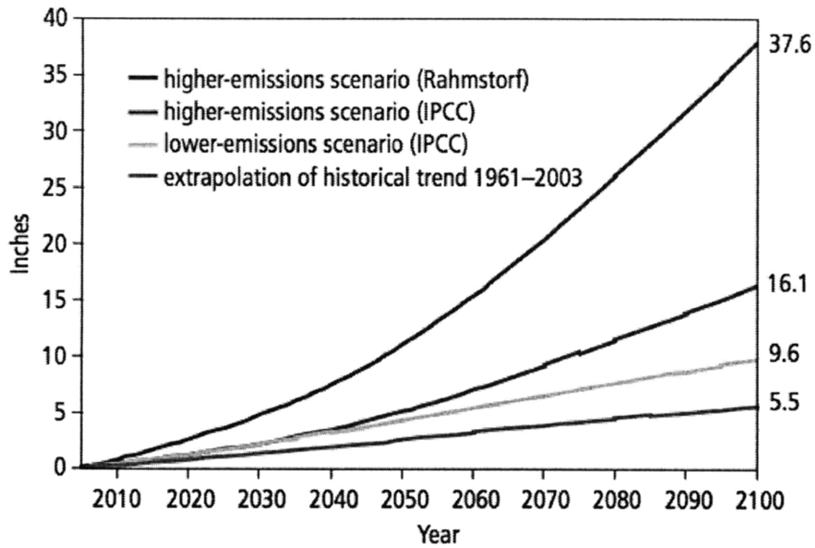


Figure 13. Projected Rise in Global Sea Level Source: NECIA Coastal Impacts Analysis Technical Appendix

analysis, however, has projected much greater end-of-century sea-level rise (compared to the assumptions used in this, the NECIA, report): on the order of 2 to 4.5 feet above 2005 levels under the higher-emissions scenario. Even these projections may be conservative in that they do not account for the rapid rate of ice breakup and melting currently being observed in the polar ice sheets, nor do they assess the potential for further acceleration of this melting."

The researchers provided a technical background paper that explained the methodology and assumptions used in the report. In this background piece, they included analysis of one more recent, and increasingly accepted, projection, that of Stephan Rahmstorf.[62] Given more recent literature and conference findings, this appears a more accurate projection to use in considering SLR than the more conservative and outdated numbers offered in the last IPCC report. Thus, the predictions for the extent of flooding used for the latter part of this paper derive from the Rahmstorf projections for SLR and the NECIA Coastal Team's further projections of local coastal flood events using the midrange of Rahmstorf's projections. All SLR projections beyond this point will be based on these assumptions unless otherwise noted.

Given this slightly higher projection, the recurrence interval of the 2005 100-year storm surge elevations will occur more frequently than every 2 years by 2050! It is important to note, as well, that the elevations (and thus extent) of the 100-year flood plain as calculated by the expert local researchers is slightly higher than FEMA's flood elevation. Of equal or more importance than understanding the recurrence interval of flooding in the current 100-year (or 1%) floodplain is understanding the elevation and extent of a likely future flood. The following chart shows the predicted elevations for the Boston area while the following map shows the flood extent of a 100-year recurrence coastal flood event (essentially a 100-year / or 1% storm) in 2005, 2050 and 2100.

Year	Storm Surge / Coastal Event elevations at MHHW (feet NAVD) in Boston (mid range of Rahmstorf Prediction)
2005	9.7
2050	11.2
2100	14.2

62 Ibid.

Elevation Indicating Coastal Flood Hazards Relative to Sea Level Rise

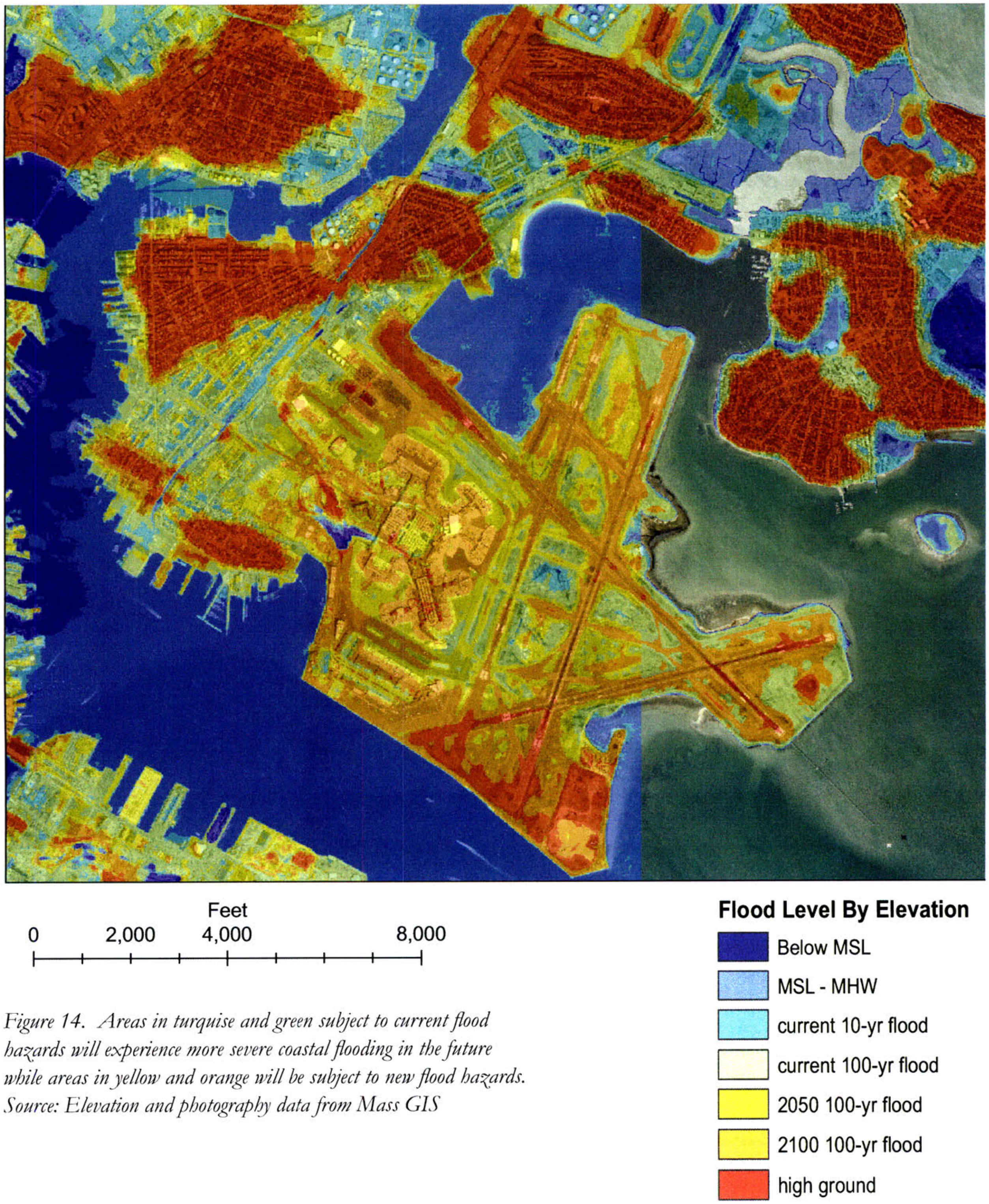


Figure 14. Areas in turquise and green subject to current flood hazards will experience more severe coastal flooding in the future while areas in yellow and orange will be subject to new flood hazards. Source: Elevation and photography data from Mass GIS

East Boston Neighborhood and Land Context

East Boston is a Boston neighborhood known for its history as a bustling industrial port area, its vast expansion through made land, its hosting New England's largest airport, its welcoming of immigrant groups, its consequently diverse group of residents, and its sense of community[63] East Boston Masterplan of 2000 describes the possibilities of the East Boston waterfront enthusiastically as it transitions to a time less dependent on marine industry in which waterfront lots that have been underused may see new life.

The Masterplan calls for a balance of open space and cultural activity with waterfront residential use and regional port-related activities.[64]

The neighborhood's stretches of low lying areas derive from its physical history. As seen in figure xx, the majority of the land, particularly that currently occupied by the ocean and along the piers, has been made in the last 200 years. What began as Noddles and Breeds Island out in the bay, became the next horizon for growth in Boston by the mid 19th century under the East Boston Company.[65]

The Eastern Railroad (later the Boston & Albany Railroad) and Saratoga Street followed bridges across the inlet separating the two islands and companies continued to wharf out along the Marginal and

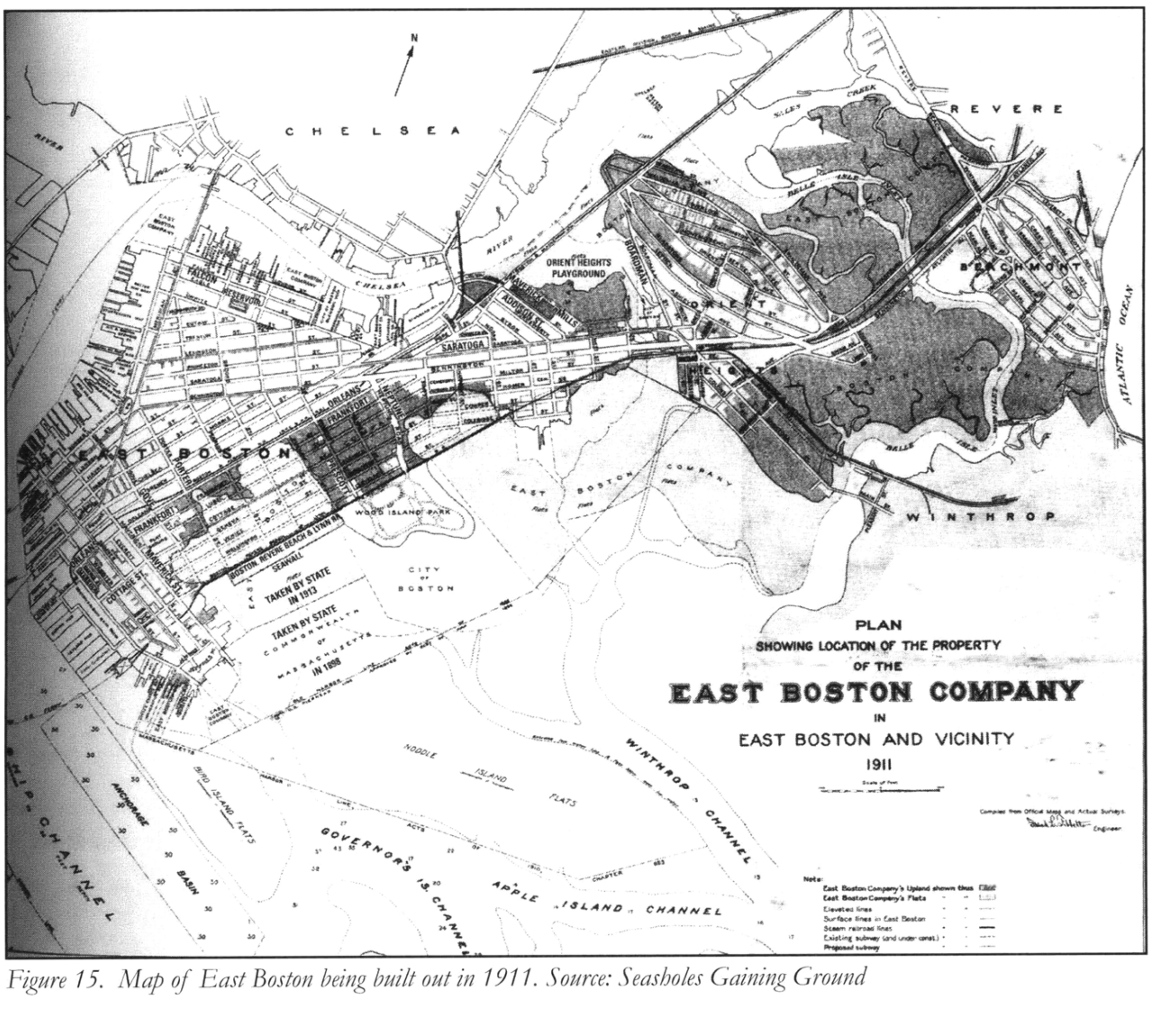


Figure 15. Map of East Boston being built out in 1911. Source: Seasholes Gaining Ground

63 *East Boston Master Plan.*

64 Seasholes, *Gaining Ground.*

65 Ibid.

Boarder Street waterfronts. With stone seawalls, wood bulkheads, rip-rap dikes, and any dredgings or fill they could obtain, they envisioned a larger future.

More dikes and fill closed off the inlet once separating Noddles and Breeds Island, making a continuous stretch of land for East Boston. Then, atop one long seawall, the Boston Revere Beach and Lynn Railroad was built. The dike allowed for easier fill of the basin that remained between this railroad and the land. The railway remains behind Constitution Beach as an egress for the mass transit Blue Line train. While the ports, with their connection to two railroads, took off early on, the grand plans for residential use of filled lands never materialized. This made way for the state of Massachusetts to take the rights to these tidelands through eminent domain to further develop the port. The planned port, however, was replaced by the initially small and later much expanded Logan Airport, occupying 1,413 acres of filled land along the flats off the East Boston Shore. [66]

It is upon this mass of filled lands stabilized between early hills and century old seawalls and dikes that the neighborhoods, airport, and industries of East Boston now base their foundations.

East Boston serves as a useful case study area for understanding the effects of coastal flooding due to SLR in Boston for several reasons. As seen in the map (figure reference) its low edges are somewhat exposed to today's coastal floods and notably more so to the floods expected in 2050 and 2100. While East Boston is a thoroughly urban neighborhood, its coastal edges display a variety of urban conditions. Furthermore, a

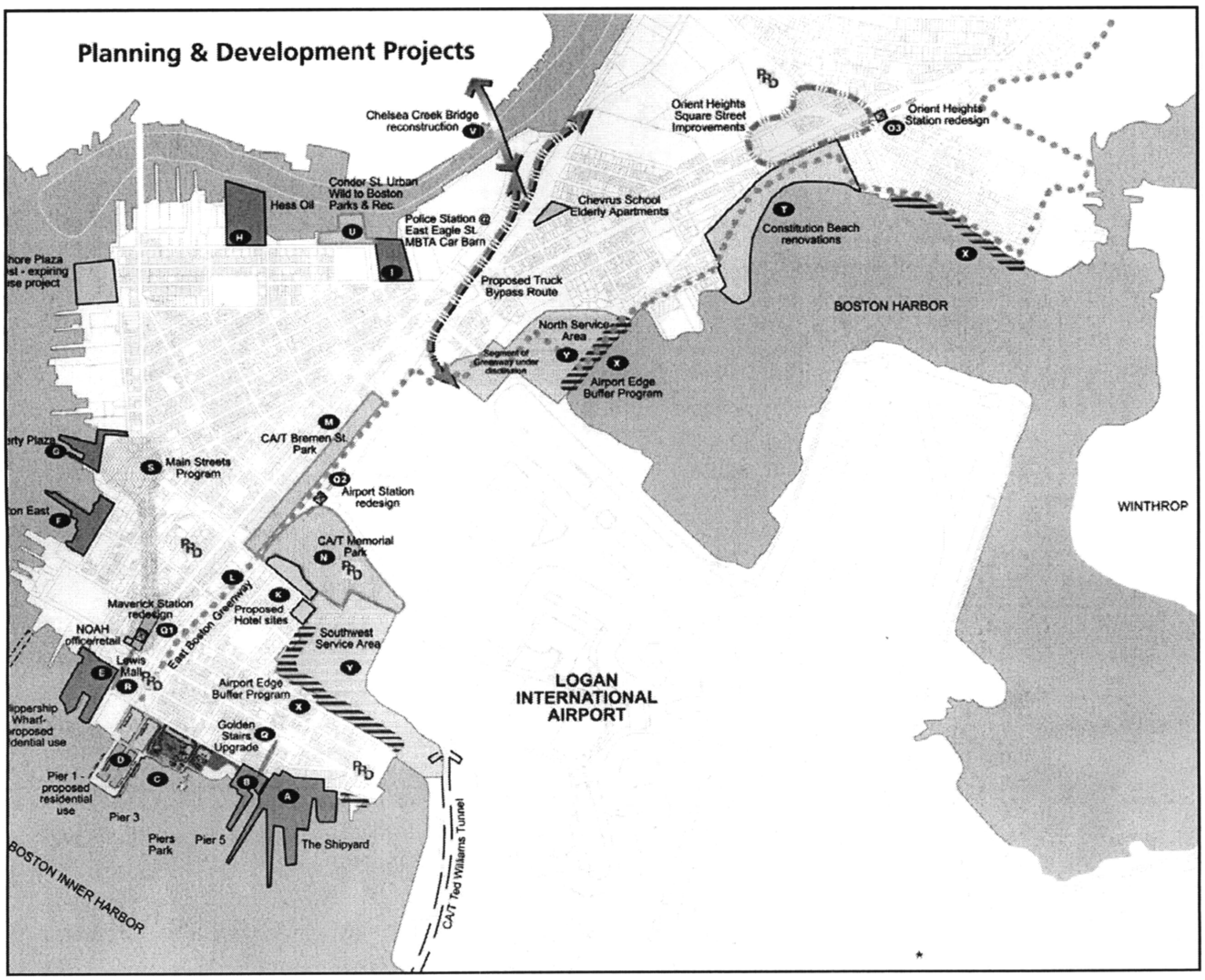


Figure 16. Planning, development, and some renovation projects from 2000. Source: East Boston Master Plan

66 Fort Point Associates, Inc., *Boston East Project Notification Form.*

large number of currently underused or unused old marine-industrial coastal properties that would be highly exposed to future flood risks, appear, to some, ripe for new development

The two sites explored in this thesis complement each other in their somewhat different, but related urban conditions.

Case Study Site Introductions

Boston East is a 4.8 acre vacant parcel along the piers off of Border Street (indicate with map). Half of this parcel reaches the coast at a hard edge, in a sea of dilapidated piers while the other half reaches the coast along a slope of earth, though it appears this land may have previously been stabilized by a revetment or other hard coastal structure. A plan for a multi-use development has been proposed and nearly approved on this city owned parcel of land, though it will probably be several months before site preparation begins.

The Constitution Beach Site includes half of Constitution Beach itself, as well as the MBTA train tracks and the commercial development behind it. The Massachusetts Department of Conservation and Recreation, has recently renovated the beach and its amenities, which are well used by the public, particularly during summer weekends. Thus, there are no plans to replace the current use. The wide, soft edge invites somewhat different flood mitigation approaches from those used where dense development draws near a hard-edged waterfront.

Chapters five and six analyze these sites before offering design alternatives that respond to future flood scenarios while allowing the site to serve the community and landholders.

CHAPTER 5: BOSTON EAST SITE ANALYSIS AND DESIGN

Boston East Introduction

Boston East, the first site considered for design analysis, is defined by the City-owned parcel from 102-104 Border Street, indicated by the yellow dotted on the site context page. This parcel offers insight into a common and timely challenge for the East Boston Inner Harbor: large new residential development proposals on low-use or abandoned marine waterfront subject to current and future coastal flooding. As the future risks of SLR and the costs of protecting or losing existing infrastructure becomes ever more apparent, it is imperative that we minimize risk and costs associated with NEW building in flood hazard areas. That said, coastal, residential, infill development may offer a good deal of revenue and regeneration to the area. Thus, solutions for accommodating flooding along with new structures or for allowing this land to be developed on the condition of its protection are integral to Boston's future.

As shown in the Boston East site analysis, the southwestern portion of the Boston East site is particularly derelict with dilapidated marine railways, entrance posts, outfall pipes, old bulkheads, and approximately 25,000 SF of dilapidated timber pilings.[67] However, the northeastern part of the site has more stable flat ground and both enjoy panoramic views of Charlestown, the Tobin and Zakim bridges, and some of the Boston skyline.

Trinity East Boston Development Limited Partnership has proposed two buildings for the site. In addition to their intention to build a marine industrial facility on the newly condensed designated port area portion of the site, they have proposed, in some detail, the development of a largely residential 196 unit building with underground parking and a public gallery as part of the facilities of accommodation for the neighborhood. They have also proposed to provide a portion of the East Boston Harborwalk with about twelve feet of access along the waterfront portion of the site. Their proposal is indicated on the following pages as part of the base map in both Boston East design schemes.[68]

Given the unique position of the site, upon filled (previously flowed) tidelands, in the East Boston Municipal Harbor Plan area, and partly within the designated port area, the project requires many permits, approvals, or variances at the federal state and local level. These include a conditional use permit for residential programming on the first floor, a reconfiguration of the designated port area, chapter 91 and article 53 approvals for protecting public rights for active water dependent uses in flowed tidelands, and storm water management approvals indicating erosion and sediment controls for the site. There are some requirements related to the FEMA 100-year flood plain, but, unlike other estimates of the 100-year coastal storm, the conservative FEMA map shows this area only skirting the site. Furthermore there are no requirements, or even official recommendations, that the developers consider future coastal flood predictions due to SLR.[69]

The designs for this site, detailed in the Scheme A: Elevated Building and Scheme B: Sea Wall drawings, alter the existing proposal to accommodate a similar program and form on the site while accounting more critically for the risks of coastal flood exposure. Both approaches aimed at protecting the site through hard engineered barriers and safely accommodating floodwaters are explored. Both include components of landscape flood mitigation and creative land uses.

Outline of Design Drawings

Boston East site analysis and design drawings on the following 7 pages include:

1. Boston East – Site Context
2. Boston East – Site Analysis (2 pages)
3. Boston East – Scheme A: Elevated Building – Plan
4. Boston East – Scheme A: Elevated Building – Section
5. Boston East – Scheme B: Sea Wall – Plan
6. Boston East – Scheme B: Sea Wall – Section

67 Fort Point Associates, Inc., *Boston East Project Notification Form*; The Cecil Group, *Amendment to the East Boston Water Front District Municipal Harbor Plan.*

68 Fort Point Associates, Inc., *Boston East Project Notification Form.*

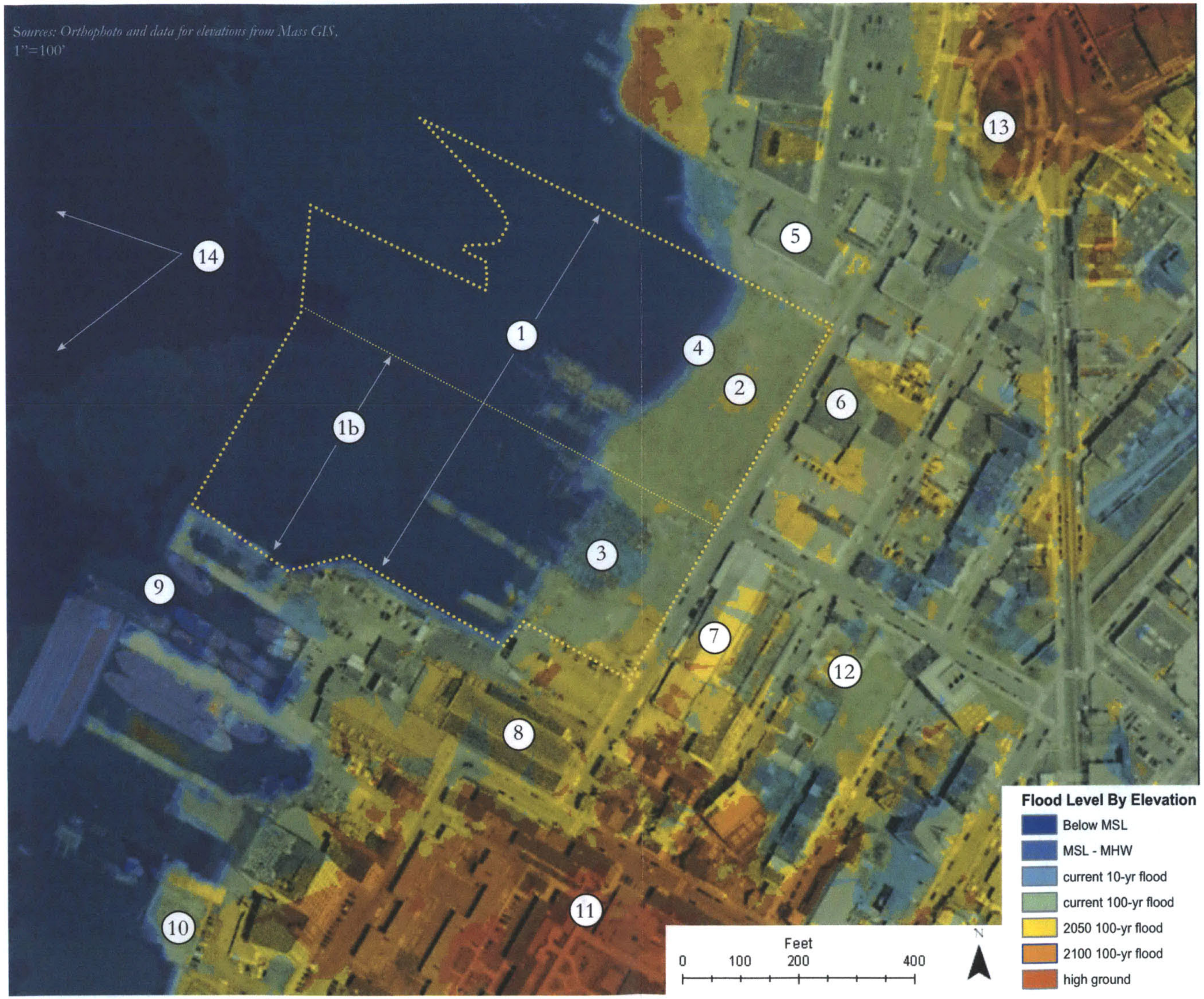
69 "Conversation with Julia O'Brien, DCR."

In addition to annotated drawings, the design pages include text boxes that detail the major considerations in the designs broken into four categories:

1. Hard Engineered Barriers
2. Landscape Flood Mitigation
3. Flood-Resistant Building Design
4. Land Use Planning and Policy Tools

Findings are summarized in the Benefits and Drawbacks sections at the end of the text boxes, and the chapter concludes with a prose summary of these findings.

BOSTON EAST – SITE CONTEXT



BOSTON EAST – SITE CONTEXT

On Site

1. 102-148 Border St. "Boston East" approximate boundary
    - A private development proposal submitted for this site including residential uses, some community uses, and undetermined marine uses

1b. Designated port area (DPA)
    - Special land use restrictions apply to the DPA

2. Solid, if low-lying, land on Boston East site
    - The most buildable portion of the site
3. Dilapidated piers, old concrete foundation, marine rail
    - Debris creates a safety hazard and visual blight. Land requires clean up and fill before being used.
4. Sloping dirt shoreline
    - Unusual compared to the pier and bulkhead hard shoreline that extends a ways in both directions

Direct Surroundings

5. Mystic Shore Warehouse
    - An abandoned-looking warehouse abuts the property.
    - A strip of run-down commercial and storage buildings with one or two newer buildings, including the headquarters of a community organization
6. American Architectural Iron Corp. light industrial
    - A blank corrugated metal face to the street
7. Atlantic Works artist studios, gallery and day care in a rehabbed brick building
    - Newly renovated building with artist studios and a day care to serve the larger residential community

Wider Context

8. Boston Towing
    - An active port area with the kind of use expected to exist in the DPA portion of the Boston East site.
9. Proposed New Street Development
    - One of several residential proposals made for the East Boston waterfront during the last boom
10. Maverick Landing public mixed-income housing
    - Over 420 residential homes including family units
11. London St. play area
    - An outdoor amenity that serves a large surrounding residential population
12. Central Square
    - A neighborhood square and commercial center with supermarket and other daily amenities
13. Views of Boston and Charlestown waterfront
    - Improves land value for residential development.

BOSTON EAST – SITE ANALYSIS

Birds eye view of the site looking west
Source: Microsoft Live Local

View of Charlestown waterfront from site.

Abandoned-looking Atlantic Shore Warehouse as closest neighbor.

View from Border St. across the site to the working pier Boston Towing.

Dilapidated piers, concrete foundations, and marine railways, largely on the DPA portion of the site.

Sewer overflows on site.

Dilapidated piers, along the sites watersheet with building cranes in the distance.

BOSTON EAST – SITE ANALYSIS

Birds eye view of the site looking south
Source: Microsoft Live Local

Industrial building renovated as artist lofts, a gallery and a day care.

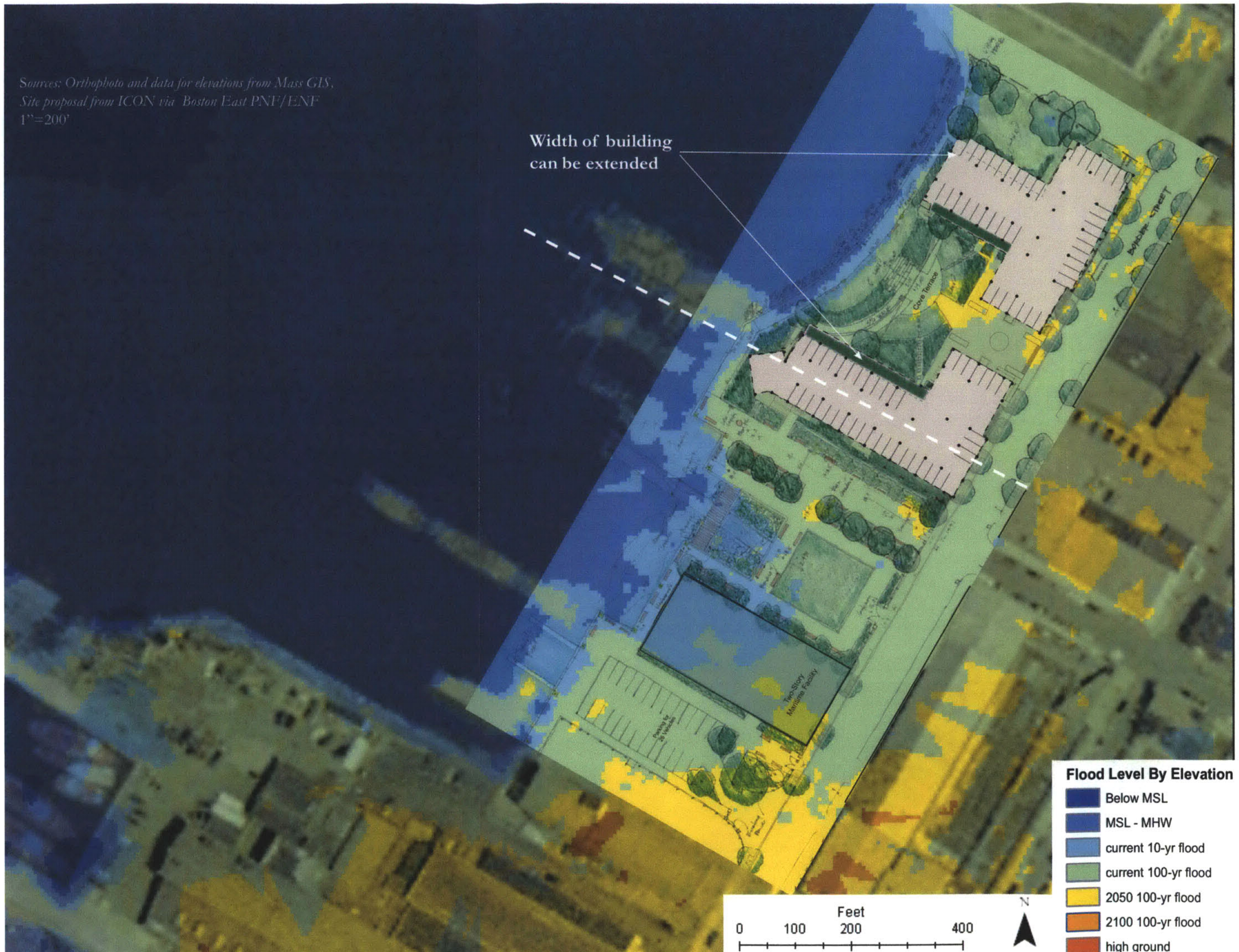
A decayed pile of timbers from historical wharves make up part of the ground plaIn of the DPA portion of the site.

New Office Building with Headquarters for NOAH; First furnished floor is raised above the lowest row of windows.

Several unused-looking buildings along this block.

Signs of flooded areas on a sunny day.

BOSTON EAST – SCHEME A: ELEVATED BUILDING – PLAN



BOSTON EAST – SCHEME A: ELEVATED BUILDING

Hard Engineered Barriers

- Line the coast with rock revetments to stop modest flood waters and absorb wave energy

Landscape Flood Mitigation

- Make a large percentage of the ground permeable, including permeable pavement for parking.

Flood-Resistant Building Design

- Rise building on stilts 8-10 feet above ground level.
  - While higher than necessary to avoid floodwaters, this will ensure an active, programmable ground plain that is easier to maintain.
  - Parking and gardens at ground level
  - Because only a small portion of the raised buildings footprint is impermeable, the overall floor size may be increased. This could compensate for any lost residential area without requiring further height.

Land Use Planning and Policy Tools

- Condition building permits on raising the building high enough to avoid a coastal flood in 2050 or 2100.
- Require that the Harbor Walk is maintained through time via an option for rolling easements. or raising the path up on a berm.
- Incorporate flood coastal flood hazards into environmental impact assessments.
- Offer tax incentives for increased permeability
- Safety for surrounding properties may require floodproofing, change in land use, or relocation landward.

Benefits

- Maintains access to the coastline
- Minimizes impermeable area while maintaining benefits from full use of the ground plain
- Avoids the cost of a basement foundation in soft, potentially polluted soils

Drawbacks

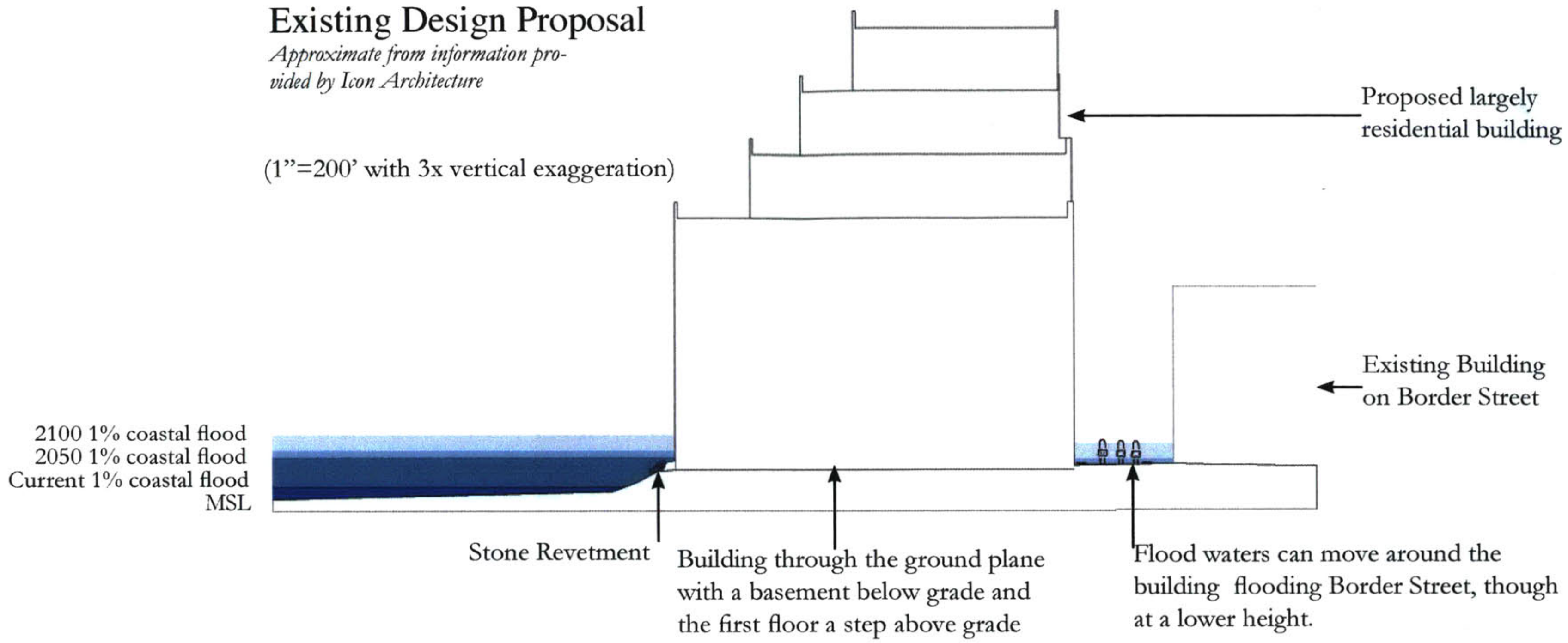
- Provides fewer parking spots than original proposal
- Ground plain has to be detailed creatively to ensure that the raised building does not detract from life at that level.

BOSTON EAST – SCHEME A: ELEVATED BUILDING – SECTION

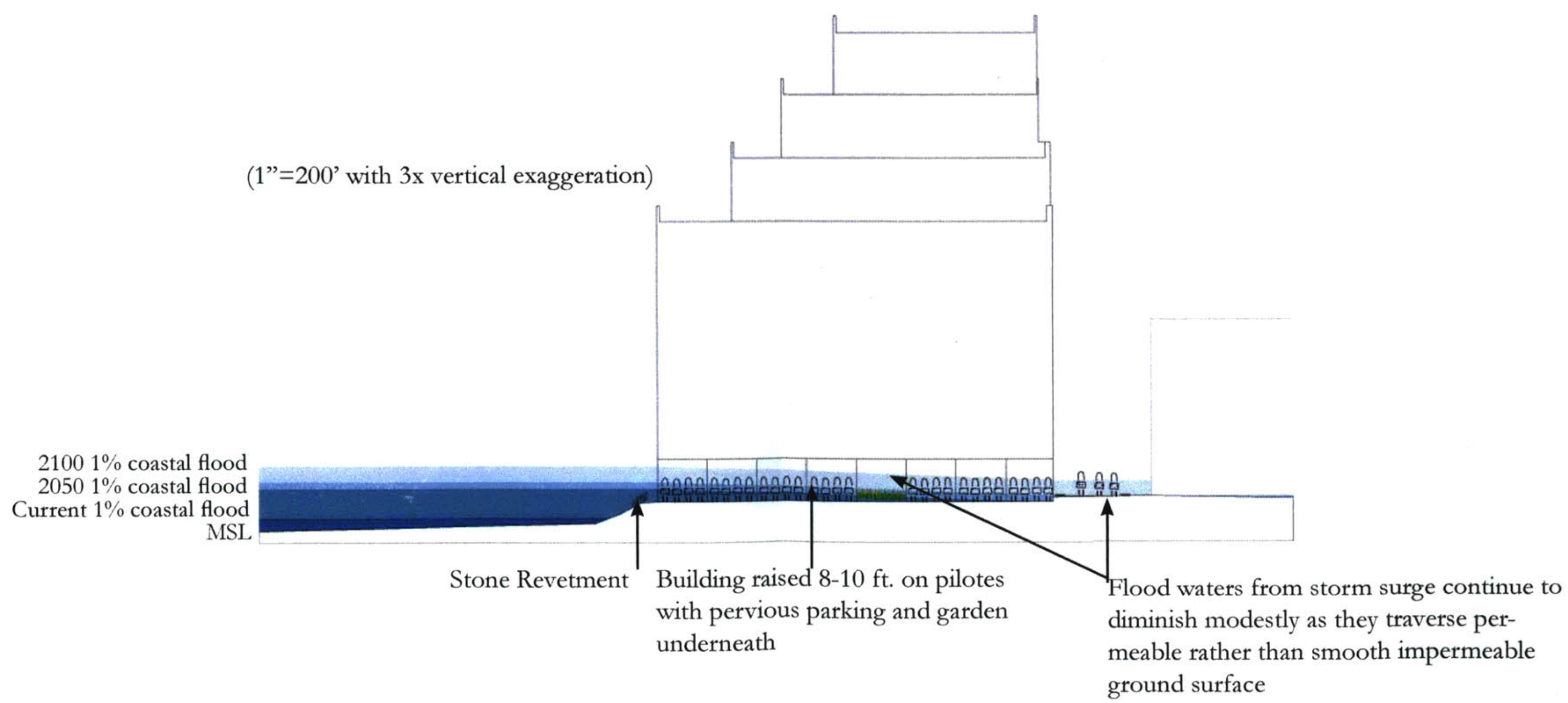
Existing Design Proposal

Approximate from information provided by Icon Architecture

(1"=200' with 3x vertical exaggeration)



(1"=200' with 3x vertical exaggeration)



BOSTON EAST – SCHEME A: ELEVATED BUILDING

Hard Engineered Barriers

- Line the coast with rock revetments to stop modest flood waters and absorb wave energy

Landscape Flood Mitigation

- Make a large percentage of the ground permeable, including permeable pavement for parking.

Flood-Resistant Building Design

- Rise building on stilts 8-10 feet above ground level.
    - While higher than necessary to avoid floodwaters, this will ensure an active, programmable ground plain that is easier to maintain.
    - Parking and gardens at ground level
    - Because only a small portion of the raised buildings footprint is impermeable, the overall floor size may be increased. This could compensate for any lost residential area without requiring further height.

Land Use Planning and Policy Tools

- Condition building permits on raising the building high enough to avoid a coastal flood in 2050 or 2100.
- Require that the Harbor Walk is maintained through time via an option for rolling easements. or raising the path up on a berm.
- Incorporate flood coastal flood hazards into environmental impact assessments.
- Offer tax incentives for increased permeability
- Safety for surrounding properties may require floodproofing, change in land use, or relocation landward.

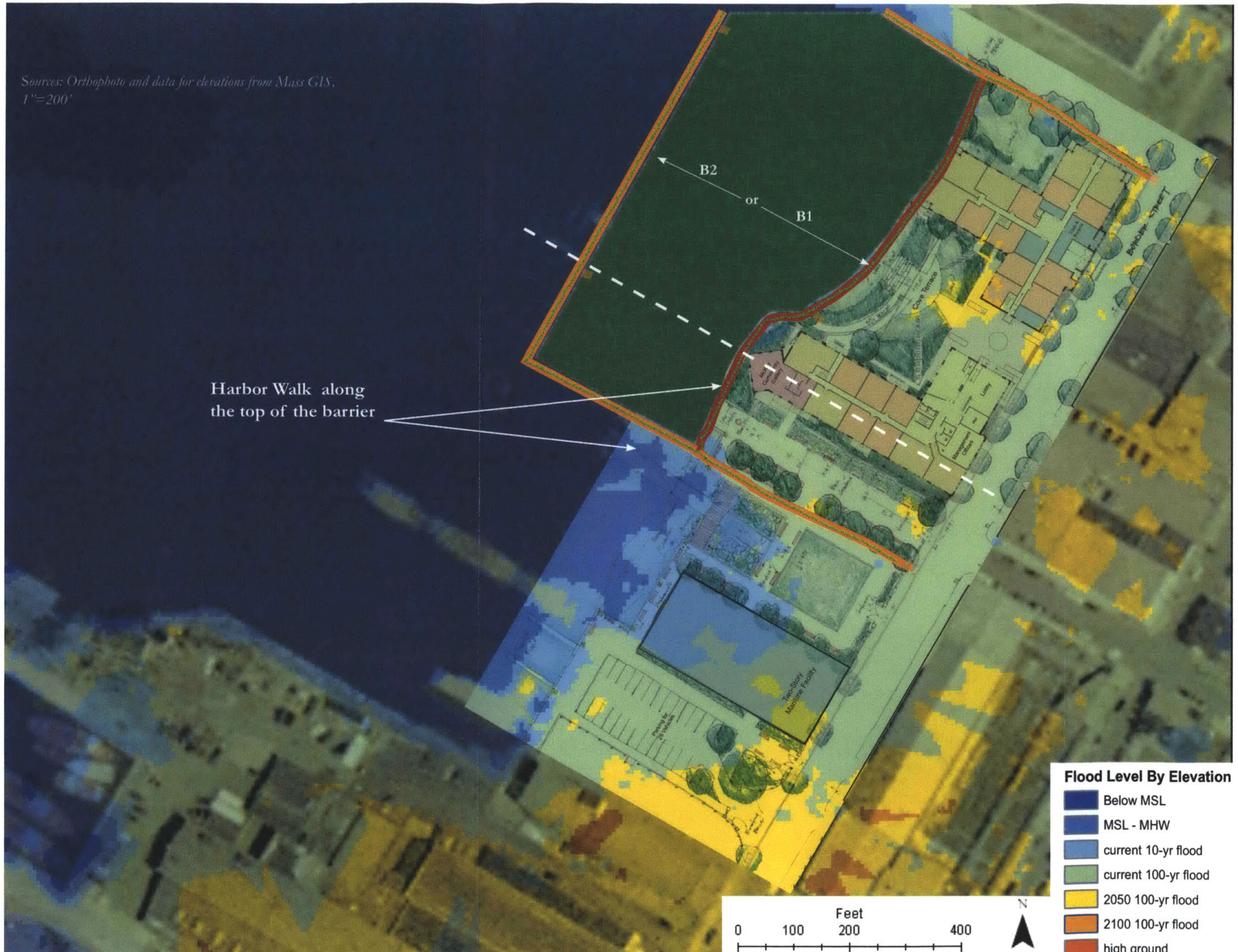
Benefits

- Maintains access to the coastline
- Minimizes impermeable area while maintaining benefits from full use of the ground plain
- Avoids the cost of a basement foundation in soft, potentially polluted soils

Drawbacks

- Provides fewer parking spots than original proposal
- Ground plain has to be detailed creatively to ensure that the raised building does not detract from life at that level.

BOSTON EAST – SCHEME B: SEA WALL – PLAN



BOSTON EAST – SCHEME B: SEA WALL

Hard Engineered Barriers (opt. B1 and B2)

- Build a protective sea wall to fully keep coastal sea waters from flowing into the residential portion of the Boston East site.
  - (B1) This wall could follow the shoreline and wrap around the building (full height).
  - or (B2) extend partial height wall out into the sea with earthen fill on the backside for support.

Landscape Flood Mitigation (opt. B2)

- In B2, land will serve as a backup protection, absorbing floodwaters that overtop the wall. This allows for the decrease in wall height.

Flood-Resistant Building Design

- Slightly raise entrances and use flood resistant materials at ground level.

Land Use Planning and Policy Tools

- Condition a building permit for the wall on proof that it will not increase flooding of neighboring properties.
- Require developer to show that their project accommodates or protects for future coastal flood considering sea level rise.
- B2 Allow barriers to be built out beyond the existing shoreline.
- B2 Ensure that landowners manage the new open space so that it serves and is accessible to the broader community.

Benefits

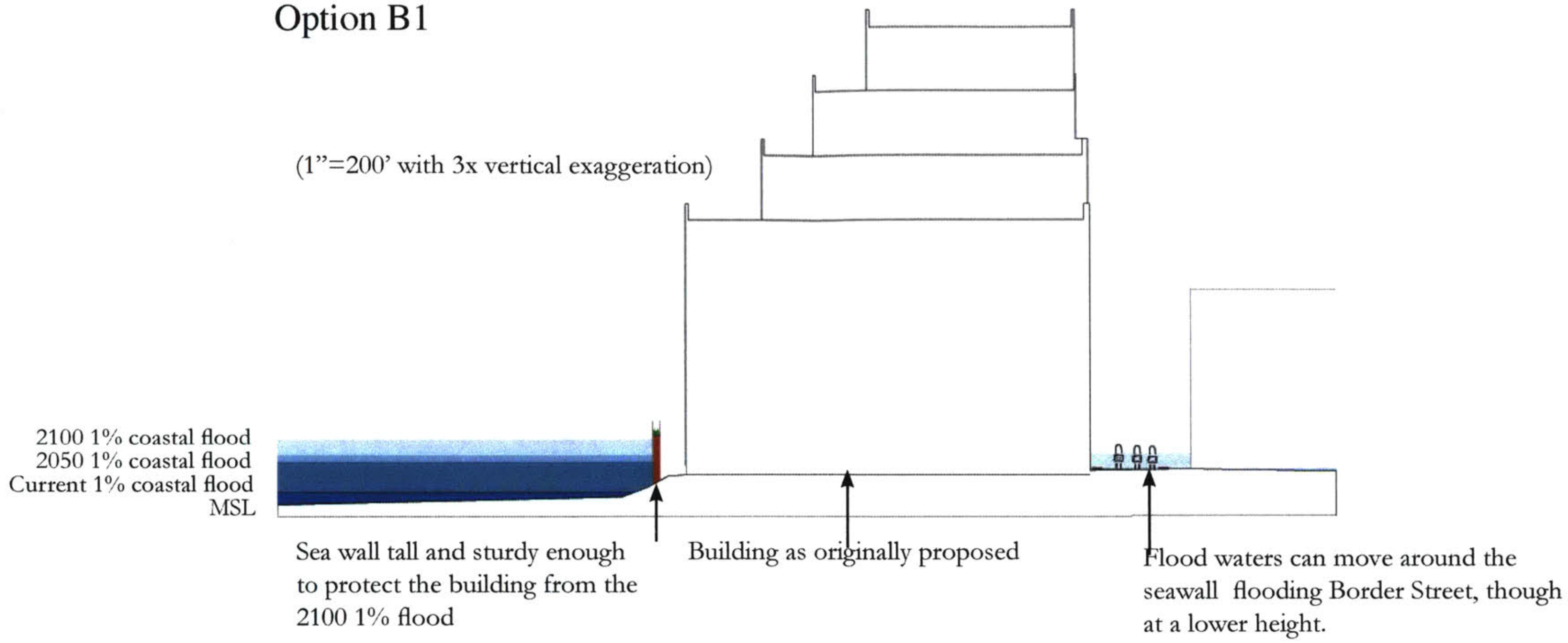
- Provides high actual security and a visual sense of security from coastal floods.
- Incorporates the wall with the Harbor Walk making programmatic use of the structure.
- B2 provides an extra public amenity.

Drawbacks

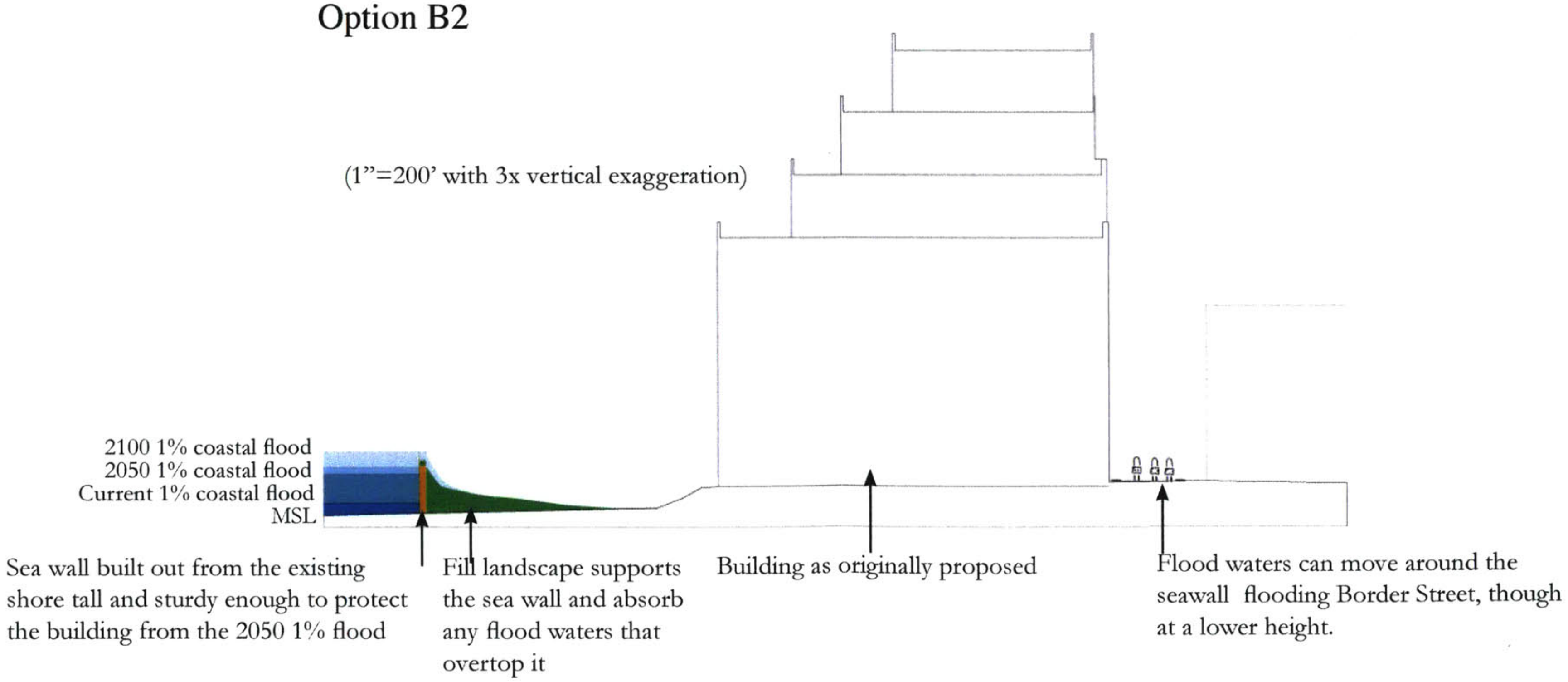
- Screens views from residential portion of site and neighbors.
- Makes access to water from the ground plain difficult (particularly B1).
- B2, presents the problem of obtaining good fill.
- Has the potential to be prohibitively costly (particularly B2).
- Presents a risk to coastal environments and habitats.

BOSTON EAST – SCHEME B: SEA WALL – SECTION

Option B1



Option B2



BOSTON EAST – SCHEME B: SEA WALL

Hard Engineered Barriers (opt. B1 and B2)

- Build a protective sea wall to fully keep coastal sea waters from flowing into the residential portion of the Boston East site.
    - (B1) This wall could follow the shoreline and wrap around the building (full height).
    - or (B2) extend partial height wall out into the sea with earthen fill on the backside for support.

Landscape Flood Mitigation (opt. B2)

- In B2, land will serve as a backup protection, absorbing floodwaters that overtop the wall. This allows for the decrease in wall height.

Flood-Resistant Building Design

- Slightly raise entrances and use flood resistant materials at ground level.

Land Use Planning and Policy Tools

- Condition a building permit for the wall on proof that it will not increase flooding of neighboring properties.
- Require developer to show that their project accommodates or protects for future coastal flood considering sea level rise.
- B2 Allow barriers to be built out beyond the existing shoreline.
- B2 Ensure that landowners manage the new open space so that it serves and is accessible to the broader community.

Benefits

- Provides high actual security and a visual sense of security from coastal floods.
- Incorporates the wall with the Harbor Walk making programmatic use of the structure.
- B2 provides an extra public amenity.

Drawbacks

- Screens views from residential portion of site and neighbors.
- Makes access to water from the ground plain difficult (particularly B1).
- B2, presents the problem of obtaining good fill.
- Has the potential to be prohibitively costly (particularly B2).
- Presents a risk to coastal environments and habitats.

Boston East Findings

Despite being constrained by its modest size, storm exposure, and flatness, this site can accommodate a variety of different solutions. The raised building option, offers a straightforward response to the problem. The ground floor remains useable with parking and public gardens; excavation along a shallow, filled shore is minimized; and the added detail of increased permeability mitigates flood effects on site and for neighbors. At the same time, direct, ground level access is maintained to the shore, a cultural and natural amenity

The Scheme B – Sea Wall options allow the building to be developed as designed while offering new challenges with the building of hard engineered seawalls to bear the brunt of the ocean. A more traditional relationship between the first floor of the building and street level is maintained. Meanwhile, a more creative, if potentially less intimate, relationship between the sea and residence is established with the continuation of the East Boston Harborwalk atop the wall.

The Scheme B2 option to extend a sea wall out into the inner harbor directly challenges the concept of retreat, actually claiming more land to protect the existing. It similarly challenges the concept of hard structures providing support, as the filled land behind the while actually acts to stabilize it. While the fiscal, visual, and connective costs of these options are suspect, such creative solutions should be considered.

One legitimate land use option for this area involves restricting it to low-built recreational and marine access uses. However, to respond to a dynamic city interested in sustainable density and growth, the designs included in this thesis show the possibility to respond responsibly to growing coastal threats within an increasingly urbanizing context.

Depending on the solution chosen, government will need to institute some combination of strong recommendations and policies, including building codes, coastal flood zone setbacks, coastal protection guidelines, and related environmental due diligence. The earlier these measures appear, the less the government and residents will need to spend on damages or adaptation down the line.

CHAPTER 6: CONSTITUTION BEACH SITE ANALYSIS AND DESIGN

Constitution Beach Introduction

This site, indicated by the dotted yellow line on the following map, includes about half of the Constitution Beach park area, the active blue line train tracks directly behind the park, and the strip of low-density commercial and parking flanked by the tracks and Bennington Street. The commercial establishments extend from the Orient Heights commercial center and MBTA transit stop. The blue line tracks run from downtown Boston, through East Boston, and out to Revere.

The beach and park, while technically part of the state system, serves mostly locals, who maintain a sense of ownership over it. Renovations, planned and largely implemented throughout the 1990's, have introduced a softer edge to what was once a more utilitarian hardscaped design, and residents, who offered their input during several community meetings, seem to appreciate the changes. The rolling hills, highest in the center of the beach, may offer minimal protection against coastal flooding and the force of waves, though their purpose is to offer an elegant landscape solution to provide accessible access from the pedestrian overpass to grade.[70]

The extent of existing soft landscape in an urban context makes this site a particularly intriguing test case for understanding different adaptation solutions (explored in Scheme B – Dunescape) The railroad track stretching the length of the site and separating the recreational unbuilt area from the built area also offers an interesting situation. (explored in Scheme A – Track and Building Elevation) As detailed on the following pages, both schemes take advantage of multiple and complementary mitigation options for robust solutions to facing increasing coastal flood situations.

Outline of Design Drawings

Constitution Beach site analysis and design drawings on the following 7 pages include:

1. Constitution Beach – Site Context
2. Constitution Beach – Site Analysis (2 pages)
3. Constitution Beach – Scheme A: Track and Building Elevation – Plan
4. Constitution Beach – Scheme A: Track and Building Elevation – Section
5. Constitution Beach – Scheme B: Dunescape – Plan
6. Constitution Beach – Scheme B: Dunescape – Section

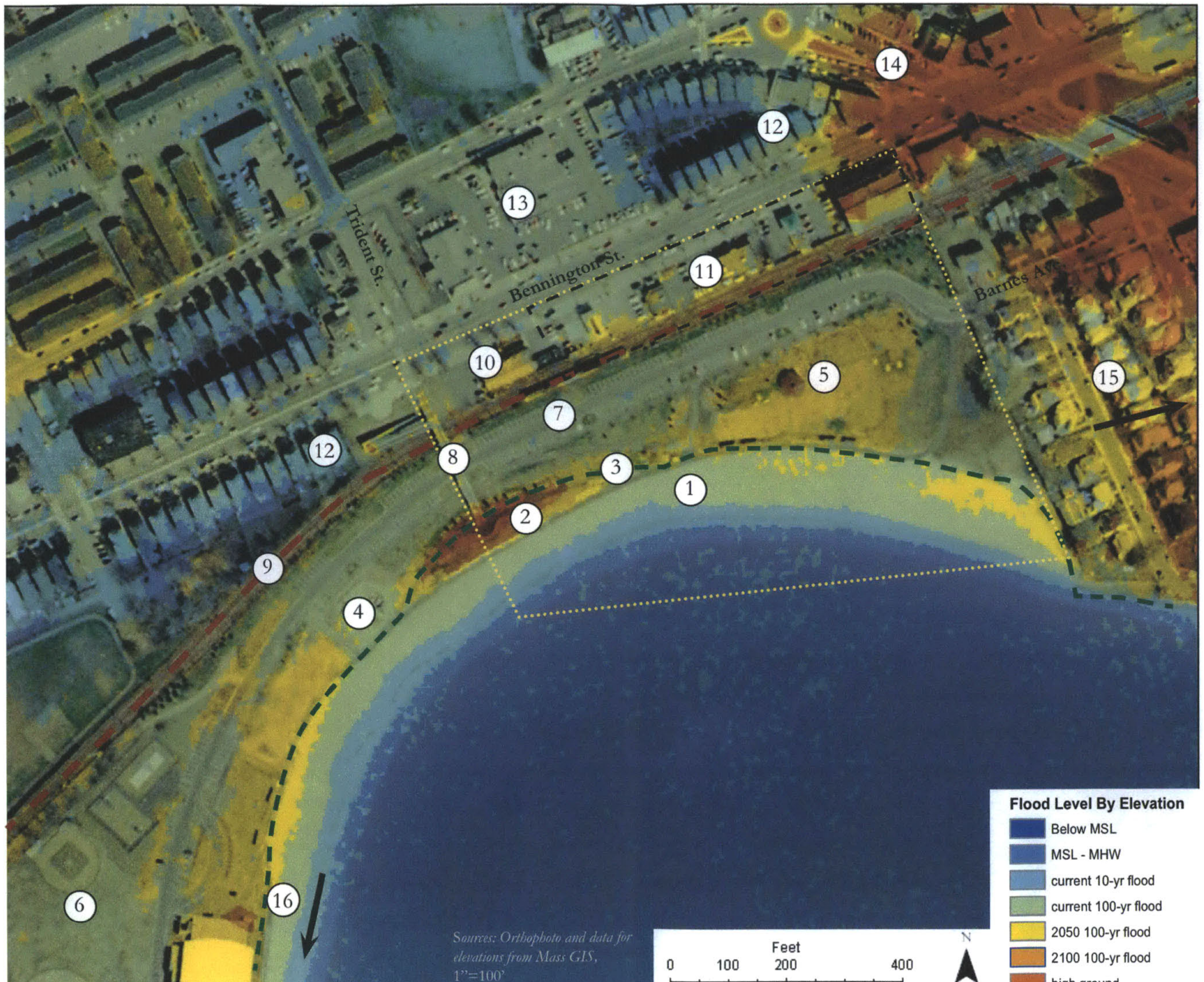
In addition to annotated drawings, the design pages include text boxes that detail the major considerations in the designs broken into four categories:

1. Hard Engineered Barriers
2. Landscape Flood Mitigation
3. Flood-Resistant Building Design
4. Land Use Planning and Policy Tools

Findings are summarized in the Benefits and Drawbacks sections at the end of the text boxes, and the chapter concludes with a prose summary of these findings.

70 Stern and Great Britain Treasury., *Stern review on the economics of climate change.*, viii.

CONSTITUTION BEACH – SITE CONTEXT



CONSTITUTION BEACH - SITE CONTEXT

Beach Area

1. Public beach with sand replenished seasonally
   - A neighborhood asset highly utilized during the summer Constitution Beach is managed by Mass DCR.
2. Landscaped small hills with grass and small trees
   - Visually dune-like, but made of dirt and grass, and does not extend the length of the beach at any height.
3. East Boston Harborwalk
   - An extension of the Boston Harborwalk with an effort to reconnect citizens to the waterfront
4. Playground
   - Newly built, programmed, and flood resistant use
5. Covered pavilion
   - Open with concrete base and picnic tables
6. Constitution Beach athletic field and courts
   - Recreational amenities of the beach.

Outbound Access with Beach

7. Road lined with parking
   - Impermeable asphalt. Highly used by beach visitors on sunny summer weekends; otherwise sparsely used
8. Pedestrian overpass of train tracks and parking
   - The primary pedestrian connection from the neighbor-hood to the site
9. MBTA Blue Line tracks at grade
   - Regular train service.
   - Tracks separated from surrounding by chain link fence on both sides
10. Funeral home
    - A grade above other buildings on this commercial strip
11. Small scale commercial strip
    - Mostly one to two story free standing buildings with lots of parking

Back Slope and Adjacent Areas

12. Triple-decker housing
    - Low-lying homes in the surrounding area that appear not to be flood-proofed
13. Box retail
14. Orient Heights center and MBTA station
    - Closest rapid transit link and commercial area
15. Belle Island Reservation
    - Natural marsh conservation area
16. Logan Airport
    - International Airport with riprap revetment, but no seawall protection

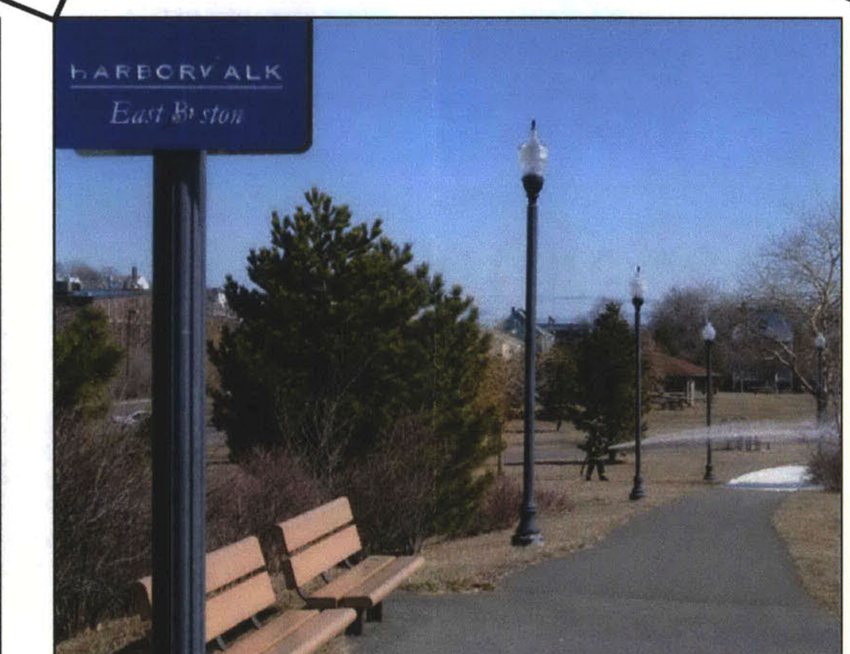
CONSTITUTION BEACH – SITE ANALYSIS

Birds eye view of site looking Northwest
Source: Microsoft Live Local

A view of the tracks from the Constitution Beach side could be improved.

A Landscaped dune-like hill in the center of the beach is primarily aesthetic but would provide some sea level protection.

One building on the commercial strip acknowledges the tracks and beach behind with windows and signage.

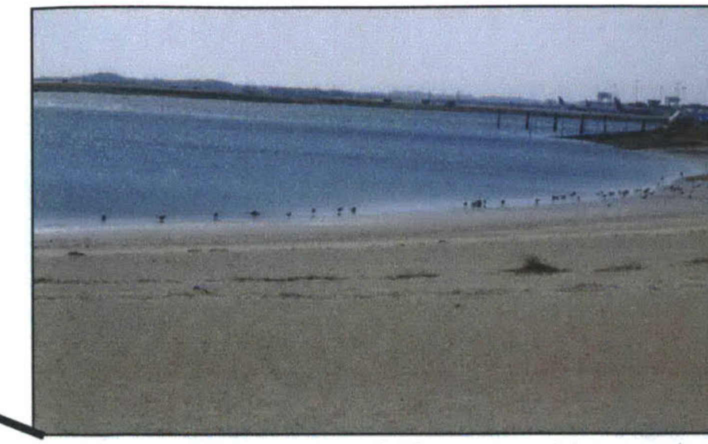


A section of the East Boston Harbor Walk moves through Constitution Beach connecting it to other parts of the waterfront.

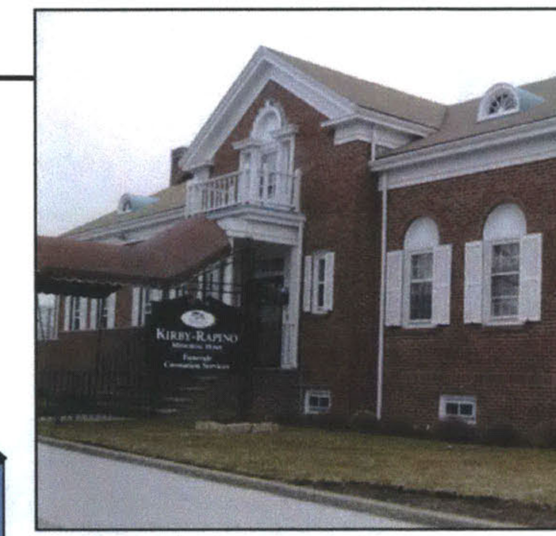
The covered pavilion is wet from rain washing in, but resilient to damage.

CONSTITUTION BEACH – SITE ANALYSIS

Birds eye view of the site looking southeast
Source: Microsoft Live Local



Sandy Beach and often swimmable bay with Airport in the distance.



Local Funeral Home.

Views of the beach from Bennington St. are not maximized.

Gigantic swaths of unbuilt but impermeable surface along Bennington St.

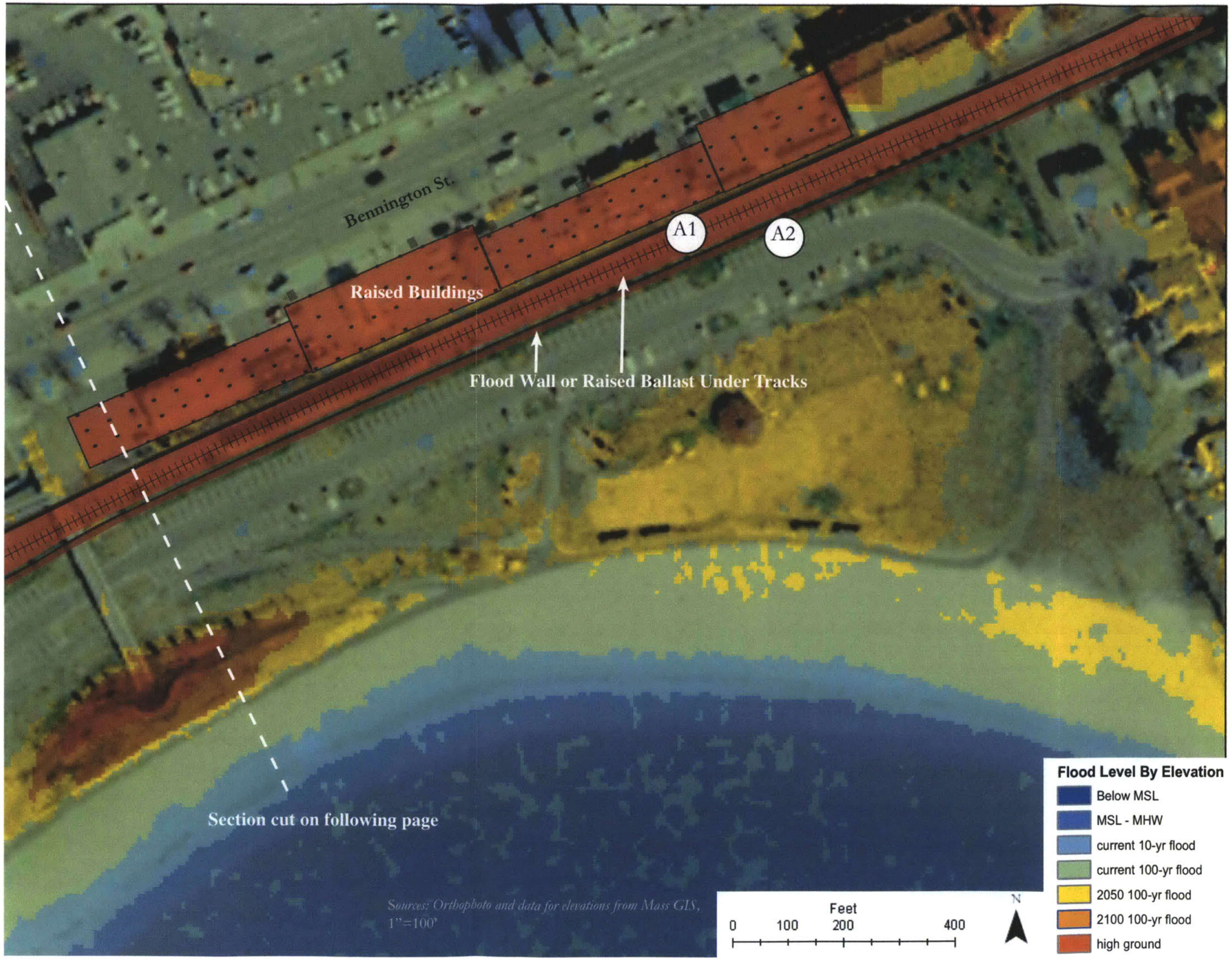
A pedestrian bridge recently built between Bennington St. and the beach.

A multi-unit brick building with newer facade treatment may, due to better construction, last longer than other buildings on the street.

A restaurant may be protected from coastal floods by the concrete wall built around the back and sides of its property.

Excessive paving at a small gas station.

CONSTITUTION BEACH – SCHEME A: TRACK AND BUILDING ELEVATION – PLAN



CONSTITUTION BEACH – SCHEME A: TRACK AND BUILDING ELEVATION

Hard Engineered Barriers

- A1 Raise the ballast beneath the track above the height of the 50 year projected coastal flood event.
- Or A2 build a flood wall along the seaward side of the tracks that exceeds the 50 year coastal flood event
  - Both as barriers protecting the development to the north from the coastal flood waters of the south.
  - A2 has elements of a landscape flood mediation or land use planning solution

Landscape Flood Mitigation

- Maintain the beach as is
  - Hills and absorbent surfaces provide some protection to the barrier itself

Flood-Resistant Building Design

- Provide basic flood proofing to commercial buildings in the short run
  - Minimizes damage from floods not directly related to coastal events
- Raise buildings approximately 3 feet above ground level upon rebuilding
  - Provides protection from future flood waters approaching from the north, but because there is good protection from the south, the height required is minimized.

Land Use Planning and Policy Tools

- Maintain the public park and beach through ownership; Require that any ancillary structures built are resistant to costly flood damage.
- Make sure that new development behind the rail ballast follows raised building guidelines through the building permit process or tax incentives.
- Offer public funds to work with the MBTA to raise and upgrade the tracks in this area.

Benefits

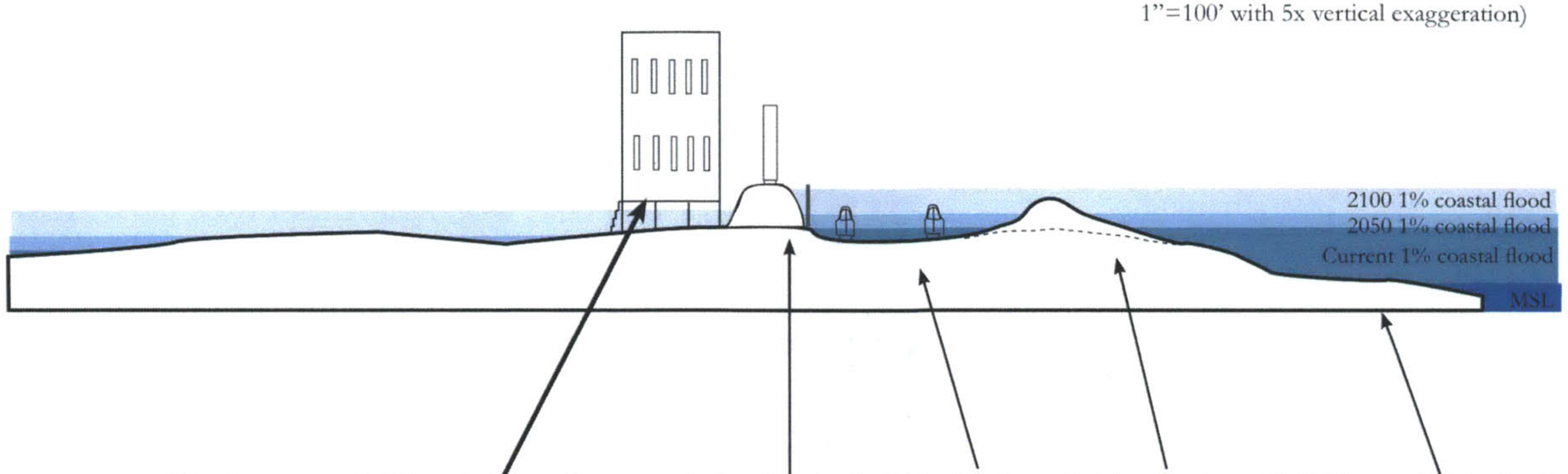
- Protects the tracks themselves
- Protects development north of the tracks
- Maintains the well-received, recently-renovated beach amenities, including parking

Drawbacks

- Potentially very large infrastructure costs for a relatively low-density population
- Interventions must extend beyond the site.
- Minimized potential for improving the view from areas north of the tracks

CONSTITUTION BEACH – SCHEME A: TRACK AND BUILDING ELEVATION – SECTION

1"=100' with 5x vertical exaggeration)



Shore Plaza East: an example of raised housing along the East Boston waterfront.

CONSTITUTION BEACH – SCHEME A: TRACK AND BUILDING ELEVATION

Hard Engineered Barriers

- A1 Raise the ballast beneath the track above the height of the 50 year projected coastal flood event.
- Or A2 build a flood wall along the seaward side of the tracks that exceeds the 50 year coastal flood event
  - Both as barriers protecting the development to the north from the coastal flood waters of the south.
  - A2 has elements of a landscape flood mediation or land use planning solution

Landscape Flood Mitigation

- Maintain the beach as is
  - Hills and absorbent surfaces provide some protection to the barrier itself

Flood-Resistant Building Design

- Provide basic flood proofing to commercial buildings in the short run
  - Minimizes damage from floods not directly related to coastal events
- Raise buildings approximately 3 feet above ground level upon rebuilding
  - Provides protection from future flood waters approaching from the north, but because there is good protection from the south, the height required is minimized.

Land Use Planning and Policy Tools

- Maintain the public park and beach through ownership; Require that any ancillary structures built are resistant to costly flood damage.
- Make sure that new development behind the rail ballast follows raised building guidelines through the building permit process or tax incentives.
- Offer public funds to work with the MBTA to raise and upgrade the tracks in this area.

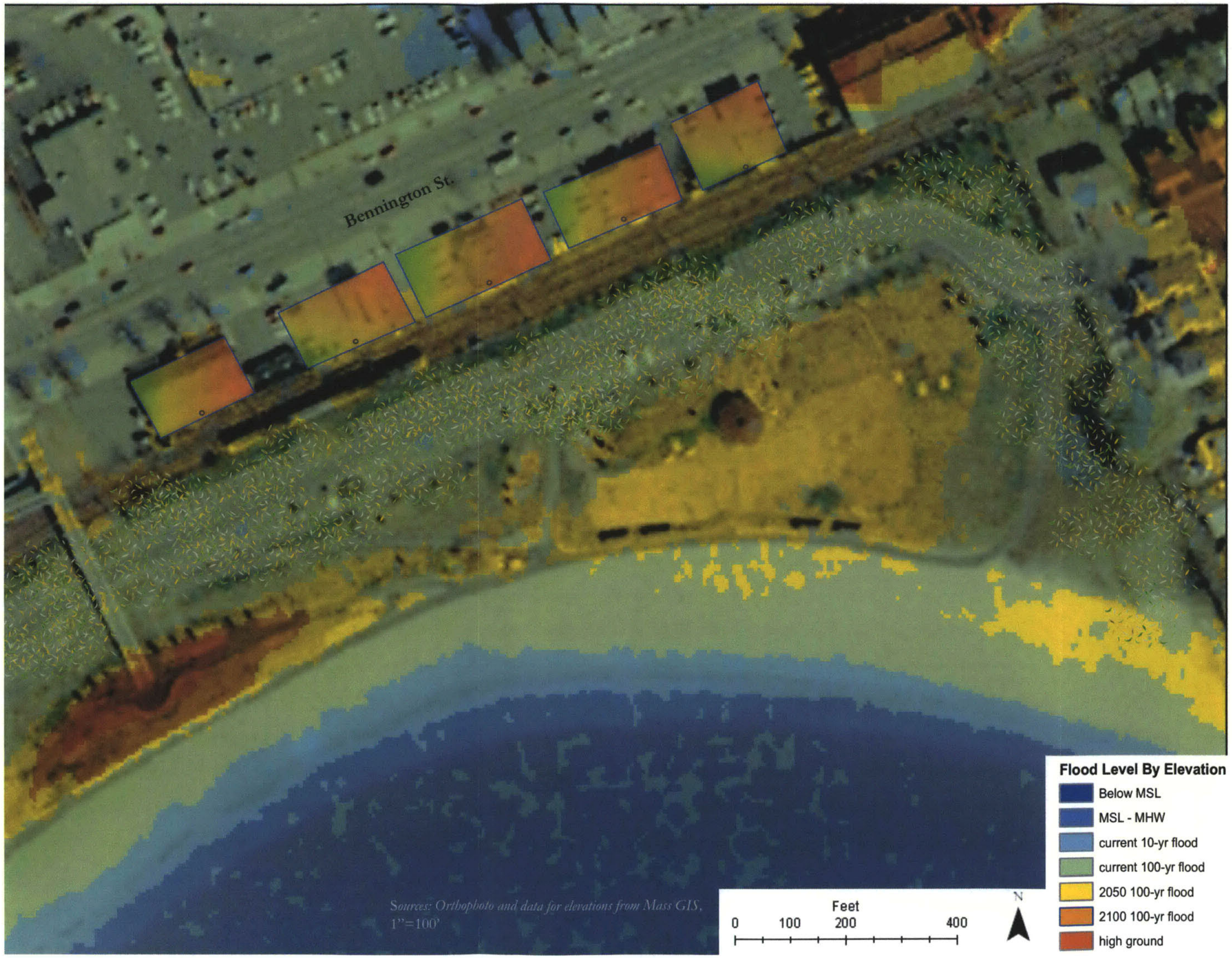
Benefits

- Protects the tracks themselves
- Protects development north of the tracks
- Maintains the well-received, recently-renovated beach amenities, including parking

Drawbacks

- Potentially very large infrastructure costs for a relatively low-density population
- Interventions must extend beyond the site.
- Minimized potential for improving the view from areas north of the tracks

CONSTITUTION BEACH – SCHEME B: DUNESCAPE – PLAN



CONSTITUTION BEACH – SCHEME B: DUNESCAPE

Hard Engineered Barriers

- No significant engineering barriers

Landscape Flood Mitigation

- Create a dunescape on the ocean side of the tracks where asphalt roadway and parking currently exist.
  - Create a large enough dune to withstand all but the worst coastal flood.
  - This will require that the beach become a pedestrian one.
  - Plant with dune grasses and other sea hardy plants that root well to stabilize the dunes as well as prickly plants that will keep people from trampling the dunes and diminishing their stability

Flood-Resistant Building Design

- Upon rebuilding, build amphibious structures: buildings that generally sit on land, but float with floodwaters while staying connected to the ground through a mooring system. This will mitigate flood impacts from the north.
  - This will mitigate flood impacts from the north.

Land Use Planning and Policy Tools

- Keep public ownership of land to allow for dune maintenance.
- Offer zoning incentives to encourage pedestrian / public transportation friendly amenities and allow minimal parking in the park and surrounding areas.
- Develop the dunescape and replenish it as needed
- Allow only flood-loss-resistant structures to reside in the coastal section of the dunescape

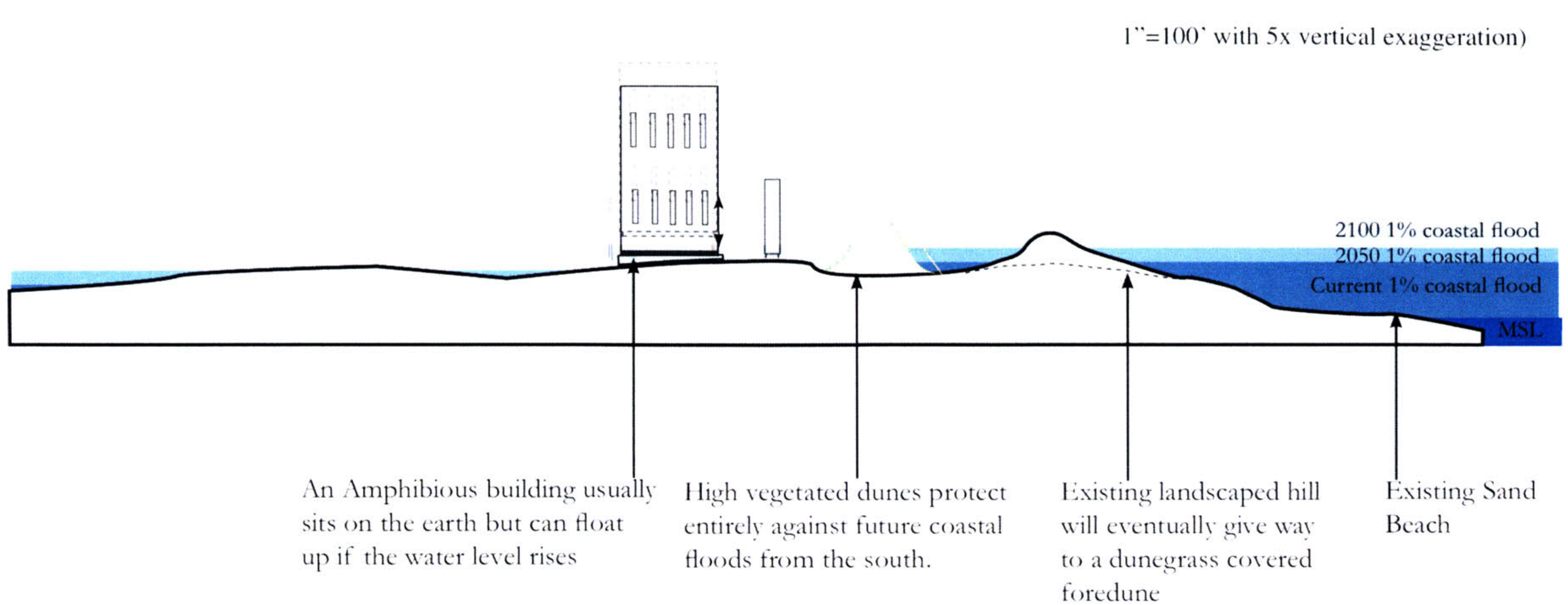
Benefits

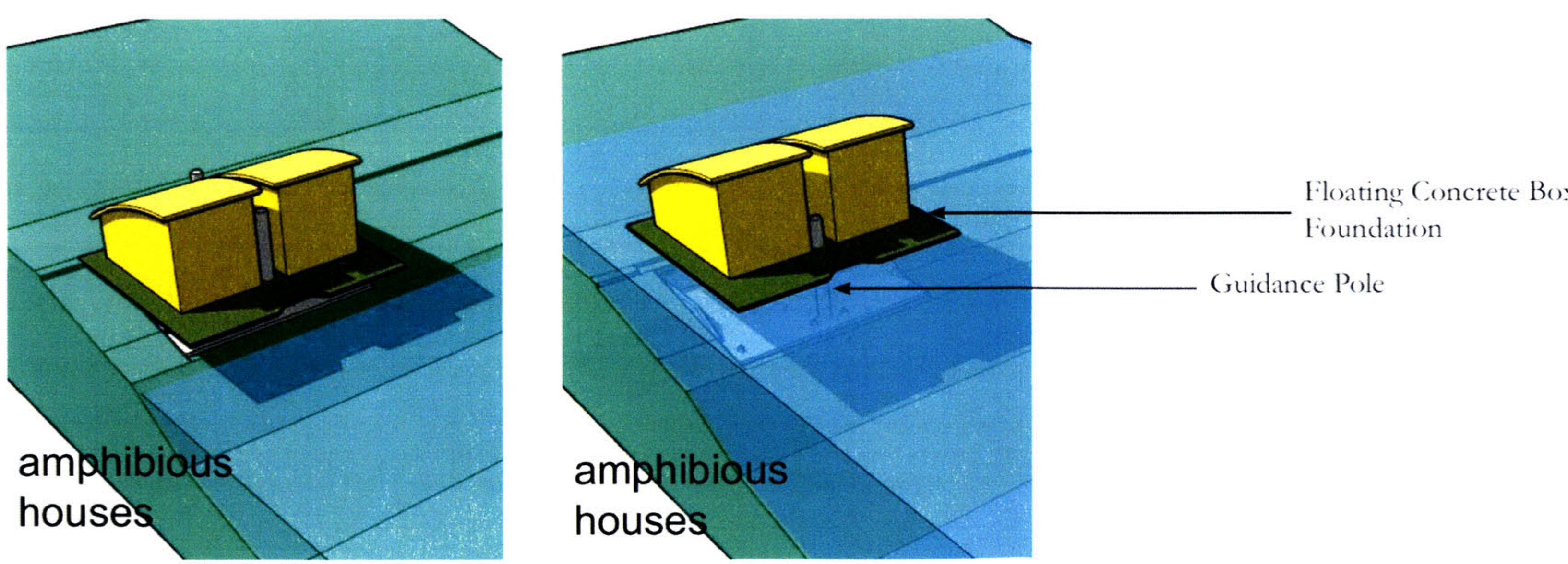
- Protects the tracks as well as the buildings
- The natural dunescape is more appealing and flexible than a wall.
- Aqua buildings allow development to rise and stay dry in the face of rising waters while still embracing the ground plain and pedestrian movement during low waters.
- Pedestrian dominance of park land

Drawbacks

- Dunes will have to be replenished requiring a safe source and maintenance costs.
- Aqua architecture might prove pricey given the relatively modest value of the land and early stage of technology.

CONSTITUTION BEACH – SCHEME B: DUNESCAPE – SECTION





Amphibious house diagram during low and high water levels

Source: Kengen presentation "Amphibious Houses, A Sustainable Alternative?"

CONSTITUTION BEACH – SCHEME B: DUNESCAPE

Hard Engineering Barriers
- No significant engineering barriers

Landscape Flood Mitigation
- Create a dunescape on the ocean side of the tracks where the asphalt roadway and parking currently exist.
    - Create a large enough dune to withstand all but the worst coastal flood.
    - This will require that the beach become a pedestrian one.
    - Plant with dunegrasses and other sea hardy plants that root well to stabilize the dunes as well as prickly plants that will keep people from trampling the dunes and affecting their stability

Flood-Resistant Building Design
- Build amphibious structures, or buildings that generally sit on land, but that can rise up on flotation materials with water level while staying connected through a mooring system

Land Use Planning and Policy Tools
- Through zoning incentives, encourage pedestrian / public transportation friendly amenities and allow minimal parking in the park and surrounding areas.
- Develop the dunescape and replenish it as needed
- Allow only flood-loss-resistant structures to reside in the coastal section of the dunescape

Benefits
- Protects the tracks as well as the buildings
- The natural dunescape is more aesthetic and less divisive than a wall.
- Aqua buildings allow development to rise and stay dry in the face of rising waters while still embracing the ground plain and pedestrian movement during low waters.

Drawbacks
- Dunes will have to be replenished requiring a safe source and maintenance costs.
- Aqua architecture might prove pricey given the relatively modest value of the land in the commercial area.

Constitution Beach Findings

The width of existing soft landscape makes this site especially conducive to large-scale landscape flood mitigation (as explored in Scheme B – Dunescape) , in a way that only a few urban coastal areas are. The communities greatest concern about this design would likely be the loss of parking, but this constraint could actually improve the pedestrian and transit oriented nature of the development and create a stronger connection for people, not water, between Bennington Street and the beach.

However, this site is in a unique position to accommodate a barrier to floods. Because the train tracks already act as a barrier to movement and, to some extent, to views, either building a hard structure sea wall or raising the ballast of the track (as explored in Scheme A – Track and Building Elevation) would prove less intrusive than other such interventions. Raising of the ballast, while intuitively a more attractive option than an inland sea wall, would pose one of the greatest logistical challenges as train service would have to be interrupted during construction. That being said, the long term benefits may outweigh the short term costs.

Both designs incorporate a backup option of flood-resistant buildings that may follow the original intervention by several years. This combination of approaches minimizes that need for a single over-engineered solution that will accommodate any future coastal situation in favor of a more flexible and incremental approach.

Both designs also rely on maintaining a permeable landscape and recreational program on much of the site. For these solutions to work, planners and the state owners of this particular property must ensure that the land continues with the same or comparable use. Flood hazard zoning or no-build easements would contribute to the desired outcome.

CHAPTER 7: SYNTHESIS AND CONCLUSIONS

Lessons from Site Designs

The proposed waterfront development of Boston East and the setback development of the Constitution Beach site present seperate urban coastal problems, which call for an array of different solutions. However, these design options and lessons can be applied to similar site contexts throughout East Boston, the City of Boston, and, perhaps, other coastal cities.

Hard Engineered Barriers

Despite some of the drawbacks of sea walls mentioned before, the option appears more reasonable where market forces in urban areas push development to the water's edge, as we see in the case of Boston East. This is particularly true where the existing edge is already artificially hardened. Existing barriers to access, also call for consideration of hard engineered barriers. Although not originally anticipated at Constitution Beach, such barriers were found to have relevance because of how their design could incorporate the train right of way in the barrier. In any situation, a sea wall will serve best where a relatively small expanse of barrier can protect a large investment (monetary and otherwise).

Hard structures such as rip-rap revetments can effectively mitigate wave impact and erosion thereby decreasing flood hazards with fewer negative effects than a sea wall. In coastal situations where sea walls are undesirable, but large landscape solutions not possible, sloping rip-rap revetments can complement other actions that minimize flood impact, as seen in the elevated building scheme for Boston East.

Whether private actors or the public sector implements hard engineered barriers, policies must ensure that these structures pose minimal environmental damage and avoid any negative impact on neighbors, be it from deflecting flood waters to other properties or increasing erosion elsewhere. Furthermore, public actors must communicate the intended effectiveness of the barriers very clearly to the public, as proposed in the Constitution Beach – Track and Building Elevation scheme. Paradoxically, flood control engineered structures in high hazard areas can provide an inflated sense of security and actually encourage development in those areas. Consequently, a breach will result in increased hazard losses over the pre-barrier situation. Thus, land developers behind a hard engineered barrier, need to understand and fully consider the designed capacity and risk of failure associated with such a structure so that they can make informed land use decisions.

Landscape Flood Mitigation

Landscape-scale solutions become very lucrative where soft edges and an existing softscape setback buffer development from the water's edge. Even in urban environments, beaches, partially abandoned sites, and low-density areas may accommodate landscape solutions with minimal cost for replacing development. Constitution Beach offers a prime example of how this can work effectively. Land filling behind a seawall, as considered in the Boston East scheme B2 design, would likely require a much greater cost. That said, where the value of buildable land is very high and a landscape scale solution is not feasible on its own, there is cause to consider integrating landscape solutions with structural ones.

In both site contexts explored here, and indeed in most other flood-prone urban contexts, a high percentage of impermeable surfaces and low impact development will help to absorb and slow the flow of floodwaters. Though likely not a sufficient response to rising coastal floodwaters on its own, permeability is easy to incorporate with other solutions, as seen in most of the proposals presented for the two sites.

Large-scale landscape flood mitigation measures such as large dunescapes, will likely be implemented through large public works projects, while some of the smaller, or even moderate scale measures can be implemented by developers and other landowners. Tax incentives to increase permeable surface and smart site design can lead towards wide involvement in decreasing flood hazard for coastal landowners and their neighbors.

Flood-Resistant Building Design

Particularly where considering new development, the long-tested practice of raising buildings on piles above floodplains can minimize the amount of protection needed, with only modest investment, and thus minimize the building of large hard or soft infrastructure projects. A full story vertical rise may be effective for the primary solution in a site like Boston East, whereas slightly lifted buildings can serve as a secondary component of mitigation as seen in the Constitution Beach – Track and Building site design. In either case, special planning consideration for how these structures interact with the ground plan would be important.

Floating and amphibious structures, which also rise above the floodwaters, provide less explored but appealing and potentially very effective solutions. In the case of any risen structure in the path of a coastal storm, but particularly floating structures out at sea, the ability of a structure to resist wind and wave forces as well as rising water levels is crucial. This is why floating buildings did not make their way into any of the proposed design solutions, and why amphibious homes are incorporated only in the semi-protected setback situation of Constitution Beach.

In terms of existing buildings, depending on their projected lifespan and the immediacy of the threat of exposure, it may make sense to either retrofit existing buildings with waterproofing materials or moving valuable items, including mechanicals, out of the first floor. On the other hand, landowners may be able to wait until the end of the structure's lifetime, or until major upgrades are required before building new and more flood-resistant structures. These stopgap options offer low-cost (if sometimes low-return) solutions.

In order to ensure that coastal buildings not otherwise fully protected remain flood-resistant, officials could draft policies that require that landowners either elevate the first floor above future coastal flood elevations (the default) or prove that using another method will result in minimal flood damage to the building. In addition to restrictive regulations, insurance companies might more aggressively encourage flood-resistant building techniques through tiered policy premiums.

Land Use Planning and Policy Tools

A land use master plan incorporating or focusing on future flood hazards provides an integral first step to guiding all land use and physical based responses to increasing coastal flood hazards. Foremost, it determines which highly exposed areas require limited land use. It will also help to determine at what point major infrastructural investments should be made, and will allow developers to make design decisions based on the expected lifespan of a building relative to the SLR projections. For example, either design scheme for Constitution Beach, shows the beach remaining undeveloped. A master plan recognizing the value of this site as undeveloped would recommend that it remain zoned recreational and that electricity or road systems need not extend into the area.

Programming exposed areas with low-impact and low-sensitivity land uses offers a logical solution to minimizing coastal flood impacts. While it may limit direct development profits for the land in question, it can also offer multiple community benefits beyond flood vulnerability protection for little cost. At Constitution Beach, not only have the community benefits of the recreational space outweighed development pressures, they are also resilient to coastal floods. The dunescape design solution ensures that this land use will also significantly mitigate flood impacts on surroundings. As flood exposure swells with higher sea levels, such a land use solution may become increasingly desirable.

Where the value of land still seems too costly to forgo more dense development up to the shoreline, a buffer of low-sensitivity land uses can be created by building the shoreline away from the development and out into the sea. This concept, explored for in the B2 sea wall design for Boston East, follows a long history of Bostonians expanding their shores. In this case, however, the newly built land could serve as a recreational space, landscape buffer, and structural enforcement. The potential costs of landfill and the building of structural edges in addition to the potential ecological impacts of such a move bring the feasibility into question. However, in highly sought after coastal areas, the option could be considered.

The tools for directing land use in areas with increasing coastal flood hazards are many. These include: directed use of government land, coastal flood hazard overlay zoning districts with setbacks, rolling easements, transfer of development rights, and reserved land through the many forms of public acquisition. On the Constitution Beach site, where the public already has control over development closest to the shore, the process of implementing land-based solutions will be much simpler. In the case of a site like Boston East, where building permits have been approved for a private developer, government will need to offer incentives or restrictive regulations that serve the public interest while minimizing negative financial impact on the developer. A well-supported requirement for easements may prove most feasible here. Furthermore, targeted investment or disinvestment in infrastructure and services will incentivize responsible land use in the private market.

Summary Findings

Combined Approaches. One thing that the design proposals in chapters five and six have in common is there reliance on a combination of interventions to address the challenge of SLR. Rather than superfluous built-in redundancy, the systems work together, each accounting for the limitations of the other. Many of the most efficient, effective, and desirable solutions to coastal flooding due to SLR use such a mixed approach.

Performance-Based Standards. Even though both sites presented different constraints, the designs showed that a variety of options were feasible for each. This suggests a preference for performance-based, rather than prescriptive zoning and regulations. As opposed to an approach that requires a specific reaction to increased flood conditions (for instance that all buildings lie two feet above the projected 2050 high water level), the performance-based approach allows the market and designers to figure out how best to respond to flood vulnerability assuming a certain standard. This will allow for more creative and site-specific solutions, such as the use of amphibious structures or incorporating landscape with seawalls, to enter the field of play where appropriate. At the same time, government can offer tax credits for land use or design that mitigates the impact of coastal flooding on surrounding lands.

Co-Benefits. It is important to note, that both sites, as depicted in the context plans, are not only highly vulnerable to future floods, they are also somewhat vulnerable to today's 1% flood. Thus, by acting early to mitigate flood hazards predicted for the future, communities can better protect themselves from today's hazards. However, given the uncertainty and complexity associated with climate change, plans should have a sufficiently flexible framework such that communities can begin to take action, while also respond to future changes in predictions with relative ease.

Further Research and Action

Primary recommendations

Detailed Cost Analysis. This thesis has presented a menu of physical infrastructure, design, planning, and policy options to address coastal flooding enhanced by SLR and explored how to best apply them in existing urban contexts in Boston. However, a detailed net cost analysis will be required to fully understand which of the several options that appear feasible will make the most of limited resources. This will include calculating and predicting the initial capital, general maintenance, and post-event costs for each option; considering environmental impacts, socioeconomic disruptions, flexibility and risk aversion; and calculating post-event savings compared to a no-action alternative.

A comprehensive cost analysis will not be easy to produce. In the Stern Review, a robust independent economic review of climate change developed in Britain, Sir Nicholas Stern notes, "Formal modelling of the overall impact of climate change in monetary terms is a formidable challenge.... However, as we have explained, the lags from action to effect are very long and the quantitative analysis needed to inform action will depend on such long-range modelling exercises."[71]

The tools for analyzing far-off future costs under different SLR conditions and adaptation scenarios are imprecise, but the estimates are necessary. This information will inform the decisions that must be made in the near term to shape future urban lands and policies.

Coastal Hazards Guide. In the short run, as coastal development proposals emerge for vacant lands, planners and technical experts should release updated local flood predictions and coastal flood-hazard design guidelines. Updated flood maps or site-specific exposure analysis can offer crucial information from which landowners and developers can base their decisions. Both design guidelines and some expertise and technical assistance will ensure developers understand how they can respond to the flood hazard scenarios.

Secondary Recommendations

Improving citywide LIDAR elevation data, planned for summer '09, will offer a much more detailed picture of coastal flood exposure. To understand site exposures more accurately, however, site-specific

71 Stern and Great Britain Treasury., *Stern Review on the economics of climate change.*, *viii.*

coastal considerations, such as areas that enjoy natural barriers to wave runup, will need to be incorporated. Additionally, analysis of a community's resilience to coastal storms, or adaptive capacity, will help to identify the most vulnerable areas.

To ensure that different needs, information and perspectives feed into any process, and to encourage ease of implementation, stakeholders, including residents, developers, planners, and experts need to spend time at the table together considering the risks, options and tradeoffs.

Though little official interaction has taken place thus far in Boston, there is hope that these conversations will begin in the near future.

As robust and inclusive solutions may take some time to create and implement, planners and policy makers might enact temporary regulations or moratoria on new coastal developments. Such regulations would be enacted with future flexibility in mind while ensuring a minimized addition to the vulnerability of our coasts. At a minimum, proposals for coastal development could be required to incorporate consideration of coastal SLR in the environmental approval process.

The impacts of climate change and SLR will significantly change the relative stability of landscapes that we have come to rely on. However, by anticipating and planning smartly for the new reality of storm events along our coasts, we can ride the wave of change rather than succumbing to its forces.

BIBLIOGRAPHY

"A sinking feeling; Climate change." *The Economist:* 390, no. 8622: 82.

Andersen , Charlotte Brix. "Rising sea levels," March 9, 2009. http://climatecongress.ku.dk/newsroom/rising_sealevels/.

Basco, David. *Coastal Engineering Manual - Part V.*: United States Army Corps of Engineers, August 2008.

Beatley, Timothy. *An Introduction to Coastal Zone Management.* 2nd ed. Washington, DC: Island Press, 2002.

Bornstein, Seth. "Northeast US could suffer most from sea rise: Add 8 inches for the region, new study says." *Boston Globe*, March 16, 2009.

"Boston Redevelopment Authority." http://www.bostonredevelopmentauthority.org/.

Burby, Raymond J, ed. *Cooperating with Nature: Confronting Natural Hazards with Land Use Planning for Sustainable Communities.* Natural hazards and disasters. Washington, D.C: Joseph Henry Press, 1998.

Chapter 298 Of The Acts Of 2008. http://www.mass.gov/legis/laws/seslaw08/sl080298.htm. General Court of the Commonwealth of Massachusetts, 2008.

"Climate Program Office (CPO)." http://www.climate.noaa.gov/index.jsp?pg=./cp_pp/description.html.

Climate: Change: The City of Boston's Climate Action Plan, December 2007.

Coastal Hazards Comission. *Preparing for the Storm: Recommendations for Management of Risk from Coastal Hazards in Massachusetts.* Massachusetts: Massachusetts Coastal Zone Management, May 2007.

Confronting Climate Change in the U.S. Northeast: Massachusetts. Cambridge, MA: Union of Concerned Scientists.

"DeltaSync: Floating Foundation." http://www.deltasync.nl/deltasync/index.php?id=33&tx_ttnews[tt_news]=17&tx_ttnews[backPid]=8&cHash=a3a2ff1903.

Douglas, Ellen, Paul Kirshen, Matthias Ruth, Allen Gontz, and Jack Wiggens. "Coastal Flooding and Environmental Justice: Developing Strategies for Adapting to Climate Change (Proposal/Overview)," 2008.

East Boston Master Plan. The Boston Redevelopment Authority, April 2000.

Faludi, Andreas. *European Spatial Research and Planning.* Cambridge MA: Lincoln Institute of Land Policy, 2008.

Fort Point Associates, Inc. *Boston East Project Notification Form*, October 19, 2007.

Frumhoff, P. C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. *Confronting Climate Change in the US Northeast: Science, Impacts, and Solutions.* Cambridge, MA: Union of Concerned Scientists Publications, 2007.

Graaf, Jan. *Europe, coast wise : an anthology of reflections on architecture and tourism.* Rotterdam: 010 Publishers, 1997.

Intergovernmental Panel on Climate Change. *Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, U.K: Cambridge University Press, 2007.

Kengen, GAL. "Bouyant Bases." *Architecture + Design* XXV, no. 12 (December 2008): 76-80.

Kirshen, Paul, Kelly Knee, and Matthias Ruth. "Climate change and coastal flooding in Metro Boston: impacts and adaptation strategies." *Climatic Change* 90, no. 4 (October 1, 2008): 453-473. http://dx.doi.org/10.1007/s10584-008-9398-9.

Kirshen, Paul, Chris Watson, Ellen Douglas, Allen Gontz, Jawon Lee, and Yong Tian. "Coastal flooding in the Northeastern United States due to climate change." *Mitigation and Adaptation Strategies for Global Change* 13, no. 5 (June 1, 2008): 437-451. http://dx.doi.org/10.1007/s11027-007-9130-5.

Kirshen, Paul, Charles Wilson, Pablo Suarez, Kelly Knee, Matthias Ruth, William Anderson, and T.R. Lakshmanan. "Integrated Impacts of Climate Change-Induced Sea Level Rise in Metro Boston and Adaptation Strategies." In *World Water & Environmental Resources Congress 2003 and Related Symposia.* New York, N.Y: American Society of Civil Engineers, Water Resources Planning and Management Division, 2003.

Kirshen, Paul, Chris Watson, Ellen Douglas, and Allen Gontz. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions: Appendix: NECIA Coastal Impacts Analysis*, 2008.

Mass. Gen. Laws ch. 91. The Massachusetts Public Waterfront Act., 1866.

McHarg, Ian L. *Design with Nature.* New York: J. Wiley, 1992.

Meier, Mark F., Mark B. Dyurgerov, Ursula K. Rick, Shad O'Neel, W. Tad Pfeffer, Robert S. Anderson, Suzanne P. Anderson, and Andrey F. Glazovsky. "Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century." *Science* 317, no. 5841 (August 24, 2007): 1064-1067.

National Coastal Zone Management Program. NOAA's Office of Ocean and Coastal Resource Management, July 2007.

Nickerson, Colin. "Holland goes beyond holding back the tide." *The Boston Globe*, December 5, 2005..

NOAA. "CHL - Types of Coastal Structures." http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=ARTICLES;513.

OAR US EPA, USGS, NOAA, and DOT. "US Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region," January 15, 2009.

O'Brien, Julia. Conversation with the Author. DCR, April 2009

Olthuis, Koen. "Building Floating Constructions." *Architecture + Design* XXV, no. 12 (December 2008): 50-52.

Platt, Rutherford H. *Cities on the Beach: Management Issues of Developed Coastal Barriers.* Chicago, Ill: Dept. of Geography, University of Chicago, 1987.

Rahmstorf, Stefan. "A Semi-Empirical Approach to Projecting Future Sea-Level Rise." *Science* 315, no. 5810 (January 19, 2007): 368-370.

Rubinoff, Pamela, Nathan Vinhateiro, and Christopher Piecuch. *Summary of Coastal Program Initiatives That Address Sea Level Rise as a Result of Global Climate Change.* Rhode Island Sea Grant/Coastal Resources Center, University of Rhode Island, February 2008.

Seasholes, Nancy S. *Gaining Ground: A History of Landmaking in Boston.* Cambridge: MIT Press, 2003.

Shaw, Wes. "StormSmart Coasts: No Adverse Impact and the Legal Framework of Coastal Management." Massachusetts Office of Coastal Zone Management. http://www.mass.gov/czm/stormsmart/other/legal_home.htm.

Stern, N, and Great Britain Treasury. *Stern review on the economics of climate change.* London: HM Treasury, 2006.

The Boston Zoning Code: Article 25 Flood Hazard Districts, 1982.

The Cecil Group. *Amendment to the East Boston Water Front District Municipal Harbor Plan.* Boston Redevelopment Authority, May 2008.

Thieler, Robert, Jeff Williams, and Erika Hammar-Klose. "National Assessment of Coastal Vulnerability To Sea-Level Rise." http://woodshole.er.usgs.gov/project-pages/cvi/.

Vermaat, Jan, L Bouwer, K Turner, and W Salomons, eds. *Managing European Coasts: Past, Present, and Future*. Environmental science. Berlin: Springer, 2005.

Waterman, Roland. "Integrated Coastal Policy via Building with Nature." In *Impact of Sea Level Rise on Cities and Regions*, edited by Roberto Frassetto, 238. Venice: Marsilio Editori, 1991.

Yin, Jianjun, Michael E. Schlesinger, and Ronald J. Stouffer. "Model projections of rapid sea-level rise on the northeast coast of the United States." *Nature Geoscience* advanced online publication (March 15, 2009). http://dx.doi.org/10.1038/ngeo462.