CLIMATE *READY* BOSTON

EXECUTIVE SUMMARY

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DECEMBER 2016

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Climate risks are not new for Boston, but they will continue to increase as the global climate changes.

Image courtesy of Sasaki

Since 1991, Boston has experienced 21 events that triggered federal or state disaster declarations.

For example, in 2011, Hurricane Irene caused downed trees and power outages across the city. In 2012, while Boston was spared the most devastating effects of Hurricane Sandy due to the storm missing Boston's high tide by five hours, the city still experienced high winds and coastal flooding. As the climate changes, the likelihood of coastal and riverine flooding—as well as other hazards, like stormwater flooding and extreme heat—will increase.

The challenges from climate change are substantial and complex but can be addressed through bold and creative actions that support the city's vitality and livability.

Boston can thrive in the coming decades if it takes action to adapt its people, its neighborhoods, and its economic and cultural assets, starting now. This work will be difficult, contentious, and complex. But if done well, it will not only create a resilient, climate-ready Boston—it will also dramatically improve the city and quality of life for all its residents.

Image courtesy of Sasaki

To address these challenges, **Climate Ready Boston** features four components.

UPDATED CLIMATE PROJECTIONS

A set of updated projections for four climate factors: extreme temperatures, sea level rise, extreme precipitation, and storms. The University of Massachusetts Boston oversaw a team of climate scientists, the Boston Research Advisory Group, to develop these projections.

CLIMATE FACTORS

- Extreme Temperatures
- Sea Level Rise (SLR)
- Extreme Precipitation
- Storms

VULNERABILITY ASSESSMENT

A comprehensive evaluation of current and potential future risks associated with each of three climate hazards (extreme heat, stormwater flooding, and coastal and riverine flooding) for Boston's people, buildings, infrastructure, and economy. Vulnerability assessment data for the three climate hazards reflects the underlying factors studied in the Climate Projection Consensus.

VULNERABILITY ASSESSMENT HAZARDS

- Extreme Heat
- Stormwater Flooding
- Coastal and Riverine Flooding

FOCUS AREAS

Eight Boston areas where the results of the Vulnerability Assessment and the climate resilience initiatives are applied in more detail to illustrate the risks Boston faces and how Boston can address them. The focus areas recognize that some risk, particularly for coastal and riverine flooding, is spatially concentrated.

ANALYSIS AREAS

- Charlestown
- Charles River
- Dorchester
- Downtown
- East Boston
- Roxbury
- South Boston
- South End

CLIMATE RESILIENCE INITIATIVES

These policy, planning, programmatic, and financial initiatives address the risks identified in the Vulnerability Assessment and work together to increase Boston's resilience. The initiatives are summarized in an Implementation Roadmap that sets forth, for each initiative, responsibility, time frame, and key milestones.

INITIATIVE LAYERS

- Updated Climate Projections
- Prepared and Connected Communities
- Protected Shores
- Resilient Infrastructure
- Adapted Buildings

Climate Ready Boston is coordinated with Imagine Boston 2030, the first citywide plan in 50 years, and 100 Resilient Cities, to guide Boston toward a more affordable, equitable, connected, and resilient future.

Through Imagine Boston 2030, the City has identified areas that have capacity to accommodate Boston's growing population and dynamic economy. Many of the areas where Boston will grow will be exposed to increasing flood risk as sea levels rise. As it grows in these areas, Boston is committing to protecting them. While we do not know all the mechanisms for protection yet, Boston is investing in developing local climate resilience plans for vulnerable areas. These plans will identify multilayered investments needed to enable climate-ready growth.

Boston will approach this topic dynamically and respond to new information as we have it. Climate adaptation presents Boston with opportunities for carefully managed growth and investment that ensure existing neighborhoods can thrive, new neighborhoods are ready for the changing climate, and jobs are created and expertise developed for long-term growth and protection.

PLANNING CONTEXT

Boston's favorable location, with three rivers flowing into a sheltered harbor well-suited for waterborne trade, helped it grow into a major commercial city. The city's core was once the narrow Shawmut Peninsula, but as trade and population grew to make Boston the economic center of the region, Bostonians filled in the tidal marshes with wharves, parks, and entire neighborhoods built on new land. In the three centuries following Boston's founding in 1630, the city's footprint increased by nearly 50 percent, with much of the land along the coastline and riverbanks filled to just above high tide.

Although coastal expansion in previous centuries made the city more vulnerable to climate change, it helped Boston become the largest residential and commercial center in New England. The city is home to over 656,000 residents[1] and 718,000 jobs,[2] accounting for a total of $160 billion in annual economic output. Boston is a center for financial institutions, higher education, and medical services. It is also the hub of the region's transportation system, with subway lines, bus service, commuter rail lines, ports, and Logan International Airport.

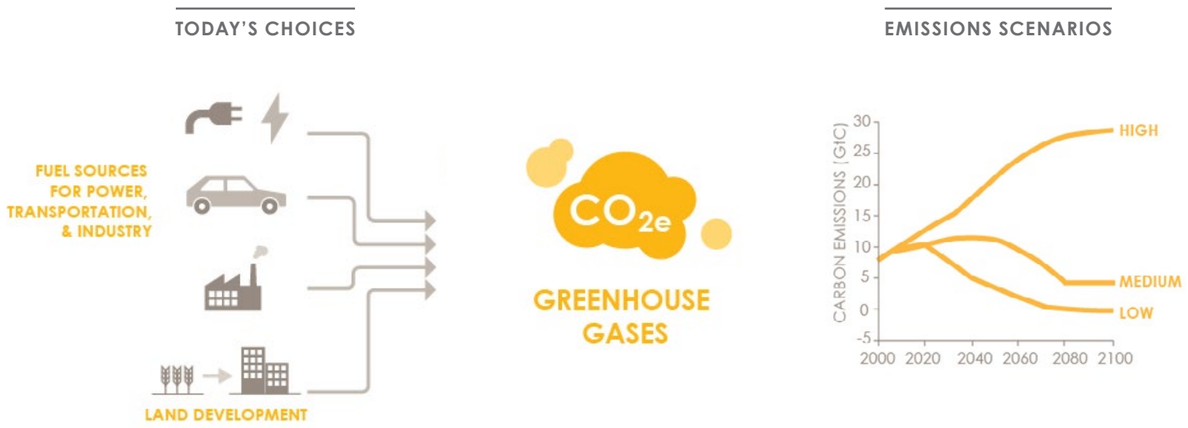
Boston recognized the threat of climate change early and has pursued an integrated approach to address it. In 2000, Boston launched its climate action program when it joined the Cities for Climate Protection Campaign of ICLEI-Local Governments for Sustainability. Over the last 15 years, the City has led a range of efforts to reduce emissions citywide to slow the pace and scale of climate change, including the 2011 commitment for an 80 percent reduction in carbon emissions by 2050. In recognition of these efforts, the City received an award at the United Nations Climate Change Conference in Paris (COP21). However, even under the most optimistic projections of global emissions reductions, Boston faces serious risk from climate change and must adapt.

[1] Source: "ACS 5-Year Estimates (2011–2014)." U.S. Census Bureau.
[2] Source: Boston Planning and Development Agency Analysis.

ABOVE
Boston's Present & Historical Shoreline

Climate Ready Boston will guide Boston's adaptation efforts, building upon recommendations from the City's 2007 Climate Action Plan and its 2011 and 2014 updates. Based on the most up-to-date scientific consensus of future climate conditions, Climate Ready Boston provides an evaluation of potential impacts from Boston's three major climate hazards: extreme heat, stormwater flooding, and coastal and riverine flooding. Climate Ready Boston then identifies climate resilience initiatives to enable Boston to address these risks and continue to thrive in the face of climate change.

Boston's Future Climate



Bostonians must first understand the likely impacts of climate change in order to plan for a strong, resilient future.[3]

To help us understand climate change impacts at the local level, Climate Ready Boston convened a working group of the region's climate scientists. The Boston Research Advisory Group (BRAG), overseen by the University of Massachusetts Boston School for the Environment, developed this consensus about how Boston's climate will change over the course of the twenty-first century.

The longer-term impacts of climate change are largely dependent on the global community's success at curbing emissions of greenhouse gases. Because we do not know how well we will do, scientists use multiple emissions scenarios as the bases for their projections. Climate projections for the next few decades are relatively consistent, regardless of which emissions scenario they rely on. However, the projections become increasingly different the further we look into the future.

Climate Ready Boston's climate projections use three emissions scenarios from the Intergovernmental Panel on Climate Change:

- **A HIGH-EMISSIONS SCENARIO** often characterized as a continuation of *business as usual;*
- **A MEDIUM-EMISSIONS SCENARIO** in which emissions remain around their current levels through 2050 and then are slowly reduced in the second half of the century through *moderate emissions reductions and;*
- **A LOW-EMISSIONS SCENARIO** in which net global emissions are reduced to less than a third of their current levels by 2050 and are brought to zero by about 2080 through *major emissions reductions.*

These findings emphasize that a critical strategy for climate adaptation is the expansion of efforts to reduce our carbon emissions.

[3] This section is a summary of the BRAG Climate Projection Consensus report, which describes future climate conditions in the Boston region, including extreme temperatures, sea level rise, heavy precipitation, and coastal storms. The full report is available at climateready.boston.gov/findings.

EXTREME TEMPERATURES

Average temperatures in the Northeast have been slowly rising for over a century. Temperatures in the northeastern United States increased by almost two degrees Fahrenheit between 1895 and 2011.

The rate of increase in average temperatures is accelerating, and Boston's average summer temperatures and number of days with extreme heat will increase. Heat waves will become more common, last longer, and be hotter. While the average summer temperature in Boston from 1981 to 2010 was 69 degrees, it may be as high as 76 degrees by 2050 and 84 degrees by 2100. In other words, by 2050 Boston's summers may be as hot as Washington, DC's, summers are today, and by the end of the century, they may be hotter than Birmingham, AL are today. Compared to the period from 1971 to 2000, when there were 11 days per year over 90 degrees, there may be as many as 40 by 2030 and 90 by 2070—nearly the entire summer. Heat waves—extended periods of extreme heat—are a leading cause of weather-related mortality in the United States.

Although winters will be warmer, the risk of frost and freeze damage and cold snaps will continue. While from 1981 to 2010, Boston reached below freezing almost one out of three days per year, by the end of the century, this may happen only around one in ten days.

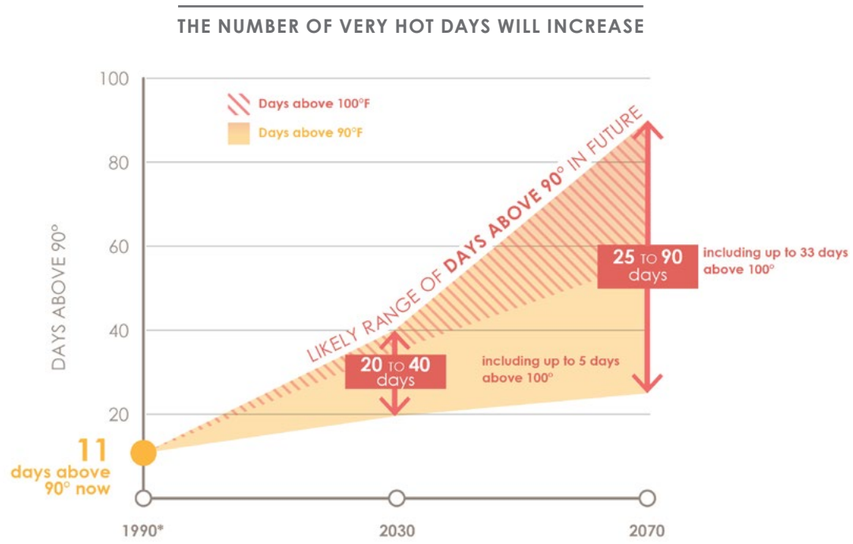
As an urban area, Boston tends to be hotter than surrounding communities that are more suburban or rural. Urban areas generally tend to be hotter than nearby rural areas because concrete, steel, and other building materials retain more heat than vegetation. This phenomenon, known as the "urban heat island effect," is compounded by climate change.

Future temperatures in Boston will depend on how much we are able to cut our greenhouse gas emissions. The rise in temperatures between now and 2030 is largely consistent between all emission scenarios. However, the scenarios show that cutting emissions now can greatly slow the rise in temperatures in the second half of the century.

SEA LEVEL RISE

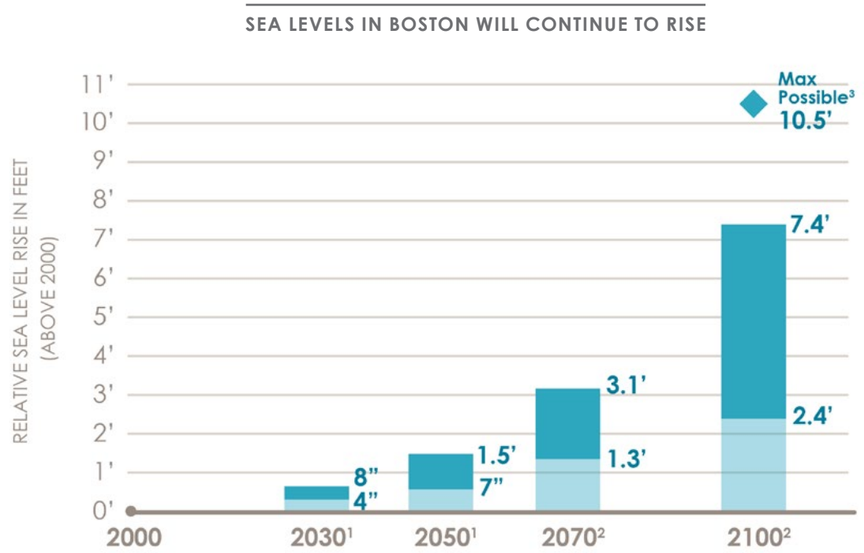
The pace of relative sea level rise is accelerating. Over the entire twentieth century, sea levels rose about nine inches relative to land. Another eight inches of relative sea level rise may happen by 2030, almost three times faster. By 2050, sea levels may be as much as 1.5 feet higher than they were in 2000, and by 2070, they may be as much as 3 feet higher than in 2000. This is driven by a combination of the melting of land ice, the expansion of water as it warms, and changes in the amounts of water extracted from below ground or stored behind dams.

A major reduction in global greenhouse gas emissions can have a tremendous impact on the future of Boston Harbor. While sea level rise projections for 2030 are about the same across all emission scenarios, in later years there are big differences between scenarios. With a sharp reduction in global emissions, end-of-century sea level rise could stay under two feet, but a continuation of business as usual may result in over seven feet of sea level rise.



Data source: Rossi et al. 2015

* Baseline represents historical average from 1971-2000
Upper values from high emissions scenario. Lower values from low emissions scenario.



Data Source:
BRAG Report, 2016

1 - Likely under all emission scenarios
2 - Likely under moderate to high emission scenarios
3 - Low probability under high emission scenario

Image courtesy of Sasaki

Rising sea levels mean that any given storm will cause more flooding in the future than it would today.

EXTREME PRECIPITATION

In the Northeast, there has already been a very large increase in the intensity of extreme rain and snow. From 1958 to 2010, there was a 70 percent increase in the amount of precipitation that fell on the days with the heaviest precipitation. This increase is greater in the Northeast than for any other region of the country.

The increase in extreme precipitation is expected to continue. As the climate warms, more ocean water evaporates into the air, and warmer air can hold more water, supporting heavier precipitation events. Heavy precipitation events will continue to increase in Boston. However, due to the complexity of the processes underlying precipitation as well as natural variability, the magnitude of this increase is not yet clear.

If we take action to cut global greenhouse gas emissions, we can prevent the most extreme precipitation projections from becoming a reality. A commonly used measure of major rain and snow events is the "10-year, 24-hour storm," or the amount of precipitation that has at most a one-in-ten annual chance of falling during a 24-hour period. While projections for these events are similar in the short term across different emissions scenarios, by the end of the century, the difference between medium and high scenarios is about 10 percent.

STORMS

Current climate projections do not provide a clear projection of how the intensity, frequency, and trajectory (tracks) of tropical and extratropical storms will change. Extratropical storms (like blizzards and nor'easters) have cold air at their centers. Tropical storms, on the other hand, have warm air, which means that they can develop into hurricanes more quickly. There are large uncertainties about how climate change will affect future storms. This is particularly true for extratropical storms. For tropical storms, there is some evidence that their intensity has been increasing. If tropical storm intensity increases, there could be more frequent major hurricanes (Category 3 and greater), even if the total number of tropical storms does not increase.

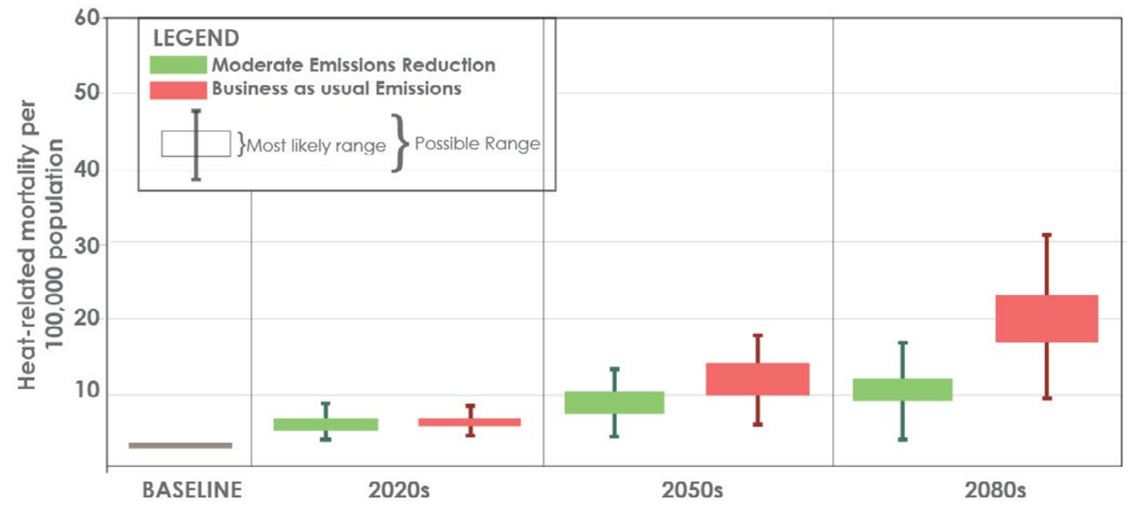
Rising sea levels mean that any given storm will cause more flooding in the future than it would today. During a storm, winds can blow ocean water towards the land, creating a "storm surge" on top of the baseline sea level. When storm surge is combined with tidal processes, the result is known as a "storm tide." With higher seas, it takes less precipitation and a less powerful storm surge to produce the same amount of flooding as a more powerful storm would produce when the seas are lower.

Boston's Increasing Climate Vulnerability

The Vulnerability Assessment analyzes how Boston's people, buildings, infrastructure, and economy will be affected by climate hazards.

In considering the impacts on people, the assessment focuses on socially vulnerable populations, people who are more vulnerable to climate hazards because they already experience stressors, such as poverty, poor health, and limited English proficiency. For property, the assessment considers direct and indirect impacts, in terms of both structural damage to buildings and site-access challenges. For infrastructure, it analyzes expected impacts on Boston's transportation, power, water and sewer, emergency response, and environmental systems. Finally, it evaluates the potential economic impacts of flooding, such as the loss of jobs and disruption of business operations.

THE NUMBER OF HEAT-RELATED DEATHS EACH YEAR IN BOSTON WILL TRIPLE

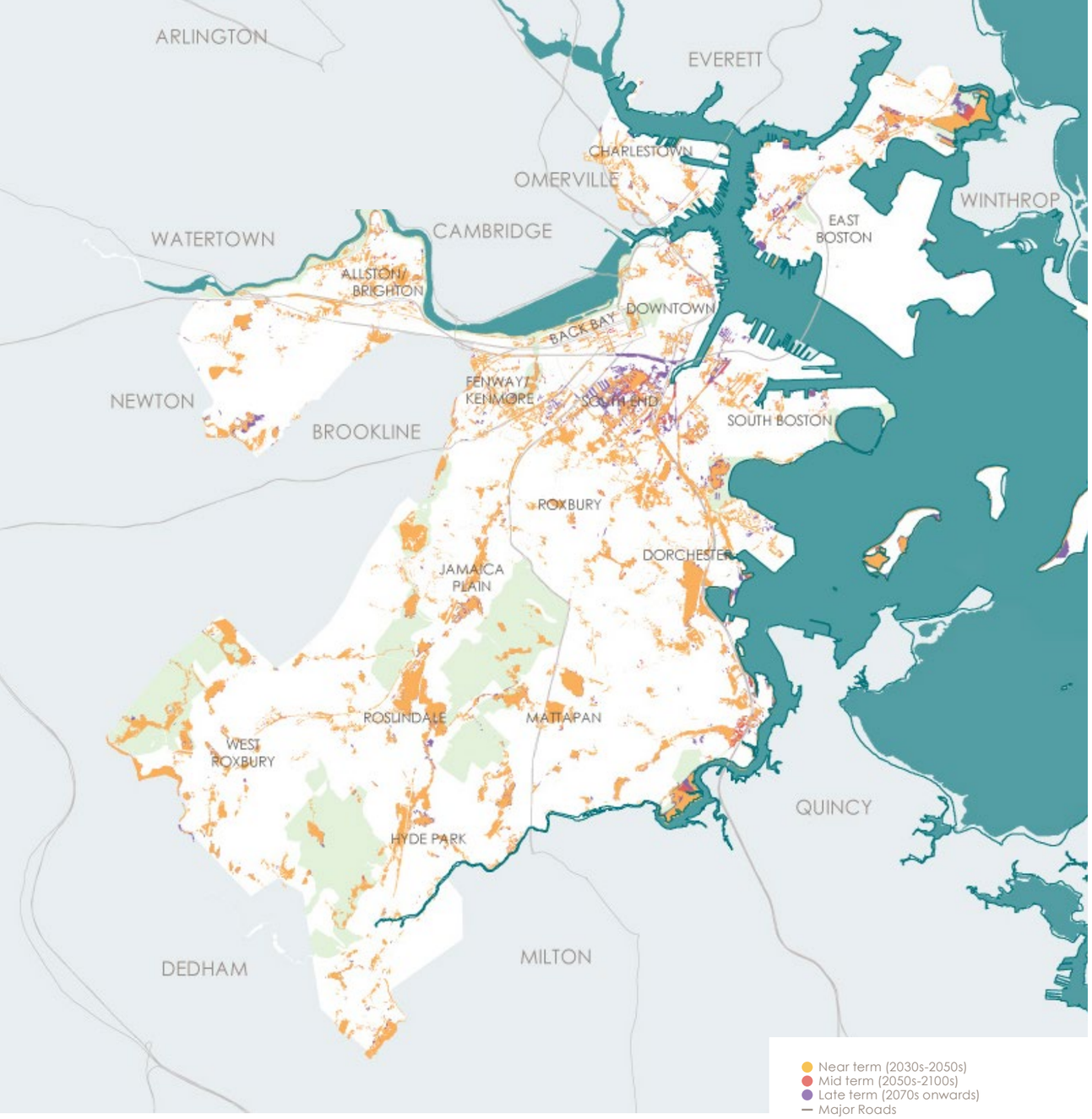


EXTREME HEAT IMPACTS

With climate change, Boston will experience both increasing average temperatures and increasing frequency, duration, and intensity of heat waves. While temperatures are hottest in areas of the city that experience localized urban heat island effects, on very hot days, the entire city is at risk for the negative impacts of extreme heat.

Extreme heat can cause negative health impacts, including direct loss of life, increases in respiratory and cardiovascular diseases, and challenges to mental health. In the baseline period (1985 to 2016), the heat-related mortality rate was about 2.9 per 100,000 people in Boston. During the 2020s, this rate is expected to more than double. By the 2080s, this rate may more than triple to 10.5 per 100,000 people under a moderate emissions reduction scenario or reach as high as 19.3 per 100,000 under the business-as-usual emissions scenario. Climate change can also harm air quality, leading to increasing risks for diseases such as asthma. Health impacts will be especially significant for populations such as older adults, children, and the medically ill.

Heat can have negative consequences for Boston's infrastructure, presenting further challenges for health and quality of life. Power failures are more likely during heat waves due to the increased demand for electric power for air conditioning, as well as the added stress of the heat on mechanical and electrical assets. High temperatures can also cause thermal expansion in roads and railroad tracks, leading to damage or requiring speed reductions. As rising temperatures lead to a potential increase in tree mortality, any loss of canopy coverage or green space will only contribute to the urban heat island effect, reduced air quality, increased stormwater runoff, and decreased quality of life.



STORMWATER FLOODING FROM 10-YEAR, 24-HOUR STORM WITH VARYING CLIMATE CONDITIONS

Without improvements to the stormwater system, over 11,000 structures and 85,000 people will be directly exposed to frequent stormwater flooding as soon as the 2070s.[4]

[4] Current building stock and population in areas expected to be exposed. The building stock and population have not been projected.

STORMWATER FLOODING IMPACTS

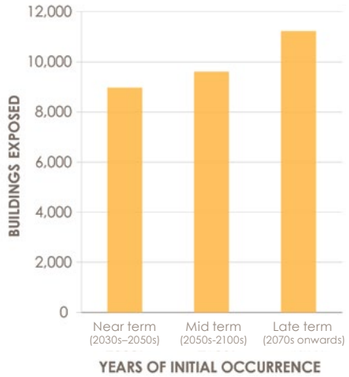
Stormwater flooding occurs throughout Boston today, as the city's drainage system struggles to manage intense rain events, rising sea levels, and less permeable ground surface that would slow and absorb stormwater. Common areas for stormwater flooding are along the coast, where outfalls may be unable to discharge; transportation corridors with impervious surfaces where water cannot percolate; and designed drainage areas whose capacities are exceeded. The drainage system requires ongoing investments to catch up and keep up with climate conditions.

In the near term (2030s–2050s), rising sea levels and increasing extreme precipitation will exacerbate stormwater flooding, unless the drainage system is upgraded. Higher sea levels mean that stormwater outfalls may not be able to discharge or may even backflow, and more extreme precipitation means that drains and pipes must handle greater volumes of water in short periods of time.

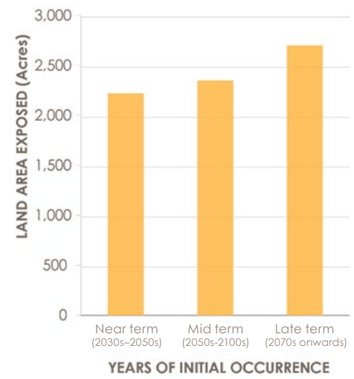
The area of Boston exposed to stormwater flooding is projected to grow steadily throughout the century. As soon as the 2050s, 7 percent of the total land area in the city could be exposed to frequent stormwater flooding from 10-year, 24-hour rain events.

Transportation infrastructure will be impacted by frequent stormwater flooding at multiple scales ranging from sidewalks to local streets to major thoroughfares like highways and MBTA lines. Frequent stormwater flooding is projected near major thoroughfares such as Columbus Avenue, Tremont Street, and Morrissey Boulevard, as well as Interstates 90 and 93 and along the MBTA Orange and Red Lines. Additionally, many of these transportation routes are also designated evacuation routes, which may become increasingly more flood prone to coastal storms with heavy rainfall.

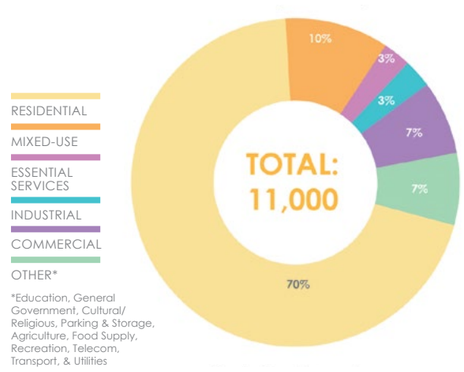
BUILDINGS EXPOSED TO FREQUENT STORMWATER FLOODING



LAND AREA EXPOSED TO FREQUENT STORMWATER FLOODING



BUILDINGS EXPOSED TO FREQUENT STORMWATER FLOODING TYPE
(2070S-2100S)



*Education, General Government, Cultural/ Religious, Parking & Storage, Agriculture, Food Supply, Recreation, Telecom, Transport, & Utilities

COASTAL & RIVERINE FLOODING IMPACTS

What Is a "1 Percent Annual Chance Flood"?

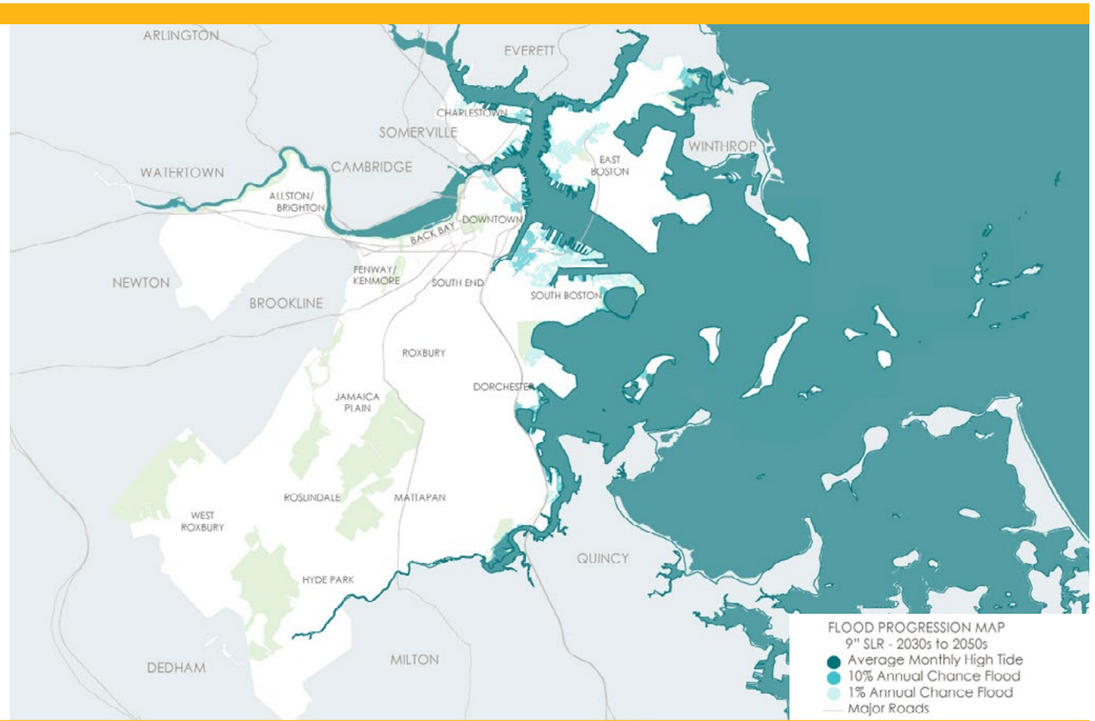
A "1 percent annual chance flood" is a flood event that has a 1 in 100 chance of occurring in any given year. Another name for this flood is the "100-year flood." Experts prefer not to use the "100-year" term since it gives the impression that a certain level of flooding will only occur once every 100 years. In fact, it has a one percent chance of occurring in any given year and can even occur multiple times in a single year or decade.

Over a 30-year period, there is almost a one in three chance that a 1 percent annual chance flood will occur at least once.

NEAR TERM (2030s–2050s)

FLOOD PROGRESSION

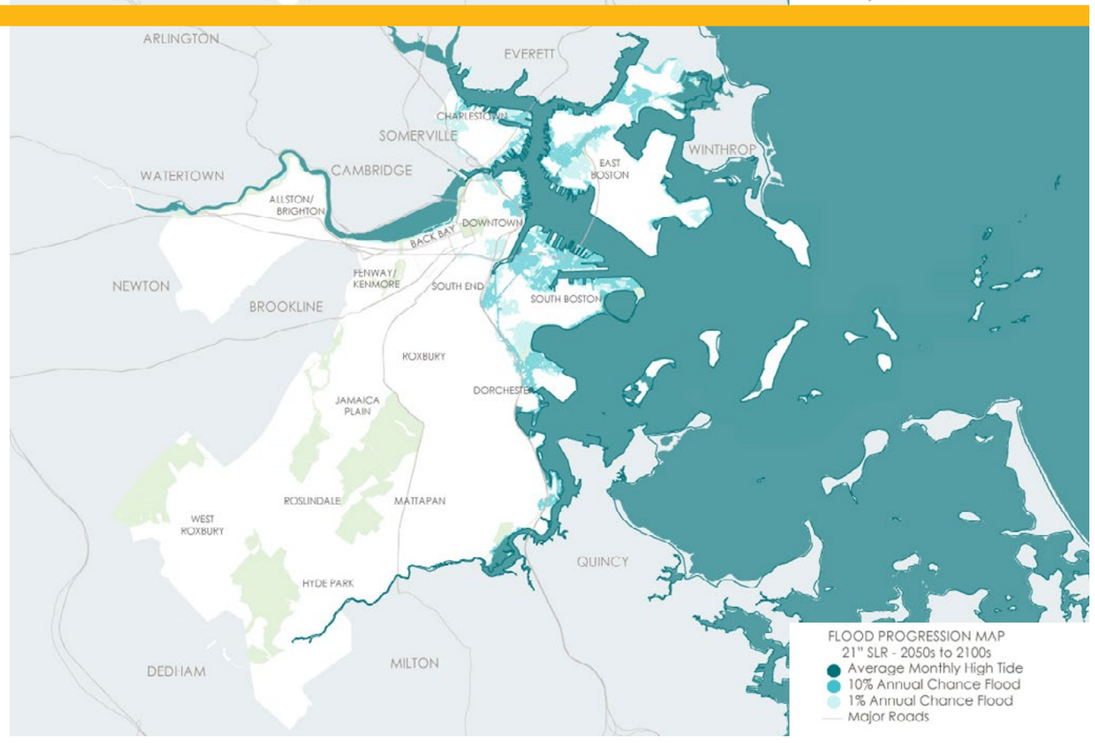
In the near term (2030s–2050s), coastal and riverine flood exposure will be concentrated in South Boston, East Boston, Charlestown, and Downtown and represents a significant threat to these neighborhoods and the rest of the city. Across the city, a severe flood with a 1 percent annual chance of occurring would inundate 2,100 buildings, representing $20 billion in real estate value, and including the homes of 16,000 Bostonians. Such an event would cause an estimated $2.3 billion in physical damages to buildings and property and other economic losses, including relocation and lost productivity. Considering the impact of flood events of multiple probabilities, 70 percent of economic losses are concentrated in Downtown and South Boston, with their high densities of businesses and valuable properties.

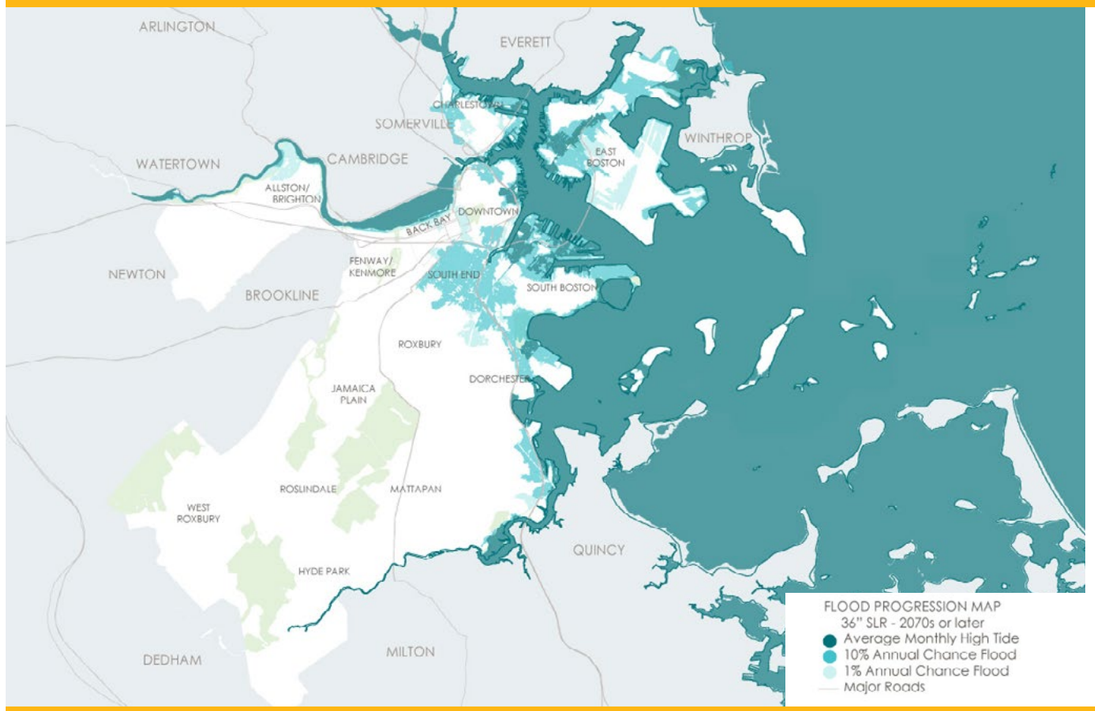


MID TERM (2050s–2100s)

FLOOD PROGRESSION

In the second half of the century (2050s–2100s), coastal and riverine flood exposure may increase across waterfront neighborhoods and start to be significant in Dorchester. As sea levels rise, the depths of flooding along the waterfront will increase, and floodwaters will start to threaten higher grounds and areas further inland that currently face little or no flood risk.





LATER TERM (2070s ONWARDS)

FLOOD PROGRESSION

In the late century (2070s or later), a significant portion of Boston's current land may be inundated every month. Exposure to severe coastal and riverine flooding will expand to vast areas of the city, including inland neighborhoods like the South End and neighborhoods along the Charles River. By penetrating past low-lying areas around Fort Point Channel and by the New Charles River Dam, floodwaters from storms can reach these areas that are not currently exposed to significant coastal and riverine flooding. Compared to the near term (2030s–2050s), over three times the amount of land—almost one-fifth of Boston's land area—will be exposed to inundation from a lower probability (1 percent annual chance) event. Five percent of Boston's total land area will be inundated at high tide at least once a month, even without any storm conditions.

Neighborhoods	Total Land Area (Acres)	LAND AREA EXPOSED (ACRES) 9" SLR 1% annual chance	21" SLR 1% annual chance	36" SLR 1% annual chance	36" SLR AMHT	PERCENT OF NEIGHBORHOOD EXPOSED 9" SLR 1% annual chance	21" SLR 1% annual chance	36" SLR 1% annual chance	36" SLR AMHT
I. Greatest Exposure & increasing throughout century									
Charlestown	870	120	310	460	110	14%	36%	54%	12%
Downtown	770	110	240	350	70	14%	31%	45%	10%
East Boston	3,340	540	1,040	1,680	480	16%	30%	49%	14%
Harbor Islands	820	200	230	260	200	25%	28%	32%	24%
South Boston	1,940	470	930	1,220	360	24%	48%	63%	19%
II. Lower Exposure today, but significant jump late century									
Allston / Brighton	2,940	30	70	240	20	1%	2%	7%	1%
Back Bay / Beacon Hill	460	<10	<10	80	<10	<1%	1%	17%	<1%
Roxbury	2,770	<10	<10	130	<10	<1%	<1%	5%	<1%
Dorchester	3,780	240	430	750	220	6%	11%	20%	6%
South End	640	<10	20	450	<10	<1%	3%	71%	<1%
III. Other Neighborhoods									
Fenway / Kenmore	620	<10	<10	<10	<10	<1%	<1%	<1%	<1%
Hyde Park	3,260	0	0	0	0	0	0	0	0
Jamaica Plain	2,260	0	0	0	0	0	0	0	0
Mattapan	1,560	0	0	0	0	0	0	0	0
Roslindale	2,250	0	0	0	0	0	0	0	0
West Roxbury	3,350	0	0	0	0	0	0	0	0
Boston Total	**31,720**	**1,720**	**3,280**	**5,630**	**1,470**	**8%**	**10%**	**18%**	**8%**

AMHT is the Average monthly highest tide

Climate Ready Boston selected sea level rise scenarios (9 inch, 21 inch, and 36 inch) that are likely to occur within the century to focus the discussion on how Boston will adapt to climate change. The actual sea level rise Boston experiences will be driven by many factors, including global carbon emissions. Climate models show that sea level rise in the near and intermediate term is largely locked in due to emissions that have already been released into the atmosphere. In the first half of the century (2030s–2050s), nine inches of sea level rise are expected even if there is a major reduction in emissions. Twenty-one inches or more of sea level rise are expected in the second half of the century (2050s–2100) regardless of the level of emissions.

The highest sea level rise considered in this report, 36 inches, is highly probable toward the end of the century if emissions remain at the current level or even if there is a moderate reduction in emissions.

If there is a major emissions reduction, the chance of 36 inches or more of sea level rise by the end of the century is still just slightly less than 50 percent. If emissions remain at current levels, there is an approximately 15 percent chance that sea levels will rise at least 7.4 feet by the end of century, a scenario far more dire than those considered here. Any adaptation to even the lower end of projections for sea level rise will require significant long-term effort, and the city must therefore start adapting now.

India Wharf view from the Harbor Walk — High Tide during October
Image courtesy of Sasaki

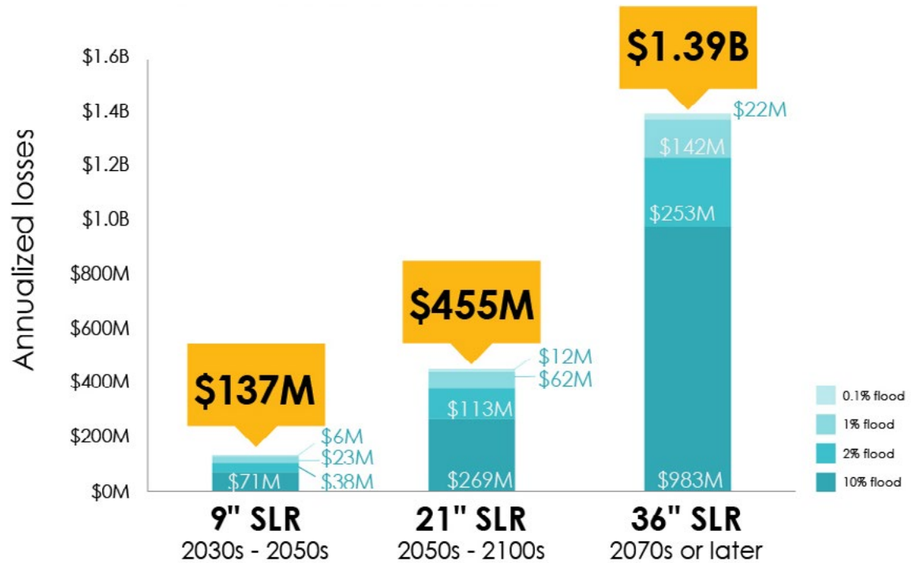
As the sea level continues to rise, the likelihood of major floods will increase from a 1% annual chance to a monthly reality.

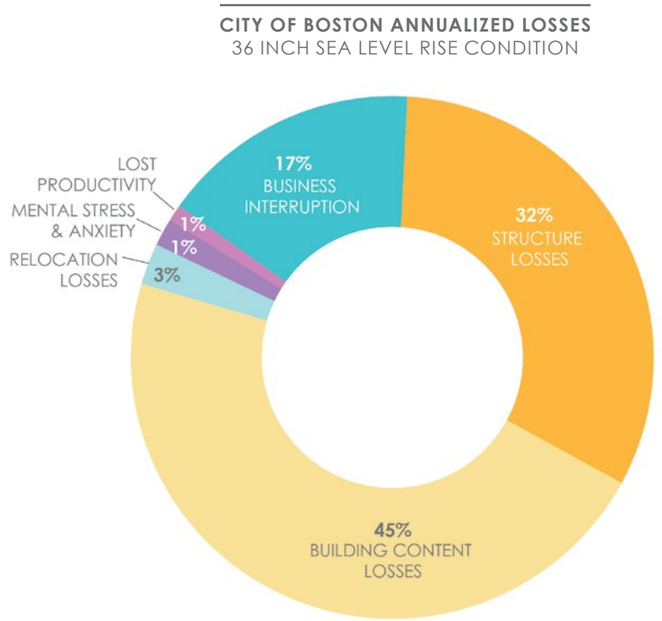
As sea levels continue to rise, severely damaging floods will shift from a rare occurrence to a monthly reality. In the near term, a flood event inundating 5 percent of the city will have a 1 percent chance of occurring in any given year. By mid-century, such a flood will become ten times more likely, and by the late century, that magnitude of flooding will occur at least once a month. This means that between 10 and 20 percent of Charlestown, East Boston, Downtown, and South Boston will face high-tide flooding, even when there is no storm.

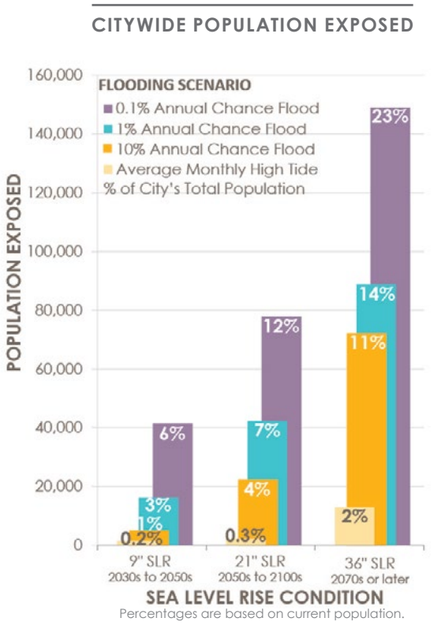
As climate change progresses over the course of this century, ever greater areas of Boston will be exposed to more frequent and more severe flooding.

- In the late century (2070s or later), 75 percent of buildings that will be exposed are either residential or mixed-use, exposing over 88,000 people (nearly 15 percent of Boston's population) to coastal and riverine flooding.
- More than 10 percent of Boston's existing buildings will be exposed to late-century coastal and riverine flooding.
- Toward the end of the century, 5 percent of Boston's real estate market value can be expected to suffer flood exposure to high tides, increasing to 25 percent for less frequent but more severe events.

Annualized losses will increase with sea level rise...







Severely damaging flood events will become more common over time. As flood risk increases this century and beyond, not only do the total expected annualized losses increase dramatically, but the share of these losses attributable to high-probability floods (10 percent chance of occurring in any given year) also becomes much greater.

Coastal and riverine flooding can impact the local and regional economy through physical damages, stress factors (mental stress and anxiety and lost productivity), displacement costs, and losses due to business interruption. Loss estimations presented in this assessment are reported as an annualized value for each sea level rise condition; annualized values represent the total of the product of single losses expected for each projected sea level rise condition and the chance of occurring in any given year.

Coastal and riverine flooding can disrupt the Critical infrastructural systems—including transportation, energy, communication, and essential facilities—on which Bostonians rely. Over time, an increasing number of these systems will be exposed to flooding.

- Key components of Boston's transportation system, most notably MBTA T service and major roads, may be at risk to coastal and riverine flood impacts in the near future.
- There are 240 essential and public facilities in the area exposed to late-century coastal and riverine flooding for lower probability storms.

Although the Vulnerability Assessment chapter of this report contains a discussion of the vulnerabilities of multiple infrastructural systems, further study is necessary, especially for energy and telecommunications systems.

The evacuation routes vulnerable to flooding include:

- I-93
- McClellan Highway Callahan Tunnel
- I-90 Ted Williams Tunnel
- Morrisey Boulevard
- Storrow Drive
- Tremont Street

Increasing Boston's Climate Readiness

Guided by the Vulnerability Assessment findings, which identified and quantified the impacts of future climate change, the City should undertake a set of climate resilience initiatives to address Boston's climate risks.

These initiatives will increase Boston's ability to thrive in the face of intensifying climate hazards, leading to improved quality of life for all residents, especially the most vulnerable, and creating stronger neighborhoods and a healthier environment.

The climate resilience initiatives build on a broad set of efforts undertaken to date by the City and its partners to prepare Boston for climate change.

To develop the initiatives, Climate Ready Boston reviewed past climate adaptation plans, conducted interviews and focus groups with a broad range of local stakeholders, and examined best practices from other cities across the world that are contending with climate change impacts.

CLIMATE RESILIENCE PRINCIPLES

The City drew on five principles for successful resilience to climate change based on lessons from other cities. These principles include the following:

1. **Generate multiple benefits.** Effective climate resilience initiatives both reduce risks from climate hazards and create other benefits. Resilience initiatives that produce multiple benefits generate more resources to support their implementation and sustainability. Flood barriers that also provide recreational open space, developable land, or upgraded roadways represent examples of multiple-benefit solutions. Nonphysical interventions also can offer multiple benefits, as evidenced by programs that help businesses and households make operational changes to reduce their flood risk while also lowering utility costs or reducing insurance premiums. Multiple-benefit approaches enable Boston to address some of the other pressing challenges that it faces beyond just climate risks.

2. **Incorporate local involvement in design and decision making.** Effective resilience initiatives require on-the-ground knowledge and sustained community support for implementation and long-term operations and maintenance. Local stakeholders can help illuminate critical resilience opportunities in their communities and generate creative ideas for solving multiple challenges at once.

3. **Create layers of protection by working at multiple scales.** Layers that are independently effective can also work together to provide mutual support and reduce the risk of a catastrophic failure associated with a single line of defense. For example, to address extreme heat, adding green infrastructure (e.g., increasing tree canopy) in combination with building-scale adaptations (e.g., using cool roofing and paving materials or increasing energy efficiency) is more effective than doing either independently. Shading from the tree canopy reduces the cooling load on the building, and the retrofitted building radiates less heat, with a failure to either layer having less impact because of the other.

4. **Design in flexibility and adaptability.** Climate conditions will continue to change over time, and resilience initiatives must be designed to adapt to them. For example, the 24-hour rainfall for a ten-year storm is projected to increase through the century. To be effective, the stormwater system must be flexible enough to adapt to this increase in extreme precipitation. In practice, this often means decentralized, distributed stormwater storage across cities that can be expanded without disrupting the gray stormwater system. Similarly, the elevation of 1 percent annual chance floods is also projected to increase throughout the century. Buildings can be built today with high ground-floor ceilings so that the ground floor can be filled in as sea levels rise over time.

5. **Leverage building cycles.** Buildings and infrastructure experience a natural cycle of rehabilitation and replacement over time. Taking adaptation actions within the context of the natural building cycle can reduce disruption and cost, as in the case of adding green infrastructure to roads as they are being rebuilt, rather than pulling them up just to install green infrastructure. While the natural building cycle progresses, operational changes, as opposed to physical adaptations, can be made to reduce risks. For example, retailers can move the inventory stored in the basement of their stores onto shelves to reduce flood damage in the near term, before local flood defenses are built. The development of new housing and job centers along the waterfront or in other flood-exposed areas presents opportunities to not only construct individual buildings prepared for flood risk but to also raise funds for the construction of area-wide flood defenses.

Addressing the Specific Characteristics of Each Climate Hazard

The resilience initiatives are designed to respond to the geographic scale, frequency, intensity, and projected growth of each climate hazard. For **extreme heat**, this calls for resilience initiatives that can be applied throughout the city, prioritize vulnerable populations, and address gaps in the capacity of buildings to cool themselves. The resilience initiatives addressing **stormwater flooding** are intended to be applied in affected pockets in each neighborhood and emphasize the ability to keep up with increased precipitation over time. **Coastal and riverine flooding** calls for a very different approach. The resilience initiatives are intended to be targeted to the areas directly exposed and involve the creation of significant new infrastructure systems in addition to the adaptation of existing systems and buildings.

LAYERS, STRATEGIES, AND INITIATIVES

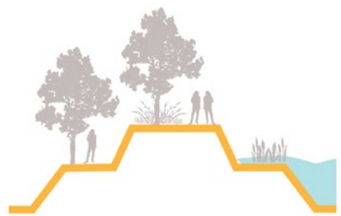
The climate resilience initiatives have been organized into four layers and eleven strategies. The layers represent an approach to building resilience at different scales: the community, the shoreline, infrastructure assets, and buildings. The layers are designed to support and reinforce each other.

UPDATED CLIMATE PROJECTIONS

Ensure that decision making in Boston is informed by the latest Boston-specific climate projections.

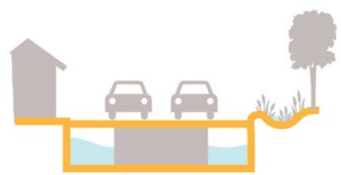
PREPARED AND CONNECTED COMMUNITIES

Support educated, connected communities in pursuing operational preparedness, adaptation planning, and emergency response.



PROTECTED SHORES

Reduce Boston's risk of coastal and riverine flooding through both nature-based and hard-engineered flood defenses.



RESILIENT INFRASTRUCTURE

Prepare the infrastructure systems that support life in Boston for future climate conditions and create new resilient systems.

ADAPTED BUILDINGS

Create a regulatory environment and financial and other tools to promote new and existing buildings that are climate ready.

Strategy 1.

Maintain up-to-date projections of future climate conditions to inform adaptation.

WHY Knowledge is the foundation for action. As global energy use and greenhouse gas emissions become clearer and as more data on the response of the Earth becomes available, climate projections will change. Bostonians need to remain informed to plan for the future.

WHAT The City should establish a Greater Boston Panel on Climate to update climate projections every five years. These projections should inform plans, policies, and regulations and be translated into readily accessible reports and maps.

Strategy 2.

Expand education and engagement of Bostonians on climate hazards and action.

WHY Climate adaptation cannot occur without an informed, engaged, and active public. Community members can provide deeper insight into how climate change is affecting their neighborhoods and businesses and create innovative and sensitive responses.

WHAT The City should work with partners from all sectors to inform and engage the Boston community on the risks from climate change and actions to reduce those risks. Different campaigns—targeting the general public, building owners, community facilities, businesses, and vulnerable populations who are more susceptible to the impacts of climate change—should promote short-term actions to reduce current risks while building support for larger-scale and longer-term measures.

Strategy 3.

Leverage climate adaptation as a tool for economic development.

WHY Over the coming decades, climate adaptation will require significant investments in the city's infrastructure, buildings, and other areas. The community can leverage this activity to promote equitable economic development, leaving Bostonians better prepared to thrive and face climate and other challenges.

WHAT The City should help train workers for jobs that will arise from climate adaptation projects and ensure that these projects follow the City's guidelines for local hiring, living wages, and employment of minority- and women-owned businesses

Strategy 4.

Develop local climate resilience plans to coordinate adaptation efforts.

WHY Some effects of climate change, such as increased temperatures, are spread across the city. Other, particularly coastal and riverine flooding, are more localized. Everywhere, these risks will interact with each other and with the social and economic needs of the neighborhood in particular ways. Coordinated adaptation actions can advance multiple community priorities simultaneously and use resources more effectively.

WHAT The City should develop local plans to address climate adaptation along with other community priorities. Through in-depth community engagement, the plans should include district-scale flood protection, infrastructure adaptation, and land-use planning, all in coordination with Imagine Boston 2030, 100 Resilient Cities, GoBoston 2030, and other planning efforts.

Strategy 5.

Create a coastal protection system to address flood risk.

WHY Coastal and riverine flooding poses a major and increasing threat to communities along Boston's waterfront and to the vitality of the city itself.

WHAT The City and its regional partners should investigate major "gray" and "green" infrastructure investments to address flood risk. The City should ensure that development in flood-prone areas does not prevent the future implementation of flood protection. The flood protection system should incorporate building-scale, district-scale, and harbor-wide measures.

Strategy 6.

Coordinate investments to adapt infrastructure to future climate conditions.

WHY Boston's infrastructure for power, water, transportation, communication, and more is a complex network with many public and private owners, operators, and regulatory authorities. As climate change presents new risks of failure, all stakeholders need to better understand the totality of vulnerabilities and to coordinate action to address them.

WHAT The City should establish an Infrastructure Coordination Committee with the region's major infrastructure organizations. The committee would develop planning and design standards aligned with up-to-date climate projections, identify cascading vulnerabilities, establish coordination mechanisms, and align adaptation efforts with other planning priorities.

Strategy 7.

Develop district-level energy solutions to increase decentralization and redundancy.

WHY Decentralized infrastructure of many kinds has the potential to combine climate adaptation with greenhouse gas reduction and economic development. Local sources that can keep operating during wider power failures could maintain the community's capacity to keep safe and cool as the frequency and intensity of heat waves rise.

WHAT The City should pursue community energy solutions, such as district energy systems or microgrids, that increase energy reliability and decrease greenhouse gas emissions. Priority sites should include areas with clusters of affordable housing or critical facilities.

Strategy 8.

Expand the use of green infrastructure and other natural systems to manage stormwater, mitigate heat, and provide additional benefits.

WHY Climate change will make it more difficult to manage stormwater and keep Bostonians cool, dry, and healthy. Green infrastructure, which relies on natural processes, can address these challenges and improve the safety and beauty of the public realm.

WHAT Building on past investments, the City should increase expand green infrastructure on public and private lands, in particular by developing sustainable funding sources and maintenance programs.

Strategy 9.

Update zoning and building regulations to support climate readiness.

WHY The current regulations that govern development in Boston do not have specific requirements for preparing for future climate conditions. In some cases, they may even pose obstacles to doing so.

WHAT Building on current requirements, the Boston Planning and Development Agency should propose land-use and other regulations that ensure that new development is ready for future climate conditions. The City should advocate for changes to the Massachusetts Building Code and explore measures that increase climate-ready retrofits in existing buildings.

Strategy 10.

Retrofit existing buildings against climate hazards.

WHY Most of the buildings in Boston that need to be prepared for climate change this century are already standing. The adaptation of existing buildings can be technically, operationally, and financially difficult. Property owners, particularly those with smaller or less valuable properties, may require technical or financial assistance.

WHAT The City should create programs to prepare existing buildings for climate change. Priorities should include buildings facing near-term flood risk and those with a public purpose or vulnerable populations. Programs could include resilience audits, investments in municipal facilities, support for backup power at facilities for vulnerable populations, and a toolkit of financing strategies.

Strategy 11.

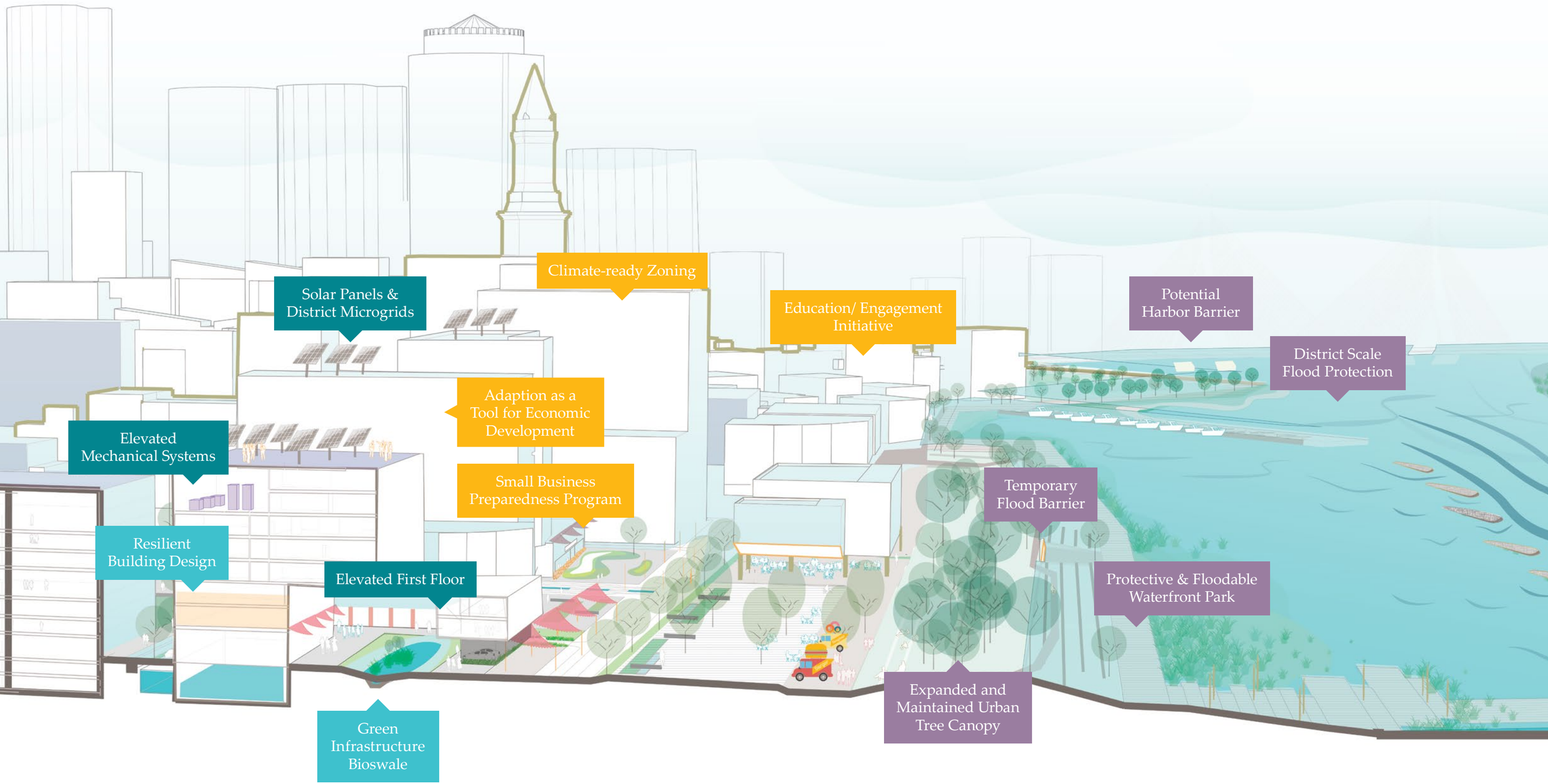
Insure buildings against flood damage.

WHY Whatever actions the community takes, natural disasters may still occur. Flood insurance is an indispensable tool for supporting recovery after a flood. Affordable access to appropriate levels of flood insurance coverage is critical to protecting property owners' investments and neighborhoods' stability.

WHAT The City should promote appropriate flood insurance for property owners. This should include joining the National Flood Insurance Community Rating System to obtain flood insurance discounts through advanced floodplain management and advocating for reforms to better align premiums with actual risk.

ADAPTING TO CLIMATE CHANGE

PROTECTED SHORES | PREPARED AND CONNECTED COMMUNITIES | RESILIENT INFRASTRUCTURE | ADAPTED BUILDINGS



Implementation

Climate Ready Boston's proposals are diverse in scope and scale. They are short term and long term, citywide and neighborhood specific, municipal and regional, regulatory and financial.

Some actions can be undertaken simultaneously; others must proceed in a certain order. They cannot all be done at once, because they would overwhelm government and community capacity. Furthermore, they do not need to be done all at once. Because climate change will accumulate over time, Boston's response, if thought through carefully, can proceed over time too.

The Recommended Roadmap presents a timeline and designated lead agency for undertaking these initiatives. The timeline has three divisions—within two years, within five years, and long-term—plus an arrow indicating if an initiative is ongoing. Over half of the initiatives will be ongoing because, once started, they will need to continue or repeat indefinitely; for example, climate projections should be updated with new data that becomes available over time.

The time divisions represent a rough prioritization based on many factors, including the following:

- Who and what are most at risk now?
- Are there existing efforts—climate related or related to other initiatives—upon which the next phase of climate initiatives can build?
- Are resources—human, technical, fiscal—available to undertake this work?
- Is one initiative a necessary or desirable foundation for another?
- What is the risk or cost of delay, and who bears that risk or cost?
- Who has to take action?
- Is there already community or sectoral support?
- How difficult is implementation?

One question underlying almost all of the initiatives is how to pay for them. Some initiatives explicitly address the financial question, but even those that do not address this question will be affected by it.

Some of the key initiatives that need to be started in the next two years include the following:

- Initiative 2-1. Expand citywide climate readiness education and engagement campaign
- Initiative 4-1. Develop local climate resilience plans to support district-scale climate adaptation (for the first selected districts)
- Initiative 5-2. Determine a consistent evaluation framework for flood defense prioritization
- Initiative 6-1. Establish an Infrastructure Coordination Committee
- Initiative 8-2. Develop a sustainable operating model for green infrastructure on public land and right-of-way
- Initiative 9-2. Revise zoning code to support climate-ready buildings
- Initiative 10-2. Prepare municipal buildings for climate change

Image courtesy of Southie Trees

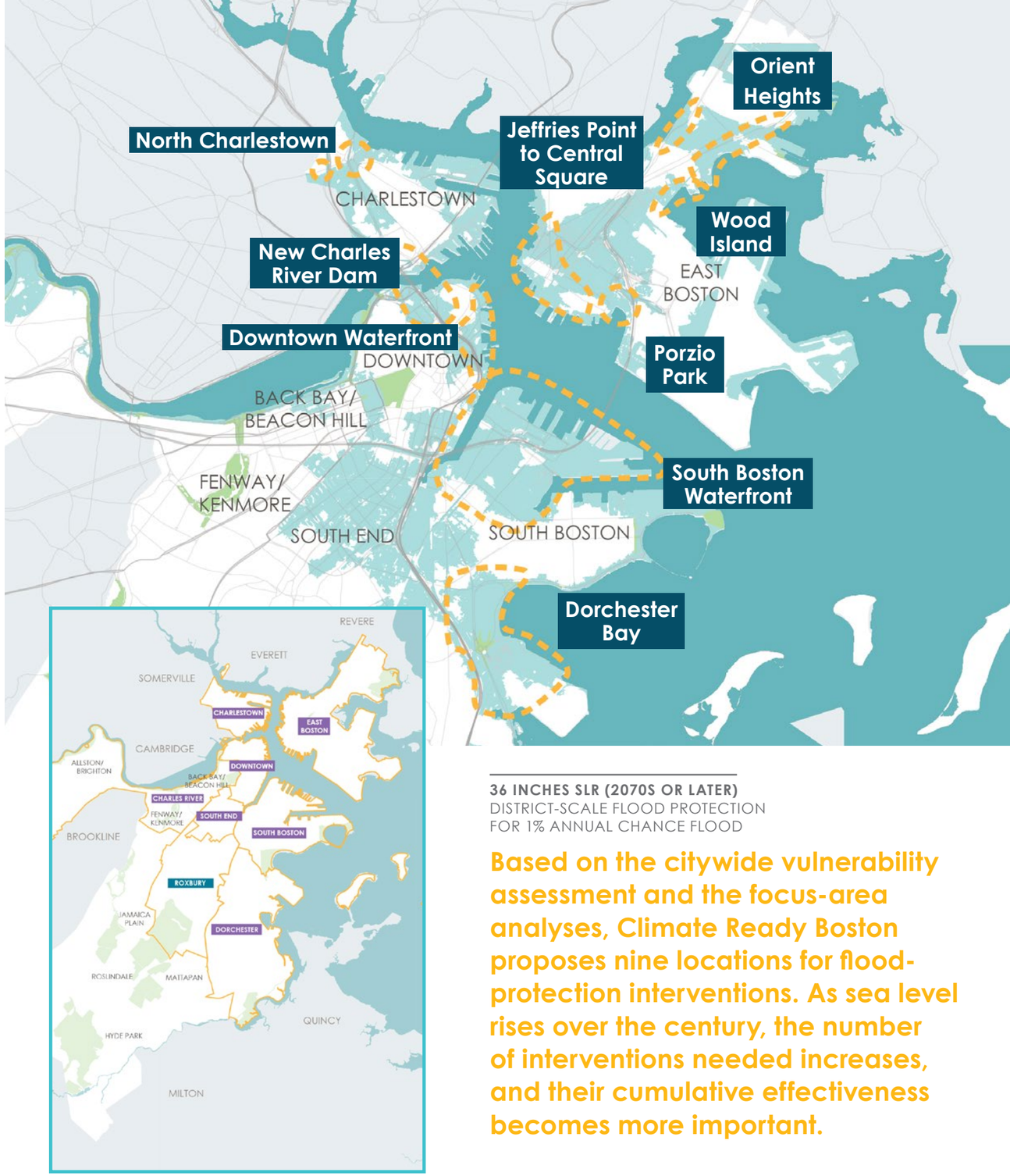
Focusing on Neighborhoods

To guide adaptation planning across Boston's neighborhoods, especially when climate vulnerabilities are spatially concentrated, Climate Ready Boston examined several areas in more detail:

- **Focus Area Vulnerability Assessments** provide deeper insight into the types of vulnerabilities that the people, buildings, infrastructure, and economy face in specific areas.
- **Focus Area Resilience Initiatives** show how the citywide resilience initiatives can be applied to specific areas within Boston.
  - Charlestown
  - Charles River
  - Dorchester
  - Downtown
  - East Boston
  - Roxbury
  - South Boston
  - South End

Seven out of the eight focus areas contain coastal neighborhoods that face significant risks from coastal and riverine flooding. Where multiple neighborhoods are exposed to flooding from the same source in the same time period, they are grouped together as a single focus area (e.g., all of the Charles River neighborhoods face flood exposure when the Charles River Dam is flanked or overtopped).

The eighth focus area, Roxbury, was developed to serve as an illustrative example of multiple vulnerabilities, based on the intersection of all three climate hazards—coastal and riverine flooding, stormwater flooding, and extreme heat—and demonstrate the application of resilience initiatives focused on these risks.



36 INCHES SLR (2070S OR LATER)
DISTRICT-SCALE FLOOD PROTECTION
FOR 1% ANNUAL CHANCE FLOOD

Based on the citywide vulnerability assessment and the focus-area analyses, Climate Ready Boston proposes nine locations for flood-protection interventions. As sea level rises over the century, the number of interventions needed increases, and their cumulative effectiveness becomes more important.

CLIMATE READY BOSTON FOCUS AREAS HEAT & STORMWATER AND COASTAL FLOODING · COASTAL HAZARD · FOCUS AREAS

Image courtesy of Sasaki

These bold and creative actions will support the city's vitality and livability.