

COASTAL RESILIENCE SOLUTIONS FOR DOWNTOWN BOSTON AND NORTH END

FINAL REPORT

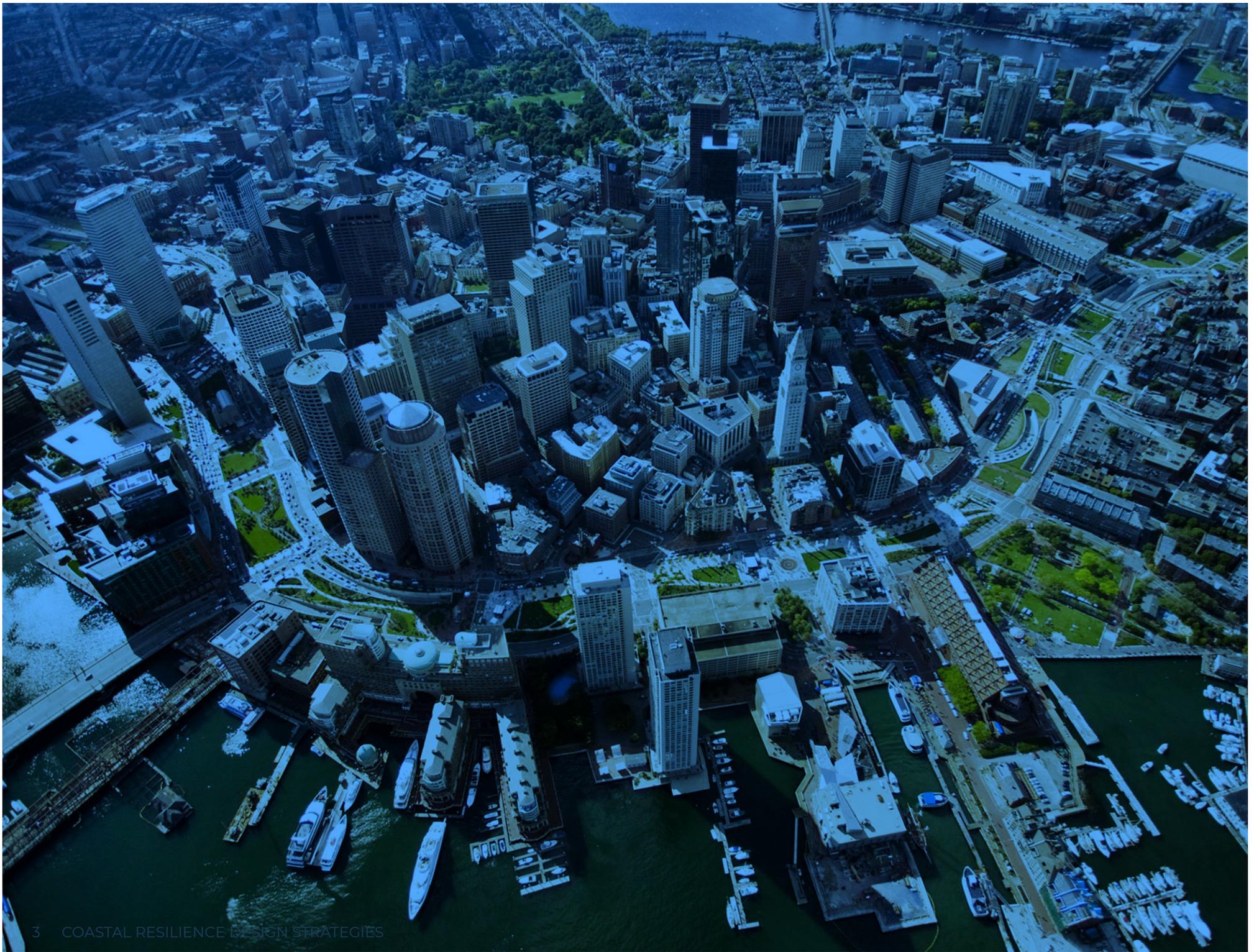
September 2020



Mayor Martin J. Walsh



**Barr
Foundation**



September 2020

Dear Neighbors,

Now, more than ever, we must take action to protect the future of our planet and our communities. The COVID-19 pandemic has emphasized how important it is to listen to scientists, plan for the future, and prioritize equity and sustainability in everything we do. That's certainly true when it comes to our approach to climate change.

We are already feeling the effects of climate change here in Boston--- in the form of historic storms, coastal flooding, and heat waves. That's why we're acting with urgency to implement solutions that will protect our city for generations to come.

In 2016, we released Climate Ready Boston. This report examined vulnerabilities in our neighborhoods and solutions that would protect people throughout our City. After releasing the report, we embarked on a series of neighborhood-specific plans. We have already completed plans for East Boston, Charlestown, and South Boston. These neighborhood plans work hand-in-hand with our

ongoing vision of a coastline built for recreation and resilience, which we call Resilient Boston Harbor.

In Downtown and the North End, we're making significant resiliency improvements at places like Langone and Puopolo Park, Paul Revere Mall, and Christopher Columbus Waterfront Park; we have raised our sustainability standards for all new development; and we are working to ensure that all of our infrastructure, parks, and public spaces are strong and resilient in the face of climate change.

The Climate Ready Downtown and North End plan is informed by community input. During the plan's development, we held open houses and public events where people who live, work, and spend time in the North End and Downtown Boston contributed their ideas. We are grateful to community partners that helped with our outreach efforts. I especially want to thank the North End Waterfront Neighborhood Council, the Wharf District Council, and Commercial Wharf East for their continued partnership.

Our waterfront is one of our most precious natural resources, and we want to make sure that everyone has access to it. This plan will help us make our waterfront and Harborwalk more accessible and welcoming to everyone.

Preparing for the effects of climate change is one of the most important challenges we will ever undertake as a city. We have a lot of work to do, but we're up to the task, and we've come a long way already. We will continue to work with the community as we implement solutions for our shared harbor, Downtown, and North End areas.

Sincerely,



Martin J. Walsh

Mayor of Boston



King tides regularly overtop the seawall at Long Wharf. Over time, increasing sea levels will make these temporary inundations more frequent.

Image courtesy of Boston Harbor Now

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Attendees at the second Open House, held July 2019 at the BSA Space, provided feedback on the design options. This feedback helped to inform the final plan.

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ACKNOWLEDGEMENTS

The City of Boston wishes to acknowledge the many partners and community stakeholders who supported this project. Without their participation, this project would not have been possible.

A Steering Committee composed of the following partners oversaw the project:

- » Boston Environment Department
- » Boston Planning and Development Agency
- » Boston Parks and Recreation Department
- » Boston Public Works Department
- » Boston Transportation Department
- » Mayor's Office of Neighborhood Services
- » Mayor's Office of Resilience and Racial Equity
- » Boston Water and Sewer Commission

The following State of Massachusetts Agencies support this project:

- » Massachusetts Office of Coastal Zone Management
- » Massachusetts Department of Conservation & Recreation
- » Massachusetts Department of Transportation
- » Massachusetts Port Authority
- » Massachusetts Bay Transit Authority

These organizations helped us engage with their stakeholder communities:

- » Green Ribbon Commission
- » A Better City
- » Boston Harbor NOW
- » The Greenway Conservancy
- » Friends of Christopher Columbus Park

- » Wharf District Council
- » North End Waterfront Neighborhood Council
- » Orient Heights Neighborhood Association

The City of Boston would like to thank the Barr Foundation for its generous support.



01 INTRODUCTION



INTRODUCTION

Coastal Resilience Solutions for Downtown and North End presents a set of district-scale strategies to protect these vital neighborhoods from coastal flooding and sea-level rise. The strategies were developed through a multi-stakeholder planning process. This plan builds off of Mayor Martin J. Walsh's Resilient Boston Harbor, a comprehensive and transformative vision that lays out strategies along Boston's 47-mile shoreline to increase access and open space along the waterfront while better protecting the City.

This report summarizes the project methodology, design concepts, and next steps. It also highlights the importance of coordination between public, private, state and local stakeholders for the implementation of near- to long-term flood management strategies. It establishes a roadmap for near-to long-term continued planning and action. Near-term projects can set an example for future partnerships and address policy challenges. They will drive and support the Mayor's Resilient Harbor Vision and build knowledge that will carry forward to long-term implementation. The strategies presented in this report will improve waterfront access for all Bostonians and visitors, provide increased district-scale flood protection, and promote effective use of

resources. While this plan presents four strategies for coastal resilience, all paths forward will require close and ongoing collaboration between the neighborhood's public and private stakeholders.

Protecting the Downtown and North End neighborhoods from coastal flooding risks comes with significant challenges and with meaningful opportunities. Historically, the project area has undergone substantial infrastructure redesign and public realm improvements. This plan is an opportunity for the City of Boston, along with property owners, businesses, philanthropy, and residents, to take on the next transformation of the district through the implementation of coastal resilience infrastructure that creates significant public realm benefits.

INITIAL FINDINGS

Boston's North End and Downtown are highly complex areas, with conditions that are distinct from previous districts studied as part of Climate Ready Boston. The project area is a dense urban waterfront, and historical center, with intensive daily use year

round. The Downtown area is a regional business center and the main marine transit hub for the Boston metro area. Findings include:

- » Some of the wharves and surrounding areas are flooding today at high tide and during some Nor'easter storms. Present-day flood risks will be exacerbated by climate change, and future flooding will follow the pathways shown on the flood risk map on page 36.
- » The wharves are mostly privately owned, with a diverse ownership and lot structure. Most of the bulkheads and seawalls are privately owned and maintained, which makes it difficult to inspect and obtain detailed data on their conditions. Some property owners have already begun risk assessments and provided materials to aid in this study.
- » The state of the bulkheads impacts soil stability at the wharves and inland. Multiple properties are considering improvements to stabilize the soil, bulkheads, and some of the deteriorating pier structures. Many of these properties have allocated funds and started exploring repair and flood protection opportunities, but they are aware of the limits of individual building protections and are interested in an integrated vision.

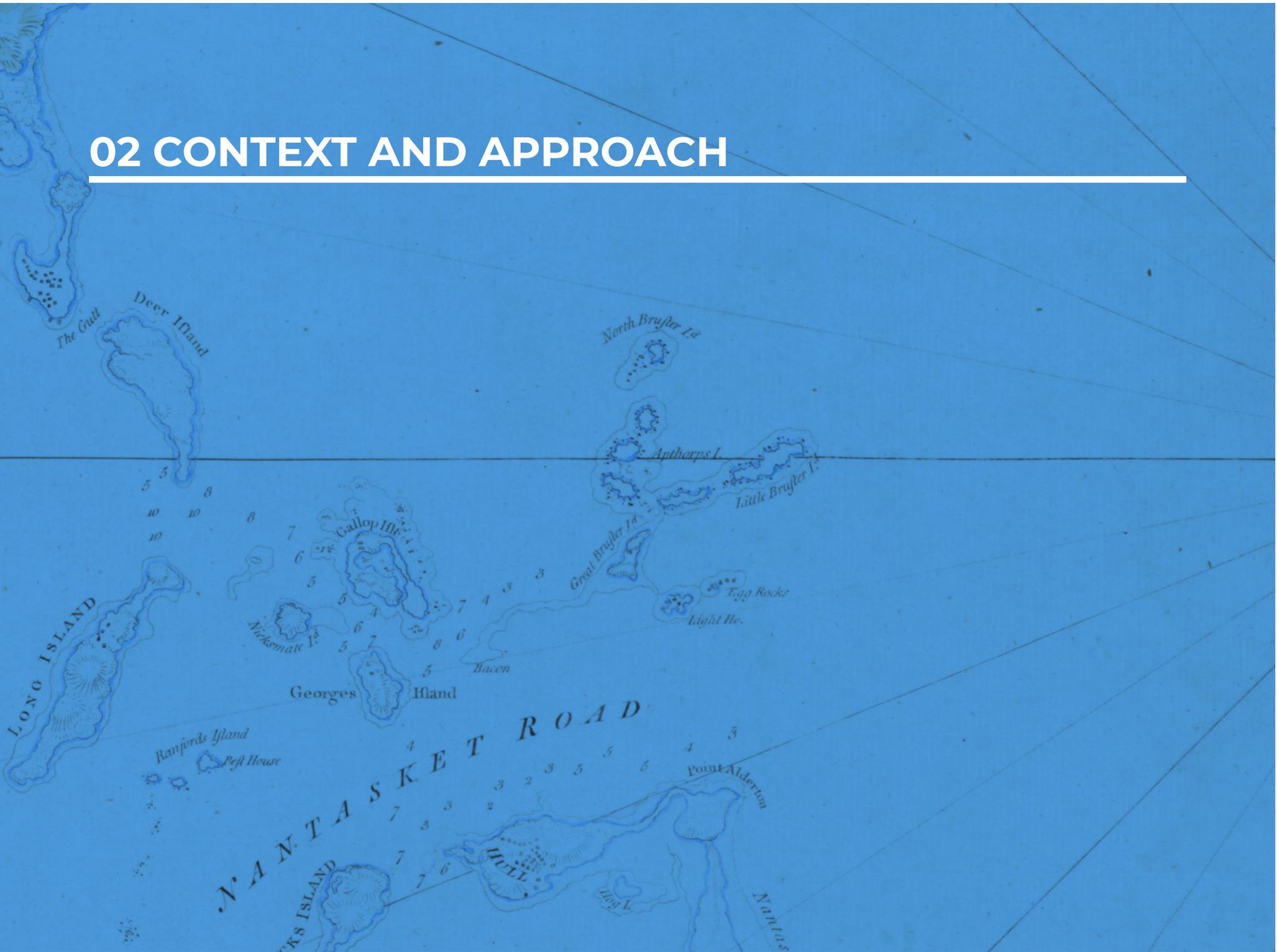
- » Access to the water for public and private marine transportation purposes is very important to the economy and character of this district. Resilience measures will need to incorporate district-wide marine transportation planning that is integrated with transportation planning for the rest of the City.
- » Building a flood protection system in the public right-of-way, without protecting privately owned wharves, brings great challenges in relation to the underground infrastructure, and would require residents and property owners to pursue their own solutions.
- » Stakeholders expressed a willingness to collaborate with the City in order to implement a comprehensive flood protection system because they understand that multiple independent construction projects across the waterfront would be less effective in the long run and lead to a fractured urban space experience.
- » One unique attribute of the Downtown and North End district is the Magenta Zone, an area in harbor waters defined as 'non-navigable' by an Act of Congress 90-312. This limits the need to comply with United States Army Corps Of Engineers (USACE) requirements for in-water

construction. This provides an opportunity to discuss extension of land beyond the current coastline to provide flood protection and open space and minimize engineering complexities. However, any in-water construction of new land or infrastructure will require a wide range of State and City permits.





02 CONTEXT AND APPROACH



CONTEXT AND APPROACH

CONTEXT

Climate Ready Boston is the City of Boston's initiative to prepare for the impacts of climate change. The 2016 *Climate Ready Boston* report assessed Boston's climate vulnerabilities, including increased precipitation, sea level rise, and extreme heat, and identified initiatives to build resilience across neighborhoods, infrastructure, and buildings. The report set the foundation for the City's ongoing climate adaptation activities and included:

- » Updated projections of climate change in Boston;
- » More detailed vulnerability assessment of the city and specific focus areas; and
- » Principles, strategies, and initiatives to achieve the City's climate preparedness goals.

Additionally, with the goal of carbon neutrality by the year 2050, the City is taking bold action to address climate change through the reduction of greenhouse gas emissions that cause climate change. Boston's *Climate Action Plan*, updated most recently in 2019, outlines the City's GHG reduction strategies.

Climate Ready Boston is an integral part of citywide planning efforts, including *Imagine Boston 2030*, Boston's first city-wide comprehensive plan in 50 years. *Imagine Boston 2030* provides an overall direction for the City's long-term planning and development, bringing together plans for housing, education, transportation, racial equity, climate preparedness, and more. One of its four overarching goals is to "promote a healthy environment and adapt to climate change." *Imagine Boston 2030* also focuses on the City's efforts on creating a waterfront for future generations. Well-planned redevelopment of Boston's waterfront could help protect the city from sea level rise and coastal storms while supporting other goals related to open space, mobility, affordable housing, economic growth, and natural resources.

One of *Climate Ready Boston's* priority recommendations was to develop district-scale coastal flood protection strategies for vulnerable neighborhood areas. *Climate Ready Boston* identified the need for the City to "prioritize and study the feasibility of district-scale flood protection" for the Downtown and North End and six other focus areas (Initiative 5.3), and "develop local climate resilience plans in vulnerable areas to support district-scale climate adaptation" (Initiative 4.1). *Coastal Resilience*

Solutions for Downtown and the North End is the third neighborhood coastal resilience plan that the City has developed to protect coastal neighborhoods from flooding.

Coastal Resilience Solutions for Downtown and North End reflects the principles and goals of *The Resilient Boston Harbor Vision* (2018), Mayor Walsh's plan for protecting coastal communities through accessible open spaces. This plan builds on that vision, focusing on critical steps to implement the planning and design ideas represented.

The City's relationship to water is one of Boston's defining characteristics. Providing flood protection is critically important in maintaining and strengthening this important connection to the waterfront.

Downtown and the North End are home to vulnerable critical infrastructure, important public waterfront access, valuable land assets, and historic wharves that still function as transit hubs and maritime centers.

As this study is being finalized, the fourth district plan, *Coastal Resilience Solutions for Dorchester*, is also being finalized. In late 2020, the City will return to East Boston and Charlestown to complete coastal resilience plans for these neighborhoods. With the



Aerial view of Boston's waterfront.

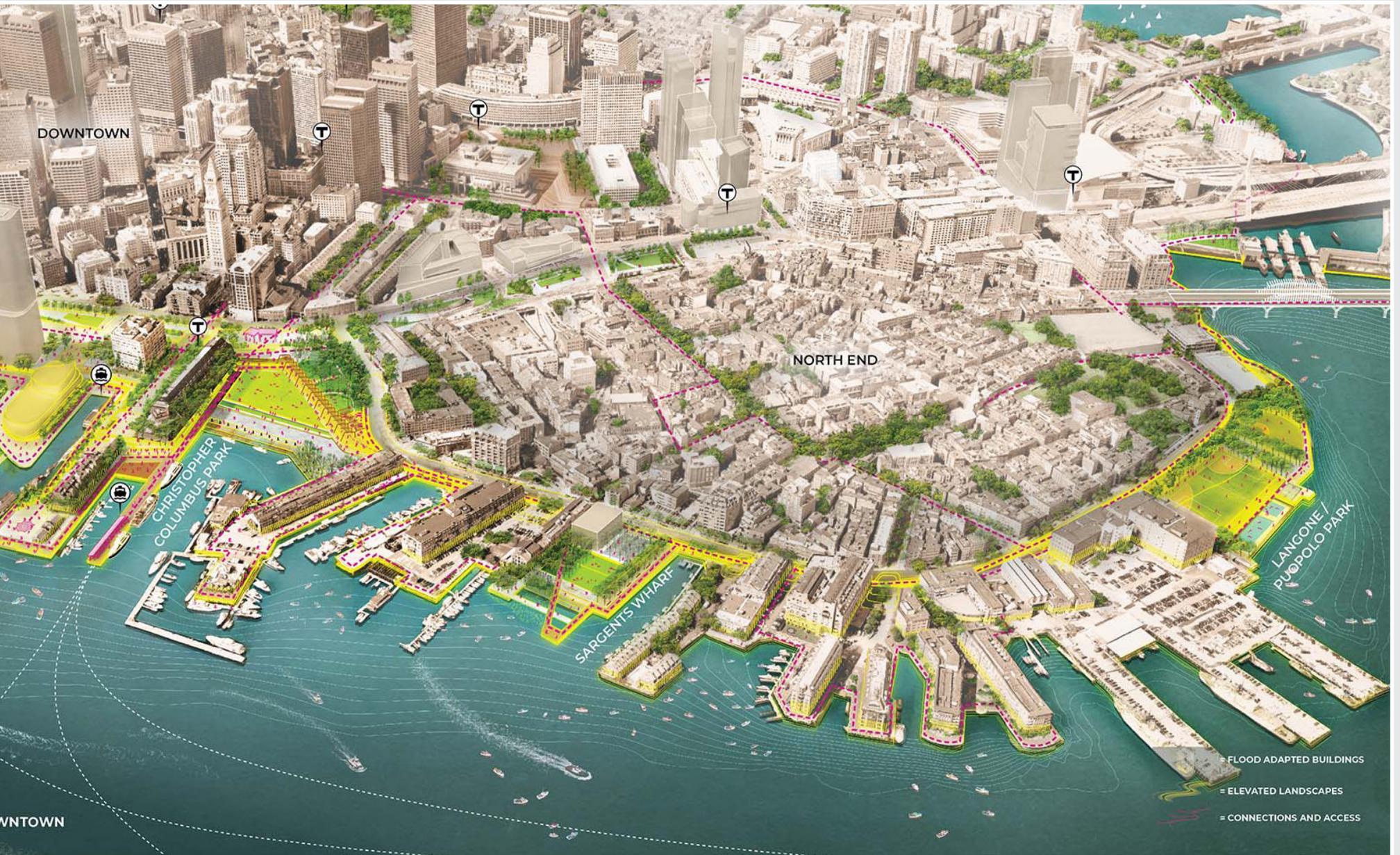
completion of these district plans, the City will have a comprehensive look at risks, options for resilient solutions, and timelines for implementation along Boston's coastal waterfront. These district plans are already being used to build a city-wide set of priorities and processes for future implementation.

The City is also working to address vulnerabilities from increased precipitation and extreme heat. The Boston Water and Sewer Commission (BWSC) is carrying out city-wide flood modeling using extreme rainfall scenarios that are becoming more likely and assessing the effectiveness of green and gray stormwater infrastructure improvements to mitigate flooding impacts. The Boston Public Health Commission (BPHC) has been working to keep residents, particularly our most vulnerable, safe and healthy in hot weather. While these other climate hazards were a factor during the *Coastal Resilience Solutions* planning process, this project focuses first and foremost on how to adapt to the impacts of sea level rise and storm surge.

Resilient Boston Harbor Vision

In 2018, Mayor Marin J. Walsh presented his Resilient Boston Harbor Vision which illustrates a continuous system of protection for Boston's 47-mile shoreline. When implemented, it will increase access and open space along the water's edge while also protecting the City from sea level rise and coastal flooding from future storms. The vision is a commitment to invest in Boston's waterfront to protect the City's residents, homes, jobs, and infrastructure. These images reflect the neighborhood planning efforts underway and help to guide the priorities and reinforce the need for collective action.





HISTORIC CONTEXT

Through well-coordinated collaboration, implementing coastal resilience can lead to a more vibrant, ecologically and economically sound and connected waterfront. Downtown Boston and the North End are no strangers to this type of change. The study area has been at the center of multiple major projects through time, each of which has left its mark.



View of waterfront in the snow, from Custom House Tower c. 1930 (upper). Bird's eye view of T-wharf and East Boston from the top of the new Custom House Tower c. 1915 (bottom) from the Leslie Jones Collection at the BPL.

Bird's eye view toward East Boston from Custom House Tower c. 1930 (upper). Long and Central Wharves, c. 1915 (bottom) from the Leslie Jones Collection at the BPL.



Aerial view of Downtown Boston and the North End in 1930
by Fairchild Aerial Surveys Inc. N.Y.C. 1930.
Source: digitalcommonwealth.com

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FAIRCHILD AERIAL SURVEYS INC. N.Y.C.



Early Waterfront

Historic maps of Boston Harbor dating back to 1630 show a series of lightly connected peninsulas surrounded by low-lying marshlands and mudflats. As populations grew and commerce expanded, Boston's waterfront developed, building out over time to a series of wharves and piers that allowed for coastal access, further growth, and development. The historic shoreline (seen on page 30) is reflected in today's coastal risk maps. Water and occasional flooding has always been a part of life on Boston's waterfront. What was once water is inclined to once again be wet.



Flooded T-wharf image - "Downtown and North End wharves and piers" by Leslie Jones, 1930.



Between the City and the Waterfront

The relationship between the waterfront and the rest of the City has long been a challenging one, with the need for transportation throughout the region conflicting with access and connectivity between the water and the upland and inland areas. A trolley along Commercial Street and Atlantic Avenue, and later the raised highway cut Downtown off from its waterfront for many years.



View Harbor Towers and Central Artery traffic, Downtown Boston by Grant, Spencer 1971 and 1978 (above) and Rail on what is today Atlantic Ave. 1930, Leslie Jones (left).



Christopher Columbus Park Harborwalk (Upper).
Lewis Wharf open space and Harborwalk (bottom
image) by Dalia Munenzon. Aerial view of the Rose
Kennedy Greenway from Wikimedia Commons by
HelloGreenway (right).

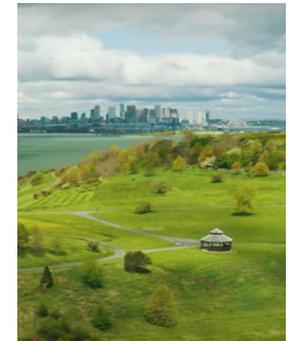
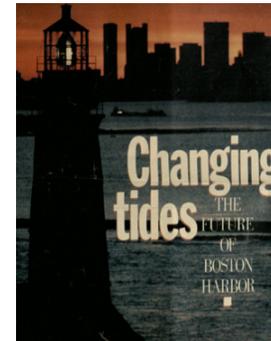
Leading with Landscape

First with the creation of the Emerald Necklace and then with the placement of the Central Artery below ground during the Big Dig and the creation of the Rose Kennedy Greenway, Boston has been an innovator in public realm enhancements tied to infrastructure projects. The Greenway, and the recently completed bike path connecting it to the North End and Langone and Puopolo Parks, act as the backbone for a resilient Downtown and North End. Langone and Puopolo parks, as part of Connect Historic Boston, have recently undergone improvements to fields and park conditions that build in protection against future coastal storms and sea level rise. Connecting new elevated public realm assets along the water back to the Greenway will generate a vibrant, active waterfront for all now and into the future.



Boston Harbor Cleanup

In 1985, Boston began a federally mandated clean-up of what was at the time, its infamously dirty harbor. That prompted a \$3.8 billion investment in facilities at Deer Island which allowed for more efficient treatment of waste. Additional efforts to improve sewer lines and reduce combined sewer overflows were conducted by the Massachusetts Water Resources Authority. These efforts protect beaches, shell fishing beds and other waters from overflows due to heavy rains. Fishing and swimming are now safe activities to enjoy in the harbor. The Environmental Protection Agency now calls the Boston Harbor a “great American jewel”. Wildlife such as Harbor seals, porpoises, and whales are regularly seen and the Harbor Islands are a popular tourist destination. Boats leaving for the islands depart from Long Wharf, at the center of this study area, and increasingly draw more and more people to the coast.



Article from the Boston Globe Year 1985, from Boston Harbor Now (BHN) (upper left), Once a City dump, a reclaimed and vegetated Spectacle Island, with Boston in the distance (upper right), Standup paddling in the clean Boston Harbor (bottom image), Deer Island (left).

METHODOLOGY

The planning process began with a review of existing and projected site conditions, including current and future flood risk and flood pathways assessments. A study of constraints and potential impacted systems such as soil stability, subsurface conditions, and utilities followed. Based on these initial findings, the design exploration phase identified concept alternatives for flood barrier strategies and produced high-level cost estimates for each. This phase studied multiple strategies and flood barrier typologies to determine the most effective and feasible options.

City and State agencies, infrastructure operators, property owners, philanthropy, business, climate groups, and community organizations met in a series of focus groups at each stage of project development to discuss findings. Two open houses engaged a broader range of Downtown and North End stakeholders to articulate planning priorities and evaluate and refine the concepts.

The proposed concepts explored local issues such as resident safety and access during extreme events, current coordination challenges such as timing for design and implementation of efforts between

adjacent property owners, as well as larger-scale challenges such as regional transportation access. The result was a set of design options that integrate ongoing and planned work and co-benefits with flood protection infrastructure.

These options became the basis for a second round of discussions with the stakeholders and the development of an implementation strategy that included project prioritization, phasing, and a benefit-cost analysis.

APPROACH

The goal of this report is to develop a neighborhood wide plan for coastal resilience. The project area extends from the Northern Avenue Bridge up to, but not including, the New Charles River Dam. This neighborhood plan connects with other studies and efforts by City and State agencies that, collectively, will create a city-wide system of waterfront climate protection. The measures presented in this report advance the ideas laid out in the Mayor's Resilient Boston Harbor Vision, provide specific strategies, options, and timelines for implementation and work in conjunction with actions already underway by property owners and City and State agencies in this district.

Because the project area has a diverse range of property owners, dense development, large infrastructure projects, and unique block-by-block characteristics, the Downtown and North End was divided into 3 sub-districts. These divisions were based on flood pathways and ownership conditions which impact the vulnerability and implementation timeline of each sub-district. The sub-districts are:

- » Downtown and Wharf District: Christopher Columbus Park to Northern Avenue Bridge
- » North End Waterfront: Battery Wharf to Commercial Wharf
- » West End-North End: the south embankment of the New Charles River Dam to the US Coast Guard Station.

These three sub-districts are tied together by Boston's Harborwalk, a cherished public amenity, and a recently-added bike lane along Atlantic Avenue, Commercial Street, and Causeway Street (the Connect Historic Boston Bike Trail). The Harborwalk, made mandatory by the Massachusetts Public Waterfront Act, Chapter 91, and further enhanced by the Boston Zoning Code, ensures that the waterfront remains accessible to Boston's communities.

Resiliency measures must promote continuity and, where feasible, enhancement of the Harborwalk as an important public amenity.

The planning process involved a detailed review of existing conditions, stakeholder engagement efforts, and development of design strategies and options for the protection of the neighborhood. Technical reviews were carried out early in the project to understand coastal flooding risks, subgrade conditions, and specific infrastructural challenges to the implementation of resilient solutions. The Climate Ready Boston vulnerability assessment, latest flood models, development plans, and other key conditions on the ground were analyzed to identify critical locations where practical measures could reduce district-scale coastal flood risks. Possible solutions included in-road and waterfront options, each of which was tested for feasibility, effectiveness, impact on the quality of the public realm, potential environmental impacts, potential challenges to implementation (such as complex ownership or infrastructural coordination required), and estimated costs. The resulting near- and long-term actions and roadmaps for implementation were further defined through community engagement and additional analysis.

In accordance with Climate Ready Boston Initiative 5.2, “Determine a consistent evaluation framework for flood defense prioritization”, The Downtown and North End plan used a similar set of evaluation criteria developed for East Boston, Charlestown, and South Boston. These criteria were adopted by and adapted through the Coastal Resilience Solutions for South Boston plan. These studies were used as a guide for this plan, focusing efforts towards feasible, effective, equitable, and adaptable solutions that achieve multiple benefits over long time horizons.

As with previous planning initiatives, residents were asked to provide input on the evaluation criteria and inform the project team as to which categories were most important to them. Participants expressed a clear preference for effectiveness, adaptability, feasibility, and consideration of environmental impact. This input helped to guide the recommendations outlined in this report.

An implementation roadmap was produced to guide future planning, design, and partnership efforts in each of these sub-districts. The roadmaps include high-level cost estimates, phasing plans, and a benefit-cost analysis. Flood risk timelines informed the prioritization of projects in the implementation roadmap.

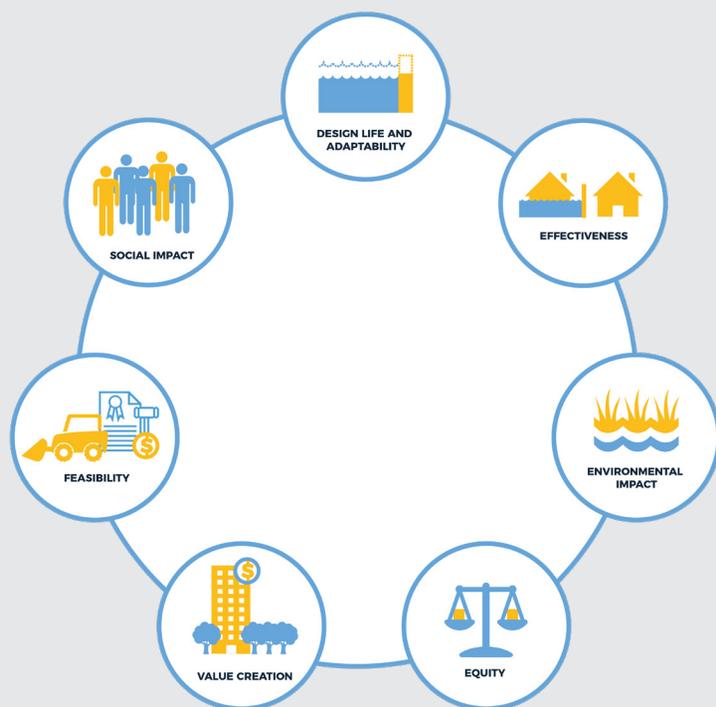
Stakeholder engagement activities included:

- » *Over 20 interviews and follow-up meetings with a broad set of State and regional agencies, City departments, and non-profit organizations were conducted to understand their interests, identify potential strategies and partnerships, and inform recommendations.*
- » *On-site meetings with property owners and interest groups to discuss and envision risks and potential solutions.*
- » *Two community open houses to discuss flood risks with residents, engage them in the decision-making process, and share resources on preparedness actions they can take.*
- » *Presentations to neighborhood residents, community civic associations, interest groups, and local media to build awareness, answer questions, and gather input.*
- » *Coordination with other planning processes including PLAN Downtown, the 2018 Downtown Municipal Harbor Plan, proposed projects within the study area, and previous Climate Ready district studies.*



The first Open House took place in March 2019 at the Pilot House. Community members shared input and concerns regarding projected climate impacts and past storm events.

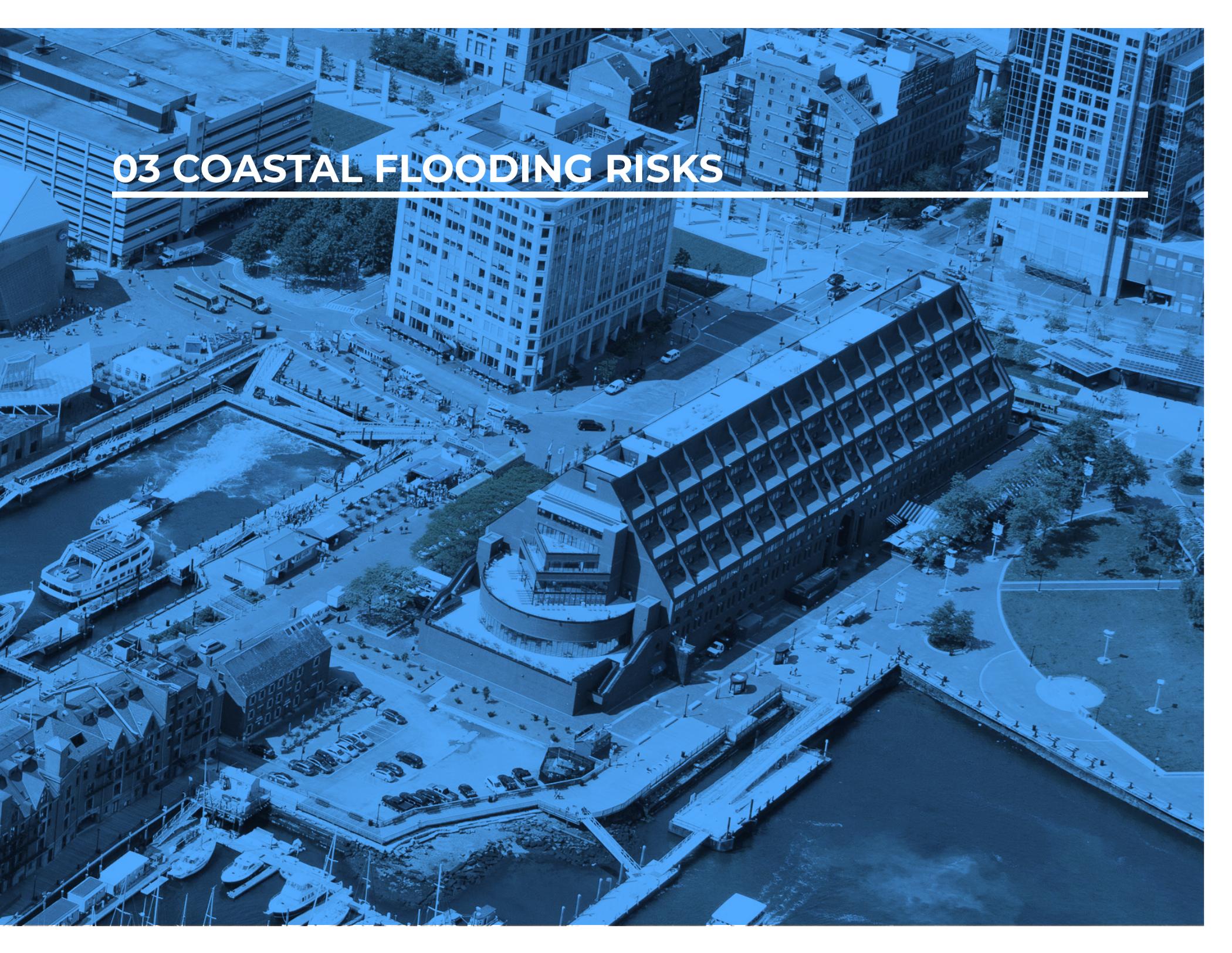
Evaluation Criteria established to help guide and rank proposed climate resilience strategies



CATEGORY	CRITERIA
EFFECTIVENESS	<ul style="list-style-type: none"> Maximum level of protection (% annual chance or sea level rise scenario) Reduction in flood extent Avoided damage and loss Residents protected Critical assets protected
FEASIBILITY	<ul style="list-style-type: none"> Stakeholder acceptance Constructability Permitting Affordability: Cost of Construction + Cost of Maintenance Replicability
DESIGN LIFE + ADAPTABILITY	<ul style="list-style-type: none"> Design Life Performance Horizon Adaptability or Flexibility Phase-ability and Time to Implementation Maintenance Requirements
SOCIAL IMPACT	<ul style="list-style-type: none"> Recreational Cultural Aesthetic
EQUITY	<ul style="list-style-type: none"> New and Equitable Access to Waterfront Additional Benefits for Vulnerable Populations Community Partnerships Protection of Affordable Housing over the Long Term
VALUE CREATION	<ul style="list-style-type: none"> New Value Created on Sites or Adjacent Sites Capacity to Catalyze Future Funding and Investment
ENVIRONMENTAL IMPACT	<ul style="list-style-type: none"> Water and Air Quality Habitat Value Human Health Benefits Mitigation of Other Climate Hazards (Heat, Stormwater)



03 COASTAL FLOODING RISKS



COASTAL FLOODING RISKS

ASSESSING VULNERABILITIES

When Boston was founded in the 1600s, the geographic area we know today as the Downtown and the North End waterfront was mostly tidal marshland. The coastal landmass was expanded in the late 1800s (see historic map on page 34) as Boston became a commercial and industrial center and the population grew. Today, Downtown still functions as an active commercial waterfront, but with a stronger residential and touristic character. The waterfront's current vitality can be traced back to the success of large-scale public and private investments. The Boston Harbor cleanup made the waterfront appealing for a variety of uses, and the "Big Dig" and Rose Kennedy Greenway projects created new and attractive connections to the waterfront.

Boston's relationship to water, that has drawn successive generations of Bostonians to the area, also comes with growing vulnerabilities. Due to sea level rise and the increased severity of coastal storms caused by climate change, the low-lying coast along Downtown and the North End is increasingly vulnerable to flooding. Although the landmass of

these two neighborhoods was originally constructed above the historic high tide, sea level rise is driving the need for additional elevation. Boston's sea levels could rise approximately 40 inches by the 2070s. High resolution data from the Boston Harbor Flood Risk Model shows the location of flood pathways and how they would impact properties and streets.

After identifying the location and scope of the neighborhood's flood pathways, the findings were used to develop near and long-term strategies to protect surrounding waterfront areas. Although Downtown and the North End have a smaller total amount of land at risk from coastal and riverine flooding than the neighborhoods previously studied, the areas at risk are densely populated and developed; floods will create substantial risks to human safety, structural damage, and economic impact. Without new district-scale coastal protection strategies to complement building- and parcel-scale strategies, the diverse populations, buildings, and critical infrastructure of these historic neighborhoods will remain at risk.

SEA LEVEL RISE SCENARIOS

Climate Ready Boston uses three sea level rise scenarios (9, 21, and 36 inches). The actual sea level rise Boston experiences will be driven by many factors, primarily global greenhouse gas emissions. Climate Ready Boston projections indicate that Boston's sea levels are likely to rise (from 2013 levels) by 9 inches as early as 2030 if emissions continue at their current pace, 21 inches as soon as 2050, and 36 inches as soon as 2070.

The Boston Planning and Development Agency (BPDA) now requires developers to evaluate and address the vulnerability of new projects to 40 inches of sea level rise through its "Climate Change Resilience and Preparedness Checklist" and "Coastal Flood Resilience Design Guidelines" which are applied to proposed projects that are subject to Article 80B of the Zoning Code. This level is equivalent to the Climate Ready Boston 36-inch level with land subsidence taken into consideration. See Climate Ready Boston for more details on sea level rise probabilities. This report refers to the long-term scenario as "40 inches" of sea level rise.



Boston Harbor Massachusetts 1781 Map - Revolutionary War Survey by British Navy - Des Barres from the Leventhal map collection BPL

POPULATION AT RISK

Five percent of Bostonians (approximately 30,000 people) live in the Downtown and North End neighborhoods.*

- » 2,100 people live in areas that have a 10 percent annual chance of a flood event with 9 inches of sea level rise (2030s).
- » 3,170 people live in areas expected to be flooded by a 1 percent annual chance of a flood event with 9 inches of sea level rise (2030s).
- » Nearly one third of the current population (~10,000) will be exposed to high magnitude flooding (0.1% annual chance or 1,000 year event) with 40 inches of sea level rise (2070s).

According to research completed for Climate Ready Boston, compared to the City average, Downtown generally has lower percentages of vulnerable populations than other neighborhoods, with the exception of older adults and people with medical illness. Downtown has a significantly lower percentage of children when compared to the City average. This urban area also has a relatively high percentage of renters and people without a vehicle. Residents rely on public transportation

and utility systems that are vulnerable to flood risk. The most vulnerable population in the North End and Downtown are the older adults and renters. In the event of a major flood, it is likely that these individuals would be displaced or affected by service disruptions. Transportation systems that are critical for evacuation, emergency response, and disaster recovery are vulnerable to flooding. The Nazzaro Community Center, the North End's emergency shelter, is centrally-located on high-ground. The City works closely with the City of Boston Office of Emergency Management (OEM) to ensure that long-term planning and emergency management activities are coordinated.

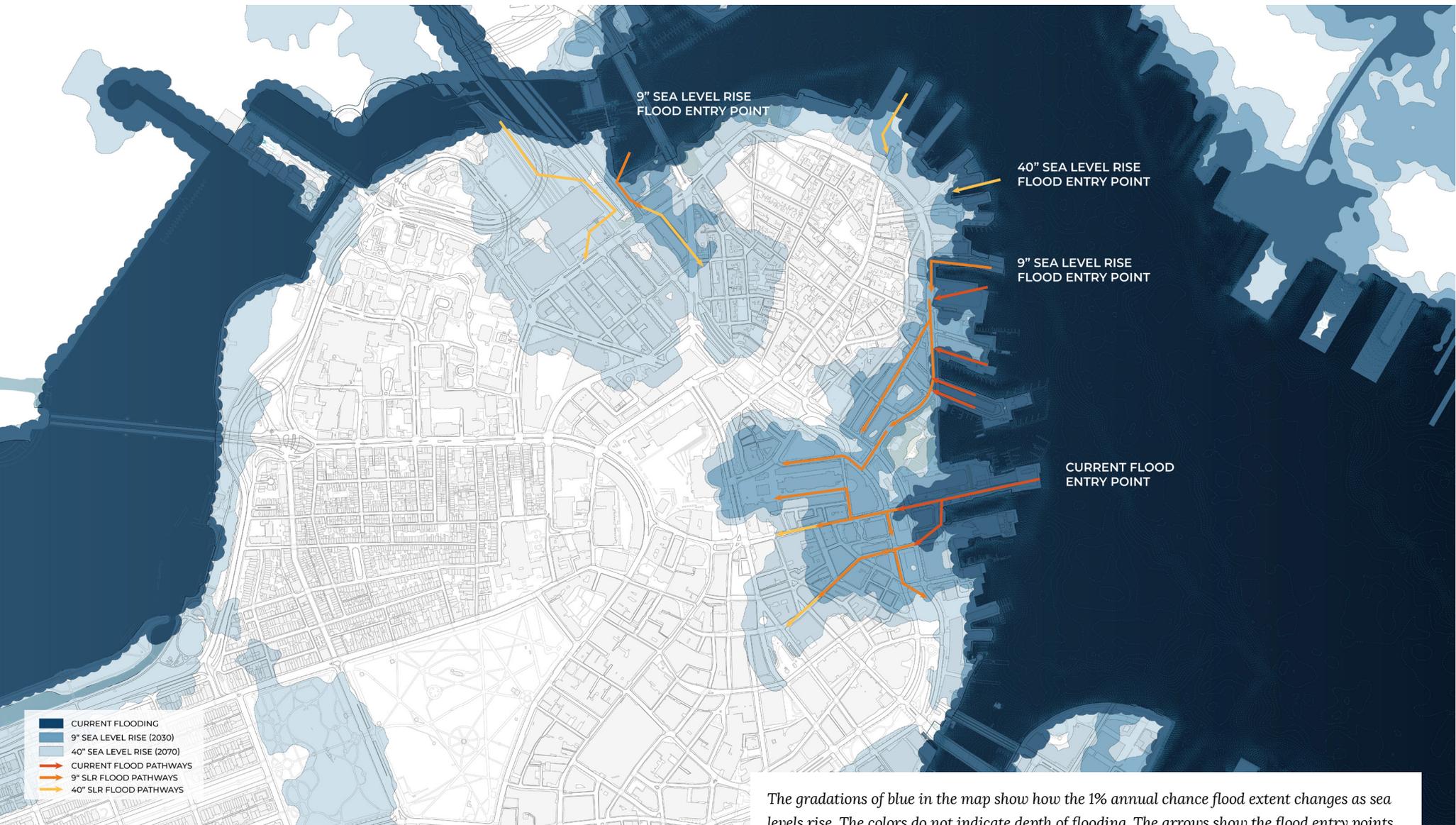
Approximately 50,000 people work within the 1 percent floodplain with 40 inches of sea level rise (2070s). If a major flood or storm event caused building damages or service disruptions, workers and businesses would experience economic and job loss. While some business losses and physical repairs may be covered by insurance, hourly workers, for instance, do not have a means of recovering lost income. Impacts to transportation services post-flood would also be economically detrimental to workers.

PERCENT ANNUAL CHANCE FLOOD

A “1 percent annual chance flood” has a 1 in 100 chance of being equaled or exceeded in any given year and is the primary coastal flood hazard delineated in FEMA flood maps. Though the chance of occurrence each year may seem relatively low, a 1 percent annual chance event could occur multiple times in a given year, decade, or century. These events have close to a one in three chance of occurring at least once during a 30-year period. Climate Ready Boston uses a 1 percent annual chance flood nomenclature rather than the “100-year” flood, in order to limit confusion related to the possible time horizon of an event occurring. The “100-year flood event” terminology is sometimes misinterpreted to imply that 100-year events will occur only once every 100 years, which is incorrect.

A “0.1 percent annual chance flood” has a 1 in 1,000 chance of occurring in any given year. It is also referred to as the “1,000-year flood.” It is 10 times less likely to occur than a 1 percent annual chance flood.

* based on 2015 population data



The gradations of blue in the map show how the 1% annual chance flood extent changes as sea levels rise. The colors do not indicate depth of flooding. The arrows show the flood entry points and pathways with current sea levels, 9 inches of sea level rise, and 40 inches of sea level rise.

INFRASTRUCTURE

Many of Boston's transportation connections are located in the Downtown area. The Central Artery Tunnel and Zakim Bridge that connect Downtown to Charlestown and the Route 1A tunnels between Downtown and East Boston are important for economic activity, evacuation, and emergency response capabilities. These are also at risk due to increased coastal flooding.

Cross-waterway connections between Charlestown, East Boston, South Boston, and Downtown may suffer from increased coastal flooding impacts and experience disruption to service between these neighborhoods, creating temporary 'island' effects.

The Massachusetts Bay Transportation Authority (MBTA) has several subway lines and associated stations located in Downtown and the North End that connect Downtown to East Boston and Charlestown. The Blue Line Aquarium Station has already experienced multi-million-dollar damages from coastal flooding and would be exposed to a 10 percent annual chance of flooding with 21 inches of SLR (2030s).

The Massachusetts Department Of Transportation (MassDOT) and the MBTA are pursuing projects to mitigate near-term coastal flooding risks to underground highway and transit infrastructure. For example, the agencies are designing flood barriers that will be deployed around Aquarium Station's vulnerable entrances and tunnel emergency exits in advance of future floods. Some of these barriers will be located on City-owned sidewalks.

HISTORIC AND CULTURAL ASSETS

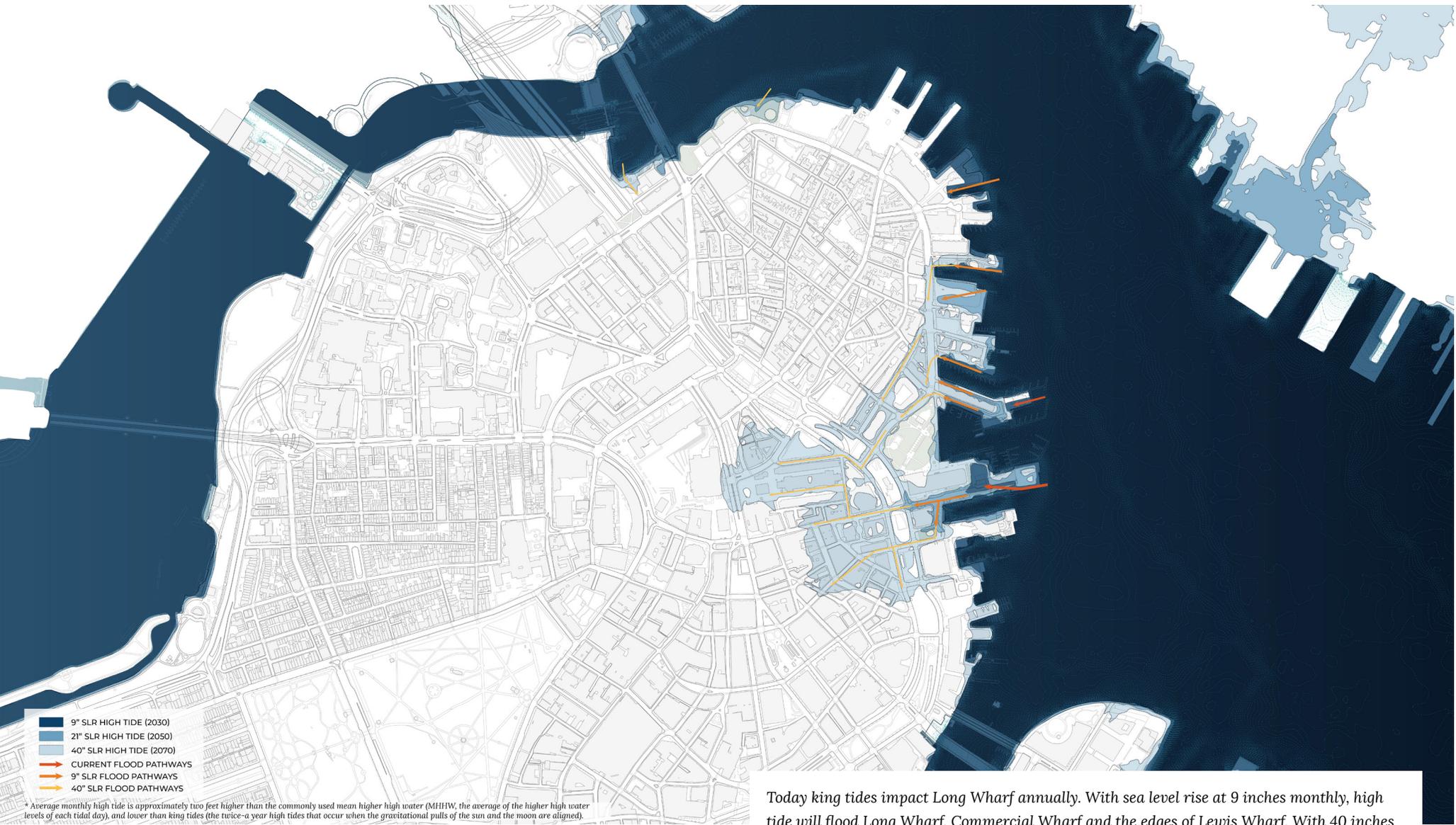
Many cherished historic assets exist today in these two vibrant neighborhoods. These include hundreds of historic buildings, many designated as City of Boston local landmarks, such as Faneuil Hall and Quincy Market, and the Blackstone Block, or listed on the National Register, including the Fulton-Commercial historic district and Long Wharf, among many others. Boston's Downtown Waterfront includes the culturally significant New England Aquarium and water transportation hubs, including the ferry gateway to the Boston Harbor Islands National Park Area. The Freedom Trail also passes through the North End and Bulfinch Triangle on its path to historic sites in Charlestown.

Not only are these assets critical to sustaining Boston's character and history, they also attract millions of tourists to Boston each year. Faneuil Hall consistently ranks among the most visited tourist attractions and landmarks in the United States. Resiliency to sea level rise impacts is fundamental to the preservation of the area's historic resources. Without adequate flood protection, they are at risk of significant damage.

FLOOD LOSS

Based on Climate Ready Boston, expected annualized losses for Downtown make up about one-third of all those expected citywide in the near-term (with 9 inches of sea level rise) and over 20 percent of all expected citywide losses toward the end of the century (40 inches of sea level rise). Based on the existing building stock, direct physical damages to over 850 buildings, displacement costs to residents, and human stress related impacts could come close to \$2 billion for a major storm event toward the end of the century.*

** Note that the area behind the Charles River Dam was removed from this planning process, but included in Climate Ready Boston report statistics.*



SUB-DISTRICT FLOOD PATHWAYS

The Downtown and North End neighborhood project area includes three sub-districts that can be defined by flood pathways. Addressing these flood pathways would help protect people, assets, and the economy, not just locally but for the region. Coastal Resilience Solutions for Downtown and North End provides flood protection strategies that would not only benefit these unique neighborhoods but would also help mitigate regional impacts.

Downtown Waterfront

The first and most significant flood pathway in the project area is at Long Wharf. During 1 percent annual chance storm events today and with increased sea levels, water will overtop the deck of Long Wharf and flow down State Street and Central Street onto Atlantic Avenue before progressing further inland. While the annual chance of a flood reaching Atlantic Avenue is only 1 percent at present, it increases to 10 percent with 9 inches of sea level rise (2030s). With 21 inches of sea level rise, anticipated roughly 2050s, Atlantic Avenue will likely experience monthly traffic closures due to tidal flooding.

With 9 inches or more of sea level rise, the 1 percent annual chance flood pathway will expand due to water overtopping parts of Central Wharf near the New England Aquarium. In addition, other flood pathways emanating from the North End Waterfront will emerge and connect with flooding from the Downtown Waterfront. The 1 percent annual chance floodplain will reach as far inland as Congress Street at the steps of Boston City Hall.

With 40 inches of sea level rise, the Downtown and North End flood pathways will merge during monthly high tides, making them functionally indistinguishable. Additional flood pathways to Atlantic Avenue will activate with at least a 1 percent annual chance of flooding over the Harbor Towers property, Rowes Wharf, and other waterfront properties to the south.

North End Waterfront

As with the Long Wharf area, the North End Waterfront experienced significant impacts during the coastal floods of January and March 2018. Flooding was reported on the decks of several North End wharves, including Commercial Wharf, Lewis Wharf, Sargents Wharf, and Union Wharf. Detailed modeling of the

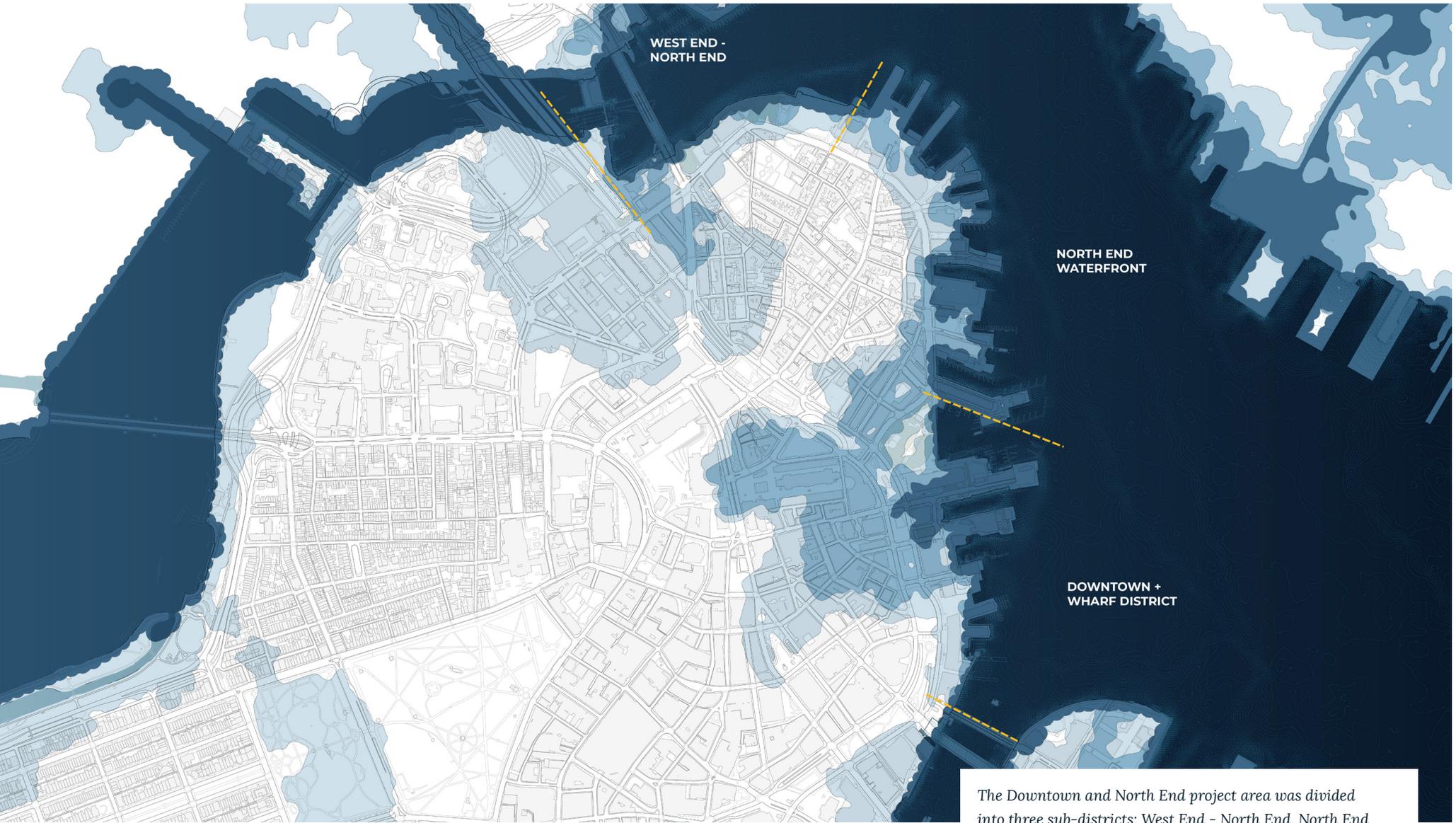
flooding dynamics in this sub-district indicates that present flood pathways from the wharves onto Atlantic Avenue have a lower than 1 percent annual chance of forming. Union Wharf is not expected to be a pathway for flooding beyond the wharf itself even in more extreme storms in this time horizon.

With 9 inches of sea level rise, 1 percent annual chance flood pathways will extend from Commercial Wharf, Lewis Wharf, Sargents' Wharf, and Union Wharf on to Atlantic Avenue and Commercial Street, before merging with the Downtown floodplain. Within the North End, the 1 percent annual chance floodplain will extend as far inland as Fulton St.

With 40 inches of sea level rise, an additional 1 percent annual chance flood pathways will form, flowing over Burroughs Wharf, Battery Wharf, and the US Coast Guard property to Commercial St before combining with flooding on Atlantic Ave.

West End - North End

Critical infrastructure in the West End - North End sub-district plays an important role in the coastal resilience of other parts of the City and the Greater Boston region. The New Charles River Dam, built



WEST END -
NORTH END

NORTH END
WATERFRONT

DOWNTOWN +
WHARF DISTRICT

The Downtown and North End project area was divided into three sub-districts: West End - North End, North End Waterfront, and Downtown + Wharf District

by the US Army Corps of Engineers and owned and operated by the Massachusetts Department of Conservation and Recreation (DCR), controls upstream water levels on the Charles River and acts as a physical barrier to storm surge spreading upstream. In so doing, the dam protects low-lying neighborhoods like Back Bay from the near-term impacts of sea level rise and storm surge. The dam's south embankment, located between the Zakim Bridge and Lovejoy Wharf, forms the boundary of the West End - North End sub-district.

The 2017 City of Cambridge Climate Change Vulnerability Assessment concluded, based on the Boston Harbor Flood Risk Model, that the Charles River Dam is at long-term risk of being flanked and overtopped due to sea level rise and coastal storm intensification. It is likely that there will be a 1 percent annual chance of the dam being flanked through the West End - North End sub-district and overtopped with between 21 inches and 40 inches of sea level rise. The risk of flanking is expected to reach the 1 percent annual chance threshold sooner than the risk of overtopping. The duration of flooding after such an event would depend on the ability of the dam to pump out the upstream basin.

Solutions to address potential overtopping of the New Charles River Dam were not within the scope of the

present study. DCR is in the process of studying the dam's long-term performance and resilience options.

This study looked at vulnerabilities adjacent to the dam. With 9 inches of sea level rise, a 1 percent annual chance flood pathway will extend from the waterfront at Lovejoy Wharf down North Beverly Street and across Causeway Street, reaching as far inland as Valenti Way. The 1 percent annual chance floodplain will be contained within a relatively small area between North Washington Street and Beverly Street. With 40 inches of sea level rise, this area will be at risk of annual flooding.

With the dam being both flanked and overtopped by a 1 percent annual chance water level with 40 inches of sea level rise, the Lovejoy Wharf flood pathway will be joined by water flowing over the other DCR and City properties along the waterfront, north of the North Washington Street Bridge. This flooding will spread south via Causeway Street, over a crest on Beverly Street to the area around North Station.

FLOOD RISK TIMEFRAMES

Near-Term (present through 2030s)

The flood model indicates two main pathways projected during a 1 percent (1 in 100) annual storm event with the

current sea level. One enters through the Long Wharf area and extends to Faneuil Hall. The second overtops the waterfront from Commercial Wharf to Union Wharf and flows to the Greenway via Fulton Street. In areas extending from Union Wharf to North Station and south of the Harbor Towers, the flooding is limited and contained within the wharves themselves.

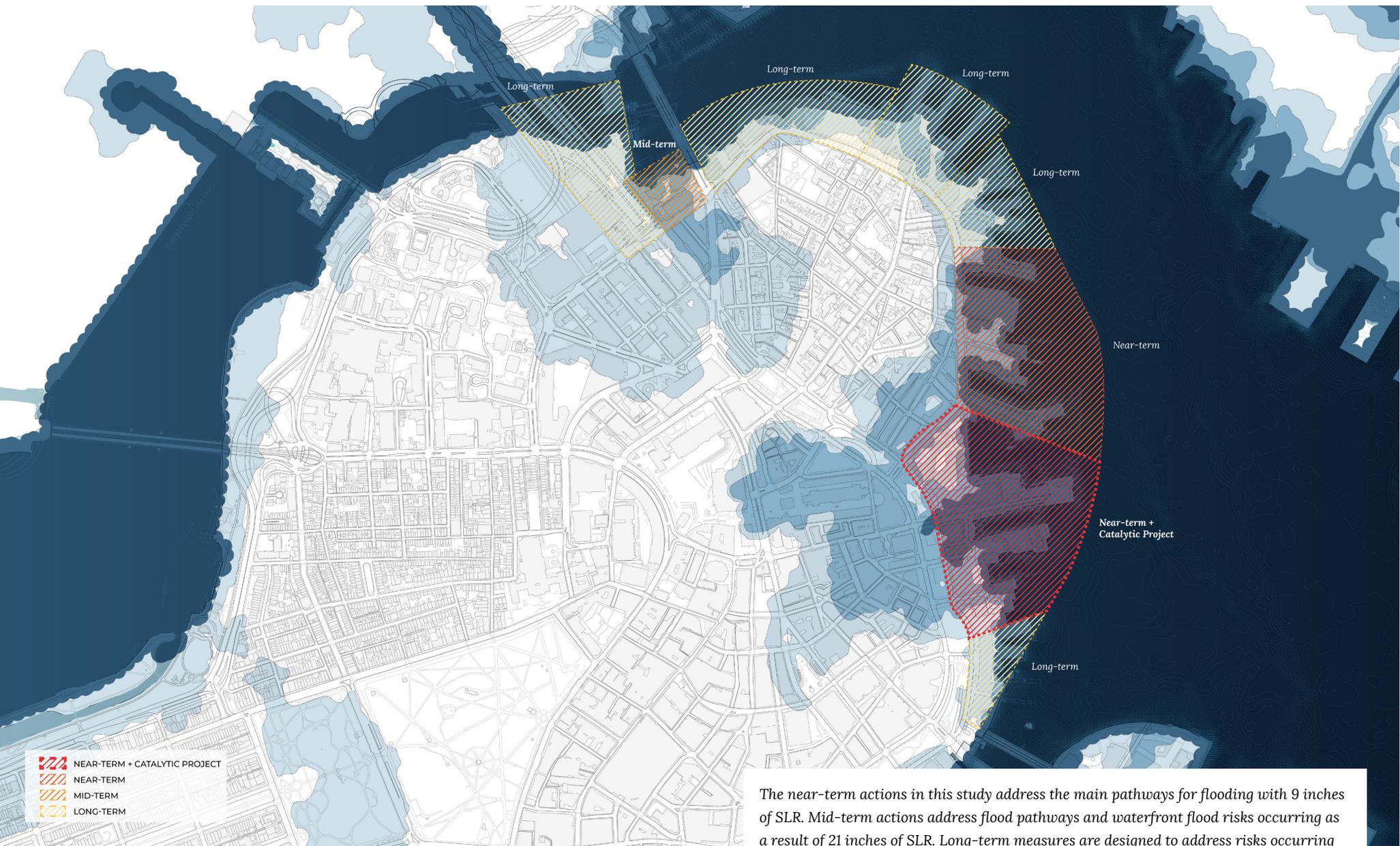
Mid-Term (2030s through 2050s)

The two flood pathways in the North End from Harbor Towers to Union Wharf converge behind Christopher Columbus Park and extend inland beyond Faneuil Hall.

Between Burroughs Wharf and the North Washington Street Bridge, the flooding is contained to the wharves and structures but does not impact Causeway Street, Commercial Street, and Atlantic Avenue. Beverly Street is a pathway that extends inland beyond Causeway Street to the south and the North Washington Street Bridge to the northeast.

Long-Term (2050s and beyond)

The flooding between Burroughs Wharf and the North Washington Street Bridge extends to Commercial Street and south of Rowes Wharf to South Station, where coastal flooding will reach the Greenway.



The near-term actions in this study address the main pathways for flooding with 9 inches of SLR. Mid-term actions address flood pathways and waterfront flood risks occurring as a result of 21 inches of SLR. Long-term measures are designed to address risks occurring as a result of 40 inches of SLR and needed for the completion of district wide solution.

SUBSURFACE RISKS

Most of the Downtown area is built on reclaimed land, constructed during the last 400 years. The quality, structural stability, and materiality changes from one site to another. Available information regarding specific fill conditions is limited.

Soil Substructure

Downtown Boston and the North End were reclaimed by filling in the existing mudflats with sand, gravel, clay, ash, refuse, and material debris from demolition of old buildings. Recent property and infrastructure developments have replaced poor quality urban fill with clean fill in some areas, including recent developments, the Big Dig Central Artery Tunnel (CAT), and Connect Historic Boston (on Atlantic, Commercial and Causeway), however much of the subgrade remains assorted fill from the era of land reclamation.

There are a number of subsurface, private utility conduits, especially stormwater outfalls, that are unidentified or unregistered in municipal utility maps. These conduits allow precipitation runoff to drain; as the sea rises, they add to flood risk. During elevated tidal conditions, water can backflow and flood streets,

even on cloudless days. The City, Boston Water and Sewer Commission (BWSC), and their partners are working to identify, map, and mitigate these outfall locations. Mitigation measures can include installation of flap gates that only allow one-way water flow, or permanent closure of abandoned conduits.

In addition, leaky seawalls and porous soil can lead to seawater infiltration below grade. Basements and underground infrastructure like transit stations and highway tunnels can flood or sustain related structural damages. Any coastal resilience design solutions will therefore need to address the risk of infiltration and flooding from below grade. This can be addressed through the use of sheet piling, soil mixing, or other related measures that block flow below grade, or clay caps used with berms at grade.

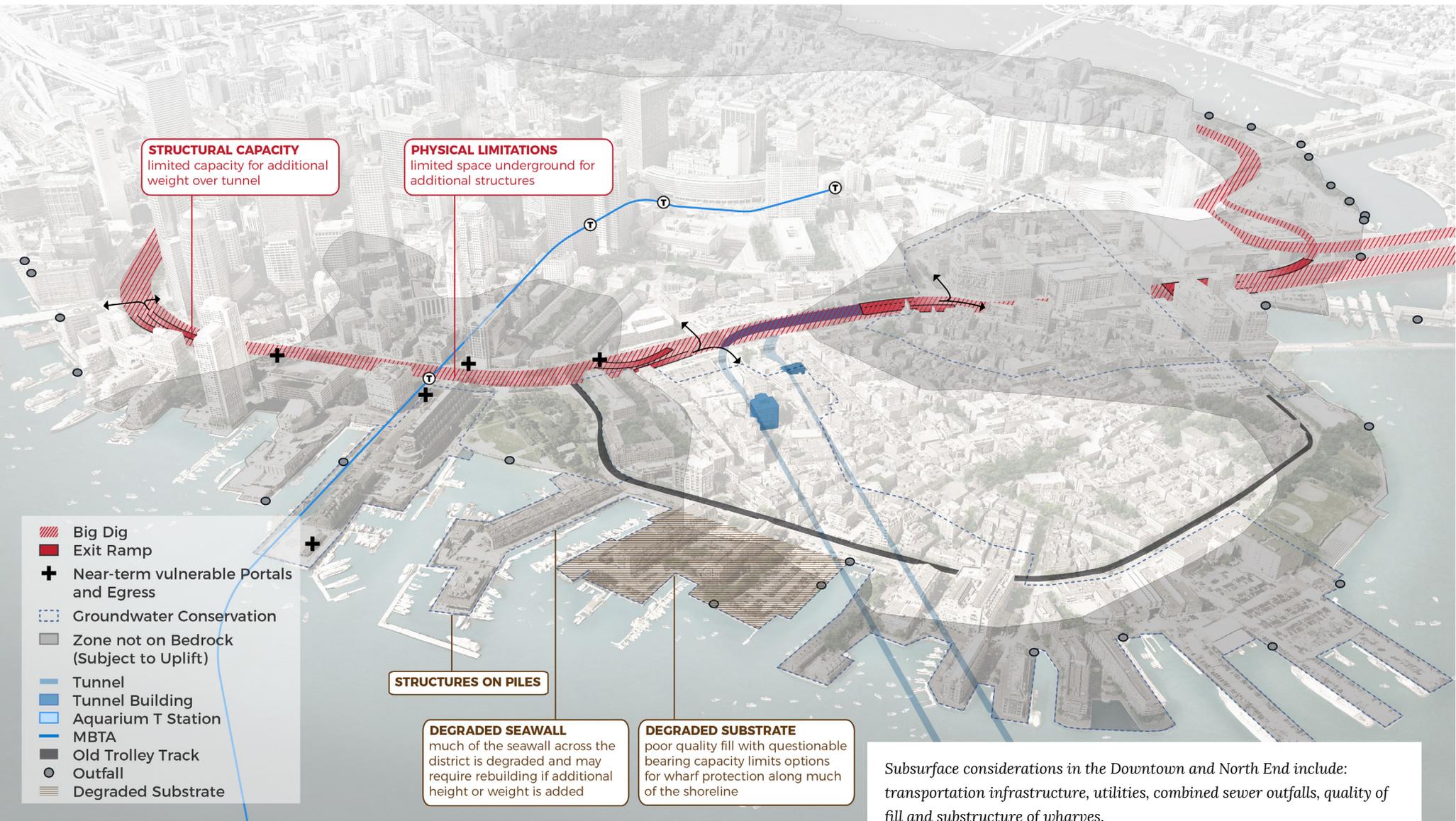
Groundwater Conservation

Much of the filled tidelands in the project area are in a Groundwater Conservation Overlay District (GCOD). Historically, buildings in these districts were typically constructed on wooden piles extending 15-20 feet underground. While these piles remain submerged or in saturated soils, they retain their structural strength. However, any exposure to oxygen

risks triggering rot. Therefore, developments in these areas are required to capture and direct stormwater underground to recharge groundwater.

In the past, structures have experienced settling due to piling deterioration after major infrastructure projects were implemented due to resulting drops in groundwater levels. Examples include the construction of transportation infrastructure, installation of seepage barriers behind bulkheads, and installation of tide gates on stormwater and sewer outfalls.

Groundwater levels are monitored at wells across the project area by the Boston Groundwater Trust. Currently, none of the wells that are regularly monitored appear to be tidally influenced. However, some wells that are no longer monitored may still be tidally influenced. Additional groundwater recharge and monitoring well infrastructure will be required as part of coastal resilience solutions in order to protect existing structures from damage, particularly for wood pile supported wharf, pier, and waterfront building structures which may have historically been exposed to tidal influence.



STRUCTURAL CAPACITY
limited capacity for additional weight over tunnel

PHYSICAL LIMITATIONS
limited space underground for additional structures

STRUCTURES ON PILES

DEGRADED SEAWALL
much of the seawall across the district is degraded and may require rebuilding if additional height or weight is added

DEGRADED SUBSTRATE
poor quality fill with questionable bearing capacity limits options for wharf protection along much of the shoreline

Subsurface considerations in the Downtown and North End include: transportation infrastructure, utilities, combined sewer outfalls, quality of fill and substructure of wharves.

- Big Dig
- Exit Ramp
- Near-term vulnerable Portals and Egress
- Groundwater Conservation
- Zone not on Bedrock (Subject to Uplift)
- Tunnel
- Tunnel Building
- Aquarium T Station
- MBTA
- Old Trolley Track
- Outfall
- Degraded Substrate

Combined Sewer Overflows (CSO)

Along the coast, sea level rise will increase water levels at storm drain outfalls reducing their capacity to drain by gravity without the need for pumping. In addition, drainage pipes that are not fitted with tide gates may be susceptible to backflow. Backflow occurs during high water levels when, instead of flowing out of pipes into the harbor, water from the harbor flows into pipes and can even spill out into basements or onto ground surfaces. The Downtown and North End areas contain historic combined sewer overflow (CSO) systems. CSOs are a sewage collection system designed to simultaneously receive both storm drainage and sewage flows during extreme rainfall events and discharge them into the harbor. These are a water quality concern and are no longer constructed, however, older systems remain in place. If water backflows, or surface flooding finds its way into CSO systems, untreated sewage releases can become more frequent and may pose public health risks. These risks may also increase due to leaky pipes that decrease groundwater levels around them, which can also negatively impact wooden pile supported structures, including historic buildings. The CSO outfalls in the project area have tide gates, but water can find its way into the system from unmapped

private drains and illicit connections. BWSC is continuously working to identify and eliminate illicit connections and to map private connections that could be a source of backflow in storm events.

Utilities

Major utilities are buried underground, beneath sidewalks and within roadway rights-of-way. During the Big Dig, many utilities that feed the Downtown Waterfront were relocated and consolidated along the sidewalk and centerline of Atlantic Avenue on the Northbound side. This required a coordinated process, which added to the complexity, timeline, disruption, and cost of the Big Dig and would similarly affect the construction of flood protection structures along roadway alignments. Existing utility infrastructure is generally not adapted to future flooding and would be degraded by saltwater exposure.

Transit tunnels

Downtown is the central business district for the region and is fully connected to the main subway lines owned and operated by the MBTA. The MBTA subway system has infrastructure in the floodplain, including the entrances to the Blue Line at Aquarium Station and

the Blue Line tunnel emergency egress on Long Wharf. The City is working with MassDOT and MBTA on installing deployable flood barrier systems to protect these vulnerable openings from coastal flooding in the near-term. Because of the presence of the transit station and tunnel infrastructure beneath Long Wharf, new waterfront flood protection infrastructure would need to be designed to avoid placing additional weight on the structures below. In addition to protecting the main station entrances and tunnel egress in the project area, the MBTA is working to identify and address other points of potential water entry, including stations and portals in East Boston and seepage through underground walls and utility conduits.

The Central Artery Tunnel, underneath the Greenway, is a complex engineered system. Construction of any additional load on top of it could harm the structure of the system and needs to be studied further.

Glossary of Terms

The following terms are commonly used to define elevations required for protection against coastal flooding. The definitions provided here were taken from Federal Emergency Management Agency (FEMA) https://www.fema.gov/pdf/fima/pbuffd_appendix_b.pdf

Base Flood Elevation (BFE) is the elevation of the 100-year flood. The BFE is determined by statistical analysis for each local area and is designated on the Flood Insurance Rate Maps (FIRMs). This elevation is the basis of the insurance and floodplain management requirements of the National Flood Insurance Program (NFIP).

Freeboard is a factor of safety usually expressed in feet above a flood level for purposes of floodplain management. Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood and floodway conditions, such as wave action, bridge openings, and the hydrological effect of the urbanization of the watershed.

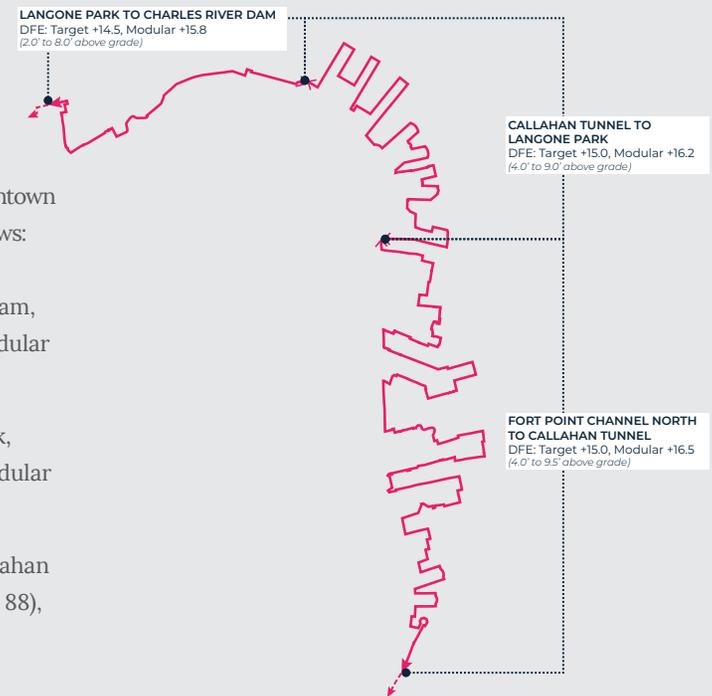
Design Flood Elevation (DFE) is the elevation of the highest flood (generally the BFE including freeboard) that a retrofitting method is designed to protect against. Also referred to as Flood Protection Elevation.

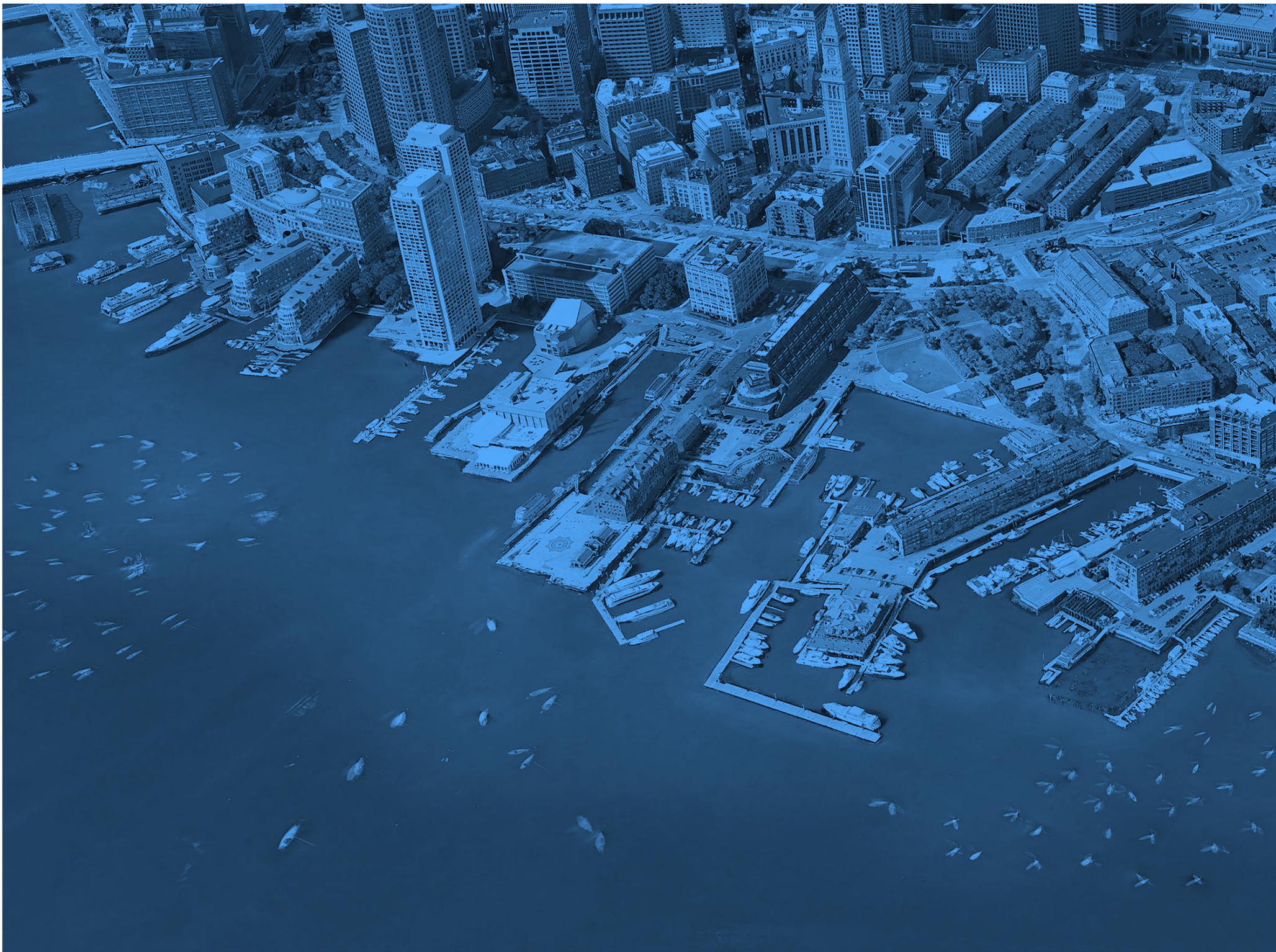
NEAR-TERM, MID-TERM AND LONG-TERM ACTIONS

The near-term actions in this study address the main pathways for flooding with 9 inches of SLR (2030s). These near-term actions are focused towards integration of ongoing and planned projects and completion of projects of critical concern that protect areas at high risk today. Mid-term actions address the expansion of flood pathways and waterfront flood risks occurring as a result of between 9 and 21 inches of SLR (2030s - 2050s). Long-term actions address areas at risk with 21 inches of SLR (2050s) (long term A) 2060 (Long Term B) and beyond. Measures are designed high enough to provide effective flood protection from the 1 percent annual chance flood with 40 inches of SLR (2070s).

The Design Flood Elevations for the Downtown and North End neighborhood are as follows:

- » Langone Park to Charles River Dam, DFE: Target +14.5 (NAVD 88), Modular +15.8 (NAVD 88)
- » Callahan Tunnel to Langone Park, DFE: Target +15.0 (NAVD 88), Modular +16.2 (NAVD 88)
- » Fort Point Channel North to Callahan Tunnel, DFE: Target +15.0 (NAVD 88), Modular +16.5 (NAVD 88)





04 COASTAL RESILIENCE DESIGN STRATEGIES



COASTAL RESILIENCE DESIGN STRATEGIES

OPEN SPACE OPPORTUNITIES AND COASTAL RESILIENCE

Open spaces have significant and unique value in the development of resilience in the urban environment. Parks, harborwalks, beaches, marshes, and other open space systems can provide protection against rising seas and increased wave action. In addition, they provide public amenities for recreation and community gathering, and provide environmental benefits such as increased tree canopy, permeability, and stormwater management. These qualities help to combat other impacts of climate change. Where open space and enhanced public realm strategies are appropriate, they score high in effectiveness, adaptability, social and environmental impact, value creation, and equity.

The tunnelization of the formerly-raised Central Artery and the construction of the Rose Kennedy Greenway prioritized a connected, healthy, pedestrian-friendly urban environment. The addition of the Connect Historic Boston Bicycle Trail, completed in 2018, linked the Greenway and Christopher Columbus Park to Langone and Puopolo Parks and Steriti Memorial Rink to the north. These

efforts have transformed the area's environment, and yet, there remains untapped potential to further connect Downtown to the waterfront.

In 2016, the New England Aquarium initiated plans for 'The Blueway' to open up access to the waterfront and increase coastal resilience. 'The Blueway' is a conceptual master plan that proposes a vibrant, educational and inclusive public landscape extending from the Greenway to the waterfront. The concept incorporates site and building level measures for resilience on the aquarium property with the ambition that these could connect to measures implemented on adjacent properties. This proposal was supported and promoted through the 2018 Downtown Boston Municipal Harbor Plan which allocated funds for its continued development.

Implementation of the Municipal Harbor Plan will create over 58 thousand square feet of new publicly accessible open space that will be designed to encourage greater public access to the water's edge, enhancing shoreline access through stronger Harborwalk connections and flood protection through well planned resilient landscape design.

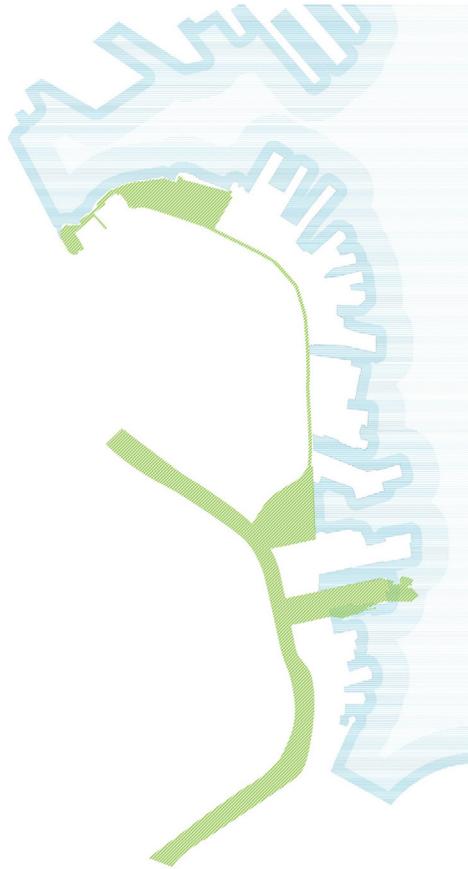
This report recommends further development of public realm connections between the Greenway

and the waterfront. Coastal protection systems along Long Wharf, Harbor Towers, Christopher Columbus Park, and City-owned portions of Sargeant's Wharf will allow for varied programming including public gardens, recreation, event programming, play, water transportation opportunities, harbor views and new opportunities to experience Boston's waterfront and the Harbor Islands. These will be most impactful if conceived of and implemented as a broader coordinated vision.

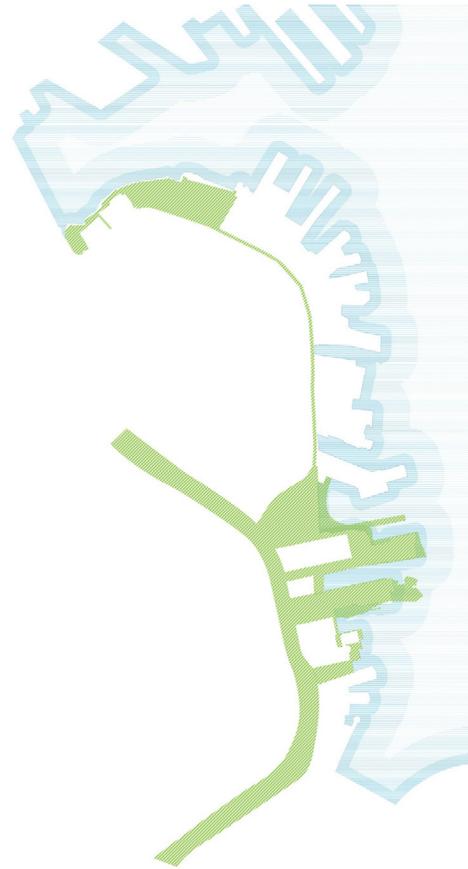
Sargent's Wharf, described in the 1990 Harborpark Municipal Harbor Plan as the last publically owned waterfront development site along the North End and Downtown waterfront, has the potential to significantly strengthen the open space and Harborwalk network linking the new Charles River dam to Long and Central Wharves. Imagine Boston 2030 underscores Boston's desire for more signature parks along Boston Harbor that are connected through strong pedestrian and bike networks to neighborhoods underserved by waterfront open spaces. While Sargents Wharf currently provides needed parking for the North End community, its current use will be extremely diminished with more frequent flooding. Continued community engagement on reuse of this site as resilient greenspace is anticipated.



Existing Parks + Bikeway



+ Blueway



+ Long Wharf
+ Harbor Towers Harborwalk



+ Harborwalk
+ Sargent's Wharf

An expanded and enhanced open space network and public realm, connected by the Boston Harborwalk is central to the vision for resilience in Downtown and the North End. Through implementation of resilience planning there is great potential to expand on and clarify existing open space networks as illustrated above.

Langone and Puopolo

At Langone Park and Puopolo Playground, a 4.5 acre open space area located along Boston Harbor in the North End neighborhood of Boston, the City of Boston is implementing innovative open space climate resilience design. This is the first project within the Boston Parks and Recreation system to integrate the standards set forth by the City's Climate Resilient Design Standards and Guidelines.

Langone and Puopolo are two of the oldest parks in the Boston Parks and Recreation system and are also the site of the Great Molasses Flood in 1919. This tragic event sparked calls for more regulatory oversight and helped serve as a catalyst for establishing professional licensure and current design practices.

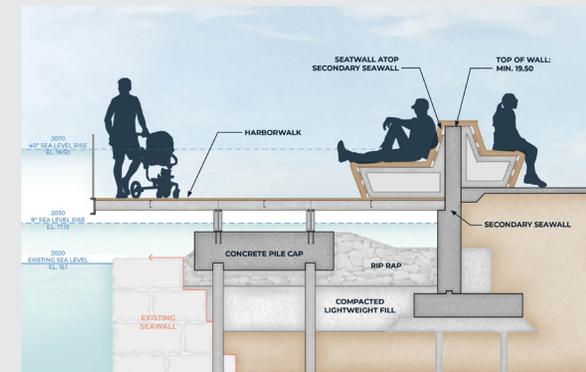
Langone and Puopolo are comprised of a children's playground area and walkways, basketball courts, bocce courts, Little League baseball field, and a multi-use rectangular field with softball and baseball overlays. They are a key asset that serves not only the North End neighborhood but

also the greater Boston community. The property is the only recreational open space with athletic fields in the North End and also includes a significant length of the Boston's Harborwalk corridor, a key link that connects Charlestown and Downtown Boston.

As climate change and sea level rise become more prevalent and a key challenge to waterfront cities like Boston, open space assets like Langone and Puopolo have been identified as cornerstones of the protection of the city's edge. Renovations to this site, undergoing construction in 2019 and 2020, include a large section of Langone and Puopolo's harbor edge that was considerably deteriorated and had been inundated during large storm events and astronomical tides. This project is a significant first in the implementation of open space as climate resilience design. It serves as a blueprint for future projects and leads the way for the Downtown and North End.

The City of Boston's Climate Resilient Design Standards and Guidelines for the Protection of Public Rights-of-way were

used to implement a variety of climate adaptation strategies. This included integrating a retaining wall through the landscape to provide up to 6 feet of flood protection without walling the park off from the Harbor; stabilizing the existing, degraded seawall and elevating a new Harborwalk path on micropiles; capturing and directing stormwater through outfalls with internal tide gates; and designing sports courts that can temporarily store stormwater and recover quickly from major storm events. The barrier height was designed for the base flood elevation (no freeboard) of a 1% annual chance flood with 40 inches of sea level rise. The walls built into the site can be raised in the future to increase flood protection as needed.





Sunny day rendering of open-space climate-resilient design methods to mitigate future flooding at Langone Park and Puopolo Playground. By Weston & Sampson (top). Section of raised harborwalk at the waterfront's edge at the park. By Weston & Sampson (left).

PROPOSED STRATEGIES

A district-wide plan requires a connected, continuous protection system in order to be effective.

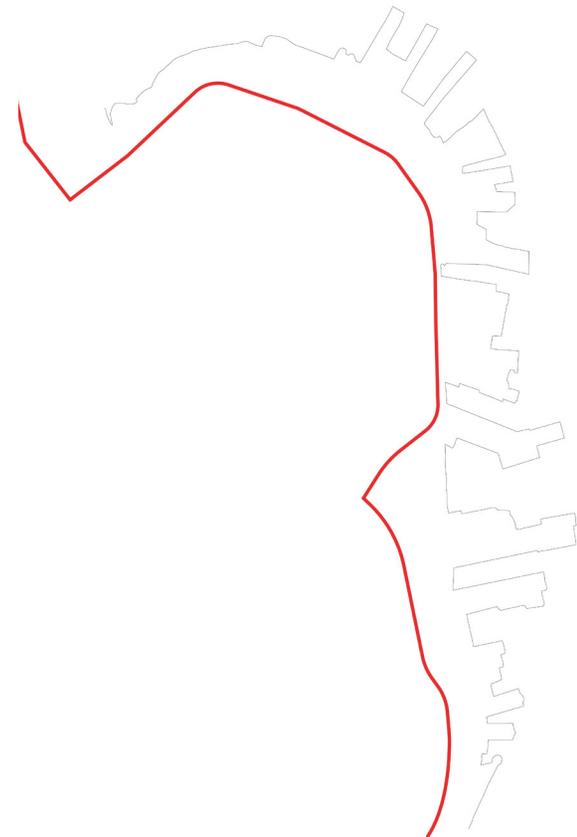
Implementation must address physical, regulatory, and ownership challenges to connectivity as well as specific site conditions and the urban character of Downtown and the North End.

The four basic strategies for integration of flood protection employed in this report are:

- » **Spines:** Linear elements existing in the landscape such as roadways, and bike paths which may be elevated to prevent influx of flood waters.
- » **Open spaces:** Existing and new public areas on or along the waterfront which may be elevated to prevent influx of flood waters.
- » **Harborwalk enhancements:** The public Harborwalk at the water's edge can be raised and integrated along current bulkhead lines, or where there is room to expand to allow for more generous public walkways and easier access to the water.

- » **Offshore elements:** Filled land allowing for space required to raise elevations, or breakwaters and ecological systems at the water's edge which reduce wave action and provide environmental benefits.

These four strategies provided a basis for generating flood protection options for a district-wide system. These range from an inland approach completed entirely on City-owned land through raising of roadways and parklands to a waterfront approach crossing both publicly and privately owned lands consisting of raised harborwalks, offshore elements and raised parklands. These approaches can, and likely will, be combined throughout the project area. A toolkit to guide design variations was created (see Appendix).



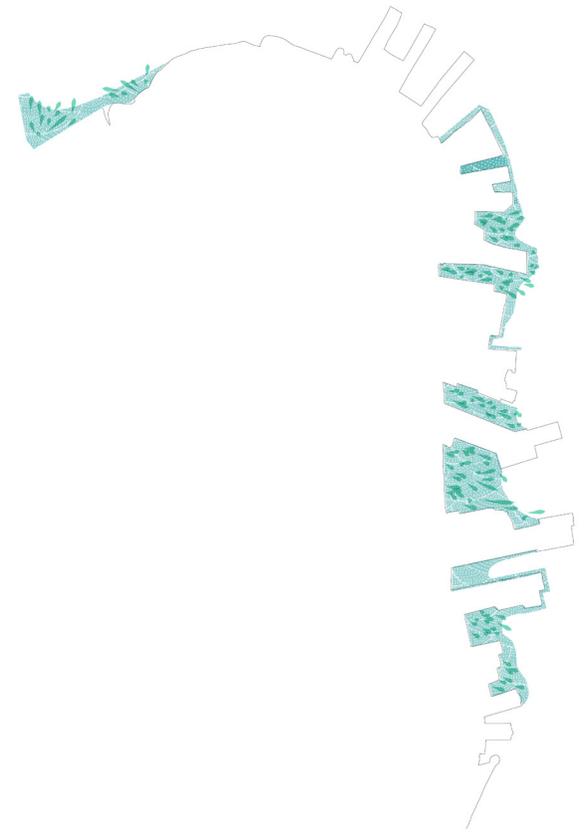
Spines



Open spaces



Harborwalk enhancements



Offshore elements

STRATEGIES AT THE WATER'S EDGE

The preferred waterfront options utilize both City-owned and privately owned waterfront lands as flood protection. These strategies would require raising the waterfront's edges to create a physical barrier against rising seas. Parks, Harborwalk, and bulkhead edges as well as offshore filling would all play a role in the development of a continuous raised waterfront. Existing elevations along the waterfront are lower than at the roadway and more variable. The elevation change required to reach the target Design Flood Elevation ranges from two to nine feet across the district.

The primary benefit of a waterfront solution is the protection of a greater number of properties and individuals within the district scale solution. Additionally, it has the potential for an overall positive impact on the public realm through enhancing existing open space networks and improving waterfront access. Depending upon final design and specific site conditions, the waterfront alignment generally has greater ability to be adapted to higher elevations in the future and can have positive ecological impacts. Challenges to this solution include costs, complexity of

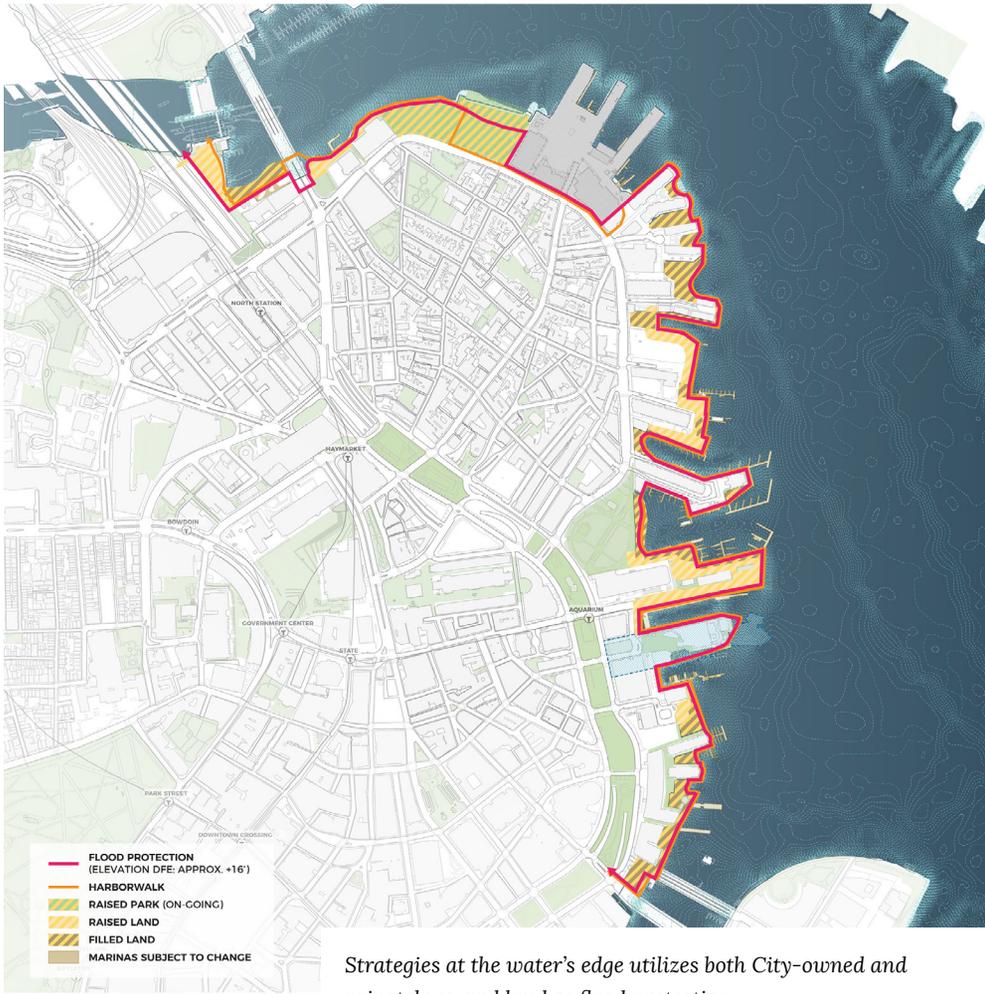
collaboration and coordination required among diverse ownership, the length of the perimeter required, and the complexity of building on and around existing bulkheads or into the water. However, given that the majority of the study area is within the 'Magenta Zone', and therefore subject to fewer federal regulatory requirements, alignments that are partly 'in water' remain a possibility. A resilience solution right at the existing bulkhead often has significant constraints and limited adaptability. In-water solutions may provide more opportunities for urban benefits than those at the existing waterfront.

Final implementation will likely prove to be a combination of the strategies presented based on outcomes of continued coordination and study with waterfront and offshore solutions coming together in a comprehensive, diverse, and protected waterfront. Should a given wharf or pier property not be able or willing for any reason to participate in the implementation of the waterfront option, a roadway strategy or "spine" can be used. This option is laid out in the next section. Such a scenario would still require significant coordination and collaboration to allow for continued access to the waterfront and the creation of a contiguous protection system throughout the district.

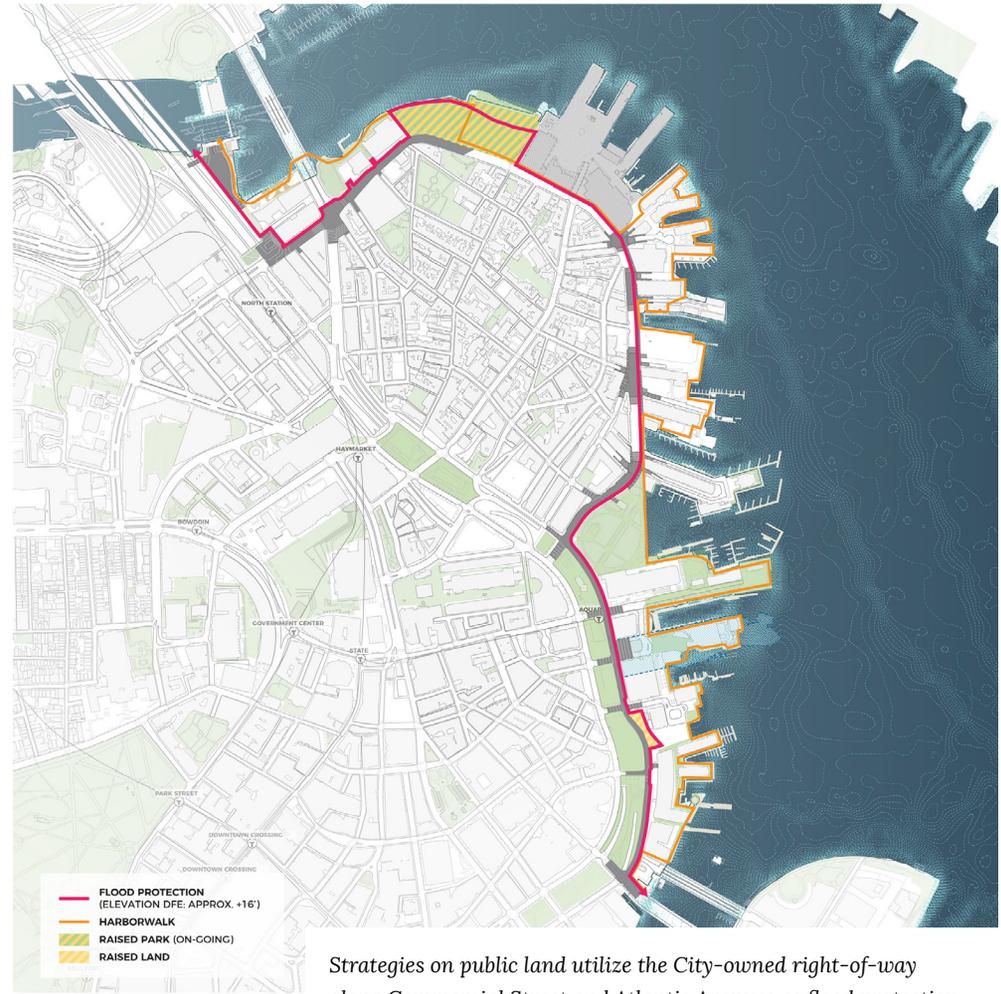
STRATEGIES ON PUBLIC LAND

The public right of way options utilize the City-owned right-of-way along Commercial Street and Atlantic Avenue as the flood protection. This option would require raising the roadway to create a physical barrier against coastal flooding. This strategy also requires the raising of intersections, to allow for access on and off of the newly raised road. As this roadway is set back from the waterfront and on higher ground in most areas, the maximum heights required to meet the Design Flood Elevation are lower than at the waterfront. Across the district, the roadway height required ranges from 2 to 5 feet above existing elevations.

The primary benefit of this option is its relative ease of implementation. Because the road is completely owned by the City of Boston, implementation and future management would require significantly less coordination than a solution crossing multiple owners' lands. While single ownership of property simplifies implementation, coordination across the many utilities within the roadway remains highly complex. As this option lies behind all of the wharves and piers it leaves those properties unprotected from flooding.



Strategies at the water's edge utilizes both City-owned and privately owned land as flood protection.



Strategies on public land utilize the City-owned right-of-way along Commercial Street and Atlantic Avenues as flood protection.

Individual owners or groups of owners would need to protect their own buildings and wharves. Raising the roadway and the recently revitalized bike path along Commercial Street may create a public realm that is both difficult to navigate for pedestrians and cyclists and separates the North End inland of Commercial Street from the waterfront.

The limited space available within the right-of-way also leads to limited ability to raise to higher elevations over time. When sea level rises above the current design target of adaptation to 40 inches of SLR, this option would leave little room to increase elevations further without significant barriers to waterfront access such as vertical walls without the usage of non-passive flood protection systems such as deployable flood barriers.

COMMUNITY FEEDBACK

Over 400 residents from Downtown Boston and the North End participated in the design process through meetings, community events, open houses, focus groups and an online survey. Residents and property owners shared their desire for effective and long lasting solutions to keep everyone safe from

coastal flooding while also placing great importance on the need for protection of key infrastructure and continued public access to the waterfront for residents and visitors alike. Business owners expressed concern regarding flood impacts on ground floor restaurants and retail, water-based transportation, rental properties and damage to historic and cultural assets such as the New England Aquarium, Custom House, and Long Wharf as well as new amenities such as the Rose Kennedy Greenway, which connects and draws people to the waterfront from inland areas.

Participants expressed a clear preference for a waterfront strategy that will protect the largest number of properties and provide the greatest community benefit. Many stated concern regarding the potential for the actions of a single property owner to harm neighboring properties or the broader community. The opinions of community members mirrored the overall preference of the other stakeholders and infrastructure providers. As such, the need for collaborative, coordinated efforts in order to develop a collective, coherent strategy was a frequent topic of conversation.

Following the January and March 2018 storms, many waterfront properties sustained damage to their basement and ground floor levels. Through the engagement process, many property owners and infrastructure providers in Downtown and the North End indicated that they are already taking action to reduce flood risk and adjust structural and operational systems to anticipate future flood events. Examples include building-level risk assessments and evaluation of critical infrastructure such as the MBTA Aquarium Station and the Central Artery tunnel. Specific short-term adaptations such as construction of deployable flood protection systems and longer term adaptations such as raised parks and landscaping around buildings are underway on many waterfront properties.

Community and Stakeholder Input

The following groups and individuals provided input to this report. Their feedback on options and guidance on specific opportunities and challenges was tremendously helpful. Their ongoing commitment to envisioning, implementing and maintaining a vibrant and resilient Downtown and North End is greatly appreciated.

- » *A Better City*
- » *Ann and Chuck Lagasse*
- » *Boston Harbor Cruises*
- » *Boston Harbor Now*
- » *Burroughs Wharf*
- » *Capital Properties*
- » *The Chiofaro Company*
- » *Commercial Wharf*
- » *Eversource*
- » *Friends of Christopher Columbus Park*
- » *Fulton Court*
- » *Green Ribbon Commission*
- » *Groundwater Conservation Overlay District*
- » *Harbor Towers*
- » *Intercontinental Hotel*
- » *Lewis Wharf*
- » *Massachusetts Bay Transportation Authority*
- » *Massachusetts Department Of Conservation and Recreation*
- » *Massachusetts Department Of Transportation*
- » *National Grid*
- » *New England Aquarium*
- » *North End Waterfront Neighborhood Council*
- » *Prince Building*
- » *Related Beal*
- » *The Rose Kennedy Greenway Conservancy*
- » *Sunstone Management Partners*
- » *Sydney Ashbury*
- » *Tavistock Group*
- » *Union Wharf*
- » *US Coast Guard*
- » *Wharf District Council*

SUB-DISTRICT RECOMMENDATIONS

The following pages outline existing conditions, proposed options of combined strategies, near-term actions, and estimated costs for each of the three sub-districts. Implementation of these recommendations will require coordination between property owners and the City on further analysis and design in order to address the complexities of implementation.

Near-term actions are those which address the most urgent flood pathways. These projects must be completed as soon as possible and before 2030. These immediate actions require initiation of next steps of design within the next two to three years in order to address flood risks and critical pathways for flooding.

Cost estimates for the design variations, such as elevated seawalls, integrated flood walls, Harborwalks, waterfront parks, and other shoreline features are based on readily available data. The cost estimates do not reflect site-specific considerations, such as as-built surveys of existing seawall conditions, underground utilities, or geotechnical information.

The estimates are generally presented as ranges and include large contingencies due to the limited information available on existing conditions and future designs. They should be used for planning purposes only.

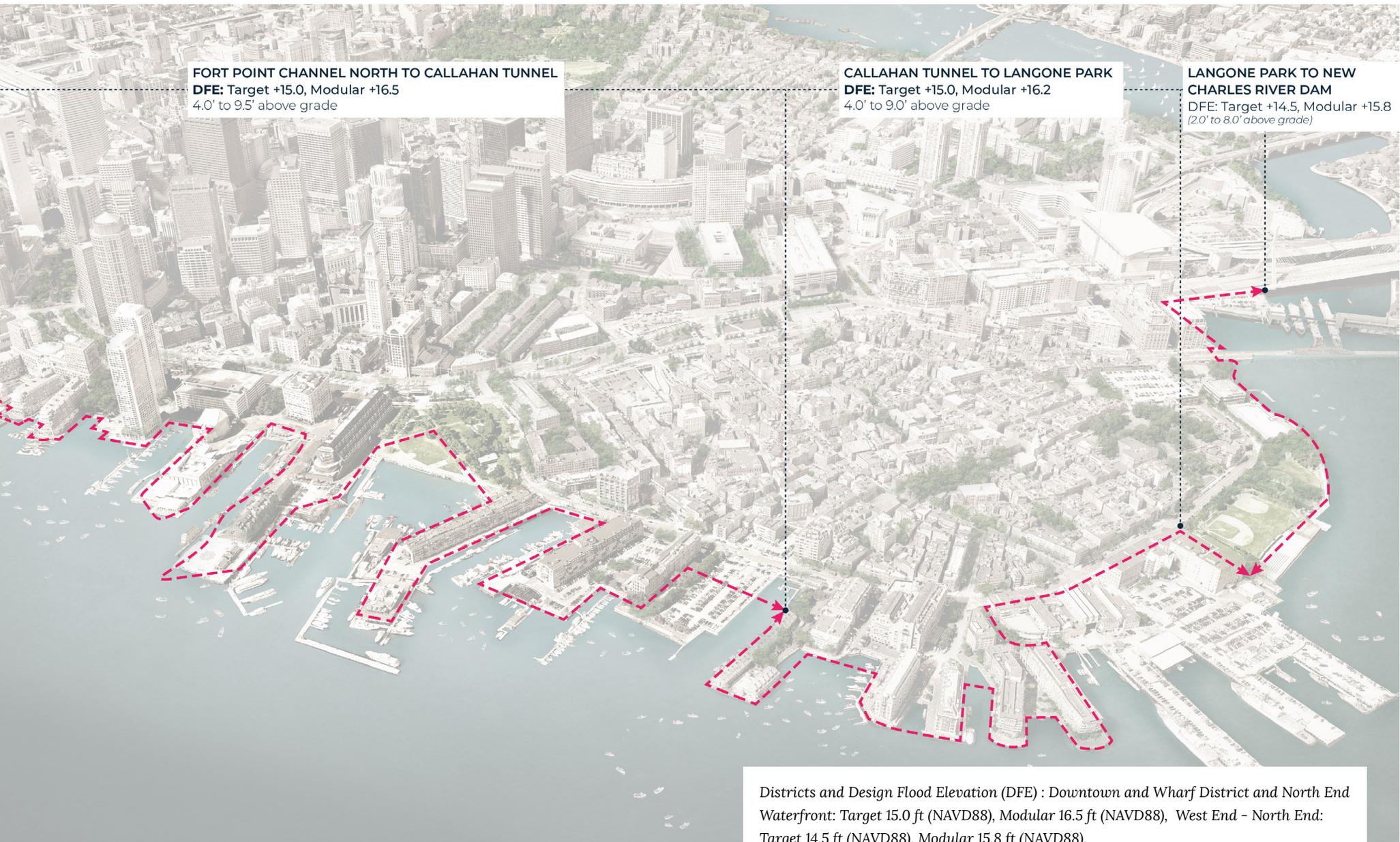
It is critical that the district solutions function as a complete system even though this plan will be implemented in phases based on the flood inundation path timelines. Where properties meet, coordination in advance and during construction is of critical importance. Additionally, it is important that potential impacts are addressed at the property level as well as the district level to protect both waterfront and inland properties and assets. For example, while the district scale solution may be in place, vulnerable waterfront properties will also require building level protections and systems for recovery from flood impact. Ensuring both district level and property protections are in place creates a system that will ensure the protection of critical infrastructure and assets.

The timeline and costs required for implementation vary based on key considerations and other currently unknown conditions. The following key considerations are similar across all three sub-districts. Sub-district specific considerations and

conditions are outlined under each of the sub-district outlines below.

Key considerations:

- » Collective action from property owners along the perimeter in order to provide complete flood protection is required.
- » Significant marine transportation infrastructure with anticipation of increased future ridership will need to be considered.
- » Structures in the future flood plain will need to be retrofitted according to the BPDA Coastal Flood Resilience Design Guidelines and the future zoning overlay district.
- » Accessibility to all properties will be required regardless of flood barrier location.
- » There is opportunity to prioritize improvements to the Harborwalk and public space.



FORT POINT CHANNEL NORTH TO CALLAHAN TUNNEL
DFE: Target +15.0, Modular +16.5
 4.0' to 9.5' above grade

CALLAHAN TUNNEL TO LANGONE PARK
DFE: Target +15.0, Modular +16.2
 4.0' to 9.0' above grade

LANGONE PARK TO NEW CHARLES RIVER DAM
DFE: Target +14.5, Modular +15.8
 (2.0' to 8.0' above grade)

Districts and Design Flood Elevation (DFE) : Downtown and Wharf District and North End Waterfront: Target 15.0 ft (NAVD88), Modular 16.5 ft (NAVD88), West End - North End: Target 14.5 ft (NAVD88), Modular 15.8 ft (NAVD88).

Principal causes of variation in time and costs required for implementation include:

- » Reconfiguration of marine transportation docking and passenger boarding structures.
- » Stormwater retention and groundwater recharge systems to protect piles after seawalls are retrofitted with seepage barriers.
- » Areas with limited space between building and bulkhead for flood protection or where part of the building extends beyond the bulkhead will need to consider raising, redesign, and reconstruction, or construction of offshore barriers beyond the bulkhead.
- » Coordination and impact on subway stations and tunnel egress infrastructure.

Current unknowns include:

- » Quality of soil and existing fill.
- » Adjustments of utilities.
- » Conditions of many existing pier structures.
- » Ability to permit in-water construction.
- » Presence of contaminated soils.

Additional considerations, causes for variation in time and costs, and unknowns specific to each of the three sub-districts are outlined later in this chapter.

The appendix to this report includes a resilience toolkit intended to provide guidance and inspiration for design variations that may be utilized based on existing conditions. Regardless of the approach chosen for implementation, each will be required to meet the established Design Flood Elevation (DFE) for that district. Final designs will be required to comply with Chapter 91 Harborwalk regulations and consider physical access as well as visual and cultural connection to the water. For this reason, nearly all approaches include a Harborwalk or public access point at a lower elevation and a higher, slightly inland elevation which meets the required DFE. The DFEs include both a 'target' and 'modular' elevation. The target is the minimum elevation while the modular is a higher elevation that may be required over time as levels rise and modelling becomes more accurate. Due to the difficulty and disruption of building along the coastline in this area, building to the modular level is recommended. These elevations, stated in North American Vertical Datum of 1988 (NAVD88) datum, are as follows:

Downtown, Wharf District and North End Waterfront:
Target 15.0 ft, Modular 16.5 ft.

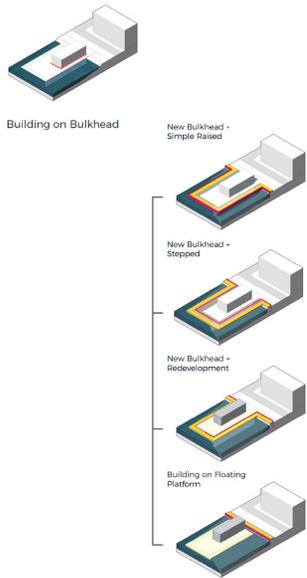
West End - North End: Target 14.5 ft, Modular 15.8 ft.

Resilience Toolkits

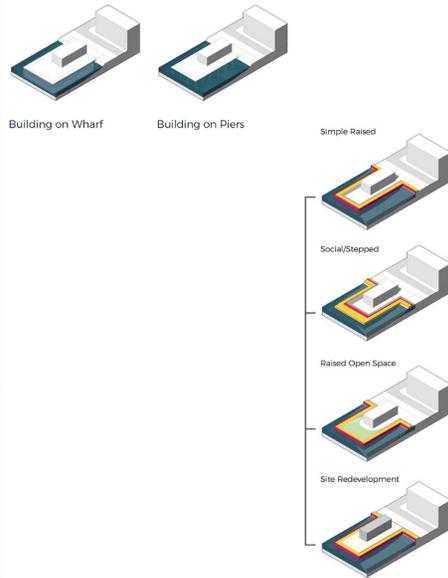
The appendix to this report includes a resilience toolkit intended to provide guidance and inspiration for design approaches that may be utilized based on existing conditions. Regardless of the approach chosen for implementation, each will be required to meet the established Design Flood Elevation (DFE) for that district. Final designs will be required to consider physical access as well as a visual and emotional connection to the water.

EXISTING EDGE CONDITIONS & POSSIBLE DESIGN APPROACHES

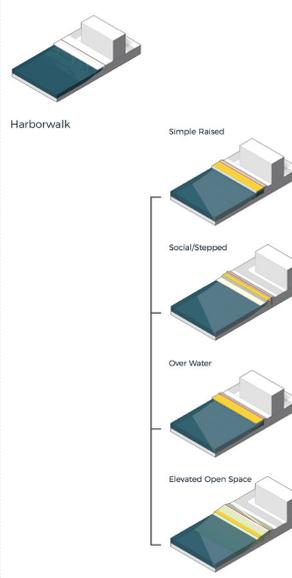
BUILDINGS ON THE BULKHEAD



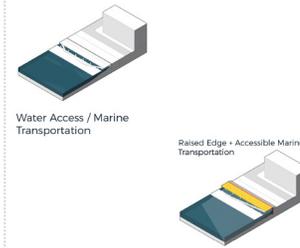
BUILDINGS ON WHARVES / PIERS



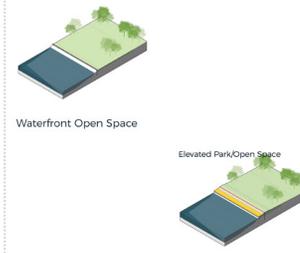
HARBORWALK



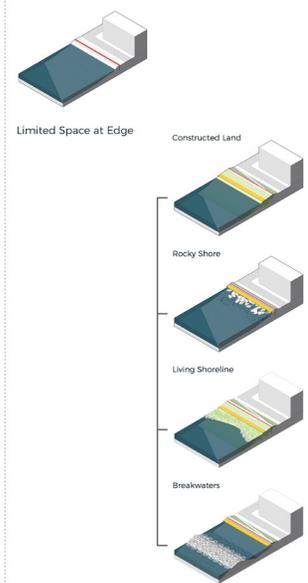
MARINE TRANSPORTATION



WATERFRONT OPEN SPACE



OUTBOARD EDGE



DOWNTOWN & WHARF DISTRICT

The largest and most immediate flood pathway, located at Long Wharf, enters Downtown at the heart of this sub-district which is home to critical water-based transportation infrastructure, civic, historic and public realm amenities as well as private residences. Public and private water transportation exists along the majority of the wharves in this sub-district. Coastal edges range from Harborwalk and structures on piers to wharves on filled land, many of which are surrounded by historic large granite bulkhead walls. The ownership is varied with a high percentage of City-owned land combined with water-based and tourism-focused businesses, non-profits, marinas, and private condominiums.

Regular surface flooding already occurs during King Tides on the lower deck Harborwalk on Long Wharf, Custom House Block access road and parking lot, and along portions of Christopher Columbus Park Harborwalk, and the seawalls at Commercial Wharf. During the coastal floods of January and March of 2018, flooding from Long Wharf reached Atlantic Avenue where it ponded up to several feet deep. Flooding at the MBTA Aquarium Station caused over \$3 million

in damages to elevators, escalators, and pumping equipment, reducing the accessibility of the station for an extended period of time.

Further assessment is required to fully understand subgrade conditions and risks in specific parts of the sub-district, however, evidence of seepage, such as sinkholes and water emerging up into asphalt at high tides and storm events is seen in areas, indicating bulkheads are highly permeable and may require significant repair.

FLOOD PROTECTION OPTIONS

The strategies outlined in this section show three possible approaches for a waterfront system of protection. Additional site specific analysis and design studies will be required to advance these strategies and effectively identify the approach given existing conditions. These strategies are not mutually exclusive, meaning they may be implemented in combination to achieve a continuous solution and accessible shoreline. Building level adaptations should be implemented with any option.

Key Downtown and Wharf District specific considerations for successful implementation include:

- » There is significant marine transportation

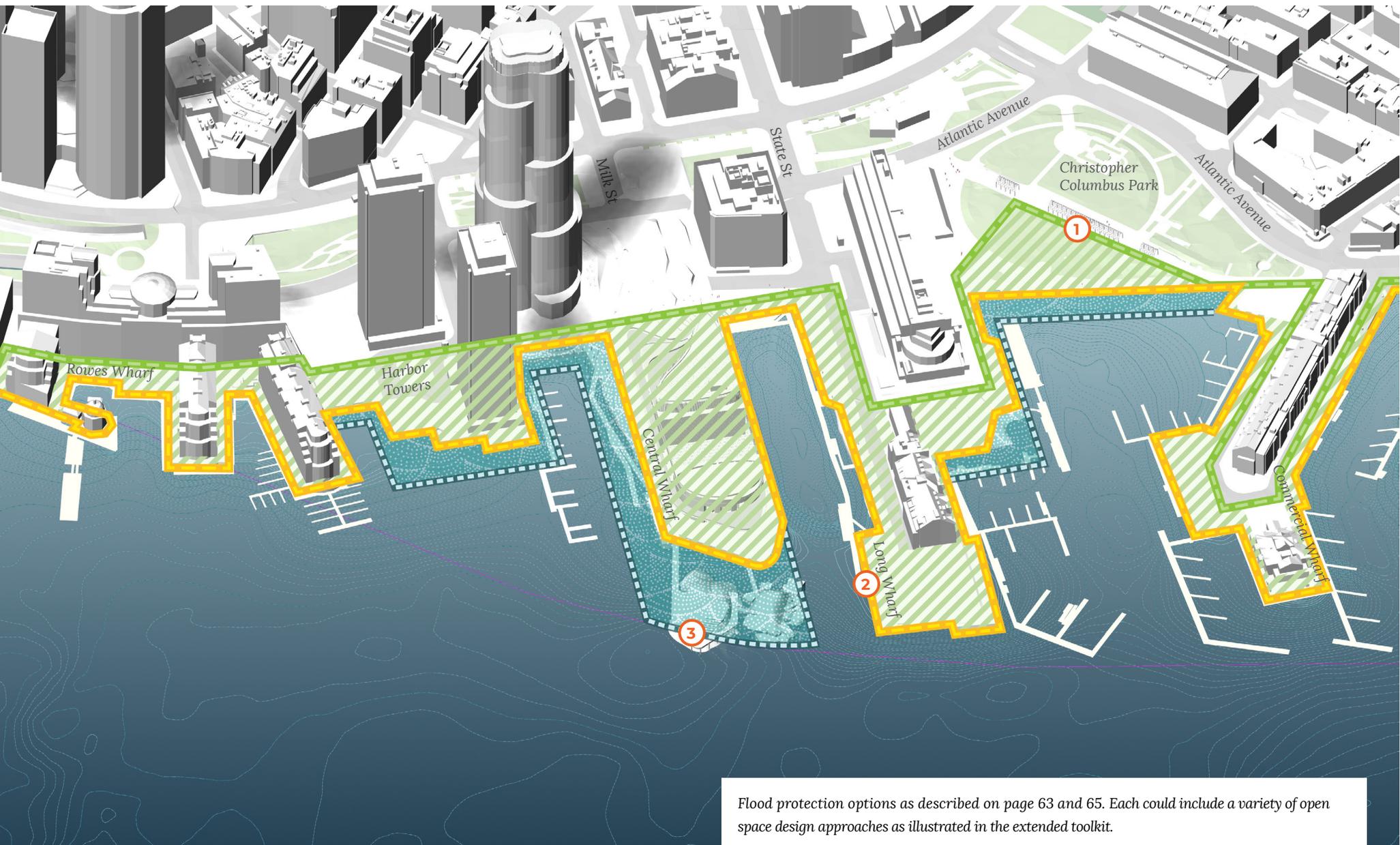
infrastructure in this sub-district with anticipation of increased future ridership. These structures will require significant coordination and could be a cause for increased time and cost required for implementation.

- » Coordination and impact on subway station and tunnel egress infrastructure could be a cause of increased time and cost required for implementation.

Option 1: This two-part flood protection system includes a slightly elevated waterfront condition and a higher inland line of defense which reaches the 40 inch modular DFE. This approach provides continued access to the water and may assist in access on and off the water where needed. The exact elevation of the lower waterfront edge can be determined based on access, anticipated design life of the intervention, costs, and the tolerance to flooding risks of assets remaining below the 40 inch DFE.

Option 2: The flood protection system is completed entirely at the water's edge, adapting the existing bulkhead wall to the required design flood elevation across the waterfront.

Option 3: Areas where outboard actions such as living shoreline or filled land may be required due to lack



Flood protection options as described on page 63 and 65. Each could include a variety of open space design approaches as illustrated in the extended toolkit.

of space at the existing edge or advantageous for ecological or social reasons are indicated. These may work alongside or in place of the alignments shown in 1 and 2 depending upon final design.

Key Stakeholders:

Downtown residents, New England Aquarium, Boston Harbor Now, Boston Harbor Cruises, Capital Properties, MBTA, Marriott, Chiofaro, Harbor Towers, Wharf District Council.

NEAR-TERM AND IMMEDIATE ACTIONS

The most immediate flood risk occurs in the stretch from the east side of Harbor Towers to the northern edge of Christopher Columbus Park including Long Wharf, Central Wharf and the New England Aquarium. With multiple property owners, significant marine transportation infrastructure and a vibrant public realm at risk, this area represents a complex set of conditions, will require ongoing coordination among property owners and both district wide and property level approaches to risk reduction. This area will benefit most from early catalytic action at Long Wharf and can serve as a demonstration of the types of solutions and organizational structures that other owner groups can build upon.

The actions here can be broken into three projects: These projects include:

- » Christopher Columbus Park and Long Wharf,
- » Central Wharf and New England Aquarium,
- » and Harbor Towers.

If envisioned as a coordinated effort these projects have the potential to transform this important civic area of Downtown into a resilient, accessible and inclusive public realm that sets an example for other cities and other areas in Boston. Each of these projects benefit today from on-the-ground-champions interested in building resilience, and, in most cases funding sources which can initiate further risk assessment studies and development of specific design proposals. These opportunities are outlined below.

Christopher Columbus Park

The Park is currently budgeted for improvements to the seawall, paving areas and play areas. It benefits from the continued support of The Friends of Christopher Columbus Park, a group which can help promote integration of park amenities with resilience infrastructure. Resilient design here should enhance

the relationship of the park to the waterfront, increase opportunities to experience the water while improvements to the park will require raising grade within the park boundaries and should consider allowing for a lower level Harborwalk, subject to intermittent future flooding, and a stepped viewing area to create a true sense of place along the waterfront.

Activity at Christopher Columbus Park is highly related to marine transportation activities and the neighboring Marriott hotel. It may be of greatest benefit to consider improvements to the park alongside the creation of a new park on the site of the current parking lot at the Chart House on Long Wharf (as outlined in the Downtown Municipal Harbor Plan). Programming, circulation, and flood protection along this stretch should be considered in unison.

Long Wharf

Owned by the City of Boston, Long Wharf is one of the City's waterfront destinations and serves as a water transportation hub taking people from Downtown to other waterfront neighborhoods, the Harbor Islands, and to North Shore and South Shore communities. Long Wharf floods regularly today on King tides and is the primary pathway for flood waters into the larger

downtown area. For this reason it is a critical site for catalytic action. Work here could be combined with Christopher Columbus Park in order to develop a contiguous solution that provides for access and programming in the public realm that exceeds the already tremendous potential it offers today. Solutions at Long Wharf will require close coordination with key stakeholders including Capital Properties, Boston Harbor Cruises, private marina owners, and Sunstone Properties as well as regular conversations with the New England Aquarium and Pembroke, owners of adjacent sites. The area will require continued marine access, harbor views and clear and coordinated pedestrian and vehicular access. Coordination with water transportation and marina operators prior to this effort will be beneficial to planning for programming, access, operations, and management.

New England Aquarium

The New England Aquarium has been considering the need for resilience efforts that promote public access to the waterfront and educate residents and visitors about the harbor and the impacts of climate change. “The Blueway Concept” is the name of their initiative. The Aquarium will continue to advance this concept further as part of a larger a flood protection solution.

Its advancement should tie into and be coordinated with the work being done by City of Boston, Harbor Towers, Pembroke, The Chiofaro Company, and Boston Harbor Cruises.

Harbor Towers

With very little room for raising elevations or implementation of other solutions along the northern edge of the Harbor Towers property, this site will likely trigger the need for outboard, in-water solutions. Discussions with property owners have indicated that they are already underway with building-level protection studies and very interested in collaboration with the City of Boston on implementation of site protections that would integrate with a district-level strategy. These building and site level efforts should be coordinated.

Rowes Wharf

Properties from Rowes Wharf South to Hook Wharf are subject to localized flooding with 21-40” of sea level rise. Rowes Wharf has completed a vulnerability assessment and has installed backflow preventers to date.

What is on the way?

Properties and stakeholders in the Downtown and Wharf District are taking measures to address flood risk.

Multiple properties are performing risk and vulnerability assessments. They are exploring various flood barrier systems and necessary building and utility retrofits.

The New England Aquarium (NEAQ) is completing its vulnerability assessment process and aims to start a fundraising campaign to renovate the build and the surrounding area.

The MBTA is performing several studies for the near term and long term flood protection solutions for the Blue Line Aquarium station.

With upcoming development in the area and funds secured via the Municipal Harbor Plan, there are opportunities to leverage open space improvements as catalyst projects.



Estimated Costs

The concept-level order-of-magnitude cost estimates below include major cost items for the primary coastal flood protection infrastructure only. The estimates are presented as a range of costs and include large contingencies due to the nature of this study. Within the ranges presented, the low end is reflective of option 1 while the high end is reflective of option 3 and option 2 falls within the ranges shown.

		LOW	HIGH
NEAR TERM	HARBOR TOWERS	\$ 4,800,000	\$ 8,000,000
NEAR TERM	CENTRAL WHARF AND NEAQ	\$ 17,900,000	\$ 29,800,000
NEAR TERM	LONG WHARF	\$ 27,900,000	\$ 46,400,000
NEAR TERM	C. COLUMBUS PARK	\$ 10,200,000	\$ 16,900,000
LONG TERM	ATLANTIC AVE.	\$ 600,000	\$ 1,000,000
LONG TERM	US COAST GUARD (SOUTH)	\$ 1,200,000	\$ 1,900,000
LONG TERM	ROWES WHARF	\$13,600,000	\$22,700,000

Properties between Rowes Wharf and Hook Wharf do not contribute substantially to a larger flood pathway and therefore solutions should be focused on self-protection in the near term and coordination across properties to prevent flooding in the longer term.

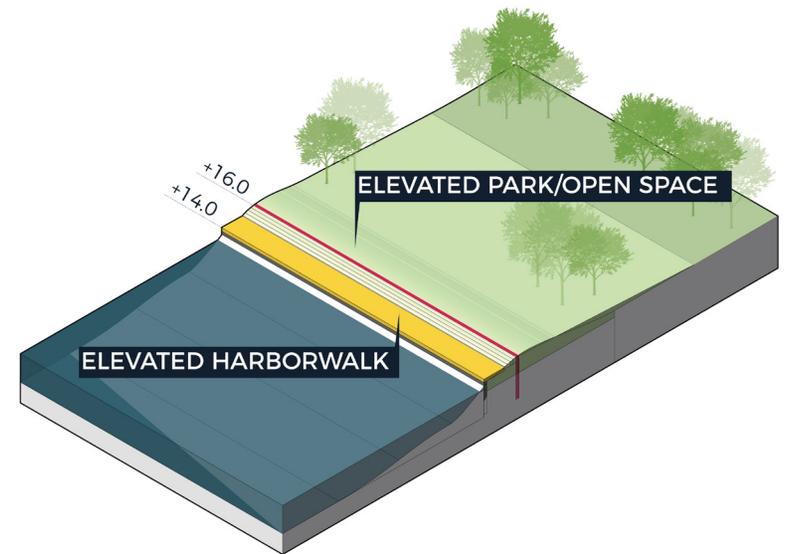
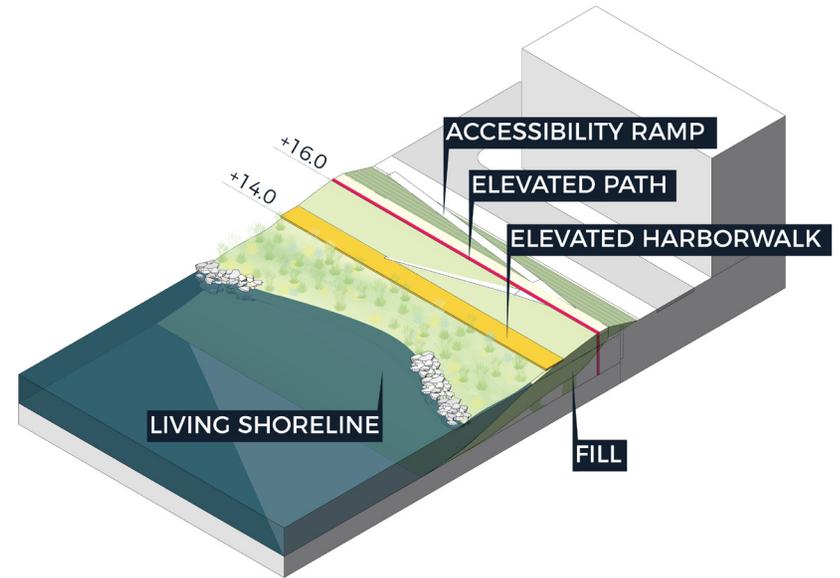
All three sub-districts have opportunities for nature-based approaches including elevated parks and open spaces and living shorelines.

LIVING SHORELINE

These living edges provide opportunities for habitat and education can provide wave attenuation where wave action poses greater risk. Locations for implementation will depend upon appropriate bathymetry and hydrologic conditions.

ELEVATED PARKS AND OPEN SPACES

In specific locations along the existing waterfront park spaces or underutilized open spaces can be improved and redesigned to function as a flood barrier. These could be designed as either soft, such as landscape with vegetation and passive recreation spaces, or hard, such as plazas, and stepped hardscapes.



NORTH END WATERFRONT

The North End Waterfront is characterized by the long and narrow buildings on piers and wharves that jut out from Atlantic Avenue and Commercial Street into the Harbor. Over time, each wharf functions as a distinct flood pathway from the waterfront onto Atlantic Avenue and Commercial Street, eventually linking up with the broader Downtown floodplain.

The uses on the wharves are mostly residential, with ground-level commercial spaces, marine uses, and offices. Ownership is complex, including multiple condo boards, marinas, City property, and private townhouses.

The current usable land area of the wharves contains many structural combinations: pier structures with buildings, historic fill with bulkhead, and terraced edges. Similarly each building is positioned differently in relation to the bulkhead and water. Many of the wharf buildings are an adaptive reuse of granite warehouses from the 19th century. Most were retrofitted as condominiums and commercial spaces around the 1970s-1980s. Battery and Burroughs Wharves have been constructed in the last 30 years on a new pier structure. This structure is higher than the average across the district and thus less prone to flooding in the near-term.

The preferred waterfront strategy in this area can include a combination of the approaches illustrated in the design variation appendix. Factors determining the approach will include structural stability of existing wharves and piers, design life of existing buildings and available space. Certain locations leave very little space for adaptation options without a drastic reconstruction of existing structures or the creation of new land beyond the bulkhead line, making this an area in which offshore options or long-term redevelopment including pier reconstruction should be considered.

Key considerations for successful implementation in this sub-district include:

- » The opportunity to improve the Harborwalk and the public space in this sub-district is more significant than in others with more robust public access.
- » In some locations buildings have been grandfathered into policy and regulations, any new construction will require permits and reconsideration of noncompliance with land use, size, and siting.

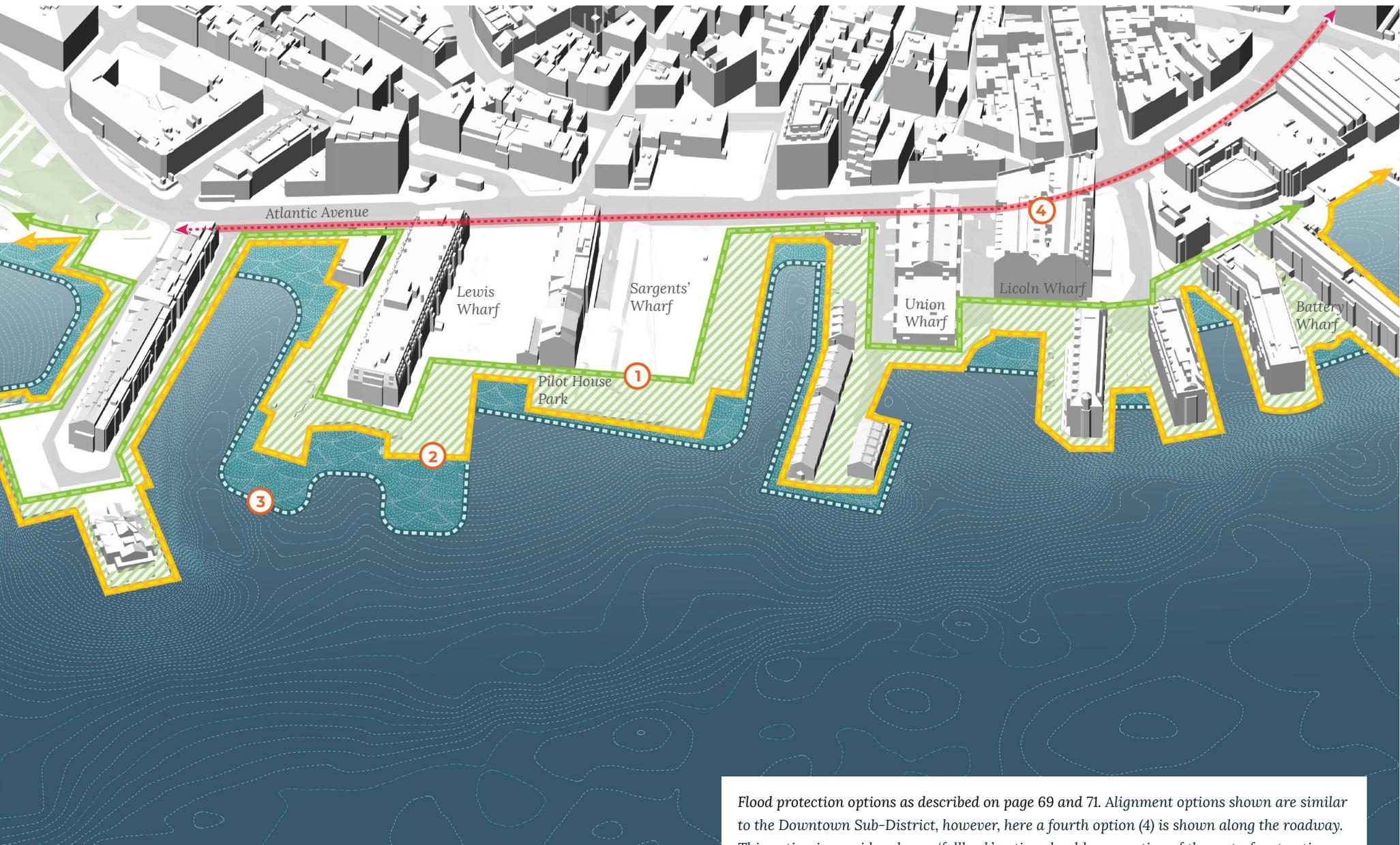
Key Stakeholders: North End residents, BPDA, USCG, Battery Wharf, Barr Foundation, Tavistock, multiple private property owners and condo boards.

Coastal resilience strategies shown are similar to the Downtown Sub-District, however, here a fourth option is shown along the roadway. This option is not preferred but will be utilized if key stakeholders are unable to reach agreement on another option or if regulatory challenges are insurmountable. Building level adaptations should be implemented with any option.

Option 1: This two-part flood protection system includes a slightly elevated waterfront condition and a higher inland line of defense which reaches the 40 inch modular DFE. This approach provides continued access to the water and may assist in access on and off the water where needed. The exact elevation of the new waterfront edge can be determined based on access, anticipated design life of the intervention, costs, and the tolerance of flooding risks to assets remaining below the 40 inch DFE.

Option 2: The flood protection system is completed entirely at the water's edge, adapting the existing bulkhead wall to the required design flood elevation across the waterfront.

Option 3: Areas where outboard actions such as living shoreline or filled land may be required due to lack of space at the existing edge or advantageous for ecological or social reasons are indicated. These may work alongside or in place of the alignment shown in 1 and 2 depending upon final design.



Flood protection options as described on page 69 and 71. Alignment options shown are similar to the Downtown Sub-District, however, here a fourth option (4) is shown along the roadway. This option is considered as a 'fallback' option should any portion of the waterfront option not be able to be completed.

Estimated Costs

The concept-level order-of-magnitude cost estimates below include major cost items for the primary coastal flood protection infrastructure only. The estimates are presented as a range of costs and include large contingencies due to the limited information available on existing conditions and future designs. Within the ranges presented, the low end is reflective of option 4 while the high end is reflective of option 3 and options 1 and 2 fall within the ranges shown.

		LOW	HIGH
NEAR TERM	COMMERCIAL WHARF	\$ 25,000,000	\$ 41,500,000
NEAR TERM	LEWIS WHARF	\$ 14,000,000	\$ 23,300,000
NEAR TERM	SARGENT'S WHARF	\$ 7,300,000	\$ 12,000,000
NEAR TERM	UNION WHARF	\$11,700,000	\$19,500,000
LONG TERM	BATTERY WHARF	\$17,100,000	\$28,500,000
LONG TERM	BURROUGHS WHARF	\$13,100,000	\$21,800,000

Option 4: Where a waterfront solution is not viable or able to be completed within the required timeline for district-wide protection, the alignment could be completed within the roadway through raising either the road itself or the bike path through the segment in which the waterfront option is not implemented.

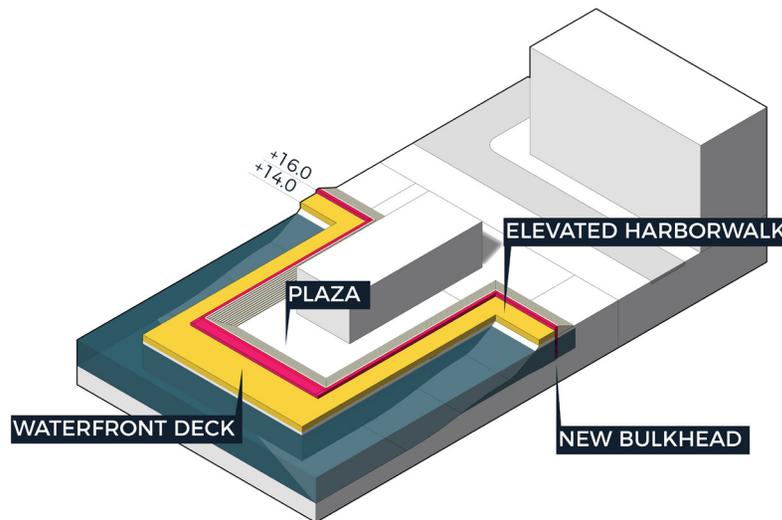
NEAR-TERM AND MID-TERM ACTIONS

This sub-district has already experienced flooding on its wharves and buildings from Commercial Wharf to Union Wharf. The first step in this subdistrict is to ask each individual property owner to conduct a risk assessment of their property if they have not already done so.

With approximately 9 inches of SLR (2030s) flood pathways will reach beyond the wharves themselves to cross Atlantic Avenue and merge with the Downtown floodplain. Thus, the district level protection measures in this sub-district are mid-term actions. However, planning for these actions is near-term as it will require significant collaboration and coordination and should begin as soon as possible with the aim of completion within the next five years. Continuation of the ongoing coordination between the City of Boston Office of Emergency Management (OEM) noted previously will be an important aspect of this planning work.

RAISED HARBORWALK

In all three sub-districts, the Harborwalk at the water's edge creates an opportunity for raising grades and integrating coastal flood protection into the public open space in many locations. Design approaches in these conditions may incorporate a raised seawall adapted to physical conditions or social functions. Varied design approaches are shown in the toolkit. Retaining a harborwalk at a slightly lower elevation and rising up to the DFE at its inland edge may help to retain physical and visual access to water. In locations where access to marinas or other docking facilities is needed, the wall design will need to include pedestrian and vehicular access. All access routes should be completed in accordance with ADA best practices and the Massachusetts Architectural Access Board (MAAB).



What is on the way?

Properties and stakeholders along the North End waterfront are taking measures to address flood risk.

Multiple properties are performing risk and vulnerability assessments. They are exploring various flood barrier systems and necessary building and utility retrofits. Properties previously impacted by floods have had to make repairs and retrofits to their properties including basements, building systems, and docks.

The team learned from information collected via stakeholder survey that several properties have flood prevention protocols in place.

Union Wharf below was impacted in 2018.



WEST END - NORTH END RESILIENCE SOLUTIONS

The West End - North End includes the area between the south embankment of the New Charles River Dam at Beverly Street to the Northern Border of US Coast Guard property where it meets Langone and Puopolo Park. Uses and ownership here consist of private condominiums, City parks, the Elliot Upper School, DCR parks and Steriti Memorial Skating Rink, and the US Coast Guard. The flood pathway at Lovejoy Wharf drives near-to-medium term flood risks in the local area, while flanking over the dam's south embankment and overtopping of the dam represent significant long-term risks.

The redesign of Langone and Puopolo parks, being completed at the time of this report, will improve coastal resilience along this portion of the waterfront. The parks have been designed to withstand 21 inches of sea level rise, with the ability to be adapted to higher flood levels in the future in accordance with the anticipated renovation cycle of the park. These improvements provide a model for other open space improvements in the sub-district and beyond, such as the DCR park space planned for the south embankment of the New Charles River Dam.

Key considerations for successful implementation in this sub-district include:

- » This sub-district is not within the Magenta Zone, meaning any outboard approaches will be subject to Army Corps of Engineers permitting and regulatory restrictions.

Key Stakeholders: West End and North End residents, Related Beal, DCR, State Police, and the US Coast Guard.

Options shown are similar to the Downtown and North End Sub-Districts. Like in the North End, a fourth option is shown along the roadway. Again, this option is considered a 'fallback' strategy should any portion of the waterfront option not be able to be completed. Building level adaptations should be implemented with any option.

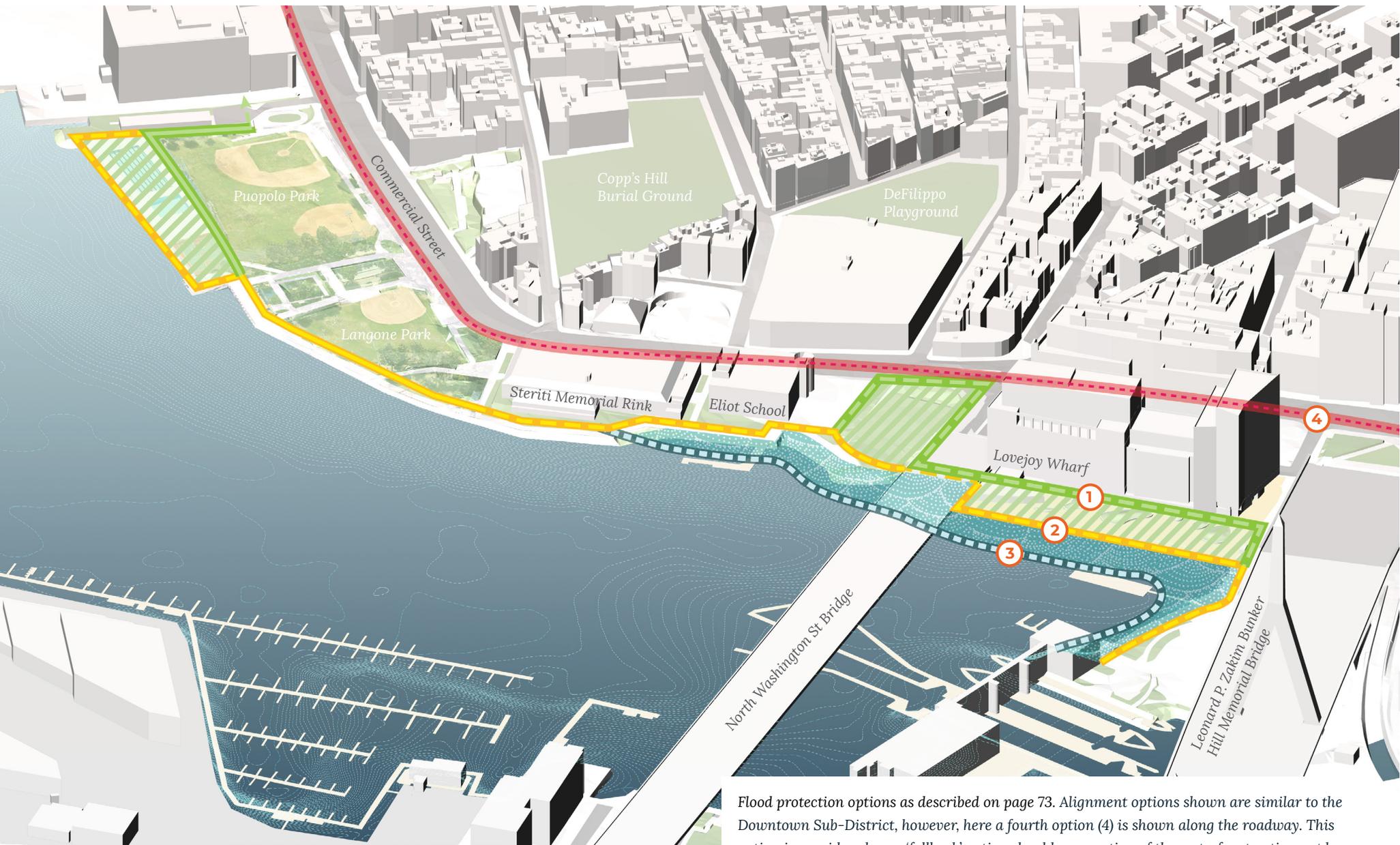
Option 1: This two-part flood protection system includes a slightly elevated waterfront condition and a higher inland line of defense which reaches the 40 inch modular DFE. This approach provides continued access to the water and may assist in access on and off the water where needed. The exact elevation of the new waterfront edge can be determined based on access, anticipated design life of the intervention,

costs, and the tolerance of flooding risks to assets remaining below the 40 inch DFE. The solid green line illustrates areas in Langone and Puopolo park which have already been elevated and are adaptable to the 40 inch DFE.

Option 2: The flood protection system is completed entirely at the water's edge, adapting the existing bulkhead wall to the required design flood elevation across the waterfront. The solid yellow line illustrates areas in Langone and Puopolo park which have already been elevated and are adaptable to the 40 inch DFE.

Option 3: Areas where outboard actions such as living shoreline or filled land may be required due to lack of space at the existing edge or advantageous for ecological or social reasons are indicated. These may work alongside or in place of the alignment shown in 1 and 2 depending upon final design.

Option 4: Where a waterfront solution is not viable or able to be completed within the required timeline for district-wide protection, the alignment could be completed within the roadway through raising either the road itself or the bike path through the segment in which the waterfront option is not implemented.



Flood protection options as described on page 73. Alignment options shown are similar to the Downtown Sub-District, however, here a fourth option (4) is shown along the roadway. This option is considered as a 'fallback' option should any portion of the waterfront option not be able to be completed.

Estimated Costs

The concept-level order-of-magnitude cost estimates below include major cost items for the primary coastal flood protection infrastructure only. The estimates are presented as a range of costs and include large contingencies due to the limited information available on existing conditions and future designs. Within the ranges presented, the low end is reflective of option 4 while the high end is reflective of option 3 and options 1 and 2 fall within the ranges shown.

		LOW	HIGH
MEDIUM TERM	LOVEJOY WHARF	\$ 8,800,000	\$14,700,000
MEDIUM TERM	NEW CHARLES RIVER DAM	\$ 3,400,000	\$ 5,700,000
LONG TERM	PRINCE STREET PARK (DCR)	\$ 800,000	\$ 1,300,000
LONG TERM	LANGONE PARK	\$ 700,000	\$ 1,200,000
LONG TERM	PUOPOLO PARK	\$ 600,000	\$ 1,000,000
LONG TERM	COMMERCIAL ST AT USCG	\$ 4,900,000	\$ 8,100,000

NEAR-TERM ACTIONS

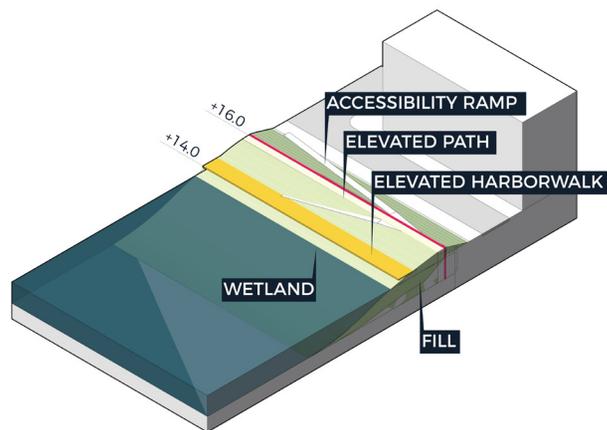
Lovejoy Wharf

With 9 inches of sea level rise, Lovejoy Wharf and immediately adjacent lands abutting the New Charles River Dam are at risk of flooding and become a pathway, via Beverly Street, to further flooding inland of these waterfront sites. Efforts to reduce the flood risk will require coordination between the waterfront property owners and occupants. These include private property owners, DCR and the Marine Police. To maintain the effectiveness of flood protection over the long-term, the dam will also need to be adapted.

Solutions at Lovejoy Wharf are complicated by the position of the waterfront buildings contiguous to the seawall below. There is little to no room to elevate without complete redevelopment or building outboard from the existing seawall. An outboard solution at this location could advance the current and generally successful pilot of the Seaport to North Station Ferry at this site and should include social and ecological benefits through landscape and clear, public waterfront connections to the DCR properties and Langone and Puopolo Parks to the North.

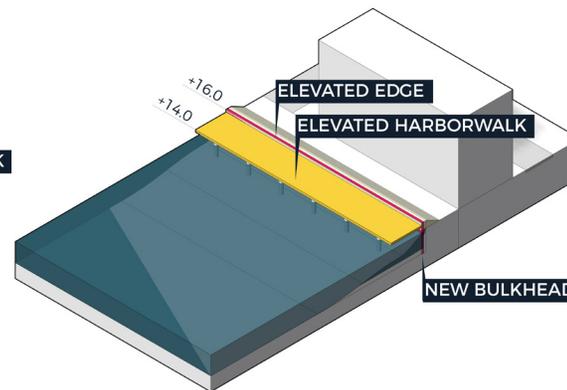
CONSTRUCTED LAND

At sites with limited space (adjacent structures or utilities) or structural constraints, building a new bulkhead with new constructed fill behind it can be the preferable option. This new land presents opportunities for an integrated flood protection system, public co-benefits in the form of new open space, stormwater retention, natural shoreline and habitat and aesthetic value. Portions of this new land must be elevated to the DFE to provide comprehensive flood protection.



EXTENDED OVER WATER

In locations where space does not allow for the required width of the Harborwalk, the design of the flood barrier can include an overhanging pier Harborwalk similar to the recently completed Pier 4 in South Boston. Such a system can provide social activities and allow for water dependent uses with access points to the water. Providing public access on a lightweight structure could ease the load on the underground structure.



What is on the way?

The City and DCR (Massachusetts Department of Conservation Recreation) are collaborating on resilient concepts and solutions at waterfront properties under DCR jurisdiction along the Boston waterfront.

Properties and stakeholders along the West End - North End waterfront are taking measures to address flood risk including performing risk and vulnerability assessments and exploring various flood barrier systems as well as building level and utility retrofits.

Langone Park winter 2018 (below)





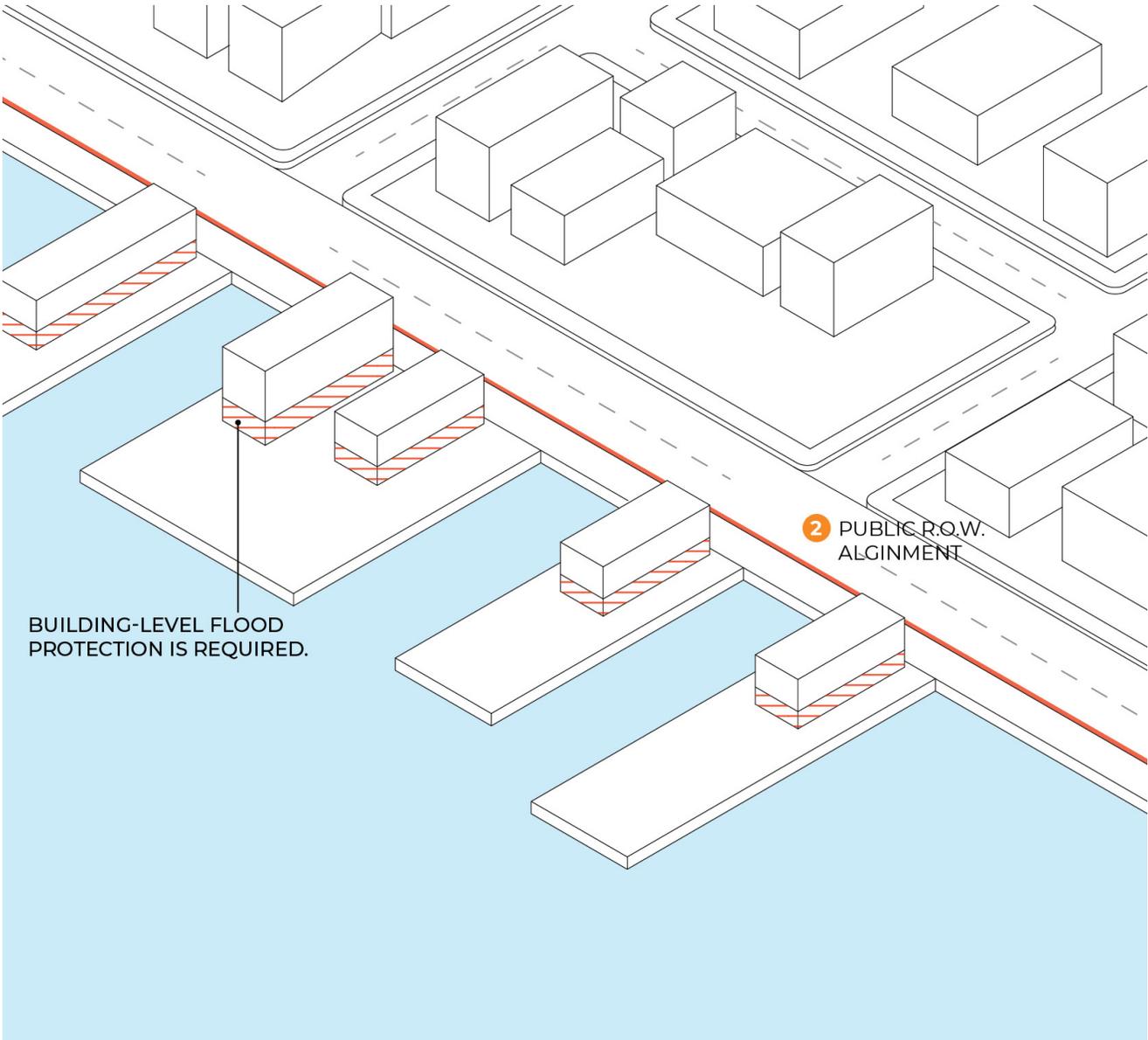
05 IMPLEMENTATION ROADMAP

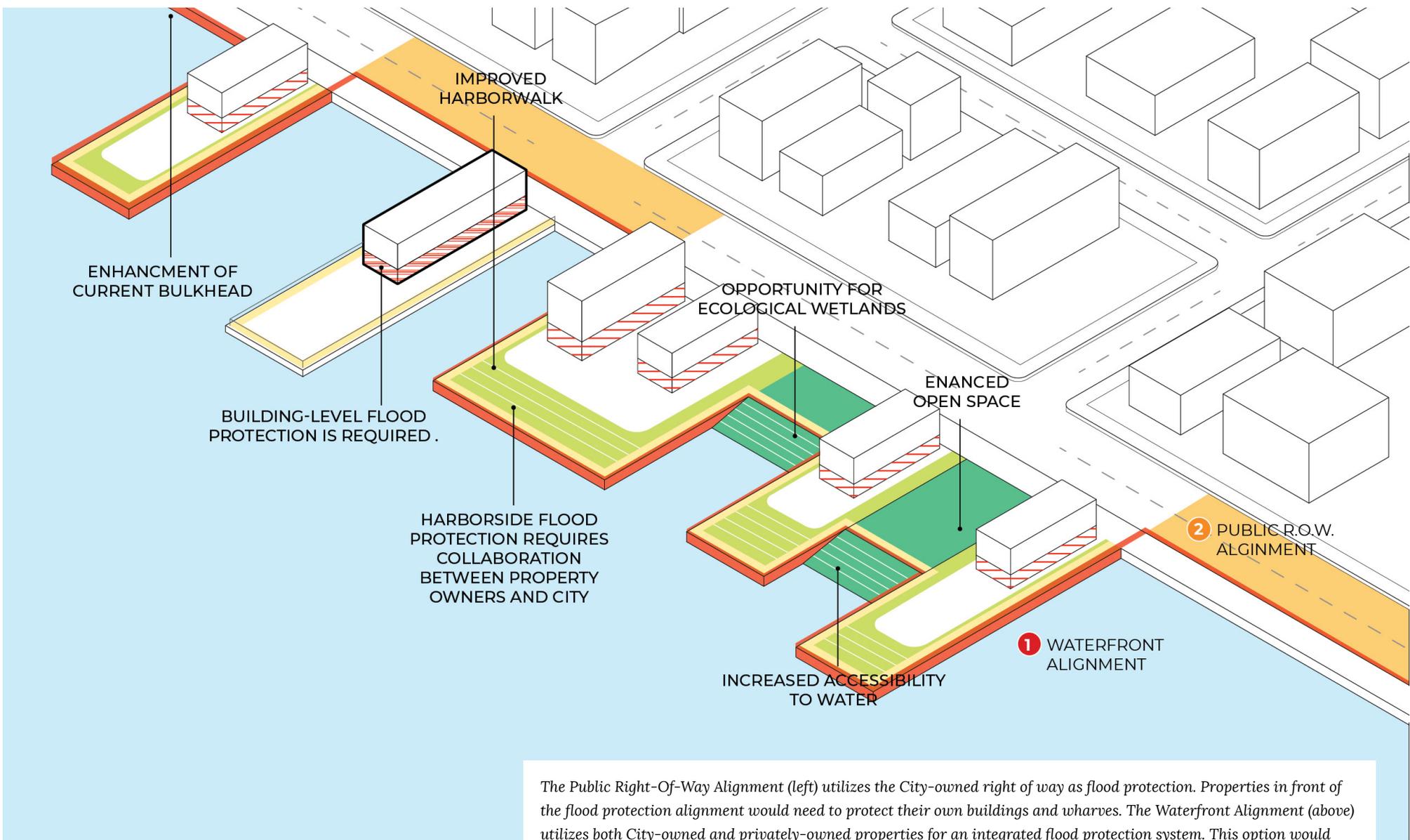


IMPLEMENTATION ROADMAP

NEXT STEPS

This chapter provides details on timelines and phasing. In Downtown and the North End, as compared with other neighborhoods, the expanse of the floodplain and the scale and relative immediateness of risk require early implementation of large portions of the system. This study includes only an initial look at some of the conditions important for final design and implementation of coastal resilience strategies. Immediate next steps include more detailed analysis of conditions and risks at the individual property level.





IMPLEMENTATION PRINCIPLES

For the district-wide strategy to be effective, it must be a contiguous system. To simplify implementation and prioritize efforts, the coastal resilience solutions can be divided into smaller segments based on flood pathways. This approach creates discrete projects that are more manageable than the whole which reduces project implementation risks, the cost and complexity of implementation, and thus increases feasibility. These completed segments will have to function as one system with coordinated management.

At every level, from district to individual property, redundancy is critical for long term success. Meaning, the implementation of multiple measures must support one another. In addition to the waterfront protections described previously, building-level protection and sub-surface protections will be critical aspects of implementation.

Building-scale measures such as floodproofing of individual structures are a critical aspect of adaptation at the property level and should be completed in addition to implementation of district scale flood barrier systems. These strategies are outlined in the 2019 BPDA Coastal Flood Resilience Design Guidelines.

Subsurface conditions must be analyzed and addressed in any building, site or district level protection system. As noted in Chapter 03, porous soils, leaky seawalls, groundwater, Combined Sewer Outfalls, utilities and transit tunnels can all be areas of risk which design solutions need to take into account. Raised elevations will need to be coordinated with stormwater management strategies to allow for flow of inland waters out through the protection systems. In addition, utility services will need to be coordinated between owners and the City of Boston to ensure ongoing provision of and maintenance access to basic services.

IMPLEMENTATION PHASING

The Boston Harbor Flood Risk Model (BHFRM) and flood projections as described in Chapter 03 lead to prioritization of action by the risk threshold: near-term by 2030 (9 inches SLR), mid-term by 2040 (9-21 inches SLR), long-term by 2050 (21 inches SLR). These time frames are not defined by the planning sub-districts. For example, near-term actions span the Downtown and Wharf District and the North End Waterfront at Commercial Wharf. Coordination at these intersections between sub-districts will be important to successful implementation. While the timeline for action is defined based on flooding projections,

the prioritization of a solution may also be based on additional factors such as asset conditions, vulnerable populations, and regional impacts.

Ongoing repairs and the design life of existing structures may also impact the sequencing of implementation. Buildings and sites require ongoing repairs and reconstruction, especially in flood prone environments. Consideration of the level of investment in ongoing repairs can inform timing and implementation of site-level and district-wide solutions. Over the life cycle of each property or asset, the owner will invest in repairs of the structure, bulkhead (if applicable), and impacts of settlement or subsurface seepage. Sea level rise, wave action, and increasing frequency of extreme weather events will create the need for more frequent repairs and maintenance of the bulkhead and ground and fill stabilization. These maintenance considerations may inform timing of initial investment in district level strategies as well as the feasibility and cost of designing to the modular DFE during initial construction.

Implementation of protections that reach the higher, modular, design flood elevation initially or which are easily adapted to higher elevations should be prioritized. This will minimize overall construction

impacts to waterfront uses by limiting repeated reconstruction activities as sea level rises.

PUBLIC-PRIVATE PARTNERSHIPS

As property owners seek to mitigate flooding on their parcels, close coordination with adjacent owners, utilities, and regulators who have jurisdiction will be required. This coordination process is crucial to the successful implementation of this plan. Property owners must work with the agreed upon design flood elevation, align their construction activities and cost contributions, and define and coordinate operations and maintenance responsibilities. The City will facilitate this negotiation process to coordinate with property owners and longer-term operations, maintenance, and jurisdiction planning.

In some cases, in order to secure public funding sources, the flood barrier will need to be managed and maintained by a public agency and potentially sited on land with public interest. Negotiation around jurisdiction and easements for ongoing management needs to occur as part of the design and funding process.

BACKUP MECHANISM

In the case that any properties are not willing or able to participate in the waterfront protection systems within the timeframe required, the City and neighboring properties will need to implement a backup option. The spine strategy, which utilizes the City-owned right of way, serves that purpose. The four design strategies, outlined in Chapter 04, are not mutually exclusive and can be implemented in portions as required with some limits based on roadway geometry and heights required for protections.

ENABLING ENVIRONMENT

There are six primary factors that will allow for the successful implementation of this plan: governance, regulations, planning, incentives, collaboration, and right of way. The City of Boston will lead the development and oversight of these factors.

Waterfront Properties Feasibility Considerations

To adequately understand and address the issues that can be encountered when implementing coastal resilience strategies, detailed vulnerability and feasibility analysis is necessary. This is especially true for properties located along the waterfront in Downtown Boston and the North End, many of which are built directly adjacent to or over water. Property owners currently undertaking resilience studies, such as the New England Aquarium, have identified a range of issues and vulnerabilities that will inform the ultimate implementation of flood protection measures. Examples of the types of climate resiliency considerations for properties on the waterfront are:

- » *Condition of seawalls and pier structures*
- » *Ability of building foundations and walls to withstand the hydrostatic pressure of flood waters*
- » *Interior drainage to manage stormwater upland of coastal resilience infrastructure*
- » *Integration of coastal resilience solutions into the public realm and public access requirements*
- » *Potential disruption of business operations during the construction of coastal resilience infrastructure*
- » *Evaluation of complex utility and drainage networks that can provide flood pathways into buildings and the landside of coastal resilience infrastructure*
- » *Coordination of tie-ins between adjacent properties*

Regulatory Considerations

Current regulatory considerations to coastal resilience design strategies:

- » *Categorical restrictions on fill may limit options in space-constrained areas*
- » *Impacts to wetlands resources and mitigation requirements present permitting challenges for large-scale fill projects*
- » *There is a possible conflict between protection of environmental resources and permitting a fill project for flood protection*
- » *The Massachusetts Building Code, MA Wetlands Protection Act*, and current Flood Overlay Zoning requirements rely on historic FEMA flood zones based on past, not future, flooding*
- » *Climate change resilient or flood protection projects don't fit into current project categories under many regulations related to the use of fill*

**The Local Wetlands Ordinance passed in December 2019 does take into account the future floodplane and resilience. Regulations will be developed in the coming year.*

Governance

Early in implementation, responsibilities and share in costs should be determined. Additionally, ongoing maintenance of flood protection systems must be determined. In order for a coordinated system to work, all parties involved must have the same understanding as to how this coordination will be achieved. A clear structure for determining cost sharing should emerge through implementation to help property owners begin to plan and coordinate with adjacent properties.

Regulatory

Solutions for flood protection must meet the requirements of City, State, and Federal regulations and policies. With increased understanding of sea level rise risks and solutions, there is an opportunity to update regulations to include resilience at all scales of development while maintaining the original mission of these regulations (e.g., to protect the environment). Many regulations were written decades ago and did not anticipate the potential impacts of sea level rise, the consequences of warming oceans, or the range of solutions that might be required to reduce flood risk. As our understanding of these issues evolves, thoughtful updates to

existing regulations could clarify and streamline the permitting process for proposed resilience strategies. These changes could have impact from individual buildings to neighborhoods to the entire City while maintaining the original mission of the regulations (e.g. environmental protection).

Ensuring that City, State, and Federal regulations allow for creative approaches to coastal resilience and establishing minimum standards will require action and coordination throughout all levels of government. Furthermore, as the City advances specific design solutions, we may discover more flexibility in existing regulations than was initially apparent. The City will continue to collaborate with State and Federal jurisdiction on regulatory issues.

The types of permitting and regulatory timeframes that will influence decisions in the Downtown and North End are dependent upon the following factors:

- » Impact to the existing waterfront and degree of intrusion on watershed.
- » Property ownership (e.g. public or private).
- » The regulatory designation of the existing area (e.g., historic water dependent use, Chapter 91).

Coastal resilience design strategies in Downtown and the North End will likely require local Conservation Commission approval, State level waterways and water quality approval.

In some cases outside the Magenta Zone, Federal permits from the U.S. Army Corps of Engineers (USACE) under the Clean Water Act will be required. Other select sites may require Boston Landmarks Commission and the Massachusetts Historical Commission approval. Solutions which require placing fill material in the water and flood control projects in navigable waters are the approaches with the most significant permitting and regulatory challenges. In some areas, these may be difficult to avoid or may be the preferred solution due to significant public access benefits and potential environmental improvements. These benefits will need to be analyzed relative to the regulatory challenges and timelines required to satisfy them.

Planning

Initial planning measures will need to be undertaken in order to ensure implementation strategies continue to be consistent with broader city-wide goals and needs. The recently completed Downtown Municipal Harbor Plan sets up parameters and

funding mechanisms for some sites within the study area to pursue coastal resilience strategies. This plan should continue to act as a reference and guide. The BPDA has completed Flood Resilient Building Guidelines and is currently working on a Flood Resiliency Zoning Overlay District. The intent of these efforts is to promote best practices for flood resistant design measures to ensure development in areas vulnerable to current and future flooding are prepared for potential coastal flood hazards. They will also provide the City with regulatory tools to better influence, guide, and streamline resilience action.

Resources

Developing resources for property owners will aid in the creation of an environment that supports implementation. This could include a series of legal clinics to advise waterfront property owners on how to establish easements, financing, maintenance agreements, vehicles to implement projects with neighboring properties (or even within their own condo association) and a property owner toolkit with checklists, template agreements, and estimated damages and costs.

Priority of implementation is based on floodplain extent and frequency of expected flood impacts. Actual timing will be affected by:

- » *Partnerships and collaborations*
- » *Planned projects and development cycles*
- » *Vulnerable assets and population*
- » *Other infrastructure improvements*
- » *Regulations and policy - coordination with authorities*
- » *Social, environmental, economic, and recreational needs*
- » *Funding availability*

Most actions in Downtown and the North End should be completed by the 2050s based on current sea level rise projections. Opportunities to speed up implementation should be taken wherever possible.

Implementation Working Groups

A series of implementation working groups, organized geographically, should be set up. An support structure for property owners to join these efforts would be beneficial. This could include a series of legal clinics to advise waterfront property owners on how to establish easements, financing, maintenance agreements, vehicles to implement projects with neighboring properties (or even within their own condo association) and a property owner toolkit with checklists, template agreements, estimated damages and cost. These groups would also be an important opportunity for adjacent property owners to collaborate on issues of design and elevation continuity.



Open House #2 presentation in July 2019.

Collaboration

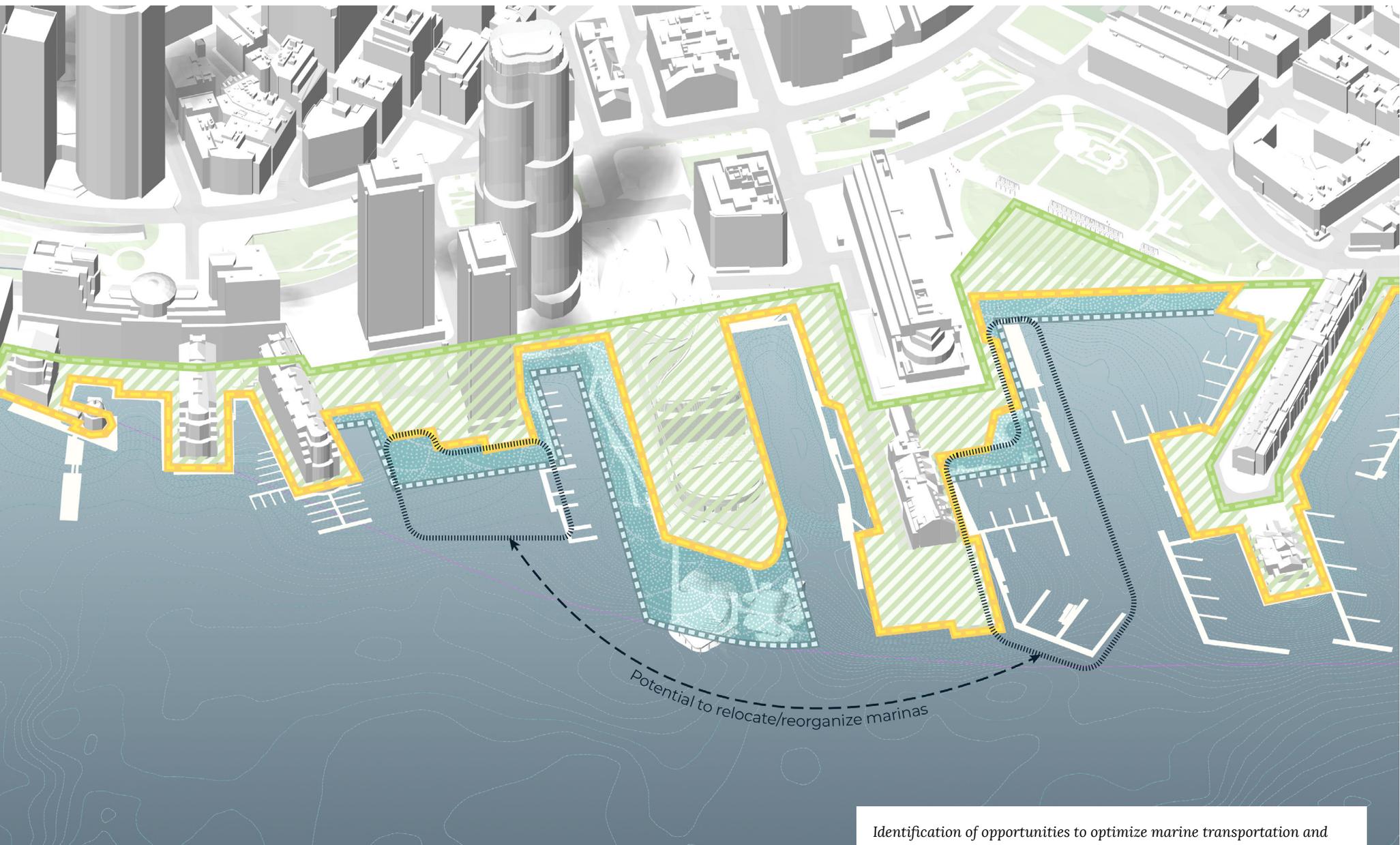
The stakeholder engagement process for this report was dedicated to setting up a collaborative dialogue between neighbors about their assets. We heard that the majority of stakeholders preferred strategies integrated at the water's edge rather than one completed within the right of way alone. To achieve this preferred solution and protect the neighborhood from storm surge and sea level rise, continued collaboration between property owners is essential. Building strong partnerships will create multiple opportunities for better protection, improved access, increased property value and commercial activity. In the creation of district-scale plans and sub-district level implementation, the continuity of the system, and its reliability, is dependent on the nodes of collaboration between adjacent properties, between City and State agencies (in particular at the jurisdictional edges where policy and oversight overlap), and between all owners, regulators, utility owners, and operators.

Focus groups held during the planning process revealed that some of the properties in the Downtown and North End have started the evaluation and design of potential projects for implementation.

During these focus group meetings, a desire to integrate these plans in order to achieve district scale resilience emerged. In each of the sub-districts, a set of one or more implementation coordination groups should be set up and regular meetings conducted in collaboration with the City, property owners, and representatives from engineering and design teams working on site or sub-district level analysis and implementation. Issues to be addressed in these ongoing conversations should include; financing, negotiation of public access and jurisdiction, public utilities, operations and maintenance, liability, and continuity and quality of design across projects.

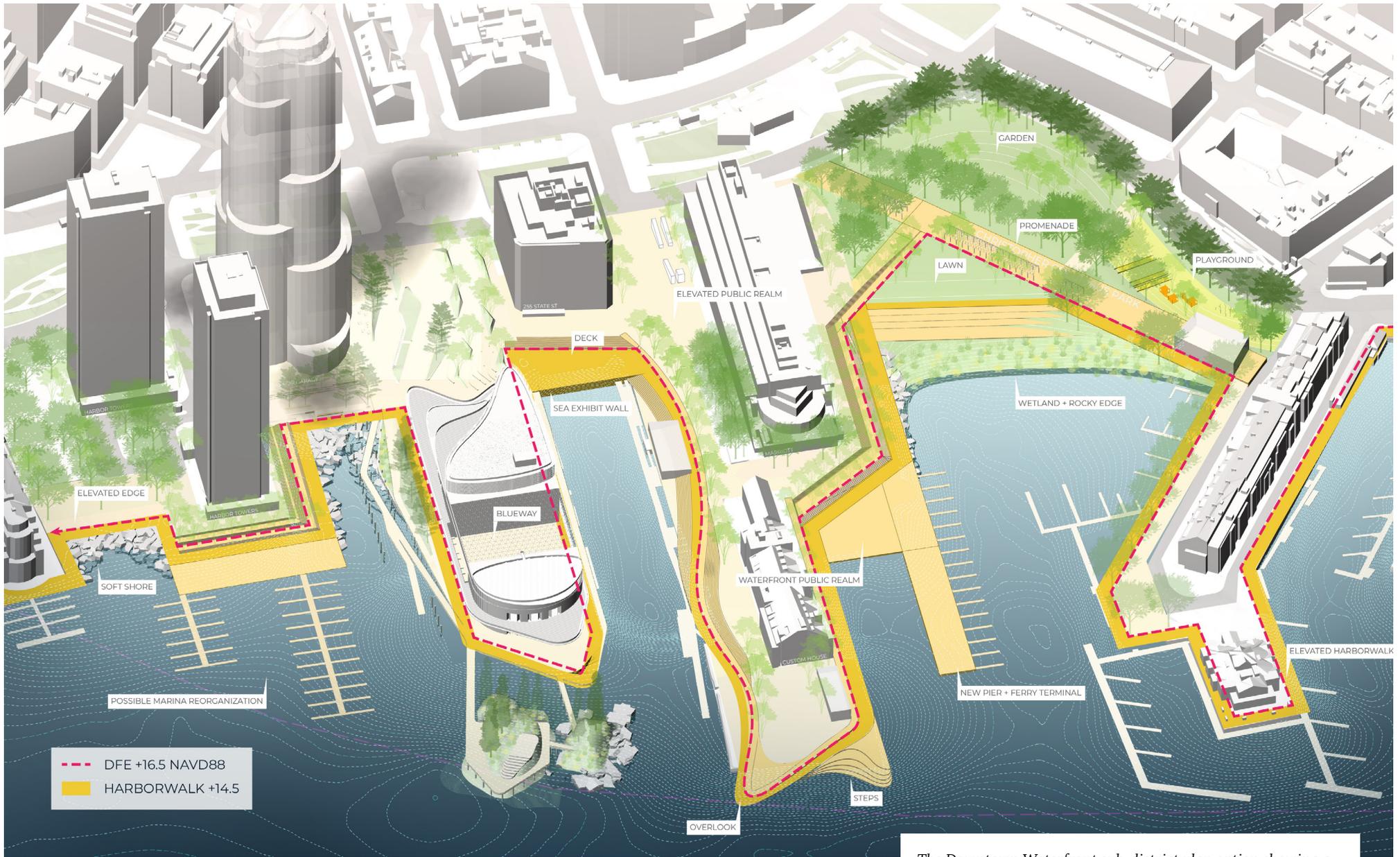
Right-of-Way

Ongoing access for operations and maintenance is critical to assure the function of a district-scale-flood-protection-system. If one section of the protection system is not properly maintained, the effectiveness of the entire system could be compromised. Therefore, agreements regarding the right of way will need to be made early on between required parties.

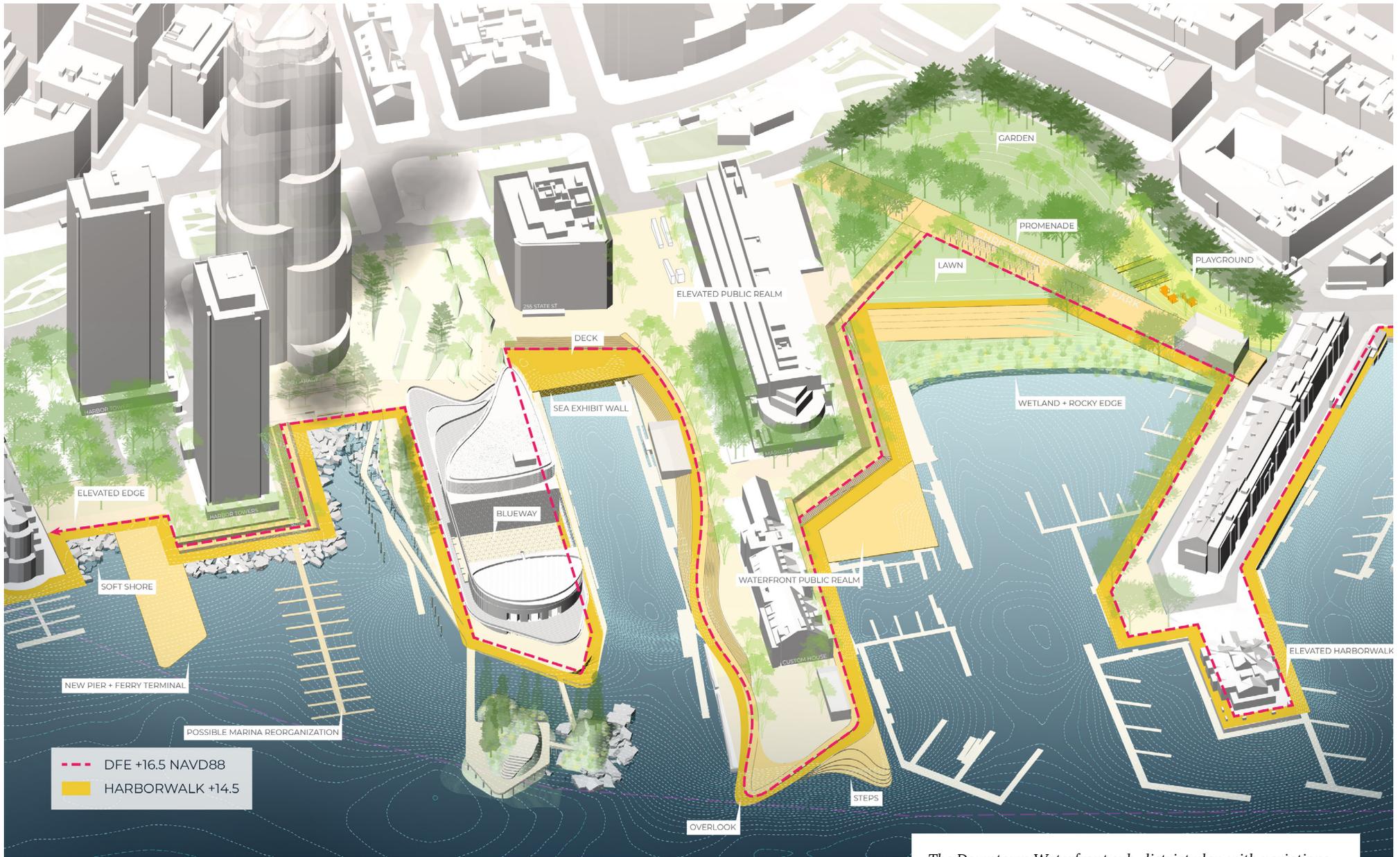


Potential to relocate/reorganize marinas

Identification of opportunities to optimize marine transportation and marina sites will be critical to guide implementation of the proposed coastal resilience solutions and coordinate usage during construction.



The Downtown Waterfront sub-district plan option showing a dock for marine transit at the historic site of T-Wharf.



The Downtown Waterfront sub-district plan with variations of dock and marine transit locations.

IMPLEMENTATION TIMELINE

Addressing near term flood impacts requires immediate action. The Downtown and North End waterfront have already experienced coastal flooding under extreme weather events. FEMA currently identifies a significant section of the waterfront as having over 1 percent (1 in 100) annual chance of flooding, a level of risk which the National Flood Insurance Program (NFIP) requires new development and redevelopment to be protected. With 9 inches of sea level rise (2030s) many of the waterfront properties and some inland areas off Long Wharf and Central Wharf will have a 10 percent (1 in 10) or greater annual chance of flooding.

To reduce this risk, immediate actions need to be taken at Long Wharf. Additional near-term resilience actions across the district should be completed by 2030. Mid-term actions are those that should be completed over the next 20 years. Long-term actions are those that can be completed in the 2040s and beyond. Long-term strategies should be reevaluated periodically as sea level rise projections are updated.

Near-term actions include the stretch of Downtown from Harbor Towers through Central Wharf, Long Wharf and Christopher Columbus Park as well as Lovejoy Wharf in the West End-North End Sub District. These specific actions are described in Chapter 04. Waterfront properties from Christopher Columbus Park north to Union Wharf are currently inundated in large storm events and will require self protection in the short-term with planning for district scale protections getting underway within the next five years.

The majority of coastal resilience solutions in Downtown and North End, including Long Wharf, Central Wharf, Harbor Towers, Christopher Columbus Park, Commercial Wharf, Lewis Wharf, Sargents Wharf, Union Wharf, and Atlantic Avenue should be in place by 2030.

Sites with recommended long-term actions include USCG properties, Battery Wharf and Burroughs Wharf, Hook property and Rowes Wharf. Properties from Rowes Wharf South to Hook Wharf do not contribute to a larger flood pathway and therefore will require only self-protection and coordination across properties to prevent flooding of each other.

This may include a simple raised Harborwalk and bulkhead. Long-term solutions may also include modifications to near- and mid-term solutions and evaluation of protections currently under construction in Langone and Puopolo Parks.

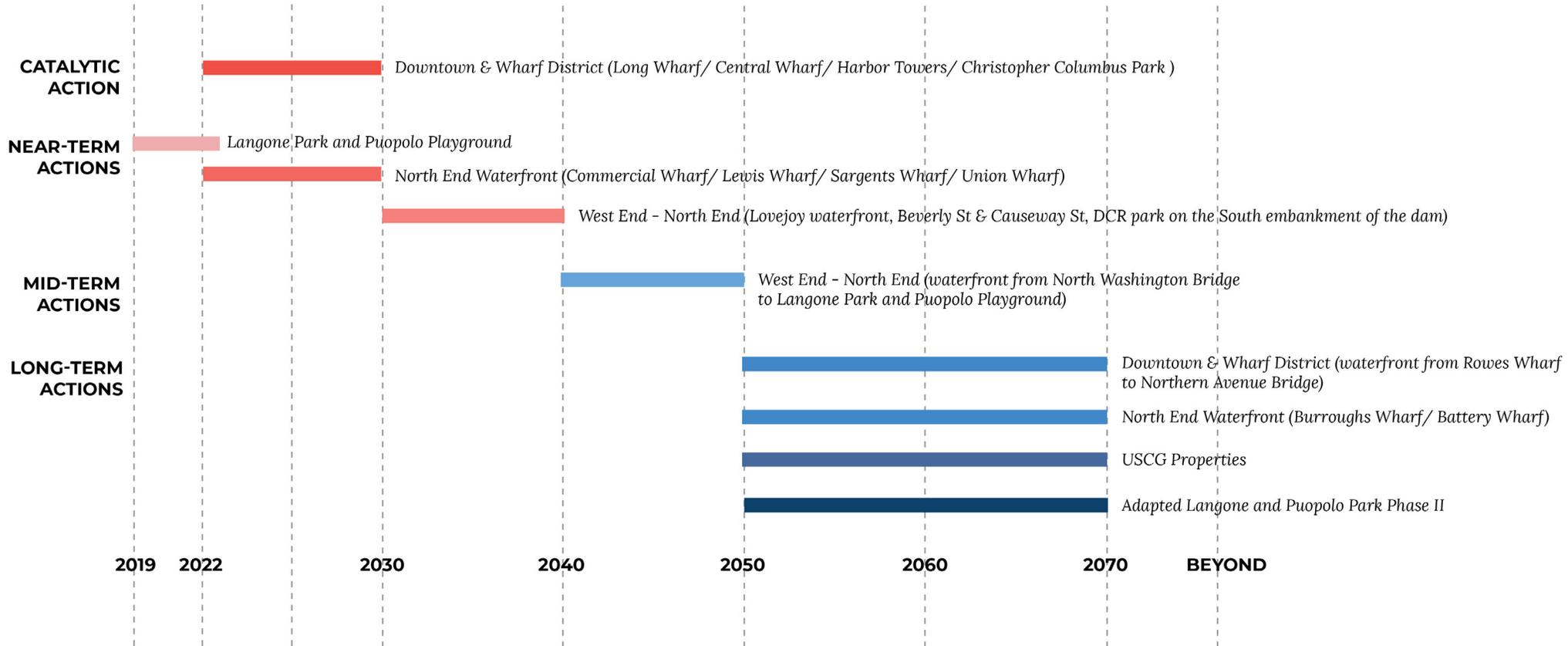
PRIVATE PROPERTY RESILIENCE STRATEGIES

For the properties waterside of Atlantic Avenue and Commercial Street, 9 inches of sea level rise (2030s) will bring an increase in the frequency of tidal flooding. While the flood risk and potential damage is anticipated to have a short duration and remain restricted to the wharf areas, the impact on private property including flooding of basements, mechanical systems, and parked cars, as well as limiting ground floor access, business disruption, and the structural stability of the wharves will result in recurrent losses.

Therefore, property-level actions are critical regardless of the district-level design strategy. These actions create redundancy in the system and allow property owners to protect critical assets in advance of implementation of district-wide protections.

RECOMMENDED TIMELINE

Recommended phasing plan for coastal resilience solutions in the Downtown and North End study area.
 Both costs and phasing plans are estimates and recommendations only, and should not be used for detailed planning.



Timeline

The timeline presented here is based on when flooding is expected to occur in a given project area, current conditions, the complexity of proposed solutions, and on when flood protection needs to be completed. The length of time allotted for implementation is determined by working backwards from the date by which protection is required. Then the timing of permitting and construction are estimated taking into account time for assessment, design, property ownership, and partnership agreements for easements and collaborations.

Projects located on existing land along the shoreline are likely to be more easily permitted than projects in or over the water. Modifications to historic seawalls will also require additional coordination and regulatory review. To some extent, tasks may be performed concurrently or may overlap, particularly agreements, funding, design, and permitting. Timeframes for specific projects will be determined through more detailed planning, design, and construction scheduling.

Projects will require private property agreements and contracts, as appropriate, as well as permitting through

the Massachusetts Environmental Protection Agency, United States Army Corps of Engineers (outside the Magenta Zone), Boston Conservation Commission, 401 Water Quality Certification, and Chapter 91.

LONG-TERM STRATEGIES

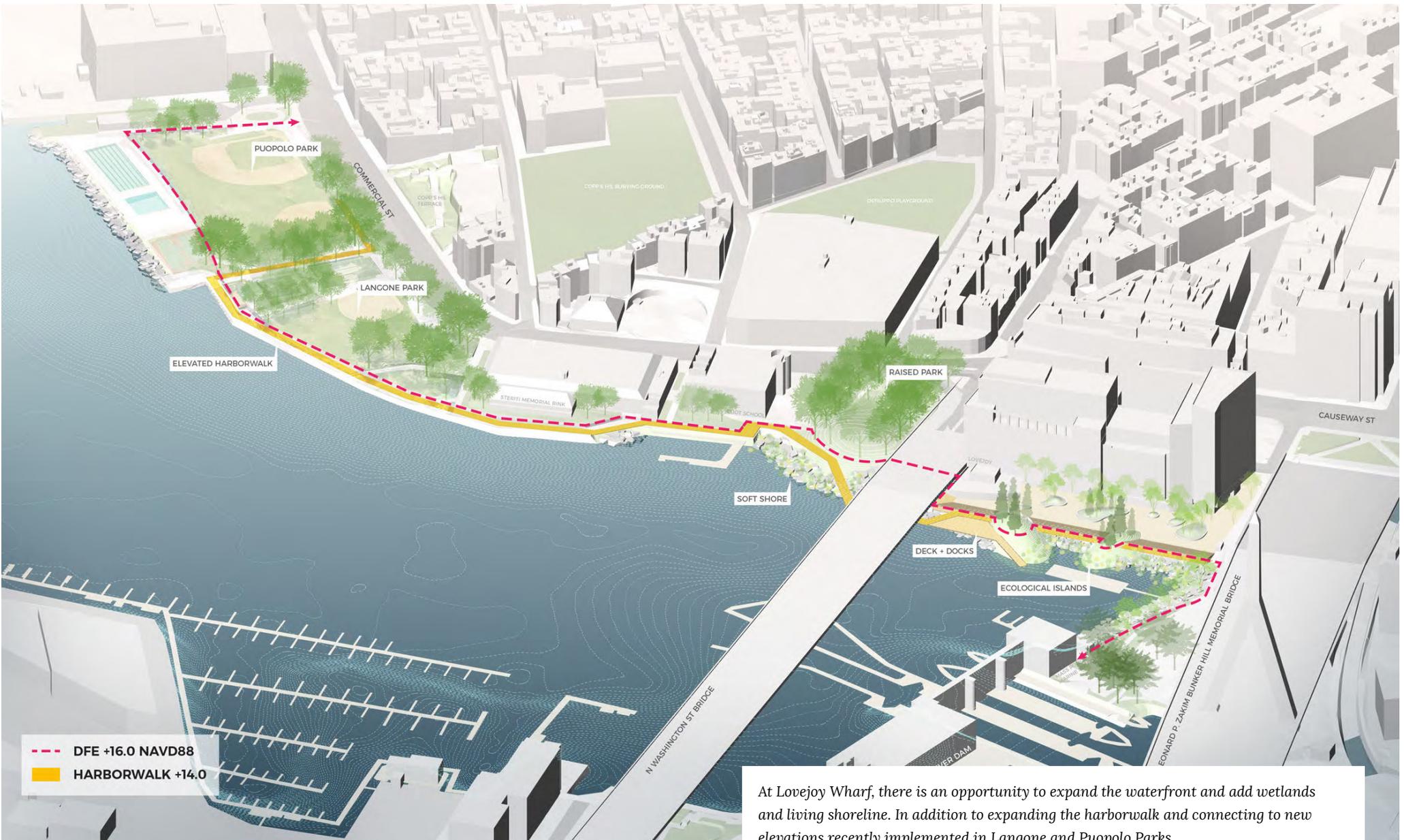
The additional development of long-term strategies are needed for areas that are not addressed in this report. The strategies presented in this report are inclusive of efforts to protect all properties against the 1 percent flood with 40 inches of sea level rise and consider their ability to adapt to future, higher levels of risk, that is, greater than 40 inches sea level rise. The majority of this work includes flood protection to the area between Union Wharf to the North Washington Bridge.

Burroughs and Battery Wharves are relatively new buildings (2007 and 1993) and constructed concrete pier structures vulnerable to 1 percent storm event with 40 inches sea level rise (2070s). Building-scale systems will provide protection in the near-term. Towards 2070 and the end of the life cycle of the property owners will need to design a flood barrier at the edge of the pier. The engineering strategies might include raising the structure or offshore solutions.

The Coast Guard site located between Battery Wharf and Langone and Puopolo Parks was not analyzed as part of this report. Members of the Coast Guard did participate in focus groups and community meetings.

Steriti Memorial Rink to North Washington Bridge is a public space owned largely by DCR. This single ownership and public nature allows for future implementation of a flood barrier tied to the improvement of the open space.

The New Charles River Dam is owned and operated by DCR, but was designed, constructed, and funded by the USACE. DCR and USACE are currently collaborating to explore options to address the dam's long-term vulnerabilities to changes in both upstream and downstream flooding conditions.



At Lovejoy Wharf, there is an opportunity to expand the waterfront and add wetlands and living shoreline. In addition to expanding the harborwalk and connecting to new elevations recently implemented in Langone and Puopolo Parks.

COASTAL RESILIENCE COST ESTIMATES

Coastal resilience actions in Downtown and the North End are expected to cost between \$189 million and \$315 million between now and the 2070s. This cost does not include floodproofing of infrastructure and buildings as a near-term or redundant layer of protection, pumping systems that may be required to maintain the performance of stormwater and sewer systems, or actions to address the long-term risk of overtopping or north flanking of the New Charles River Dam.

Order-of-magnitude cost estimates for the various feature components, such as elevated seawalls, integrated flood walls, Harborwalks, waterfront parks, and other shoreline features required to achieve flood protection are based on readily available data. They do not reflect design-level considerations for the area, such as as-built surveys of existing seawall conditions, underground utilities, or geotechnical information. The estimates are generally presented as a range of costs and include large contingencies due to the limited information available on existing conditions and future designs. They should be used for planning purposes only.

BENEFIT COST ANALYSIS

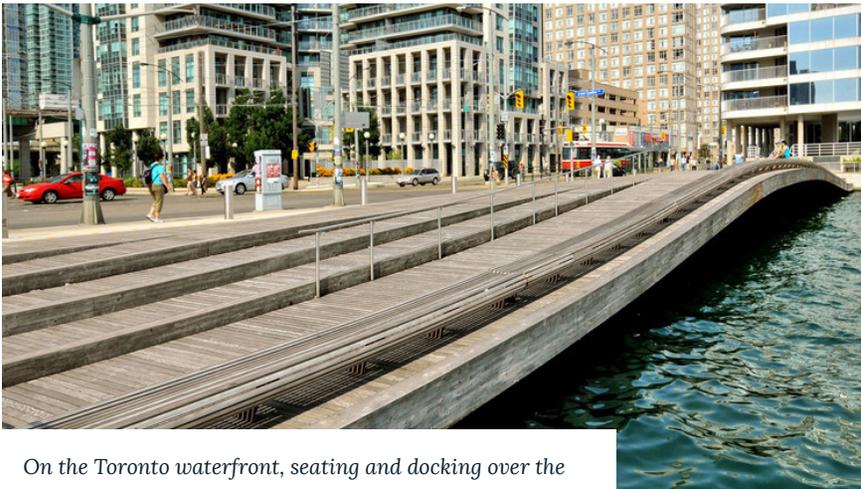
Loss estimates are derived from Climate Ready Boston data. These data include direct physical damage to buildings and their contents, displacement and relocation costs, and human impacts or stress factors as described in the Climate Ready Boston report.

The measures outlined in this report protect over 8,500 people, over 870 buildings, and avoid about \$1.4 billion in direct physical damage, displacement costs, mental stress and anxiety, and lost productivity associated with the 1 percent annual chance flood elevation with 40 inches of sea level rise (2070s). All numbers are developed using the FEMA methodology, are based on people and buildings in the area as of 2015, and do not include losses to the economy or infrastructure.

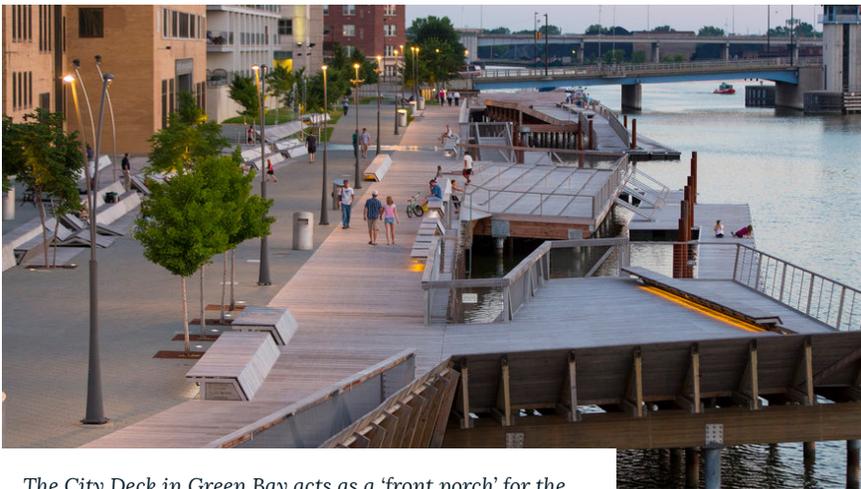
In addition to mitigating direct physical damage, displacement, and general disruption directly in Downtown and North End, these improvements will provide benefits not currently quantified that will reverberate throughout the city. Reflecting its status as a center of commerce, government, and recreation, Downtown is home to extensive transportation infrastructure, a significant part of which is underground. This infrastructure includes

tunnels and bridges, evacuation routes, stormwater pumping stations, and MBTA stations (one of which is also a hub for Amtrak). This infrastructure is critical for residents of the entire region to access jobs and essential services, like medical and emergency response. Any impacts to critical or essential infrastructure will cause cascading impacts expected to stretch beyond Downtown into other parts of the city and region. Downtown is also an economic hub. Neither direct nor indirect economic impacts, such as those generated through loss of business, have been included in these estimates.

A newly raised harborwalk is a great solution throughout Downtown and The North End and can be an opportunity for inspiring new public activation at the water's edge.



On the Toronto waterfront, seating and docking over the water activate the public realm and provide fish habitat.



The City Deck in Green Bay acts as a 'front porch' for the City that doubles as flood protection and water access.

Coastal Resilience Options in Downtown and North End Estimated Costs and Benefits

ESTIMATED CAPITAL COST*	\$189 TO \$315 MILLION
ESTIMATED ANNUAL MAINTENANCE COST	\$2.8 TO \$4.7 MILLION
NET PROJECT BENEFIT**	\$1.8 TO \$6.3 BILLION
BENEFIT COST RATIO	11.8 TO 39.4

* Includes costs for planning, engineering, permitting, construction
 **Net project benefit refers to the benefits minus costs through 2070 using discount rates of 3 percent and 7 percent. Both benefits and costs have been applied incrementally over time based on an estimated project completion schedule of 10 years per project area and sea level rise projections for 2030, 2050, and 2070. All losses expected to occur more frequently than monthly have been removed from the analysis.



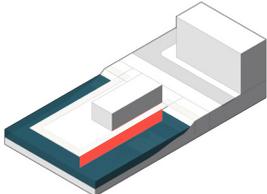
APPENDIX



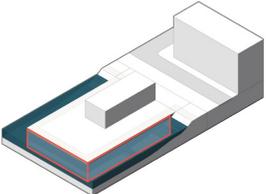
RESILIENCE TOOLKIT

The current condition of the waterfront is mostly hard-edged, defined by historic stone seawalls and bulkheads that are sometimes protected by riprap. Access to the waterfront and active marina uses are accessed through wooden boardwalks and other pile-supported structures over water. In some places the distance between buildings and the edge of the existing bulkhead is minimal to non-existent; some buildings even overhang the water. Each of these conditions require specific responses and pose unique challenges and opportunities to implement resilience measures. A toolkit of resilience measures is presented here and can be used as a guide for future design decisions. The design variations in this toolkit are intended to work together and to be combined into an integrated solution to provide comprehensive, district scale protection.

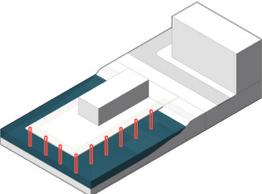
EXISTING CONDITIONS



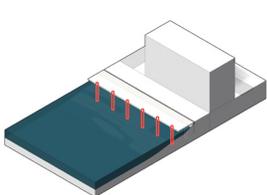
Building on Bulkhead



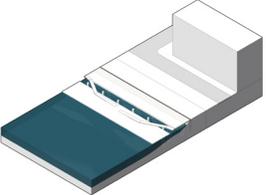
Building on Wharf



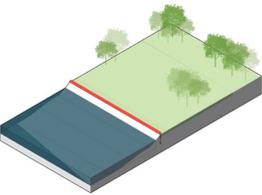
Building on Piers



Harborwalk



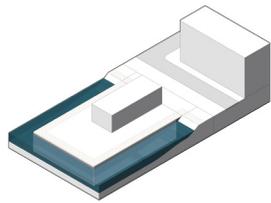
Water Access / Marine Transportation



Waterfront Open Space

HOW TO USE THE RESILIENCE TOOLKIT

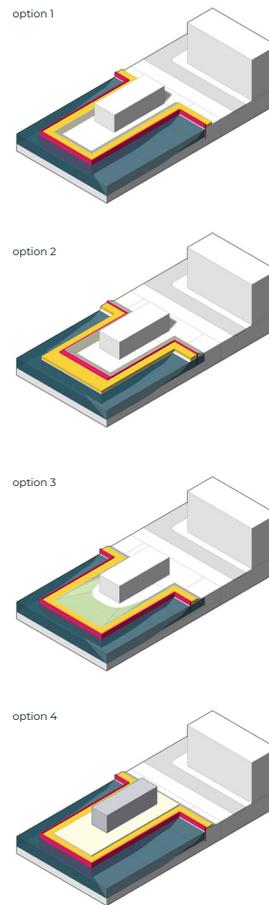
IDENTIFY SPECIFIC EXISTING CONDITION



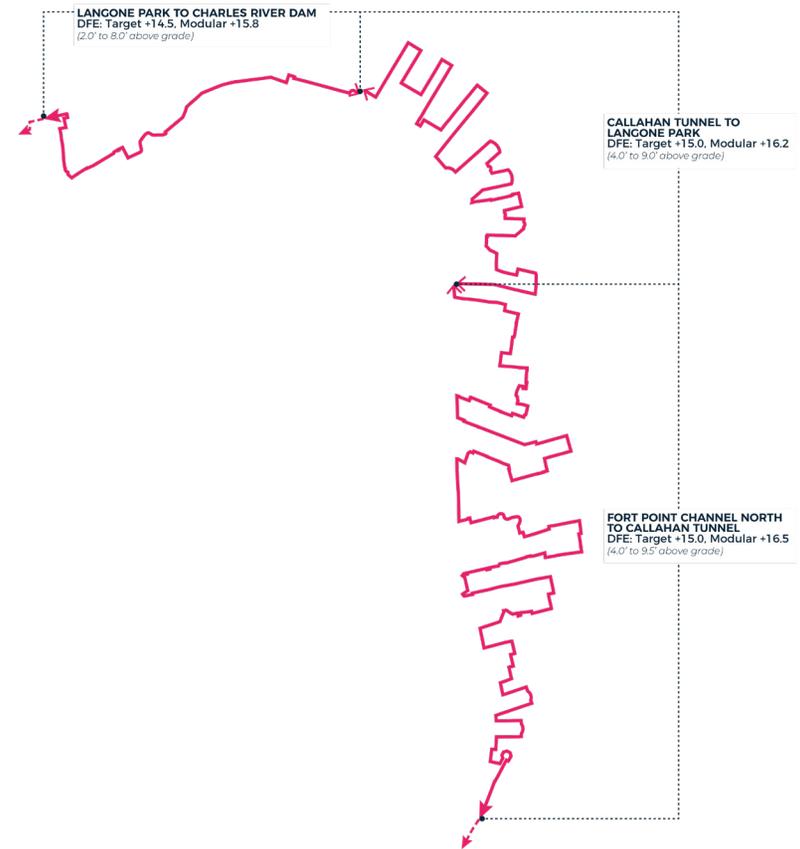
Existing condition



REFER TO CORRESPONDING TOOLKIT OF POSSIBLE DESIGN APPROACHES

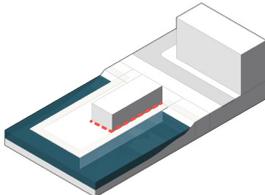


COORDINATE DESIGN MEASURES TO DISTRICT SCALE PROTECTION



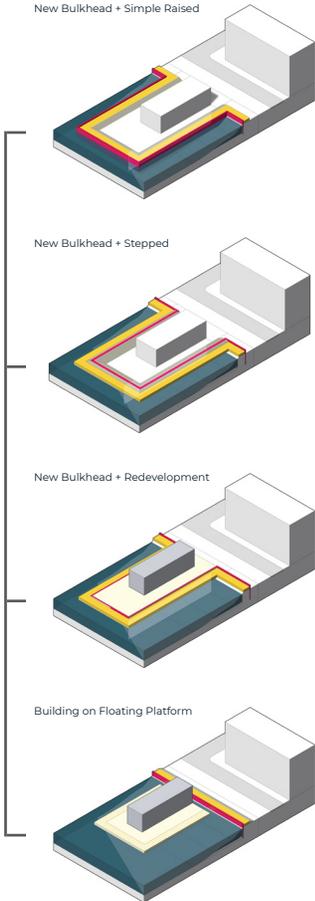
EXISTING EDGE CONDITIONS & POSSIBLE DESIGN APPROACHES

BUILDINGS ON THE BULKHEAD

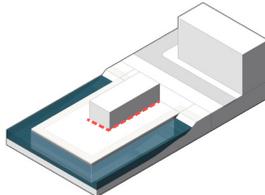


Building on Bulkhead

Building is concurrent with bulkhead wall below, leaving little space for raising elevations

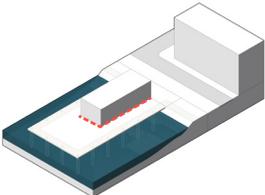


BUILDINGS ON WHARVES / PIERS



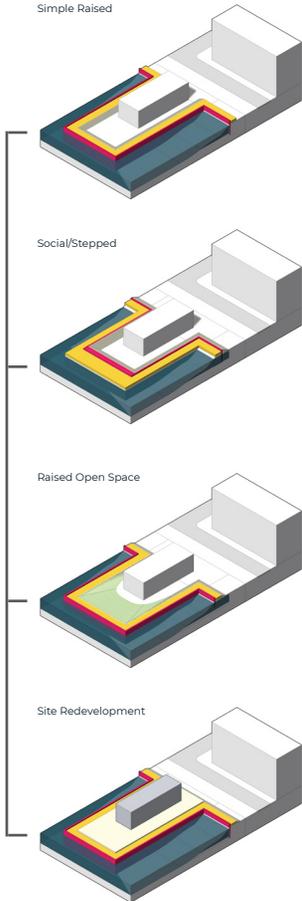
Building on Wharf

Building located on wharves built on filled land. Bulkhead is at water's edge.

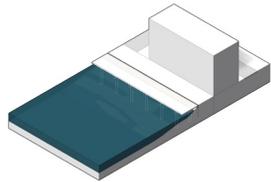


Building on Piers

Building is constructed on piers with bulkhead wall behind the building.



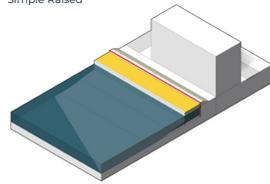
HARBORWALK



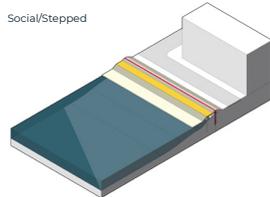
Harborwalk

Harborwalk at the water's edge

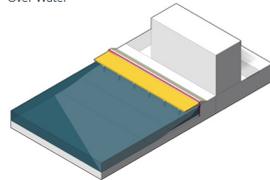
Simple Raised



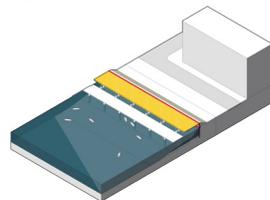
Social/Stepped



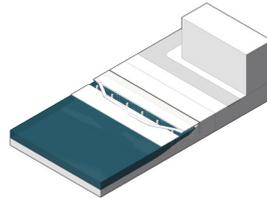
Over Water



Programmed



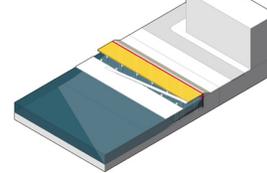
MARINE TRANSPORTATION



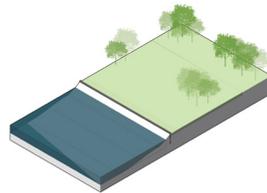
Water Access / Marine Transportation

Docking and access infrastructures at the waterfront

Raised Edge + Accessible Marine Transportation



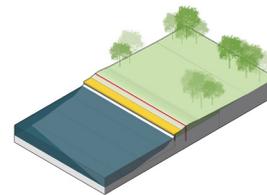
WATERFRONT OPEN SPACE



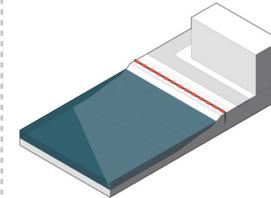
Waterfront Open Space

Existing waterfront park spaces or underutilized open spaces

Elevated Park/Open Space



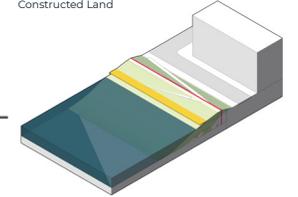
OFFSHORE



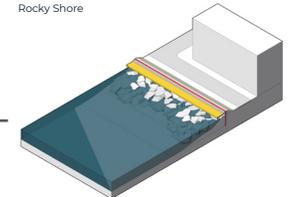
Limited Space at Edge

Locations where the land between existing buildings and the waterfront is limited or where significant social programming imposes spatial constraints

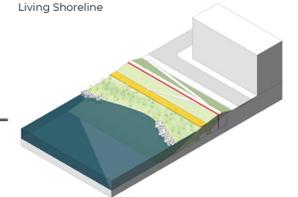
Constructed Land



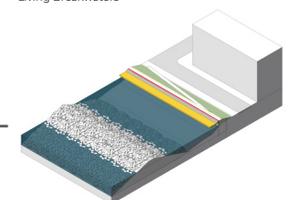
Rocky Shore



Living Shoreline

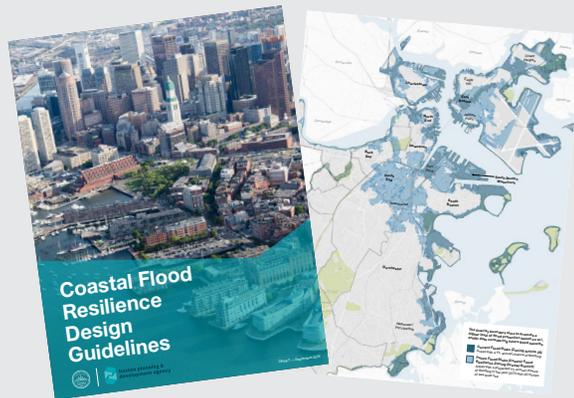


Living Breakwaters



BPDA Resilient Design Guidelines

BPDA adopted Coastal Flood Resilience Design Guidelines to guide property owners and design professionals on how to retrofit existing buildings and develop new buildings for future coastal flooding conditions. The guidelines provide a range of strategies, including technical and urban design considerations, and case studies for the most prevalent types of buildings in Boston. The guidelines were developed with input from a large number of stakeholders from the public, private, and non-profit sectors.



BUILDINGS

WATERTIGHT BUILDINGS

Buildings in the floodplain will require individual flood protection as detailed in the BPDA Coastal Flood Resilience Design Guidelines. Some buildings are located at the edge of the bulkhead and therefore have limited options for protection. Further complicating this, many of these buildings have significant apertures such as windows or access points below the DFE. In some cases the structure might require major transformations which can trigger a requirement to meet current building code and zoning policy if not currently met. These requirements may cause challenges to redevelopment. In all cases, the first step is a structural and engineering assessment, which should be undertaken as soon as possible.

Considerations:

- » Distance from the building edge to the bulkhead may impact ability to protect with temporary structures such as aquafence.
- » Ability to wetproof ground floor and maintain activity.
- » Policy and regulations addressing reconstruction or structural changes, major reconstructions, need for repair, building life cycle.

EXISTING EDGES

RAISED HARBORWALK

The Harborwalk at the water's edge creates an opportunity for raising grades and integrating coastal flood protection into the public open space in many locations. Design approaches in these conditions may incorporate a raised seawall adapted to physical conditions or social functions. These include:

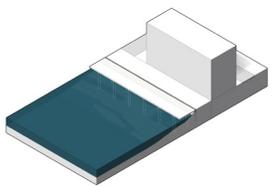
- » Simple Raised
- » Social and Stepped
- » Over Water
- » Water Access/Marine Transportation
- » Programmed
- » Elevated Parks and Open Space

These are further described below.

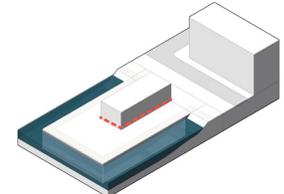
Simple Raised

A seawall constructed to the DFE along the line of the bulkhead is feasible at the waterfront in multiple locations. In locations where access to marina or docking facilities is needed, the wall design will need to include ADA compliant pedestrian and vehicular access and may require additional space landward of the seawall.

EXISTING CONDITION



Harborwalk
Harborwalk at the water's edge



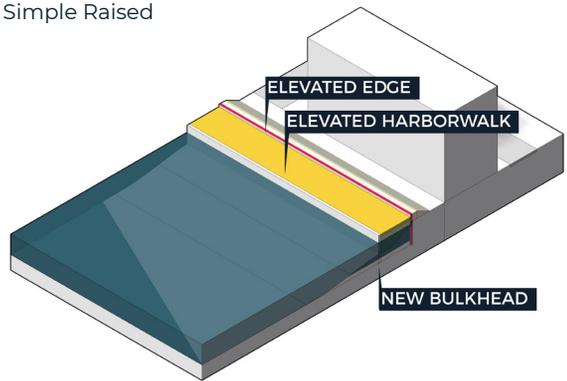
Building on Wharf/Piers
» Building located on wharves built on filled land. Bulkhead is at water's edge.
» Building is constructed on piers with bulkhead behind.

Considerations:

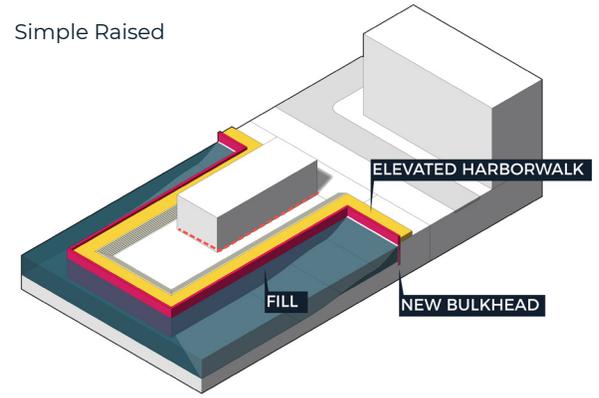
- » Depending on the wall elevation in relation to the grade, the wall is likely to block the view and access to the water. These impacts should be limited through design.
- » Ownership of the bulkhead changes along the waterfront, making coordination between all owners essential.
- » In some locations the bulkhead is encased between a pier structure and the land. Coordination for access and construction will be needed.
- » The condition of historic bulkheads should be taken into consideration and visual appearance of bulkheads preserved where possible.
- » State and local regulatory approval will be required to construct non-maintenance improvements to waterfront infrastructure, such as new or updated Chapter 91 licenses, wetlands permit, and others.

POSSIBLE DESIGN APPROACHES

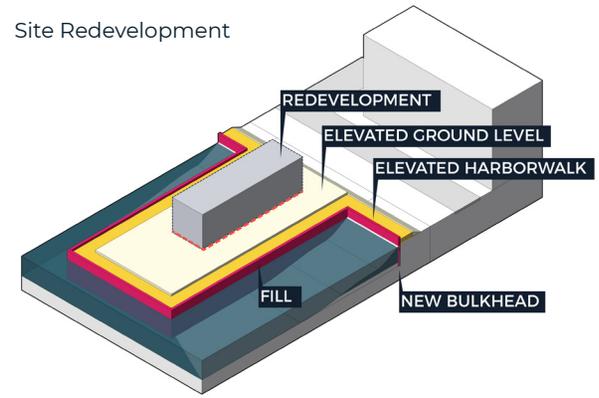
Simple Raised



Simple Raised



Site Redevelopment



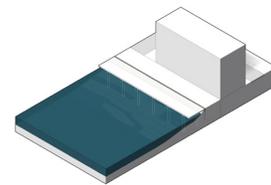
Social/Stepped

To provide access and visual connection to the water, the flood protection system can be embedded in a hard or soft slope. The design of the slope must incorporate access from the city side. The engineering of the flood barriers on the waterside can vary according to site needs. This Harborwalk can provide easier access to marine and water dependent uses. The assumption is that it will be constructed at the water's edge and be inclusive of or enhance the Harborwalk.

Considerations:

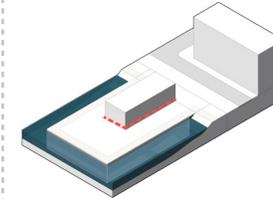
- » Space on the city side is required for a well designed system with ADA access points.
- » Harborwalk to be included along the water side of slope/steps.
- » The load of engineered structure on subsurface utilities and soil must be evaluated for stability.

EXISTING CONDITION



Harborwalk
Harborwalk at the water's edge

EXISTING CONDITION

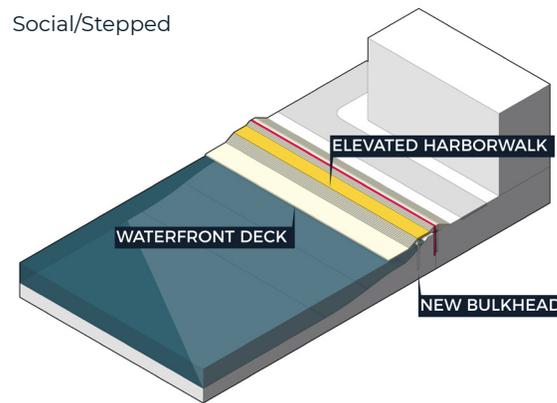


Building on Wharf/Piers

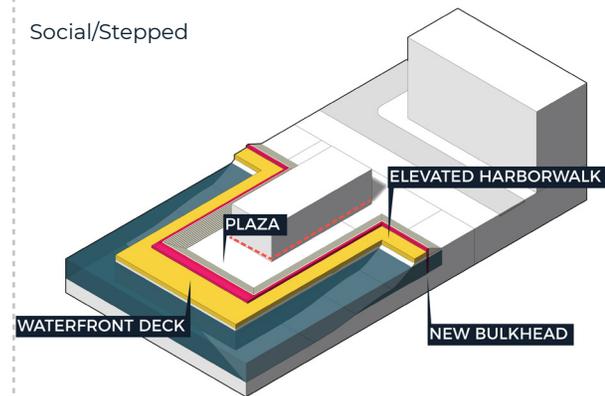
- » Building located on wharves built on filled land. Bulkhead is at water's edge.
- » Building is constructed on piers with bulkhead behind.

POSSIBLE DESIGN APPROACHES

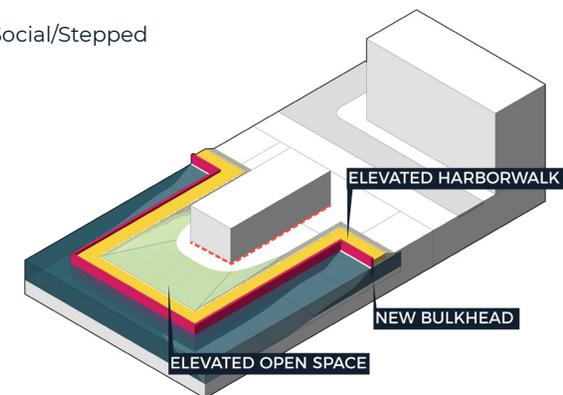
Social/Stepped



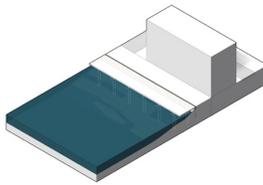
Social/Stepped



Social/Stepped



EXISTING CONDITION

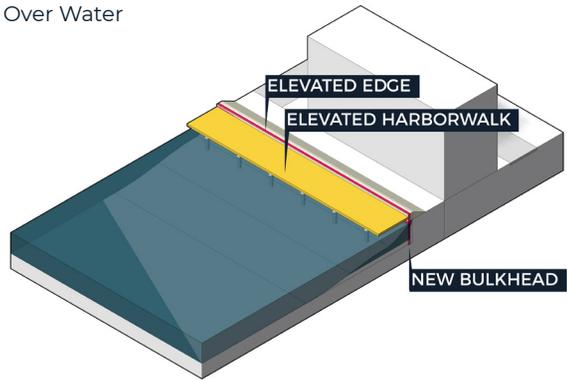


Harborwalk

Harborwalk at the water's edge

POSSIBLE DESIGN APPROACHES

Over Water



Over Water

In locations where space does not allow for the required width of the Harborwalk, the design of the flood barrier can include an overhanging pier Harborwalk such as at the recently completed Pier 4 in South Boston. Such a system can provide social activities and allow for water dependent uses with access points to the water. Providing public access on a lightweight structure could ease the load on the underground structure.

Considerations:

- » Regulations and policy requirements for in-water construction may slow construction.

Clippership Wharf

Clippership Wharf development in East Boston, completed in September of 2019, incorporates a number of resilience features. Built to anticipate expected sea level rise over the coming decades, Clippership Wharf uses technology that can be deployed up to 24 hours in advance to help keep storm surges at bay, and residential floors are 25 feet above-grade. A 'living shoreline' is featured at the center of the public realm. This new shoreline alternately submerges and emerges with changes in the tides. It incorporates native plantings and wave dissipating features, supports wildlife habitats and provides a new kind of public experience along the Boston Harbor. Mitigation measures include stabilization of existing seawall, placement of riprap, and rain gardens and bioswales to assist in stormwater management. The redevelopment also includes measures to increase energy efficiency including renewable energy from rooftop photovoltaics.



Water Access and Marine Transportation

Docking and access infrastructures currently connect to specific locations throughout the waterfront. The flood barrier can incorporate location for connections and access. In these cases, the space required for protection will need to accommodate horizontal space for queuing, ADA access, flexible connections for various boats scales, and allow for tidal changes.

Considerations:

- » These systems are highly space consuming and in most cases will need to be coordinated amongst multiple stakeholders.

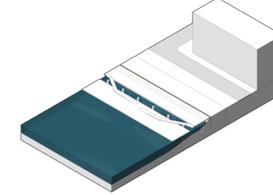
Programmed

Locations for water access can be designed into or behind the continuous line of protection. Water dependant programs may include: kayak launch, fishing piers, water play such as simple fountains, beaches, and pools. Water dependent uses are regulated and allowed within the Chapter 91 framework.

Considerations:

- » Limited space currently exists for public and private use, particularly for smaller craft.
- » Need for a comprehensive plan at the district scale to address intensity of water use and marine traffic.

EXISTING CONDITION

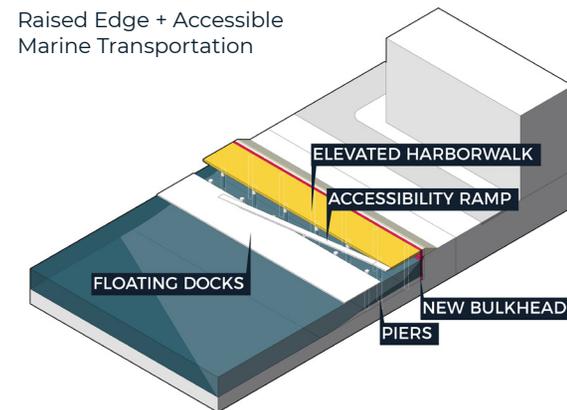


Water Access / Marine Transportation

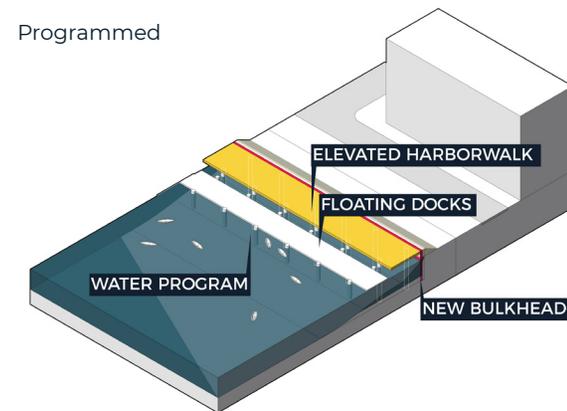
Docking and access infrastructures at the waterfront

POSSIBLE DESIGN APPROACHES

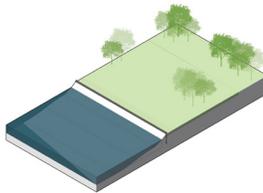
Raised Edge + Accessible Marine Transportation



Programmed



EXISTING CONDITION

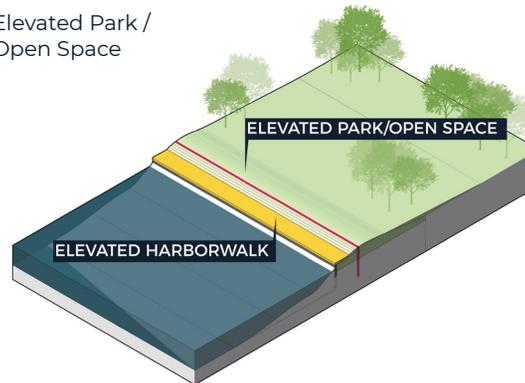


Waterfront Open Space

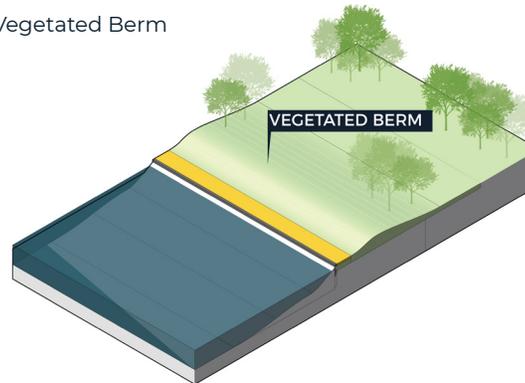
Existing waterfront park spaces or underutilized open spaces

POSSIBLE DESIGN APPROACHES

Elevated Park / Open Space



Vegetated Berm



Elevated Parks and Open Spaces

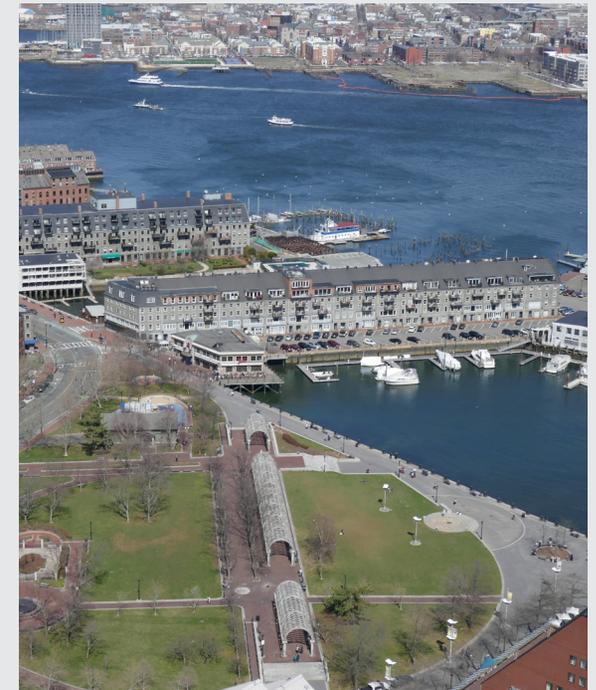
In specific locations along the waterfront, existing park spaces or underutilized open spaces can be improved and redesigned to function as a flood barrier. These could be programmed as either soft (landscape with vegetation, gardens and passive recreation spaces) or hard (plazas, steps and other paved public open spaces) .

Considerations:

- » Limited active recreation in the area makes an increase in public recreation desirable.
- » Parking facilities are limited and additional recreation will need to be considered with regard to parking and other forms of access.

Christopher Columbus Park

“Christopher Columbus Park, on the Boston Harbor, is one of America’s earliest waterfront parks of the modern era. In the 1970s, there was interest by both the public and private sectors in restoring the abandoned waterfront and the City committed public funds for a new waterfront park.” Friends Of Christopher Columbus Park website



OFFSHORE

In locations where the land between existing buildings and the waterfront is limited or where significant social programming imposes spatial constraints on what may be completed within the existing Harborwalk and edge, an offshore approach may be applicable. Offshore approaches include building into or over the water which may pose both significant regulatory challenges and potential positive or negative ecological impacts. Both approaches must be carefully considered and designed with these in mind.

Constructed land

At sites with limited space (adjacent structures or utilities) or structural constraints, building a new bulkhead with potential new constructed fill can be the preferable option. This new land presents opportunities for an integrated flood protection system, public co-benefits in the form of new open space, stormwater retention, natural shoreline and habitat, and aesthetic value. Portions of this new land should be elevated to the DFE to provide comprehensive flood protection.

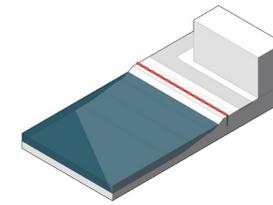
Considerations:

- » State and federal regulations might limit the ability to construct and/or extend the project timeline.
- » Impacts to wetland resources caused by filling in submerged land will need to be mitigated, potentially at offsite locations.
- » Ownership, jurisdiction, and operations and maintenance will need to be negotiated with watershed lot owners and adjacent properties.

Rocky Shore

At specific locations along the waterfront there is a potential environmental benefit to adjusting the bulkhead from a solid vertical wall to a terraced edge. This edge can act simultaneously as barrier, habitat, and may dampen wave action locally. In most areas, considering the limited available space for a Harborwalk, the elevated platform and flood protection system could be constructed at the existing edge and the ecological, habitat friendly structures constructed outboard. This outboard portion is an opportunity to reuse existing seawall granite blocks and create potential points of access during lower tides.

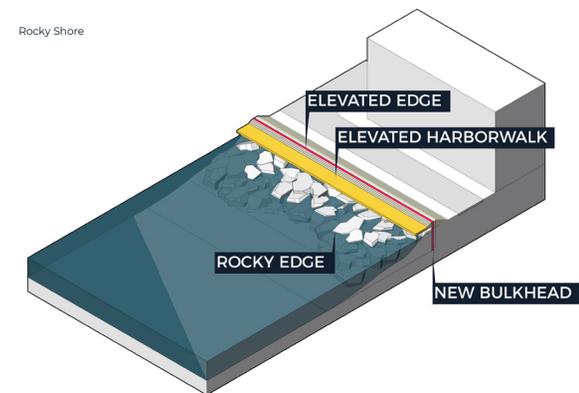
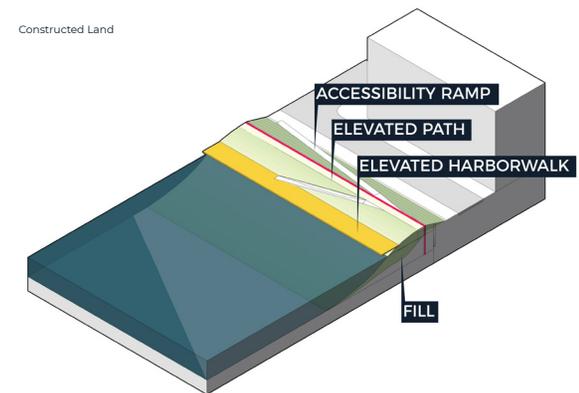
EXISTING CONDITION



Limited Space at Edge

Locations where the land between existing buildings and the waterfront is limited or where significant social programming imposes spatial constraints

POSSIBLE DESIGN APPROACHES



Considerations:

- » State and federal regulations might limit the ability to construct and/or extend the project timeline.
- » May require mitigation of impacts to underwater habitat.
- » Ownership, jurisdiction, and operations and maintenance will need to be negotiated with watershed lot owners and adjacent properties.
- » Historic assets such as seawalls will need to be considered. Wall materials may be used for construction of offshore elements where excess exists. Preservation of existing wall structures may be required or desired where in good condition.

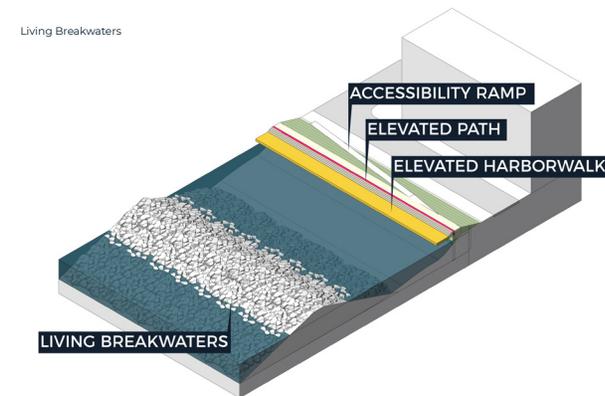
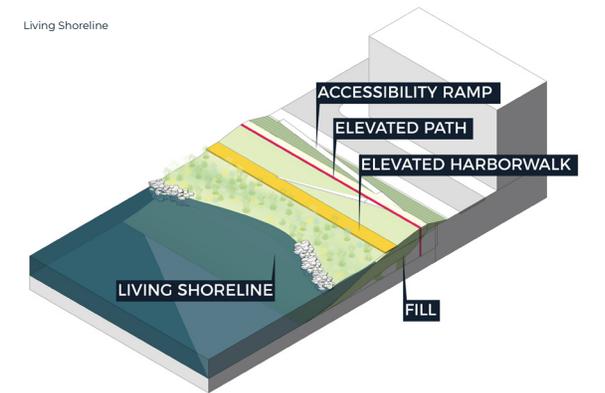
Wave Attenuation Wetland/Living Shoreline/ Breakwaters

Downtown and North End have opportunities for nature-based solutions at the outer edge of the seawall. These living edges will provide opportunities for habitat, education, historic acknowledgment of the original shoreline/mudflats, and wave attenuation where wave action poses greater risk. Locations for implementation will depend upon appropriate bathymetry and hydrologic conditions. These approaches are included in the higher cost ranges outlined in the report.

Considerations:

- » State and federal regulations might limit the ability to construct and/or extend the project timeline.
- » Mitigation for local environmental impacts may be required, or solutions can be 'self-mitigating' if creating ecological benefit.
- » Ownership, jurisdiction, and O&M will need to be negotiated with watershed lot owners and adjacent properties.

POSSIBLE DESIGN APPROACHES



From toolkit to an integrated system:

The following matrix exemplifies the potential methodology to select the appropriate solution from the resilience toolkit above in relation to the current condition and potential.

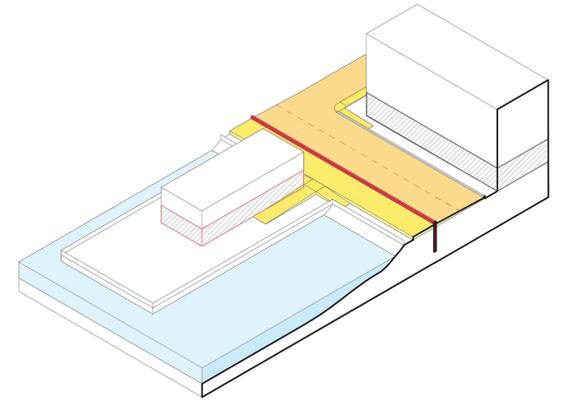
IF (EXISTING CONDITION)	THEN (APPLICABLE SOLUTIONS)	EXAMPLE SITE
<i>Harborwalk on piers</i>	<i>Raised Harborwalk</i>	<i>Wharf District</i>
<i>Building on piers</i>	<i>Fill bellow pier/ New seawall at pier edge/ Raise building/ Floating structure</i>	<i>Commercial Wharf pier structures Joe's and Boston Yacht Haven Inn & Marina</i>
<i>Open Space at waterfront</i>	<i>Elevated Parks and Open Spaces</i>	<i>Christopher Clolumbos Park / Langone and Puopolo Parks</i>
<i>Building at bulkhead wall</i>	<i>Waterproof ground floor/ Constructed land and new bulkhead / Raised building (wooden)</i>	<i>Custom House / Union Wharf townhouses</i>
<i>Building setback from bulkhead >12'</i>	<i>Elevated edge / Social space</i>	<i>Lewis Wharf and the Pilot House</i>
<i>Roadway setback from bulkhead >12'</i>	<i>Elevated edge / Social space</i>	<i>Between wharves</i>
<i>Marine transportation</i>	<i>Marine access</i>	<i>Long Wharf</i>



“Miami Beach Engineer Bruce Mowry stands on 20th Street...”
By Emily Michot from the Miami Herald

The Public Right of Way

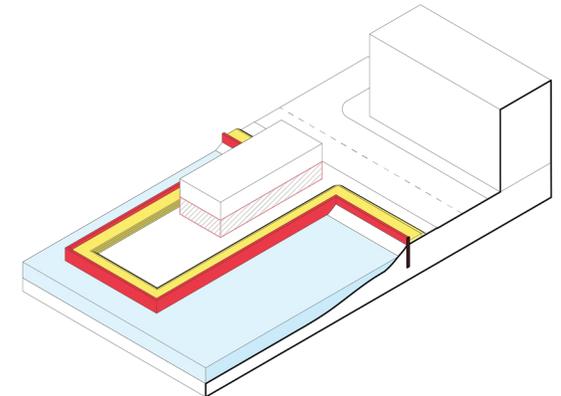
Urban impacts
Negative impact on public realm
Feasibility
Complex interference with utilities
Limited adaptive capacity beyond 40" slr



The CityDeck and Green Bay, WI. By Stoss

Raised Harborwalk - Bulkhead

Urban impacts
Moderate benefit to public realm
Feasibility
Complex interference with bulkheads
Long perimeter
Requires collaboration between owners
Some adaptive capacity beyond 40" SLR



Calgary RiverWalk in the East Village, by by Jessa Morrison from Wikimedia Commons

Improved and Extended Open Space

Urban impacts
Transformative impact on public realm
Feasibility
Complex permitting
Possibility for expanded functions
Requires collaboration between owners
Adaptive capacity beyond 40" SLR

