EXECUTIVE SUMMARY

Feasibility of Harbor-wide Barrier Systems

Preliminary Analysis for Boston Harbor

UMASS BOSTON Sustainable Solutions Lab

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BOSTON Green Ribbon COMMISSION

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To read the full report please visit *www.umb.edu/ssl/activities*.

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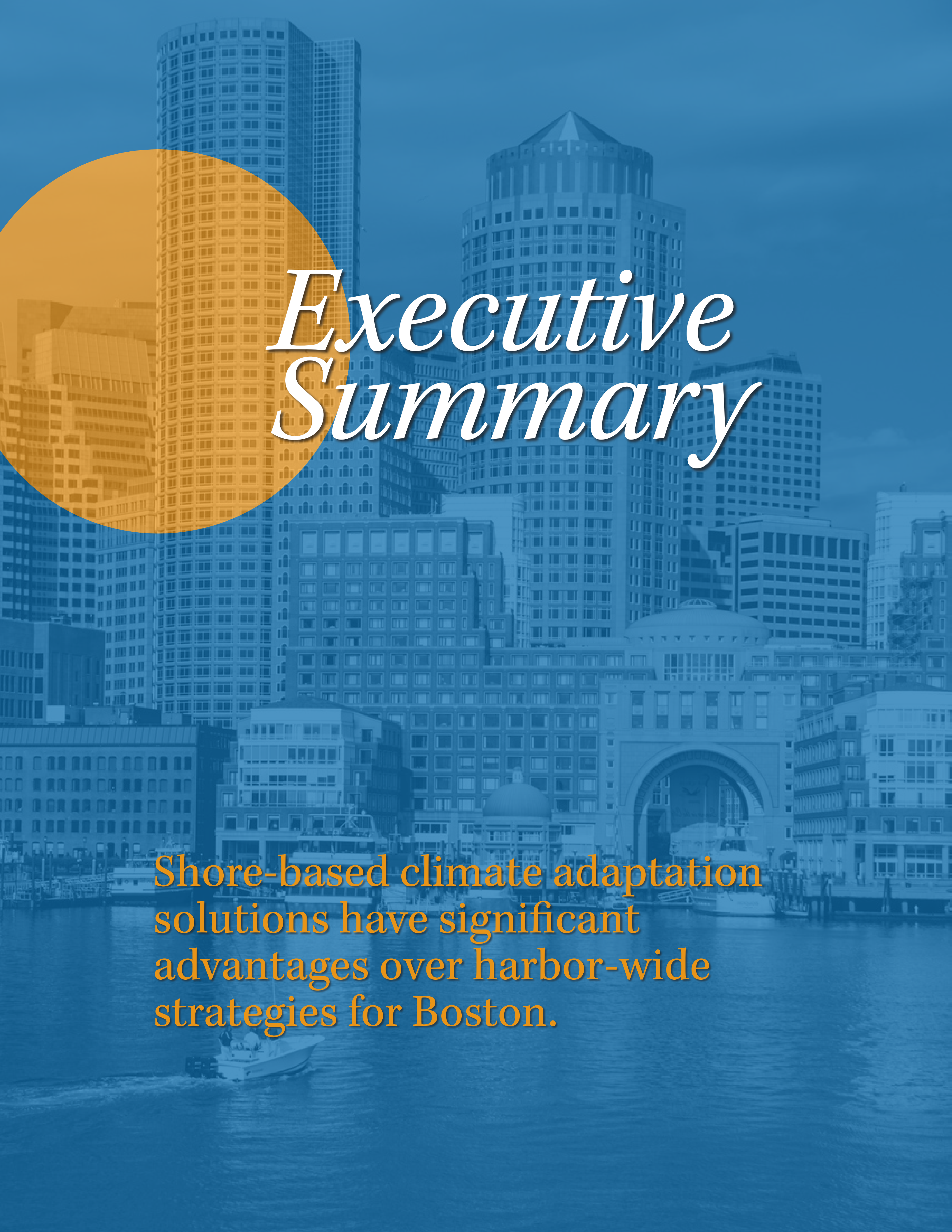


Executive Summary

Shore-based climate adaptation solutions have significant advantages over harbor-wide strategies for Boston.

As sea levels rise and climate change poses a growing threat, Boston and neighboring cities and towns along Boston Harbor and the Massachusetts coastline need to prepare. In 2016, the City of Boston began organizing a citywide response to climate change called Climate Ready Boston. This project included detailed climate change projections, a vulnerability assessment, and proposals for adapting to climate change and increasing the resilience of the city to sea level rise, heat stress, and increased precipitation. One of the recommendations from this project was to launch a feasibility study for a harbor-wide flood protection system (Strategy 5.4). This study on barriers, sponsored by the Green Ribbon Commission in support of its partnership with the City of Boston on Climate Ready Boston, responds to that recommendation. It was funded by the Barr Foundation.

The aim of this study is to provide the City of Boston with a preliminary assessment of the feasibilities and potential benefits, costs, and environmental impacts of three harbor-wide barrier configurations. The analysis was conducted by a multidisciplinary team of environmental scientists, engineers, economists, planners, and lawyers, drawing upon a wide range of data about engineered flood protection systems, climate change, coastal ecosystems, and economic impacts of flooding. We focused on barrier designs and configurations that would offer protection from coastal flooding while minimizing interference with Boston's main shipping channels and the gains that have been made in water quality over the last several decades. We also examined potential conflicts with various harbor uses, and conducted a preliminary comparison with shore-based adaptation solutions (which include district-level flood barriers as well as other structural and non-structural actions), such as those already being investigated by the City of Boston along the inner harbor waterfront in East Boston, Charlestown, and South Boston. The detailed technical report contains more analysis of the issues summarized below. Because many of the results of a section depend upon results from preceding sections, it is recommended that the sections be read sequentially.

This analysis yielded these key findings:

- The two most reasonable options for a barrier system are an Outer Harbor Barrier (OHB) from Winthrop to Hull and an Inner Harbor Barrier (IHB) between Logan Airport and the Seaport area of South Boston. Each would be a gated barrier system that would only be closed during flood conditions caused by storm surge exceeding shoreline levels of flood protection.
- Either barrier system with the gates open would not attenuate the tidal range in the harbor thus not decreasing tidal flooding ("nuisance flooding") and also not causing major environmental impacts compared to the expected changes due to climate change and sea level rise.

The aim of this study is to provide the City of Boston with a preliminary assessment of the feasibilities and potential benefits, costs, and environmental impacts of three harbor-wide barrier configurations.

- In the early years of operation, the frequency of closure of a barrier would be no more than a few times per year. Because of rising sea levels, and assuming the system was designed to be closed each time the water level is above the level of protection provided by shore-based measures, after 50–60 years the frequency of closure would likely increase so much that the barrier could no longer function as designed.
- Neither barrier system appears to be cost-effective. Depending upon assumptions made on levels of shore line protection and discount rates and assuming shore-based adaptation is effective against storm surges, the benefit:cost ratios range from 0.05 to 1.69 with most being well less than 1.0. This is very unfavorable compared to benefit:cost ratios of recently designed shore-based systems in Boston of 3.22 to 5.3.
- The anticipated increased water velocity in the barrier openings could cause navigational and safety issues for both recreational and commercial vessels near the barrier openings. The Outer Harbor Barrier could also impact the abundance, distribution, and behavior of fish populations, which would in turn impact both commercial and recreational fisheries.
- The percentage of socially vulnerable people who would remain vulnerable to flooding in the case of either an IHB or an OHB being built is the same as that of the total population in all of Boston. That is, socially vulnerable populations would not have disproportionate flooding after an IHB or an OHB was built.

- Shore-based systems, including a range of measures from zoning to various kinds of green and gray protective systems deployed along the waterfront of the inner harbor, offer many advantages over harbor-wide barrier systems. These include cost-effectiveness, community co-benefits, adaptability to changing conditions over time, and protection against tidal flooding as well as surge flooding. If over time the performance and implementation of shore-based systems lag, then decisions about barriers must be re-revaluated.

If the global community is able to dramatically decrease emissions of the greenhouse gases that cause climate change, the amount of SLR that Boston will experience can be constrained to the lower end of the future projections, thereby decreasing the number of adaptation measures that will be necessary over time.

KEY RECOMMENDATION

While this study is not comprehensive, and there are many ways that further research could refine and extend its findings, those findings were clear enough to justify making recommendations for next steps. The authors recommend that the City continue to focus its climate resilience strategy for the next several decades on the shore-based multi-layered approach described in Climate Ready Boston. Shore-based solutions would provide flood management more quickly at a lower cost, offer several key advantages over a harbor-wide barrier, and provide more flexibility in adapting and responding to changing conditions, technological innovations, and new information about global sea level rise. These shore-based solutions would be needed in any case over the next few decades to manage coastal flooding during the design and construction period of a harbor-wide barrier if a decision was made to build one in the future.

Climate Context

The climate projection consensus for Boston developed by the Boston Research Advisory Group in 2016 as part of Climate Ready Boston looked at extreme heat and cold, sea level rise (SLR), extreme precipitation, drought, and coastal storms for the region. Depending on how effectively the international community is able to curb global emissions, compared to 2013 the Boston area could experience 6 inches to 1.2 feet of relative SLR by 2050, and 1.8 to 7.3 feet by 2100. Changes in the future intensity and frequency of extratropical storms (nor'easters) are uncertain; there is more certainty, however, that the intensity of tropical storms (hurricanes) may increase. Even if the region does not see an increase in storm intensity, the storms that do occur will cause more flooding when combined with sea level rise. The biggest unknown in these projections—the reason why the ranges are so broad later on in the 21st century—is the amount of greenhouse gas reduction that will be achieved. If the global community is able to dramatically decrease emissions of the greenhouse gases that cause climate change, the amount of SLR that Boston will experience can be constrained to the lower end of the future projections, thereby decreasing the number of adaptation measures that will be necessary over time.

Given the preliminary nature of this analysis, only one scenario of sea level rise and associated flooding was analyzed compared to 2013. This is approximately 1 foot of relative SLR by 2030, 3 feet by 2070, and 5 feet by 2100. This is approximately equivalent to the IPCC RCP4.5 sea level rise scenario, a moderate scenario.

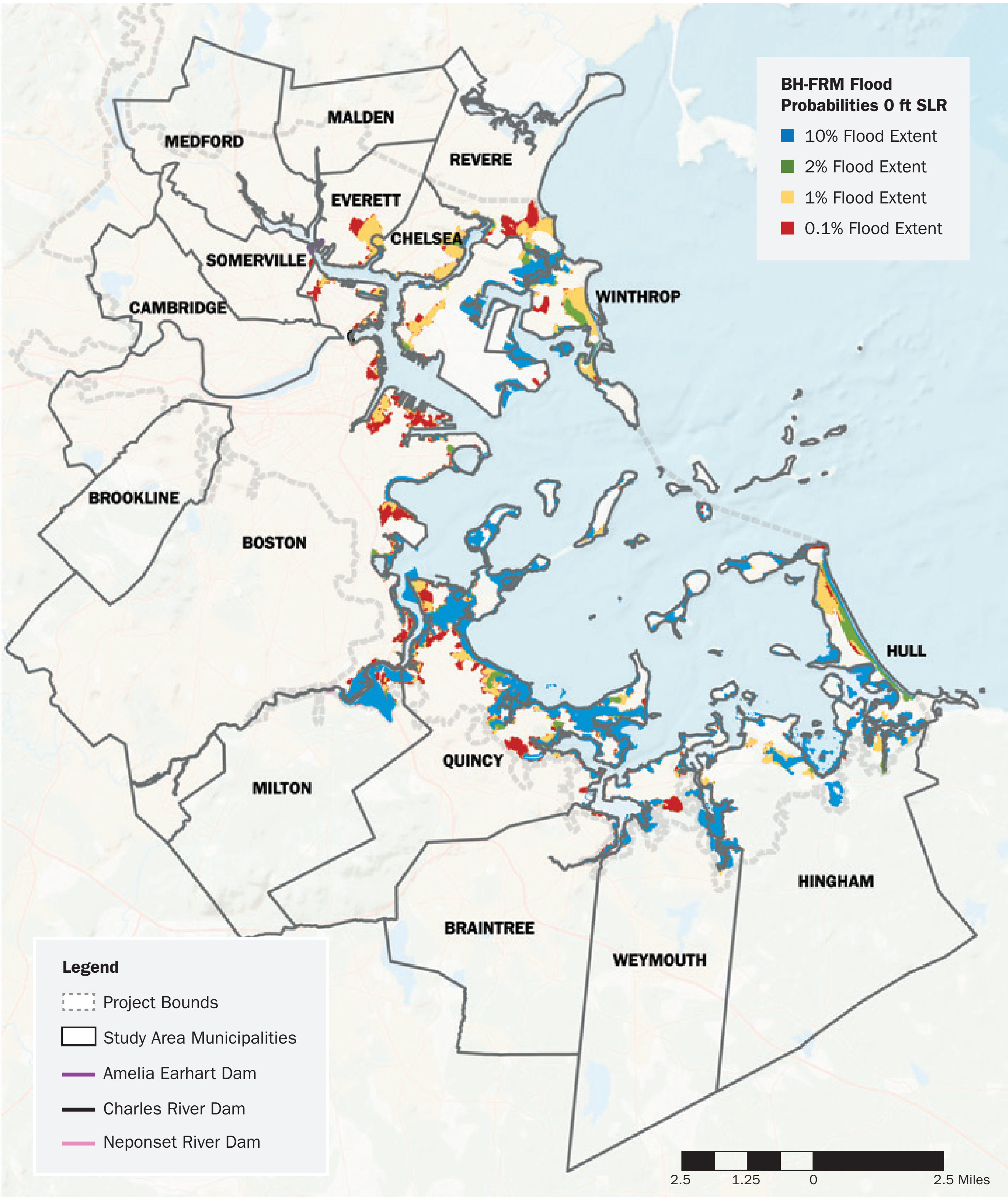
Figure ES.1 shows the present extent of coastal flooding in Boston Harbor. Figure ES.2 (p. 8) shows the estimated extent of coastal flooding with 5 feet of SLR.

Possible Barrier Configurations

This analysis assumes that the goal is not only to provide flood protection from storm surge to Boston and neighboring cities and towns along Boston Harbor, but also to maintain present and future commercial shipping and other navigation, and to preserve as much as possible the present ecological services of Boston Harbor in light of climate change. Commercial and recreational navigation is critical to Boston's historical identity as a maritime city and to its current economy. Likewise, hard-won environmental improvements in Boston Harbor over the past few decades have provided great benefits to the city and its natural resources. It is worth noting that the project team considered evaluating in detail a Metro Dike Barrier which would be an arc in deep water from Swampscott to Cohasset (see Figure ES.3. p. 9). This system would have locks that would create a major impediment to traffic in and out of the

FIGURE ES.1

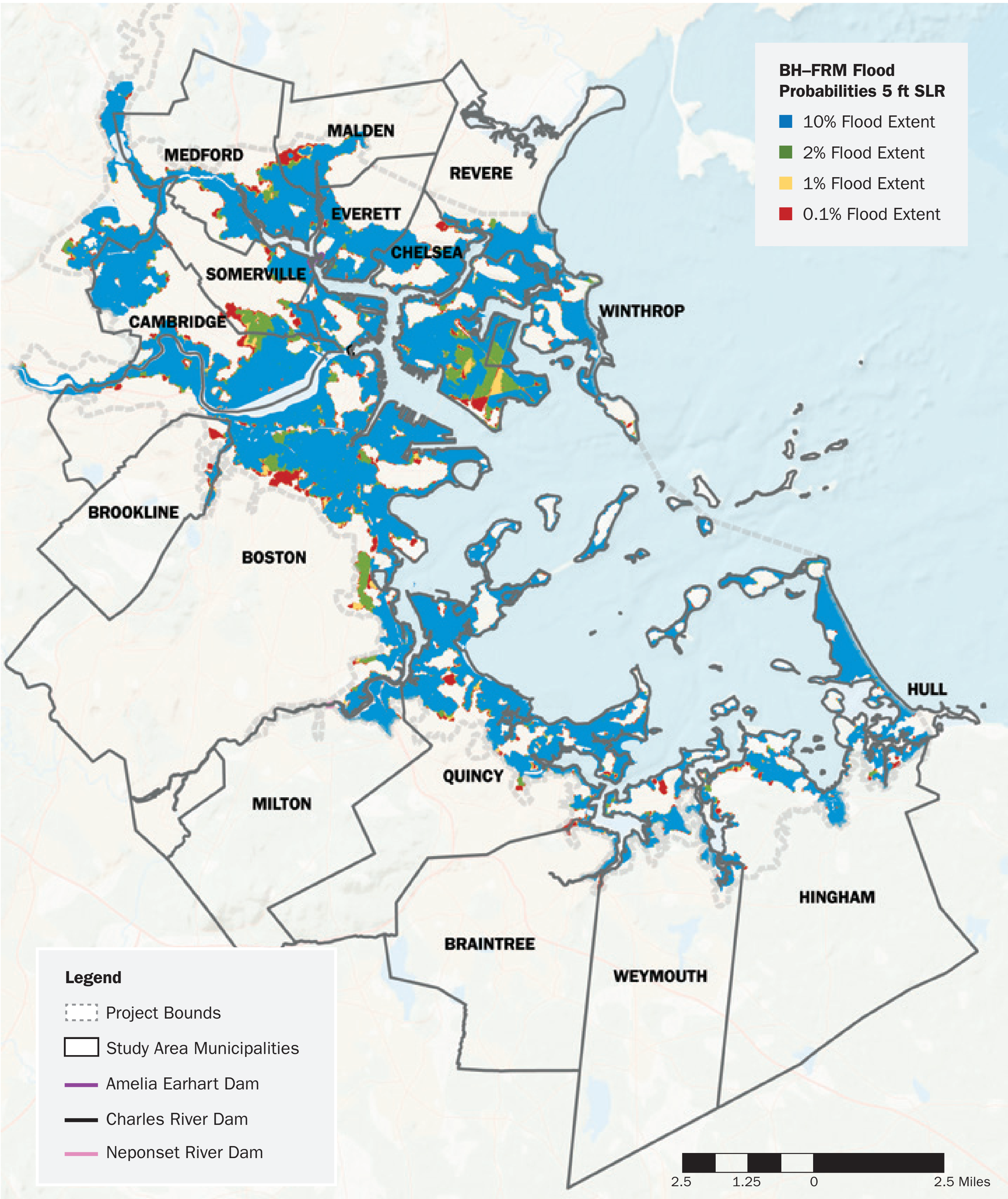
Boston Harbor—Probabilities of Flooding with 0 SLR



Sources: MassGIS, UMass Boston, Woods Hole Group, Esri

FIGURE ES.2

Boston Harbor—Probabilities of Flooding with 5 Feet SLR



Source: MassGIS, UMass Boston, Woods Hole Group, Esri harbor and hamper water exchange and, as a result, did not meet the criteria of minimally impacting shipping and navigation and ecological services. In addition, this system would be very expensive ($35–$85 billion) and difficult to construct. Therefore, this configuration was dismissed early in the project.

This analysis looked at two main options similar to those proposed by Climate Ready Boston (2106) (see Figure ES.3):

1. The Outer Harbor Barrier (OHB), a gated barrier system that would only be closed during flood conditions caused by storm surge; the OHB would cover 3.8 miles from Winthrop to Hull, with additional 9.3 miles of shore-based protection in Hull, Winthrop, and Revere to prevent floods from flanking the barrier from the ocean.
2. The Inner Harbor Barrier (IHB), a gated barrier system that would only be closed during flood conditions caused by storm surge; the IHB would be in the passage between Logan Airport and the Seaport area of South Boston. It would require approximately 18 miles of shore-based protection systems to its north and south. This configuration assumes that the barrier and shore-based system could be designed for compatibility with Logan Airport operations.

The largest of the two gates of the OHB considered for this study would be the largest built thus far and its in-water span length the longest in the world. Opening and closing gates of these types of barriers is a cumbersome process that takes several hours. The gates of these types of barriers are designed for a small number of closures over a year or more, and with SLR would be closed more frequently. For example, the gates discussed in this analysis are similar in scale to the Maeslant Barrier protecting Rotterdam. It was designed for a closure frequency of approximately once every 10 years. Studies suggest that rising sea levels could increase its closure frequency to once every 3.2 years in 2050 and once every 1.1 years in 2100.

Conceptual Designs and Costs

OUTER HARBOR BARRIER

We chose a configuration for the OHB that would make use of Lovells, Gallops, and Georges Islands and stretches of shallow water, minimizing materials needed for construction, and avoiding impacts to shipping channels. It would have two floating leaf sector gates; the northern one in the President Roads navigation channel with an average low tide depth of 35 feet (soon to be dredged to 45 to 51 feet), and the southern one in the Nantasket Roads channel with an average low tide depth of 32 feet. Each floating leaf sector gate consists of two leaves that are closed only during storms. The total width of the northern barrier would be 1500 feet—making it the largest gate system of this type yet constructed—and the width of the southern barrier would be 650 feet. This design is based on the minimum navigation size according to the US Army Corps of Engineers. Vertical lift gates (smaller, non-navigable openings that can be shut during storms but allow some tidal exchange when open) would also be built into the barrier to mitigate some of the localized negative water quality impacts. Since securing enough clean and compatible sediment to build a natural barrier would

FIGURE ES.3
Barrier Alternatives in Boston Harbor

Sources: Arcadis, Esri World Imagery

be a challenge, the barrier would be constructed of gray (e.g., concrete and steel) features and then could be "greened" (covered to form a core of an island or land mass) over time as additional funds and sediments were identified. It would be possible to increase the height of the barrier if necessary after it was constructed, but not the height of the sector gates. As a result, this solution is not fully adaptable to the uncertainties of sea level rise.

The modeling indicated that there would be no tidal attenuation caused by the gate openings in either the OHB or the IHB. Thus a barrier would not protect Boston Harbor from nuisance flooding associated with sea level rise and normal tidal cycles without closure of the gates.

Total design, engineering, permitting, and construction costs could range from $8.0–$11.8 billion (2017 dollars) with annual operation and maintenance costs estimated at approximately 1% of total construction costs. Over 60% of the costs are for the floating sector gates. Given the extensive time to design, permit, finance, and construct the project, including the several miles of structures and berms needed to prevent flanking of the barrier to the north and south, the earliest it could be functioning would likely be 2050.

INNER HARBOR BARRIER

The main channel at the location of the IHB is approximately 1,200 feet wide with depths of approximately 35 to 40 feet. This would be spanned by one large floating leaf sector gate and artificial islands to support the leaves when the gate is open. No vertical lift gates would be needed. Pumps would be needed at the IHB to adequately control upstream freshwater levels during times when the IHB is closed because of a storm surge, as the closed gate would block the egress of flood water from the inner harbor. The pumps would maintain the water elevation inside the barrier with the goal of allowing the Charles River and Amelia Earhart dams not to close or pump, or at least to pump less frequently.

Total design, engineering, permitting, and construction costs could range from $6.5–$8.7 billion (2017 dollars), including the many miles of structures and berms needed to prevent flanking. Approximately 60% of the cost is the floating sector gate. Annual operation and maintenance costs are estimated at approximately 1% of total construction costs. Given the proximity to Logan Airport, Massport and FAA regulations governing the air space around the airport must be considered as well. Preliminary analysis indicates that the height of the barrier is likely less than the air-space requirements at this location, but this aspect will require further investigation if more detailed planning and design for a barrier are ever pursued for this site.

Hydrodynamic Analysis

We applied the Boston Harbor Flood Risk Model (BH-FRM), used in both the Boston Central Artery/Tunnel project and Climate Ready Boston, to determine hydrodynamic conditions with and without harbor-wide barriers. Conditions were analyzed for relative SLR scenarios of 0, 1, 3, and 5 feet since 2013. The 1 and 3 feet scenarios are approximately the same as used in the vulnerability assessment conducted for Climate Ready Boston.

TIDAL ATTENUATION

One of the key questions this research sought to answer was whether building a barrier in the harbor would impact the tides, as well as provide protection from storm surge. Would it be possible to lower the high tide, and as a result, protect the waterfront from tidal flooding exacerbated by SLR and moderate storm surge flooding for the medium term without even closing the gates? Because the openings are so large, the modeling indicated that there would be no tidal attenuation caused by the gate openings in either the OHB or the IHB. Thus a barrier would not protect Boston Harbor from nuisance flooding associated with sea level rise and normal tidal cycles without closure of the gates.

Since there is no tidal attenuation, the quantity of water entering and leaving the harbor during tide conditions would not change significantly. The openings through which the water would flow, however, would be much smaller. As a result, significant changes in current velocities in the vicinities of the OHB gates openings would be expected. At normal flood tide, the peak velocity through the northern gate could increase from approximately 2 feet per second to 5 feet per second (1.2 knots to 3 knots). For the southern gate, the peak velocity could increase approximately 2 feet per second to

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8 feet per second (1.2 knots to 4.8 knots). These high velocities would make navigation challenging for certain vessels. Therefore, it is unlikely that entry and exit into the harbor would be available throughout the entire tidal cycle, especially for recreational boats with limited power. At the same time, some new zones of stagnation in the harbor would be expected.

In our analysis, we found there were no differences in circulation dynamics outside of the OHB when the barrier was open under normal tidal conditions compared to present circulation. With the gates closed during storms, however, local circulation dynamics outside of the barrier would change. In particular, the flood tidal currents with the gates closed during storms could be perpendicular to the coast of Hull instead of generally parallel now—potentially increasing erosion on the Hull coastline.

The IHB would have minimal impact on the tides and currents in the harbor since the gate opening is not much less than the width of the current channel.

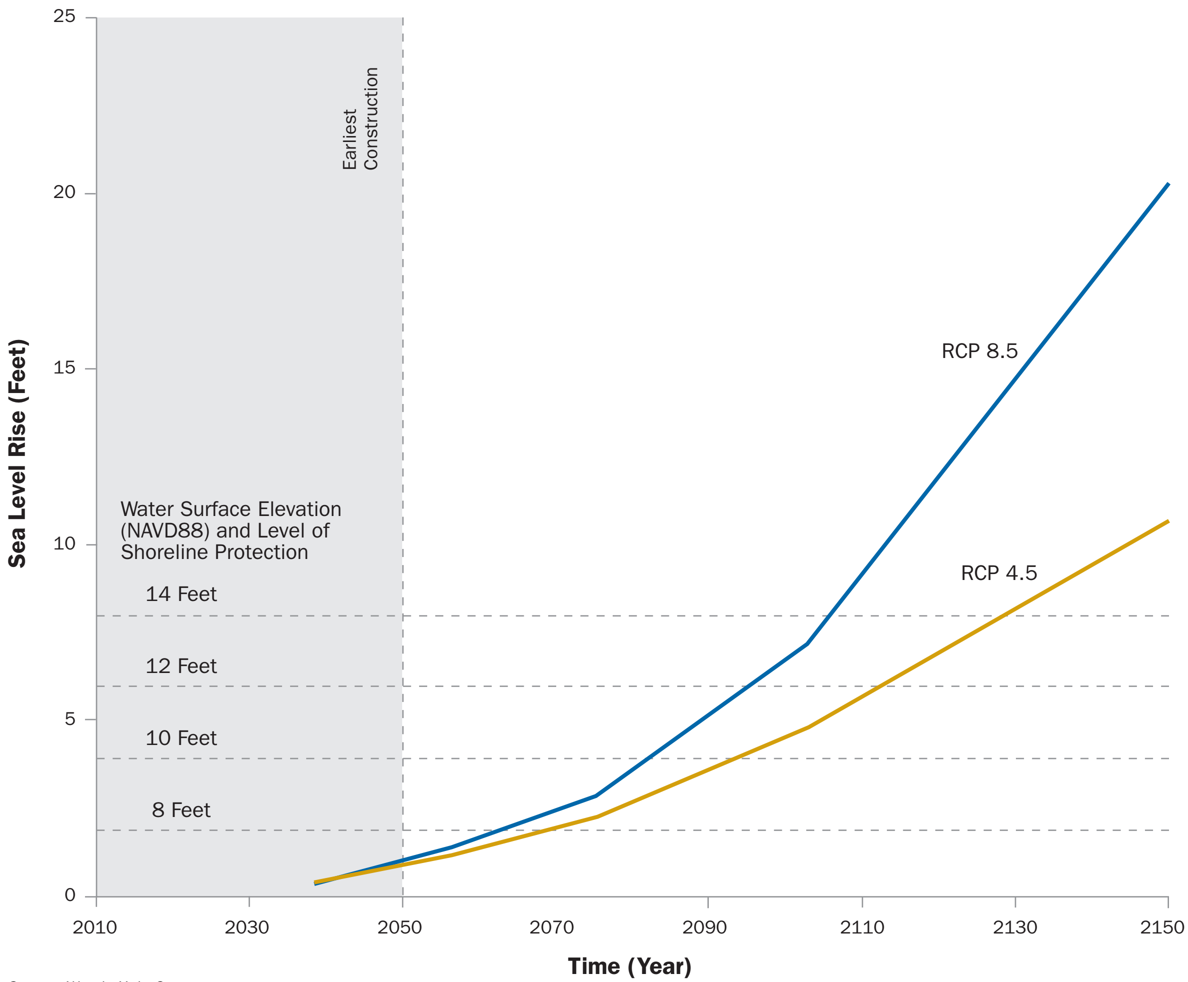
CLOSURE ANALYSIS

As described earlier, barriers of the size discussed in this project are not designed to open and close frequently. Any increase in closure frequency leads to higher risks of mechanical failure, environmental impacts, and shipping disruption, among other impacts. This analysis assumes that the maximum number of times the gates could be closed per year is fifty. This is a very high number (approximately once per week) compared to how often comparable systems worldwide are designed to close. We drew upon the historical record of tides and storms in Boston with projected sea level rise to forecast how many years after barrier construction the annual gate closure would exceed this number.

As shown in Figure ES.4 (p. 10), the closure analysis found that with no additional shore-based protection compared to the present (present protection is assumed to be 10 feet NAVD88—the approximate elevation of the present 1% storm), a barrier system under RCP 4.5 would be functional to approximately 2100 if it were able to close 50 times per year (the number of closures in earlier years would be considerably less, no more than a few times per year, if that). If fewer closures were permitted, the functional life decreases. At the end of this period, it would no longer be feasible to close the barrier gate sufficiently often to manage all storm surge events greater than 10 feet NAVD88. Similarly, if shore-based protection was at 12 feet NAVD88, the functional period would end in approximately 2110 (note in the subsequent economic analysis, this time was assumed to be

FIGURE ES.4

End of Functional Period of a Barrier System with Various Levels of Shoreline Protection



Source: Woods Hole Group

2100). With 14 feet NAVD88 shore-based protection, the functional period would end in 2130.

At the end of these periods, a barrier could still be used to lessen the impacts of the increasing number of storm surges, but not eliminate them as before.

Environmental Impacts

Environmental impacts of an inner and outer harbor barrier were considered under present and future (with 5 feet of SLR) conditions. Because of the tidal attenuation finding mentioned above, it was assumed that the presence of either barrier would not affect the tidal range in the harbor, and that the barriers would be closed for 46 to 84 hours during a nor'easter to reduce storm surge—less during a hurricane. This environmental assessment is based on an assumption of several (3-10) closures per year for major storms. Under future scenarios of up to weekly closures for regular tidal flooding, the environmental impacts are not discussed in detail in this report.

It should be noted that the environmental condition of Boston Harbor has undergone great change in its history with slow degradation before and rapid improvement after 1990 and the Boston Harbor Cleanup. Boston Harbor is currently undergoing, and will continue to undergo, great change with expected sea-level rise and a temperature increase of about 2.7 to 3.7 C by 2100. The future impacts of a harbor-wide barrier, then, must be considered in the context of other ongoing and anticipated changes in the harbor environment.

It does not appear that the construction of the OHB or the IHB would cause any irreversible negative transformations of the entire harbor environment in terms of water quality, habitat quality, or ecosystem services. While there are some foreseeable impacts, most of these are modest or limited spatially or temporally. For a great part of the harbor system, 5 feet of SLR and expected increases in sea surface temperature could cause more environmental impact than the construction of a harbor-wide barrier. In a separate analysis, these overall findings were confirmed. The team analyzed the change in the economic value of ecological services in Boston Harbor with and without a barrier assuming marshes could migrate inland as SLR occurred. This analysis showed some change in services due to the barrier, but it was not dramatic.

Economic Analysis

The economic feasibility of a harbor-wide barrier is based upon its benefits and costs. Damages avoided by the barrier system are the economic benefits. The benefit:cost analysis was done for several levels of shore-based protection implemented in different time periods with low and high estimates of project costs and discount rates.

The results are approximately the same for the IHB and the OHB. As in the case of the closure analysis, the benefits of a barrier system depend upon the elevation of shore-based adaptation. If the shore-based systems are effective in managing flooding, and a barrier is designed to manage all the events greater than the elevation of the shore-based protection, the benefit:cost ratios (BCR) of any barrier system are low—ranging from 0.05 to 0.33 for 7% discount rate and from 0.20 to 1.69 for 3% discount rate. If the shore-based measures are not effective, and a low discount rate of 3% is used, then in some cases, particularly if a barrier is built in 2050, the BCR may be more favorable (as high as in the range of 3.69–5.42). Under the higher discount rate of 7% and ineffective shore-based adaptation, most of the BCRs are less than 1.0. The results indicate a low cost-effectiveness of barrier systems if shore-based systems function as designed.

Since this analysis differs from Climate Ready Boston (2016) in both the approach and data used due to the size of the study area and project constraints, the expected benefits for some subareas of Boston in this analysis could be as much as 50% less than the benefit values using the methodology of CRB (2106). Even if this were the case in all subareas, if shore-based adaptation is effective, the BCRs are still less than 1.0 in most cases.

If the shore-based systems are effective in managing flooding, and a barrier is designed to manage all the events greater than the elevation of the shore-based protection, the benefit:cost ratios (BCR) of any barrier system are low.

The low BCRs for the barrier configurations we investigated in this study are likely to make eligibility for federal funding very challenging, if not impossible.

Shipping and Recreational Use Analysis

One of the guiding assumptions of this analysis was the importance of finding a solution that would minimize the disruption of the various uses of Boston Harbor. Many commercial and recreational activities occur within Boston Harbor. This analysis determined that the proposed inner and outer barriers could have both positive and negative impacts on these activities. Generally speaking, the proposed barriers would provide added protection to activities occurring within the harbor—including commercial shipping and fishing, and recreational boating and fishing—as they would protect shoreside infrastructure and vessels from storm turbulence and flooding.

The openings to the barriers would generally accommodate federal requirements for navigation channels, minimizing impacts to commercial vessels entering and exiting Boston Harbor (including the new post Panamax vessels for which Massport is enlarging its facilities at Conley Terminal). Vessels would not be able to enter or exit when the barriers are closed, and would have to plan travel in advance of closing.

The anticipated increased water velocity in the barrier openings could cause navigational and safety issues for both recreational and commercial vessels near the barrier openings. Additionally, there could be greater vessel congestion near the openings in the OHB, especially the northern barrier opening as its water velocity is expected to be more manageable than the southern barrier opening. The OHB could also impact the abundance, distribution, and behavior of fish populations, which would in turn impact both commercial and recreational fisheries.

Social Vulnerability Analysis

The social vulnerability analysis sought to determine the impact an IHB or an OHB would have on socially vulnerable populations as compared to the broader population. In particular, the analysis sought to understand if a barrier system would inadvertently disproportionately impact socially vulnerable populations.

Importantly, the analysis found that there is not a disproportionate negative impact on vulnerable populations from either the IHB or OHB. More specifically, the percentage of socially vulnerable people who would remain vulnerable to flooding if a barrier were to be constructed is not different from the percentage of socially vulnerable population in Boston as a whole. This analysis did not look at different factors that would allow socially vulnerable populations to recover from a storm or take into account the disparate challenges that different groups have after an emergency event. Instead, the focus was on exposure to flooding caused by storm events.

Comparison to Shore-Based Adaptation

While this study focused primarily on the feasibility of different harbor-wide barrier systems, a decision about whether or not to build a barrier should not be made in isolation but in comparison with other options. Our analysis identified several key advantages that shore-based solutions have over a single harbor-wide barrier.

MULTI-FACETED OPTIONS

Shore-based adaptations can fall under the general categories of protection, accomodation, and retreat. Within each of these categories, a mix of different strategies exists. These include policy-level actions such as flood insurance, zoning, or managed retreat from the coast. Shore-based protection systems can include "green" and/or "gray" approaches to flood walls, elevation of land using berms and other features, additions of transparent flood barriers, and temporary flood walls that can be deployed in advance of impending floods. They can be employed at the regional scale or the individual asset scale, and if designed correctly, can provide multiple layers of effectiveness and safety. In addition, they can provide management of high tide nuisance flooding, which harbor-wide barriers do not. Most of the shore-based solutions provide many co-benefits such as recreation, public access, open-space, and urban heat island cooling. These co-benefits might be particularly important in communities suffering from environmental and social injustice.

FLEXIBILITY AND ADAPTABILITY

Another advantage of shore-based solutions is that they provide a flexible, adaptive management approach to coastal protection. As a result, responses can be implemented over time as SLR and flooding increases, projections improve, and more is known about future socio-economic conditions.

RISK MANAGEMENT

The risk of singularly relying on a barrier, even if technology could be developed to ameliorate the concerns around closure frequency, is that if completion is delayed or the barrier is less effective than designed, then the City and the region may be left completely exposed, and in the words of Climate Ready Boston, having "catastrophic" results.

BETTER BENEFIT-COST RATIOS

The benefit-cost ratios at a 7% discount rate of harbor-wide barriers that effectively manage flooding above the level of shoreline protection range from 0.05 to 0.33.

For the same level of protection at the same discount rate (7%) and a shorter functional lifetime (20 years), Climate Ready Boston estimates a benefit-cost ratio of 3.22 to 5.3 for a shore-based flood protection system in the Greenway/Border Street area of East Boston, and a benefit-cost ratio of 4.3 to 7.9 for a shore-based protection project for Charlestown. Therefore, shore-based adaptation approaches, at least for these two districts, appear far more cost effective.

More evidence of the cost effectiveness of shore-based adaptation compared to harbor-wide barriers can be shown by examining a potential choice point the city of Boston could face in the future. If the city is protected to 14 feet NAVD by only shore-based protection, at a certain point that amount of protection will no longer be sufficient. Leaders will need to decide on additional protections.

Assuming shoreline protections can be built up, this would cost an estimated $508 million (2017 dollars based on $4,500 per linear foot for additional walls and $2,250) to expand existing walls to provide protection equivalent to the Outer Barrier for Boston. Even assuming that the City of Boston would not pay for the entire cost of building a barrier, the cost of shore-based protections is dwarfed by the potential cost of a barrier which could be $8–$12 billion.

Findings and Recommendations

Based upon the analyses conducted for this report, it is clear that shore-based adaptation strategies, if effective, have significant advantages over harbor-wide strategies for Boston, at least for the next few decades when a decision on a harbor-wide barrier could be re-examined if shore-based systems are not effective. The same finding likely applies to other municipalities in Boston Harbor.

KEY FINDINGS

The analysis has shown that while a harbor-wide barrier system could manage some coastal flooding with perhaps minimal environmental impacts and moderate impacts on harbor users, its cost-effectiveness is low and its operational life would be limited. With limited potential to adapt or adjust the barrier once it is in place, it could be challenging to respond to the uncertainties of climate change over time. The alternative of a wide spectrum of shore-based, district-level solutions located around the inner harbor waterfront, however, has the potential for high cost-effectiveness, and has several key advantages. With proper planning and design, these solutions have the potential to incorporate multiple levels of protection, manage coastal flooding, provide flexibility and adaptability, offer co-benefits that address social justice, endure for long operational lifetimes, and carry minimal impacts to the environment and harbor users.

KEY RECOMMENDATION

The authors recommend that the City continue to focus its climate adaptation strategy for the next several decades on the multi-layered, shore-based approach described in Climate Ready Boston (2016). Within a few decades, more will be known about the rate of sea level rise, the effectiveness of shore-based solutions, and technological advances that could improve the feasibility and cost of harbor-wide barrier systems. In the meantime, focusing on shore-based solutions will provide flood protection more quickly at less cost. These shore-based solutions would be needed in any case over the next few decades to manage coastal flooding during the design and construction period of any harbor-wide barrier if it is decided to build one in the future. Shore-based solutions are also more adaptive and can provide substantial co-benefits, while protecting the harbor's surrounding communities from sea level rise and storm surge. Any future barrier would probably best be used to complement shore-based systems by managing very large floods with the shore-based systems managing smaller events and helping to manage the very large events. This would limit the annual number of closures of a future barrier system. The decision regarding a barrier is very much dependent upon the future risk tolerance of the city and the performance of shore-based systems.

It will be especially important to monitor the actual and projected pace of sea level rise in Boston Harbor over the next several decades to determine whether shore-based solutions being implemented in Boston and adjacent cities will be adequate.

ADDITIONAL RECOMMENDATIONS

While moving forward with a harbor-wide barrier is not prudent, we recommend that the City continue to monitor climate, environmental, economic, and social changes, the risk tolerance of the city, the continuing evolution of the technology of harbor-wide barriers, and the global experience with existing storm surge barrier systems, to determine if the feasibility of a harbor-wide barrier should be re-examined at some point in the future. It will be especially important to monitor the actual and projected pace of sea level rise in Boston Harbor over the next several decades to determine whether shore-based solutions being implemented in Boston and adjacent cities will be adequate for the remainder of the century and beyond.

If the feasibility of a harbor-wide barrier is reexamined at some point, there are several engineering, hydrodynamic, environmental, climate, economic, and planning analsyes that would warrant more detailed examination than was conducted for this study. Regardless, the City should undertake strong greenhouse gas mitigation actions in concert with cities and nations globally to lessen the rate of climate change. Strong mitigation starting now could limit SLR by 2100 to 2 or 3 feet or less. This would greatly reduce the need for future consideration of harbor-wide barrier systems in this century and early next century.

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