Retrofitting Boston Buildings for Flooding: Potential Strategies

Photo: Harborwalk in the South Boston Waterfront

Retrofitting Boston Buildings for Flooding: Potential Strategies

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Contents

All images, drawings, and diagrams are by Adria Boynton, unless otherwise noted

PART I: INTRODUCTION

Photo: Fort Point Channel

Summary

This exploratory study outlines potential strategies for retrofitting Boston buildings for today's 100-year flood. This report is intended to facilitate a conversation about flood resilience and adaptation in Boston. The main goals for this body of work include:

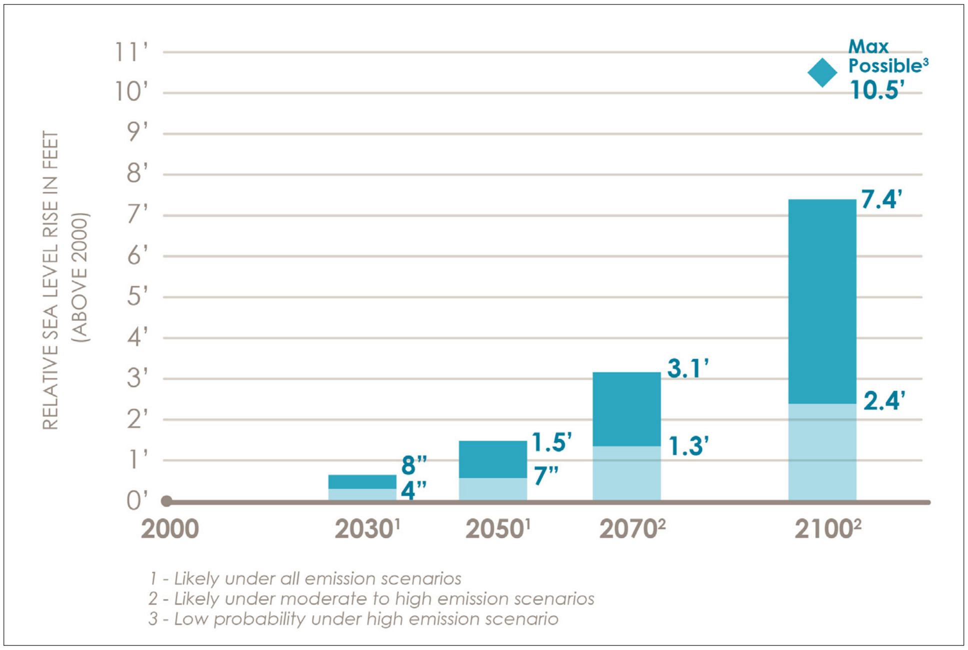
1. Distinguishing between FEMA requirements for post-FIRM buildings and supplemental design recommendations.

2. Demonstrating how retrofitting strategies might apply to Boston building typologies, including triple-deckers and historic buildings.

3. Addressing potential conflicts between retrofitting strategies and current zoning codes by making recommendations for policy and regulatory interventions.

Retrofitting buildings for flooding can help prepare property owners and tenants for the next big storm. There are also other benefits: certain retrofitting strategies can lead to individual discounts on flood insurance premiums. Community-wide discounts may also be possible if Boston joins the NFIP's Community Rating System (CRS), which will be discussed in more detail later.

While this report covers current retrofitting strategies required by FEMA and related design recommendations, new approaches will be needed by 2050, when Boston could be dealing with 1.5 feet of sea level rise, and by 2070, when sea level rise could reach 3 feet. There will certainly be a need for new adaptation strategies by the end of the century, when today's 100-year flood could be as frequent as the twice-daily high tide.



Sea level rise projections. Graphic courtesy of Climate Ready Boston, 2016.

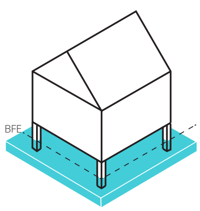
Glossary

100-Year Flood
Also known as the base flood and the 1% annual chance flood. A flood with a 1% annual chance of occurring or being exceeded. For Boston, 100-year flooding causes at least five feet of flooding above the average high tide, also known as Mean Higher High Water (MHHW). Climate change makes it likely that 100-year floods will occur more often than once every 100 years. Climate Ready Boston's projections show that a coastal flood with a 1% annual chance of occurring in 2000 could have a 20% annual chance of occurring by 2050, and could be as frequent as the twice-daily high tide by 2100.

100-Year Floodplain
The boundary of a flood that has a 1% annual chance of occurring or being exceeded.

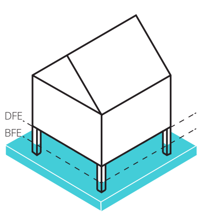
500-Year Floodplain
The boundary of a flood that has a 0.2% annual chance of occurring or being exceeded. This floodplain is not included within Special Flood Hazard Areas.

AE Zones
Special Flood Hazard Areas shown on FEMA Flood Insurance Rate Maps (FIRM). AE Zones include annotations listing Base Flood Elevations (BFE).

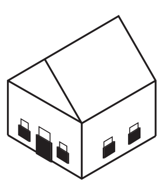


Base Flood Elevation (BFE)
The height that floodwaters are projected to reach during a 100-year flood. BFEs are rounded to the nearest foot.

Community Rating System (CRS)
An optional program for communities that meet minimum National Flood Insurance Program (NFIP) requirements. CRS works by assigning points and a "class" to each community, from 1-10. Towns that adopt requirements that go above and beyond baseline floodplain management regulations get more points and are assigned a lower class number. Communities with a lower class number get higher discounts on their flood insurance. For example, Class 10 communities have less than 500 points and do not receive a community-wide discount on flood insurance premiums. Class 1 communities have 4,500 points or more, and receive a 45% community-wide discount on flood insurance premiums. Participating communities are periodically audited to confirm compliance with floodplain management regulations.



Design Flood Elevation (DFE)
The height of the lowest occupiable floor (when wet floodproofing), or the height of the lowest structural member of an inhabitable floor (when elevating a building). Depending on building type and location, the DFE is usually separated from the BFE by one to two feet of freeboard. Post-FIRM residential spaces cannot be located below the DFE.



Dry Floodproofing
Sealing a space or a building up to the level of the DFE or higher, in order to keep water from entering. When dry floodproofing, property owners must strengthen structural members in anticipation of the hydrostatic and hydrodynamic pressure caused by floodwaters. In post-FIRM buildings, dry floodproofing can only be used for non-residential spaces in A Zones.

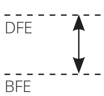
Federal Emergency Management Agency (FEMA)
Manages the federal government's preparation for, and recovery from, natural and man-made disasters. FEMA also manages the National Flood Insurance Program (NFIP). Retrofitting strategies outlined in this report that are required or encouraged by FEMA will be called out by the icon shown to the left.

Floodproof or Submergible Materials
Materials that can be submerged in water without causing damage. Examples include tile and concrete. Stainless steel, hot-dipped galvanized metal, or other corrosion resistant materials must be used for metal connectors that could become corroded after being exposed to salt water or salt spray. Refer to ASCE 24-14 for minimum elevations below which flood-damage-resistant materials must be used.

Flood depth
The distance from the ground to the top of floodwaters.

Flood elevation
The distance from a particular datum to the top of floodwaters.

Flood Insurance Rate Maps (FIRM)
Maps produced by FEMA that delineate the borders of Special Flood Hazard Areas (SFHA) and their corresponding Base Flood Elevations (BFE). The flood projections shown on FIRMs are based on historic data, and do not include factors related to future sea level rise or future coastal erosion.

Freeboard


The distance between the Base Flood Elevation (BFE) and the Design Flood Elevation (DFE). Freeboard provides a buffer between projected flood elevations and a building's lowest inhabitable floor. Refer to ASCE 24-14 for freeboard requirements.

Mean Higher High Water (MHHW)
There are two daily high tides. Taking the average of the higher high tides over a period of 19 years (otherwise known as the National Tidal Datum Epoch) results in Mean Higher High Water. As of 2003, Boston's MHHW was 13.80 feet.

Mean Range of Tide (MN)
The difference between mean high tide and mean low tide. As of 2003, Boston's Mean Range of Tide was 9.49 feet.

National Flood Insurance Program (NFIP)
Managed by the Federal Emergency Management Agency (FEMA). Communities that agree to participate in the NFIP also agree to enforce floodplain regulations that meet FEMA requirements. Property owners in participating communities are able to purchase two types of flood insurance from the NFIP: building coverage (which includes the building, foundation, appliances and essential systems), and contents coverage (which includes belongings damaged during a flood).

National Tidal Datum Epoch (NTDE)
A period of 19 years determined by the National Ocean Service and used to create standardized tidal datums. The current National Tidal Datum Epoch is 1983-2001 and most NTDEs are updated every 20-25 years.

North American Vertical Datum of 1988 (NAVD)
A base elevation used when comparing tidal datums. BFEs listed on FEMA FIRMs sometimes reference NAVD.

Pre-FIRM (Flood Insurance Rate Map) Building
A designation used by FEMA for buildings that were constructed before a community joined the NFIP.

Post-FIRM Building
A designation used by FEMA for buildings that were constructed, substantially improved, or substantially damaged after a community joined the NFIP. Post-FIRM buildings must comply with floodplain management regulations and must pay an actuarial flood insurance rate, which reflects their property's true level of risk. The post-FIRM designation does not include alterations to historic structures and improvements that correct code violations.

Resilience
The ability of a system to prepare for, adapt to, and recover quickly from a disaster. Ideally, resilient systems should recover from an event by becoming stronger than they were prior to the stress. A resilient system should be flexible and adaptive, and should be composed of multiple, independent layers.

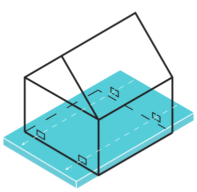
Retrofi+ (Retrofit Plus)
A term that is only used within the context of this report to differentiate between retrofitting strategies required by FEMA and additional design recommendations that can supplement FEMA requirements. Retrofi+ strategies outlined in this report will be called out by the icon shown to the left.

Substantial Damage
Any damage that requires repairs equal to or exceeding 50% of the market value of the building before the damage was caused. The damage does not have to be flood related. Buildings that have been substantially damaged by flooding may be eligible for up to $30,000 Increased Cost of Compliance coverage from the National Flood Insurance Program (NFIP).

Substantial Improvement
Any improvement equal to or exceeding 50% of the market value of the building before improvements were made. Some communities consider the cumulative cost of all improvements made after the town joined the NFIP, or the cumulative cost of all improvements made during a certain number of years. Other communities consider only the cost of improvements made during a single project or after a single event. The substantial improvement designation does not include alterations to historic structures and improvements that correct code violations. Buildings that have been substantially improved must comply with floodplain management requirements for new construction. For that reason, substantially improved buildings in SFHAs must be floodproofed or elevated above the Base Flood Elevation (BFE). Substantially improved buildings lose their eligibility for subsidized flood insurance and pay an actuarial rate, which reflects their property's true level of risk.

Special Flood Hazard Area (SFHA)
Land at a 1% or greater annual chance of flooding. Also known as the 100-Year Floodplain and the Base Floodplain. SFHA designations include the following flood zones: A, AE, AH, AO, AR, A99, V, and VE. "V Zones" along the coast, are subject to high-velocity wave action, while "A Zones" are further inland and do not experience high-velocity hazards. Buildings within SFHAs are required to be covered by flood insurance.

V Zones
SFHAs along the coast, subject to high-velocity wave action. FEMA standards are stricter for buildings in V Zones, due to high levels of wave action. Structural fill and below-grade excavation is not allowed in V Zones. The lowest horizontal structural member of new and substantially improved buildings must be located above the DFE. Below that member, the building structure must remain open. The only enclosures allowed are those built with breakaway walls, which are designed to collapse during severe flooding and include flood openings.



Wet Floodproofing
Designing for the movement of water through a space or a building, which equalizes hydrostatic pressure and helps prevent structural failure. Wet floodproofing is only allowed for parking, access, crawl space, and storage. For post-FIRM buildings, at least one side of the wet floodproofed space must be above grade and the lowest occupiable floor must be elevated to at least the level of the DFE. Pre-FIRM subgrade spaces can be wet floodproofed, but water must be pumped out after flooding recedes, which can be dangerous if surrounding soils are still saturated.

Wet floodproofed spaces must have openings in at least two walls, at no more than one foot above grade. If non-engineered, these openings should be equal to one square inch for every one square foot of enclosed space. If engineered, these openings must be certified by a registered design professional. Wet floodproofed spaces should include floodproof materials up to one inch above the DFE. Wet floodproofing is acceptable for use in A Zones.

The Impacts of Climate Change in Boston

Boston's ability to mitigate the impact of climate change will determine its future. The risks faced by the city include extreme temperatures, high winds, increased coastal erosion, encroachment of saltwater on freshwater aquifers, and flooding from increased precipitation, storm surges, and sea level rise. Coastal flooding can also occur during clement weather, at times of high tides and lunar high tides. Since Boston's tidal range is close to ten feet, a combination of these factors can be disastrous: a storm that hits Boston at high tide will have a much more severe impact than a storm that hits the city at low tide.

When it comes to flooding from major storms, Boston has a history of near misses. Superstorm Sandy, which hit Boston during low tide in October 2012, is a well-known example. What's less commonly cited are the four storms that Boston experienced between 2013 and 2015, that also could have caused 100-year flooding if they had hit at high tide rather than at low tide.

Boston's coastal landforms; including the Harbor Islands, Winthrop, and Hull; make Boston Harbor more sheltered and protected against storm surges than many other coastal cities. However, Boston's history of infilling land has put the city at risk of flooding from sea level rise. If sea levels rise five feet by 2100, a level that falls towards the higher end of most projections, then today's 100-year flood could become the twice-daily high tide by the end of the century.

In a 2013 report entitled, "Preparing for the Rising Tide," Boston Harbor Now analyzed the impact of a 100-year flood hitting the city at high tide. The report found that today's 1% annual chance storm would flood 6.6% of Boston. The impacts on specific neighborhoods are summarized in the table below:

Neighborhood	Flooded at Mean Higher High Water (MHHW) + 5 ft.		
	Flooded Area (million sq. ft.)	% of City Area	% of Neighborhood Area
Dorchester	22.6	1.8%	12.5%
East Boston	24.3	2.0%	14.1%
South Boston Waterfront	10.2	0.8%	30.7%
Fort Point Historic District	1.2	0.09%	70.8%
Downtown	2.2	0.2%	9.9%

Data from "Preparing for the Rising Tide," Boston Harbor Now, 2013

There are a number of Boston-wide initiatives that address climate change and adaptation strategies. These programs include Imagine Boston 2030, Complete Streets, Grow Boston Greener, 100 Resilient Cities, and Climate Ready Boston. Climate Ready Boston has identified several Resilience Initiative Layers that can help guide future work, including a category that focuses on climate adaptation strategies for new and existing buildings.

There are several ways that buildings can be damaged during flooding. These risks include water damage, hydrostatic pressure exerted by water and saturated soils, hydrodynamic pressure caused by moving water, and damage from large objects and debris propelled by water and wind during a storm. Retrofitting existing buildings can help minimize the damage caused during flooding events. Particular care should be taken when considering the impacts of climate change on vulnerable populations. As cited by Boston's Chief Resilience Officer, Dr. Atyia Martin, vulnerable populations can include children, the elderly, the sick, the disabled, renters, low-income communities, minority residents, those with less than a high school education, and those with limited English proficiency.

This document addresses potential retrofitting strategies for existing buildings along the Boston waterfront. The report focuses on four case studies that represent typical building typologies, and outlines adaptation options that fall within two categories:

FEMA 1. FEMA and NFIP requirements for retrofitting existing buildings.

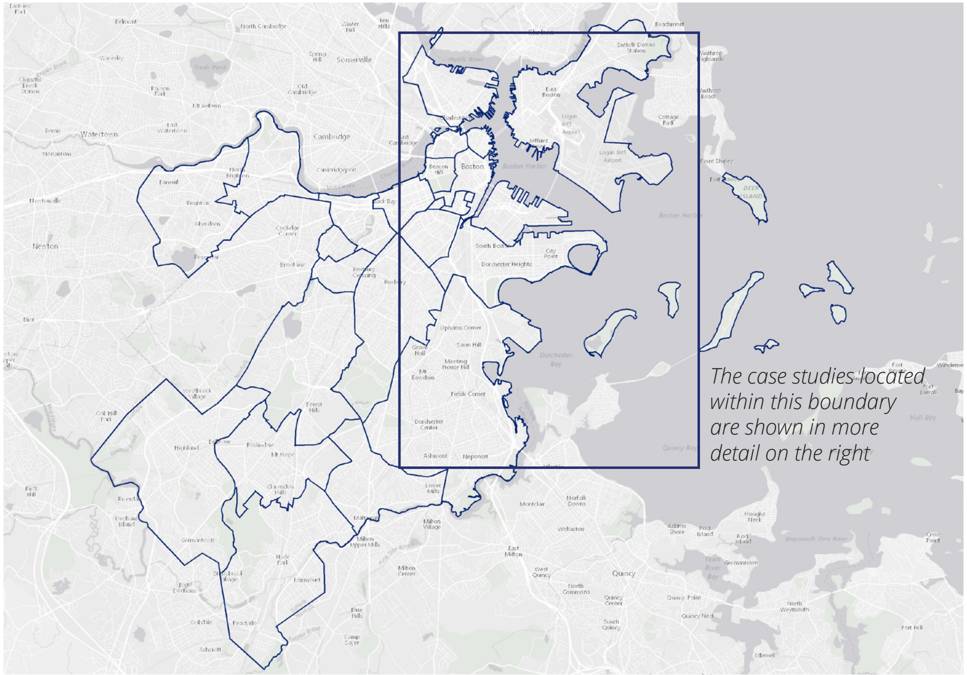
2. Additional design strategies that can help mitigate the unintended impacts of individual retrofits on a neighborhood's urban design.

Boston Neighborhoods and Building Typologies

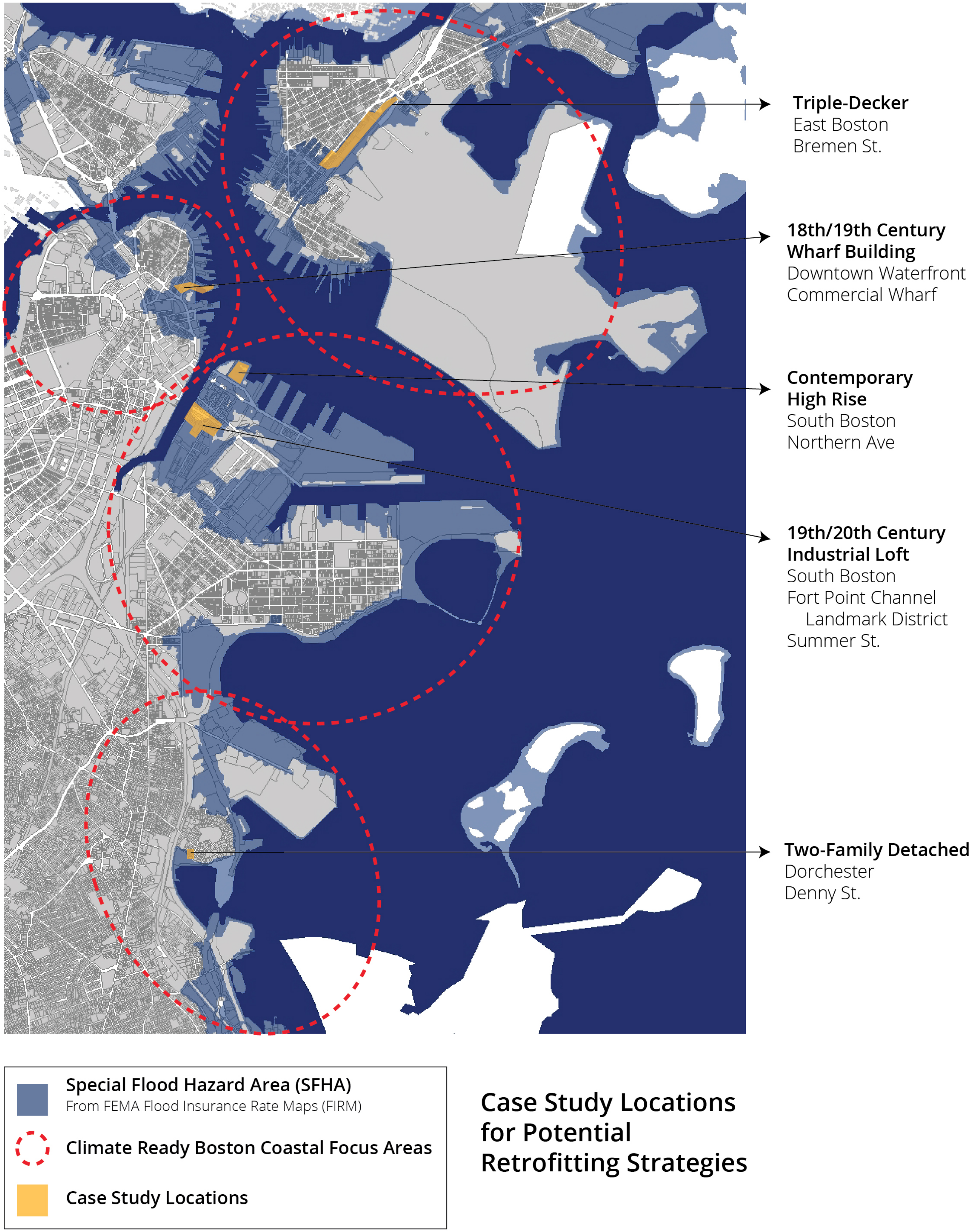
Boston neighborhoods at high risk of flooding from storms and sea level rise include East Boston, Charlestown, the Back Bay, Downtown, the South End, South Boston, and Dorchester. From this list, four neighborhoods (shown at right) were selected as areas of interest for this report. All four neighborhoods are included in the BRA's Waterfront Planning, FEMA's Special Flood Hazard Areas (SFHAs), and Climate Ready Boston's Coastal Focus Areas. East Boston and Dorchester are also home to vulnerable populations. As cited by Boston's Chief Resilience Officer, Dr. Atyia Martin, vulnerable populations can include children, the elderly, the sick, the disabled, renters, low-income communities, minority residents, those with less than a high school education, and those with limited English proficiency. In addition, The Downtown Waterfront and South Boston both have historic buildings, and South Boston includes a historic district along the Fort Point Channel.

Common building typologies in Boston range from two family homes and triple-deckers, to six family homes and row houses. Five building types have been chosen as case studies for this report, including 18th and 19th century wharf buildings, 19th and 20th century industrial lofts, triple-deckers, two family homes, and contemporary high rises. For the purposes of this report, each building type has been linked to one of the four areas of interest, to better understand typical building context. Some of these building types can be found in neighborhoods across Boston. For example, while triple-deckers are common in East Boston, they can also be found in other residential areas in South Boston and Dorchester.

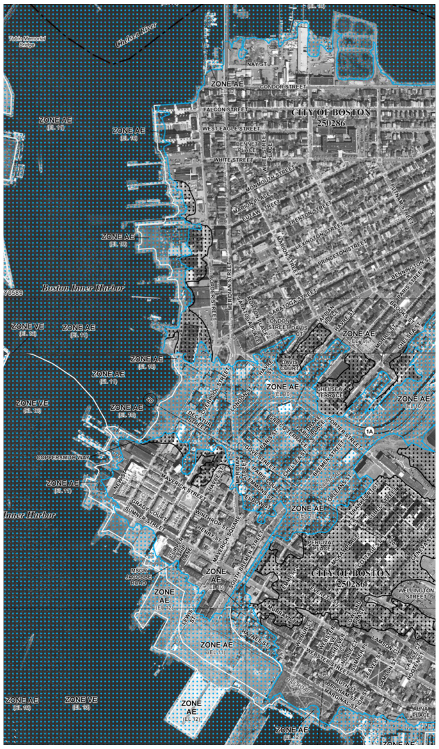
The map at right shows the overlap between FEMA's Special Flood Hazard Areas (SFHA), four of Climate Ready Boston's Coastal Focus Areas, and each case study location.



Context map of Boston neighborhoods



Case Study Locations for Potential Retrofitting Strategies



FEMA FIRM detail, 2016
Image courtesy of FEMA

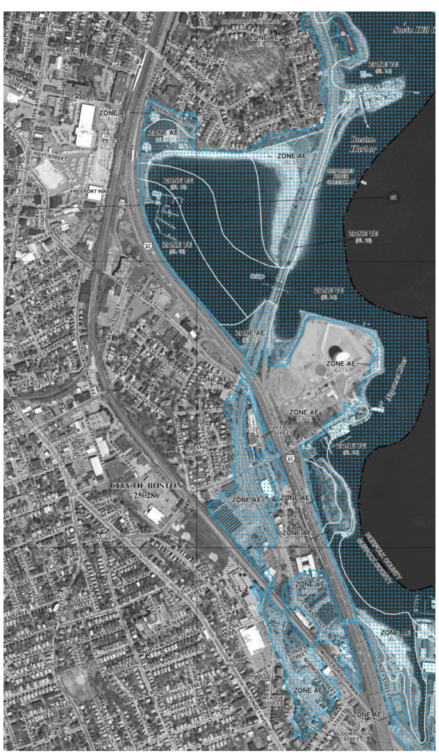
East Boston

Risk Profile:
East Boston is a Climate Ready Boston Coastal Focus Area and much of the neighborhood is included in FEMA's Special Flood Hazard Areas. East Boston is also home to vulnerable populations. Apart from Logan Airport, East Boston is a largely residential neighborhood, with some commercial and industrial uses. Triple-deckers and mixed-use buildings with first floor storefronts are common.

East Boston Metrics:

Unemployment Rate	10.6%
Median Household Income	$50,385
Owner Occupied Housing Units	27.9% of Occupied Housing Units
Children	20.1% of Neighborhood Population
Elderly	9.4% of Neighborhood Population
Foreign-Born Population	50.5% of Neighborhood Population

Data from "Unemployment in Boston" (BRA 2014), "Boston by the Numbers" (BRA 2015), and the 2010-2014 American Community Survey.



FEMA FIRM detail, 2016
Image courtesy of FEMA

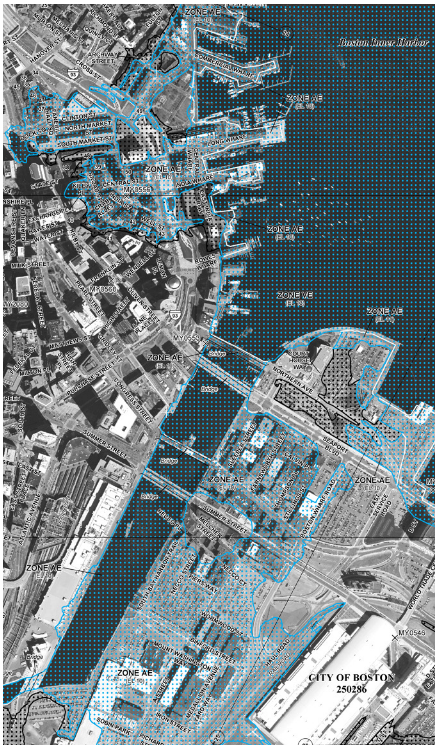
Dorchester

Risk Profile:
North Dorchester is a Climate Ready Boston Coastal Focus Area and parts of the neighborhood are included in FEMA's Special Flood Hazard Areas. Dorchester is also home to vulnerable populations. The neighborhood is a mix of residential and institutional uses, with some commercial and industrial facilities. Triple-deckers, two and six family homes, and mixed-use building are common.

Dorchester Metrics:

Unemployment Rate	16.2%
Median Household Income	$46,769
Owner Occupied Housing Units	33.8% of Occupied Housing Units
Children	24.2% of Neighborhood Population
Elderly	9.0% of Neighborhood Population
Foreign-Born Population	32.0% of Neighborhood Population

Data from "Unemployment in Boston" (BRA 2014), "Boston by the Numbers" (BRA 2015), and the 2010-2014 American Community Survey.



FEMA FIRM detail, 2016
Image courtesy of FEMA

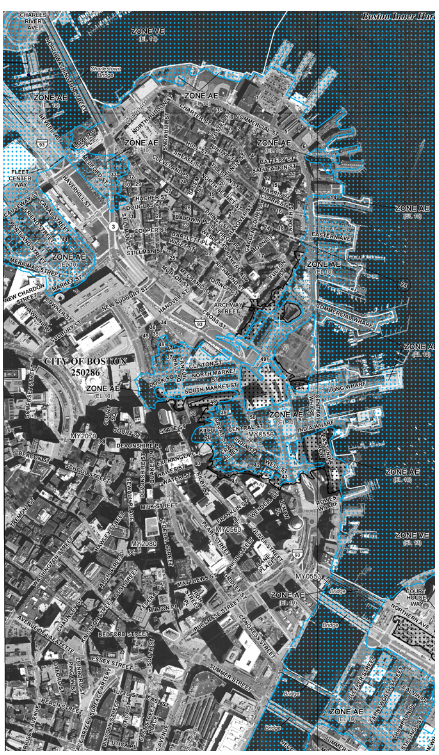
South Boston Waterfront
Fort Point Channel Landmark District

Risk Profile:
The South Boston Waterfront is home to the historic Fort Point Channel Landmark District (FPCLD). The FPCLD is included in FEMA's Special Flood Hazard Areas and is a Climate Ready Boston Coastal Focus Area. The land along the Fort Point Channel is already susceptible to flooding during lunar high tides. South Boston is mostly residential and institutional, with some commercial and industrial facilities along the waterfront. 19th and 20th century industrial loft buildings are common along the Fort Point Channel.

South Boston Waterfront Metrics:

Unemployment Rate	3.2%
Median Household Income	$102,148
Owner Occupied Housing Units	36.2% of Occupied Housing Units
Children	3.4% of Neighborhood Population
Elderly	9.9% of Neighborhood Population
Foreign-Born Population	12.5% of Neighborhood Population

Data from "Unemployment in Boston" (BRA 2014), "Boston by the Numbers" (BRA 2015), and the 2010-2014 American Community Survey.



FEMA FIRM detail, 2016
Image courtesy of FEMA

Downtown Waterfront

Risk Profile:
The Downtown is a Climate Ready Boston Coastal Focus Area and most of the waterfront is included in FEMA's Special Flood Hazard Areas. The historic wharves along the Downtown Waterfront are already susceptible to flooding during lunar high tides. This neighborhood is a mix of commercial, institutional, and residential uses. 18th and 19th century wharf buildings are common on the wharves that line Atlantic Avenue and the Harborwalk.

Downtown Metrics:

Unemployment Rate	8.4%
Median Household Income	$61,477
Owner Occupied Housing Units	28.6% of Occupied Housing Units
Children	6.1% of Neighborhood Population
Elderly	15.4% of Neighborhood Population
Foreign-Born Population	32.8% of Neighborhood Population

Data from "Unemployment in Boston" (BRA 2014), "Boston by the Numbers" (BRA 2015), and the 2010-2014 American Community Survey.

Overview of Retrofitting Strategies

Understanding Flood Risk

1 The first step towards understanding flood risk is to find a property's FEMA Flood Insurance Rate Map (FIRM). Although FIRMs are now used as regulatory tools, they were originally intended only to help establish flood insurance rates. Find a property's FIRM by visiting FEMA's Flood Map Service Center:

https://msc.fema.gov/portal/

After typing in a building's address, a Locator Map will display the entered location as an area divided into separate panels. Each panel is a FIRM. Selecting a panel that contains a certain building will trigger an option to view that particular map in a new browser window. There will be an option to save the map and to view an interactive version of the map on ArcGIS Online. An example of a downloaded FIRM is shown below.

Image courtesy of FEMA

The FIRM will show an aerial image of the entered address and the surrounding area, along with an overlay of FEMA Special Flood Hazard Areas (SFHAs). SFHAs are also known as the 100-year floodplain or the base floodplain because they include land at a 1% or greater annual chance of flooding. At that probability, a home in a SFHA would have a 1 in 4 chance of experiencing a 100-year flood during a thirty year mortgage. However, sea level rise makes it likely that 100-year floods will occur more often than once every 100 years. Climate Ready Boston's projections show that a coastal flood with a 1% annual chance of occurring in 2000 could have a 20% annual chance of occurring by 2050, and could be as frequent as the twice-daily high tide by 2100.

2 After locating a particular building, check the map legend to see if the structure is included within a SFHA. If it is, check the map legend to see which zone the building falls within. SFHA designations include the following flood zones: A, AE, AH, AO, AR, A99, V, and VE. "V Zones" along the coast, are subject to high-velocity wave action, while "A Zones" are further inland and do not experience high-

Buildings within SFHAs are required to be covered by flood insurance. Communities that participate in the National Flood Insurance Program (NFIP) must enforce NFIP's floodplain management regulations in SFHAs. Visit FEMA's website to see a list of participating communities.

velocity hazards. This difference is significant because buildings and foundations are designed differently if they need to withstand wave action, which applies more pressure to a structure than standing water. Because of sea level rise, buildings that fall within the A Zone now may become part of the V Zone later, and retrofitting a building to deal with high-velocity wave action is difficult. There is a substantial difference between a building's ability to weather a one-time storm that recedes, versus a building that is subjected to the twice daily high tide.

Some FEMA flood zones include annotations that show Base Flood Elevations (BFE) and some do not. If a building is in a zone that includes a BFE, the number will be written in feet and will reference the North American Vertical Datum of 1988 (NAVD). NAVD is the base elevation used when comparing various tidal datums. Property owners should work with a surveyor to determine BFEs from grade.

3 After identifying the BFE, consider the Design Flood Elevation (DFE). A DFE is the height of the lowest occupiable floor (when wet floodproofing), or the height of the lowest structural member of an inhabitable floor (when elevating a building). In new, substantially improved, or substantially damaged buildings, residential spaces cannot be located below the DFE. The distance between the BFE and the DFE is called freeboard. Freeboard requirements differ depending on building type and SFHA zone. A draft update to the Massachusetts building code (approved by the Board of Building Regulations and Standards in 2016) includes a new requirement for buildings and mechanical systems to be elevated one to two feet above the BFE.

4 Consider the type of building in question. FEMA categorizes buildings based on two criteria: what the building is used for, and when the building was built or renovated. Buildings constructed before a community joined the NFIP are called pre-FIRM buildings. Buildings constructed, substantially improved, or substantially damaged after a community joined the NFIP are called post-FIRM buildings. Post-FIRM buildings are subject to floodplain management rules. Retrofitting regulations for residential buildings are stricter than those for non-residential buildings.

Understanding Retrofitting Regulations

There are a number of regulations surrounding retrofitting Boston buildings for flood risk. A few to be aware of include:

National Flood Insurance Program (NFIP)

The NFIP is a flood insurance program managed by the Federal Emergency Management Agency (FEMA) and regulated by Congress. The NFIP was established by the 1968 National Flood Insurance Act, which was a reaction to the devastation caused by Hurricane Betsy in 1965. The intention was to use federal management to keep the cost of flood insurance low. Historically, flood insurance purchased through FEMA has been cheaper than the private insurance market in the United States.

New or substantially improved buildings in FEMA flood zones must be covered by flood insurance to be eligible for federal disaster assistance and loans from federally insured banks. Communities that agree to participate in the NFIP (which is a voluntary program) also agree to enforce floodplain regulations that meet FEMA requirements. This can include encouraging development outside of Special

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It's important to consider a building's lifespan when building or retrofitting in the 100-year floodplain. FIRMs are based on historical data, so their flood projections don't include factors related to future sea level rise or future coastal erosion. When considering new construction or a retrofit, think about what a building's site might look like in thirty or sixty years. Will the SFHA Zone designation or the BFE change? The most resilient projects go above and beyond today's requirements in anticipation of tomorrow's risks.

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Because of the increased risk of loss of life, it's advisable to exceed freeboard requirements when retrofitting homes and critical facilities. When adapting a 1-2 family home, a hospital, a building used for emergency response, or something similar, consider using two feet of freeboard or more.

Flood Hazard Areas (SFHAs) and requiring new, substantially improved, and the renovation of substantially damaged buildings in the 100-year floodplain to comply with floodplain management codes and regulations. Participating communities also require property owners in SFHAs to buy flood insurance. Towns can be put on notice or potentially removed from the NFIP for giving property owners too many variances, or for granting variances that diverge too drastically from baseline floodplain management regulations.

Boston has participated in the NFIP since 1992 but is not currently participating in the NFIP's Community Rating System (CRS). Homeowners, renters, and business owners in participating communities are able to purchase two types of flood insurance from the NFIP: building coverage (which includes the building, foundation, appliances and essential systems), and contents coverage (which includes belongings damaged during a flood).

When retrofitting a building after a flood, a property owner may be eligible for benefits under the NFIP's Increased Cost of Compliance (ICC) coverage. Property owners are eligible if a building is located in a SFHA, covered by a Standard Flood Insurance Policy, and has been substantially damaged or repetitively flooded, as reported by the community. If a building meets these conditions, ICC may help pay up to $30,000 towards elevation, relocation, floodproofing or demolition.

Biggert-Waters Flood Insurance Reform Act of 2012

Biggert-Waters extended the NFIP for five years and implemented actuarial flood insurance rates for some properties, which reflected a building's true level of risk. These rates were raised before structures were damaged, and caused "sticker shock" for property owners whose flood insurance skyrocketed. Biggert-Waters was meant to boost NFIP's finances so that the program could be better prepared for the next major flood. When the NFIP runs out of money while paying insurance claims after a storm, it borrows money from the Treasury.

Homeowner Flood Insurance Affordability Act of 2014

This act was a response to the aftermath of major storms, when some property owners could not afford to repair or sell their buildings, in part because of high flood insurance rates. This act made changes to the NFIP and repealed some aspects of the Biggert Waters Act. The law reinstated grandfathered ratings, slowed the phasing-out of some subsidies, limited yearly increases on flood insurance rates, mandated a surcharge for all participants in the NFIP, and created a Flood Insurance Advocate to assist policyholders.

American Society of Civil Engineers

· **ASCE 24: Flood Resilient Design and Construction**

ASCE 24 is a standard referenced in the International Code Series (I-Codes) and outlines requirements for structures in flood zones. FEMA considers the I-Codes to be consistent with NFIP requirements, allowing participating communities to reference I-Codes when setting standards. The ASCE 24 standard goes into more detail than the minimum NFIP requirements by addressing requirements for different flood zones, flood damage-resistant materials, floodproofing strategies, mechanical systems, freeboard levels, and building access.

FEMA

Post-FIRM residential buildings in SFHAs must be elevated above the Base Flood Elevation (BFE). Post-FIRM non-residential buildings must be floodproofed or elevated above the BFE.

The post-FIRM requirements were instituted to help FEMA work towards two goals:

(1) implementing higher building elevations and more restrictive programmatic uses below the BFE in SFHAs, and

(2) bringing buildings in SFHAs into compliance with floodplain management regulations over time.

· **ASCE 7: Minimum Design Loads for Buildings and Other Structures**
Section 5.3 outlines requirements for designing and constructing buildings in SFHAs to withstand flood loads. This section of the code details standards for dealing with erosion and scour, hydrostatic and hydrodynamic loads, wave loads, impact loads, and breakaway walls.

Massachusetts Building Code

· **780 CMR 1612.0 Flood Loads**
This section of the state building code specifies that the design and construction of buildings in flood zones should comply with ASCE 24 and 780 CMR 120.G and that flood loads should be calculated by referring to ASCE 7, Section 5.3.

· **780 CMR 120.G: Flood-Resistant Construction and Construction in Coastal Dunes**
Also known as Appendix G, this section of the code outlines standards for structures in flood-prone areas or coastal dunes, stating that buildings must comply with the code's requirements for construction and elevation.

These standards apply to new, substantially improved, or substantially damaged buildings that are being repaired, in FEMA SFHAs. A draft update to the building code (approved by the Board of Building Regulations and Standards in 2016) includes a new freeboard requirement for buildings and mechanical systems to be elevated one to two feet above the BFE.

Massachusetts Public Waterfront Act, Chapter 91
Chapter 91 regulates the uses of the state's waterways and tidelands, promoting and protecting public access to the shoreline. Waterfront property owners should refer to Chapter 91 before demolishing, altering, or constructing any building on the shoreline.

Massachusetts Wetlands Protection Act (WPA)
The land included as part of FEMA's Special Flood Hazard Areas (SFHA) is also designated as a Wetland Resource Area by the Wetlands Protection Act. Any project located in a SFHA must be reviewed under the WPA.

Massachusetts Floodplain Manager
Joy Duperault, from the MA Department of Conservation and Recreation (DCR), is the state's Floodplain Manager. The DCR coordinates with FEMA and the NFIP through the department's Flood Hazard Management Program (FHMP).

Boston Zoning Code

· **Article 80: Development Review**
Article 80 establishes guidelines for the development review process for four types of projects: large projects that add more than 50,000 square feet, small projects larger than 20,000 square feet, institutional master plans, and planned development areas. Any project subject to Article 80B, Large Project Review, must also complete the BRA's Climate Change Preparedness and Resiliency Checklist. This framework lists considerations related to climate change adaptation, including sea level rise, extreme weather events, FEMA flood zones, LEED rating, energy usage, extended blackouts and strategies for "islanding," pervious surfaces, and other resilient design strategies.

· **Article 37: Green Buildings**
Any project subject to Article 80B, Large Project Review, must also comply with Article 37. This section of the zoning code requires all projects equal to or larger than 50,000 square feet to be LEED certified.

· **Article 25: Flood Hazard Districts**
The city of Boston adopted Article 25 in order to comply with NFIP requirements. This section of the zoning code is designed to allow for two actions: floodplain management, and restricting buildings and uses that can create flood hazards.

Choosing a Retrofitting Strategy

An independent study conducted by the Multihazard Mitigation Council found that, "a dollar spent on mitigation saves society an average of four dollars." Resiliency strategies often have multiple benefits. For example, adding landscaping to the front of an elevated building helps to preserve the connection between the raised building and the streetscape, while also increasing the property's stormwater retention rate.

When planning a retrofit, talk to an insurance agent, local officials, and a design professional. Retrofitting strategies can be grouped into five main categories: elevate, wet floodproof, dry floodproof, barrier systems, and backup measures. It's possible to think about these strategies as a kit of parts, and in some cases it may be advisable to mix and match retrofitting methods. For example, a mixed-use building could use both wet floodproofing and dry floodproofing on the ground floor: the lobby could accommodate flooding while the mechanical room could stay dry.

NFIP does provide flood insurance premium reductions for interior modifications (including basement infill, abandoning the lowest floor, and elevating the lowest interior floor), and wet floodproofing using flood openings.

FEMA recognizes other retrofitting strategies but has not yet tied them to flood insurance premium reductions. These strategies include some aspects of wet floodproofing (including elevating building utilities, floodproofing building utilities, and the use of flood damage-resistant materials), dry floodproofing (including passive dry floodproofing systems), and barrier systems (including flood walls with and without gates, and levees with and without gates).

1 Elevate

FEMA

This strategy includes elevating an entire building, elevating only the ground floor, and elevating critical systems.

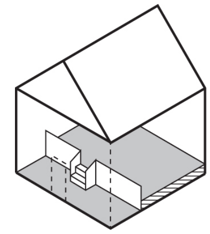
Raising a building three feet or less is fairly common, and doesn't change much about the connection between the building and the public realm. When raising a building by an entire floor, it is important to find uses for the space below the first inhabitable floor. The only permanent programmatic uses allowed by NFIP below the lowest occupiable floor of an elevated building are parking, storage, crawl space, and building access. The bottom of the lowest structural member must be at, or above, the DFE.

When elevating a building, it's also important to preserve the connection between the building and the street. There are a number of design strategies that can help preserve this connection and will be covered in more detail at the end of this section.

+

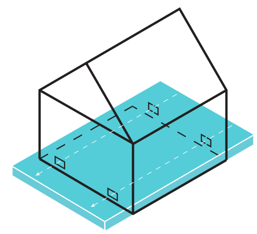
Other potential temporary uses could include mobile community facilities, markets, pop-up retail, art exhibitions and performances.

When elevating critical systems (including mechanical equipment from electrical, heating, ventilation, plumbing and air conditioning systems) it may be possible to move some equipment onto the roof. If not, raise critical systems above the base flood elevation (BFE).



If the first floor of a building is partially below the BFE but has a generous ceiling height, it may be possible to raise the level of just the first floor rather than having to elevate the entire building. This works particularly well for first-floor commercial spaces, which can retain their ground level storefront windows by providing access to the raised first floor in an interior vestibule.

2 Wet Floodproof



Wet floodproofing allows for the movement of water through a space or a building, which helps to equalize hydrostatic pressure and prevent structural failure. A sacrificial, floodable, or porous first floor is one example of a wet floodproofing strategy. The building above a sacrificial first floor can be supported by columns rather than walls, but it's also possible to use glass and brick panels that are made to break when hit by a storm surge. These breakaway walls help relieve pressure on primary walls and columns, and are required for elevated buildings in V Zones.

When retrofitting a building to incorporate a floodable first floor, it may be possible to recapture some of the lost first floor space by moving all or some of that square footage to the roof. This strategy may require structural reinforcement and may conflict with current height requirements.

Wet floodproofed spaces can only be used for parking, access, and storage. For post-FIRM buildings, at least one side of the wet floodproofed space must be above grade and the lowest occupiable floor must be elevated to at least the level of the DFE. Pre-FIRM subgrade spaces can be wet floodproofed, but water must be pumped out after flooding recedes, which can be dangerous if surrounding soils are still saturated.

Wet floodproofed spaces must have openings in at least two walls, at no more than one foot above grade. If non-engineered, these openings should be equal to one square inch for every one square foot of enclosed space. If engineered, these openings must be certified by a registered design professional. Wet floodproofed spaces should include floodproof materials up to one inch above the DFE. Wet floodproofing may not be appropriate for all building types. For example, repeated saltwater inundation can deteriorate the mortar in brick and stone foundations.

Wet floodproofing strategies pair well with resilient landscaping systems. Porous surfaces, like landscaping and permeable pavement, can help improve a property's stormwater management. Rain gardens and bioswales can soak up water and filter runoff, while drainage systems and sloping grades can help increase groundwater infiltration.

3 Dry Floodproof

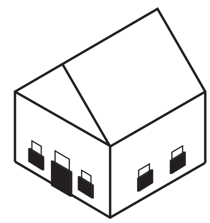
Dry floodproofing involves sealing a space or a building up to the level of the DFE or higher, in order to keep water from entering. When dry floodproofing a building, property owners should strengthen structural members in anticipation of the hydrostatic and hydrodynamic pressure caused by floodwaters. As an additional measure, hydrostatic pressure pop-up valves can help prevent floors from buckling upwards due to pressure from floodwaters outside the building. Although sealants and flood shields can be effective dry floodproofing tools, some water may still enter the building. Property owners should equip dry floodproofed buildings with a sump pump and water damage-resistant materials in areas where floodwaters may seep past barriers.

Dry floodproofing can also be used at a smaller scale, to protect utilities that cannot be elevated above the BFE. Watertight rooms or containers can shelter critical systems, including HVAC, fuel, electrical, sewage management, and potable water systems. However, mechanical equipment must be elevated above the BFE for buildings in Zone V.

In a mixed use, post-FIRM building, a first-floor retail space could be dry floodproofed, but any residential entryways would have to be wet floodproofed.

In post-FIRM buildings, dry floodproofing can only be used for non-residential spaces in A Zones. Dry floodproofing is not recommended for buildings with basements because of the pressures exerted by wet soils on basement walls.

Any pre-FIRM building can be dry floodproofed, but it will not lead to a reduction on flood insurance rates. FEMA does not allow dry floodproofing post-FIRM residential spaces because of the risks associated with this strategy. Due to hydrostatic pressure, dry floodproofing can lead to catastrophic structural damage. Homeowners may not be able to set up temporary flood shields on their own, and dry floodproofing may encourage them to shelter in place during a storm. FEMA does not want to encourage homeowners to stay home during a severe flood. Dry floodproofing is also coupled with the installation of sump pumps, which must be able to continue working (either through a generator or a battery) in the event of a power outage. If a dry floodproofing system is seriously breached, pumps will not be able to keep up with the rate of flooding.



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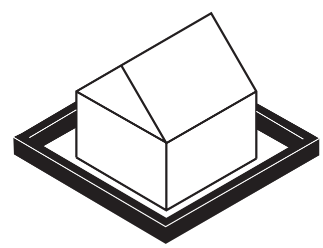
FEMA

Barrier Systems

Deployable flood barriers can be erected around some properties, as long as they don't disrupt normal circulation and egress pathways. Temporary floodwalls without gates include ramps or pedestrian stairs. If a property is large enough, some homeowners may choose to use permanent or modular seawalls, or to construct a levee. Levees are usually no higher than six feet, and floodwalls are usually no higher than four feet.

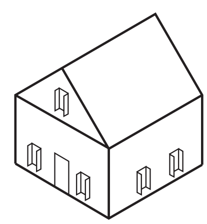
While levees and floodwalls are recognized by FEMA as retrofitting strategies, they can't bring a post-FIRM building into compliance with NFIP regulations.



5

Backup Measures

Resilient systems should be comprised of multiple layers. If one layer fails, the overall system can continue to function. The following backup measures reflect that idea. These suggestions can also be used as part of a partial mitigation strategy if property owners are unable to complete a full retrofit, although the NFIP does not provide rate reductions for partial mitigation measures.



Possible backup measures could include:

- Septic line backflow prevention valves
- Sump pumps and discharge pumps
- Backup generators
- Renewable energy systems and clean, potable water sources to facilitate "islanding" during extended blackouts
- Water catchment systems for uses other than drinking or washing food
- The installation of a toilet and faucet that can operate during power outages

· Operable windows that allow for escape and ventilation during heat waves

· Securing large objects that could float away and cause additional damage during flooding (for example, an outdoor fuel tank)

· Elevators that are programmed to go to the second floor during flooding, rather than defaulting to the ground floor

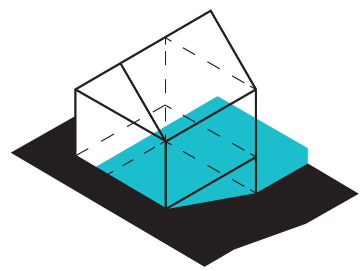
· Emergency lighting in residential hallways and staircases

· Enhancing a building's foundation and structure to withstand extreme water loads

· Installing permeable pavement in a driveway and/or adding landscaping to increase a property's stormwater retention rate

· Developing an emergency preparedness plan for a building. Knowing in advance what to do, where to go, and who might need assistance during an emergency. Gathering supplies beforehand, which could include food, water, a flashlight with extra batteries, and portable chargers for phones, laptops, and other devices.

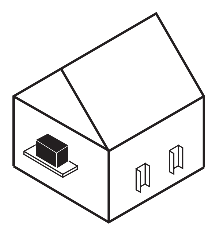
Additional Challenges



FEMA

Basements

Post-FIRM subgrade basements must be infilled. Post-FIRM basements with at least one exit at grade (often called walkout-on-grade basements) can be wet floodproofed and used for parking, storage, crawl space, or building access. Pre-FIRM subgrade basements can be wet floodproofed but water must be pumped out after flooding recedes, which can be dangerous if surrounding soils are still saturated.



FEMA

Moving Mechanical Equipment

Mechanical equipment is often located in basements, which can cause problems when retrofitting buildings in SFHAs. For some buildings, it may be possible to relocate systems to the roof or to an upper floor. For example, equipment that's usually mounted on an outside wall, like a telephone or television line, could be mounted further up the same wall. It may also be possible to build a new mechanical room above the BFE, as an addition to a building.

For equipment that cannot be relocated, it may be possible to elevate those systems in place by raising them onto a platform above the BFE. For example, air conditioning equipment could be placed on an elevated pedestal inside the building or on a cantilevered platform attached to the outside of the house. Check with a utility company before moving service equipment, and anything that is elevated should have enough space around it to allow for maintenance work. Some equipment, like water heaters, furnaces, and boilers, will require certain clearances and venting systems. And if a building has plumbing fixtures located below the manhole cover serving the building, the state plumbing code requires the installation of backflow prevention valves.

Systems that are too difficult to elevate, which could include fuel storage tanks, should be sealed and anchored in place so that they don't become debris during a storm. Equipment that cannot be elevated could be dry floodproofed instead, using flood shields and low floodwalls.

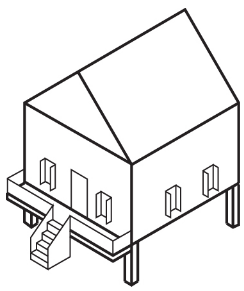
The best time to move mechanical equipment is when those systems need to be upgraded. Consider investing in a smaller, more efficient unit that can more easily be elevated or relocated.

Urban Design Considerations

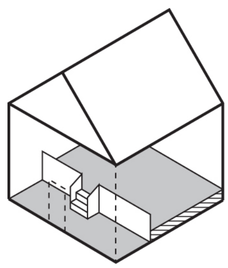
Some retrofitting strategies that work well for individual buildings can have unintended consequences on a neighborhood's overall urban design. For example, elevating a building can protect a structure from flood damage, but can also create a disconnect between the building and the public realm.

When elevating an entire building, it's important to preserve the connection between the building and the street. There are a number of design methods that can help maintain this connection. These streetscape mitigation strategies include landscaping, a raised yard, front stoops and porches, ramps, an articulated façade or latticed walls, and interior vestibules that provide access to a raised first floor.

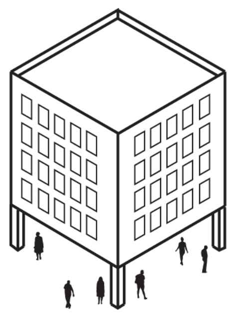
Raised yards should include well-designed drainage and access elements as part of the landscaping. When designing an articulated façade or latticed walls, take cues from the surrounding context. It's often advisable to collaborate with neighbors to create a cohesive streetscape. Consider strategies for incorporating ADA access and universal design into your retrofits. For large buildings like row houses or a block of adjoining stores, a single ADA compliant ramp can serve multiple entrances while also acting as a floodwall.



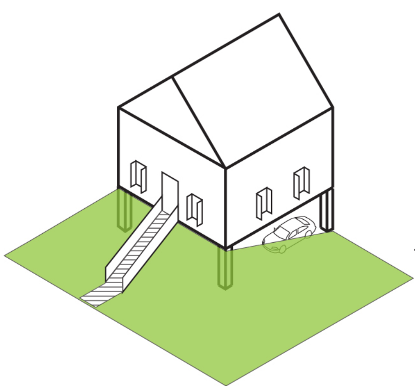
Front porch and stairs



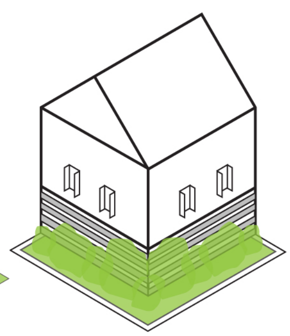
Interior vestibule



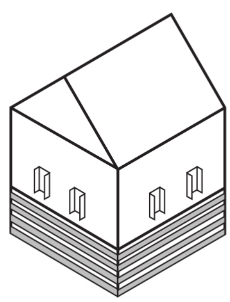
Temporary programming



Raised yard



Landscaping



Lattice or screens

PART II: CASE STUDIES

Photo: Fort Point Channel Landmark District

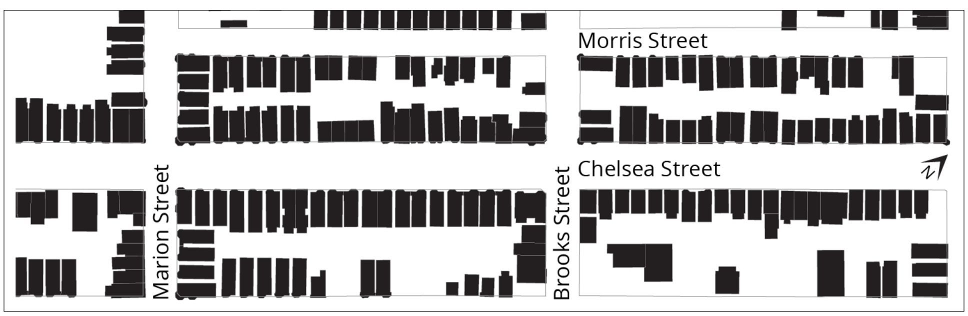
Triple-Decker

Triple-deckers are one of the most common and iconic building types in Boston. Many of them were built in neighborhoods like East Boston, Jamaica Plain, and Dorchester during the late 19th and early 20th centuries.

With room for three units, working-class families were able to buy a triple-decker, live on one floor, and rent out the remaining two units. Other triple-deckers were home to entire families, a multi-generational living arrangement that facilitated childcare and eldercare and fostered tight-knit communities.

Triple-deckers typically utilize wood-framed construction, double-hung windows, and a raised stoop above a stone or brick base. Many have multi-tiered porches in the front or back yard, along with decorative molding and a three-sided bay. All three floor plans above grade are identical, which allows for relatively cheap and efficient construction. Triple-deckers also have windows on all sides, a point of pride for the homeowners who moved into these buildings after living in tenement conditions.

The building in this case study was modeled based on triple-deckers along Bremen Street in East Boston. These structures fall along the edge of Zone AE in FEMA's SFHAs. The BFE shown on the FEMA FIRM is 10 feet, which references NAVD. Property owners should work with a surveyor to determine BFEs from grade. For the purposes of this report, the BFE has been shown at 1.0 foot from grade. Since triple-deckers are typically residential buildings, which have an increased risk of loss of life during an emergency, the DFE has been shown at 3.0 feet from grade, separated from the BFE by two feet of freeboard.



Triple-decker massing in East Boston

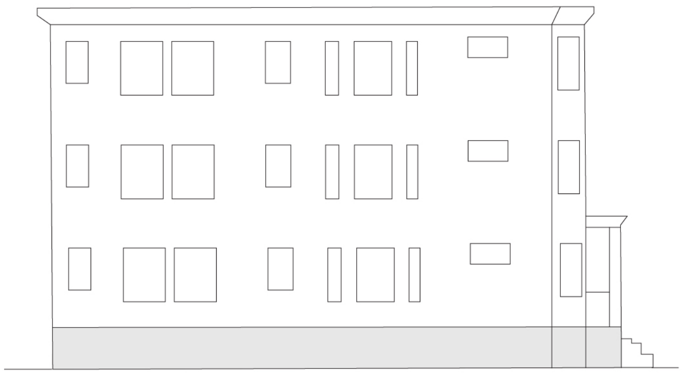
Triple-deckers along Bremen Street in East Boston, composite image
Image capture ©2016 Google

Triple-decker detail

Triple-Decker

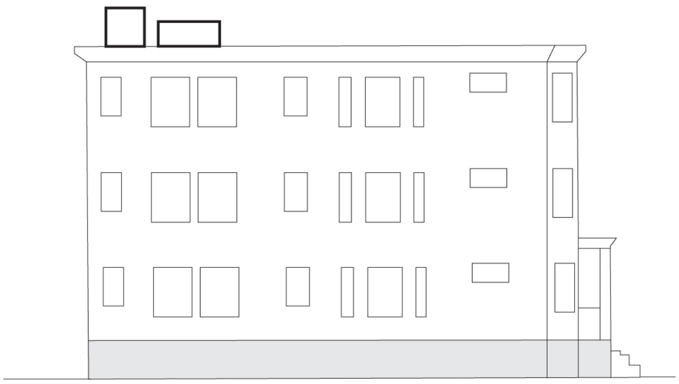
SFHA Zone: AE
BFE: 1’ from grade
Freeboard: 2’
DFE: 3’ from grade

Existing Conditions: residential building with mechanical equipment in the basement



FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

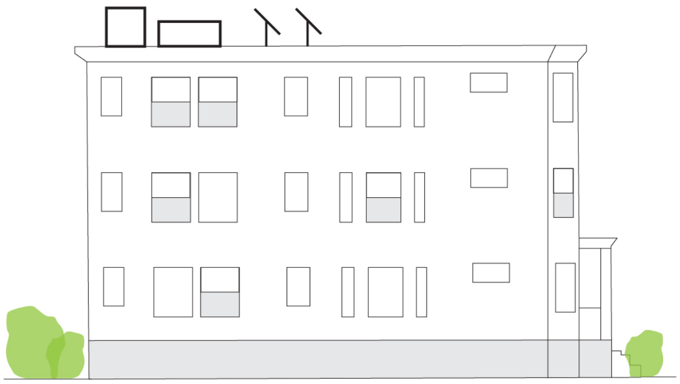


Infill the basement and move mechanical systems to the roof, or to a floor above the BFE.

Strategies eligible for NFIP flood insurance reduction: Infilling basement

Retrofi+

Retrofitting strategies that incorporate additional design recommendations



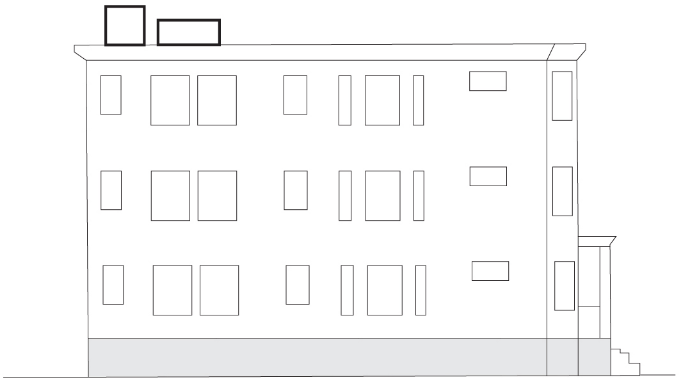
Upgrade mechanical equipment to more efficient models before relocating. Add landscaping to increase stormwater retention. Consider installing “backup measures,” which could include operable windows and toilets and faucets that don’t require power to operate.

FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

Retrofi+

Retrofitting strategies that incorporate additional design recommendations

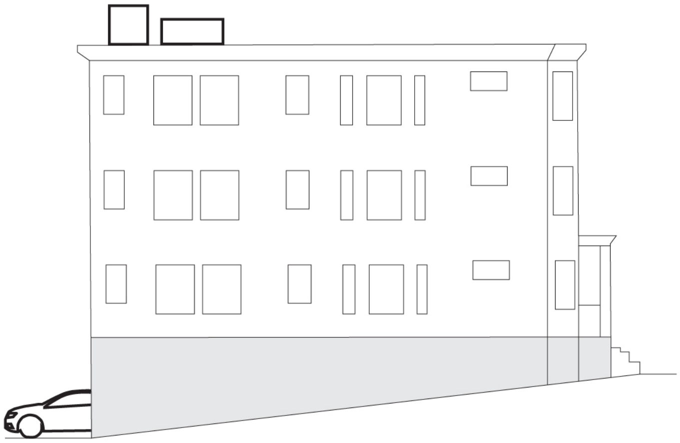


Infill the basement and move mechanical systems to the roof, or to a floor above the BFE.

Strategies eligible for NFIP flood insurance reduction: Infilling basement

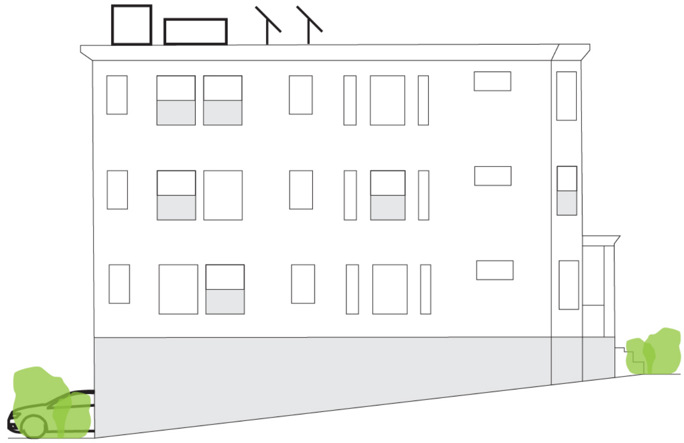
If the building had a basement apartment, relocate some of that lost square footage to the roof (this may require structural reinforcement). Add a roof deck in front of the addition, to help preserve the original look of the triple-decker.

Upgrade mechanical equipment to more efficient models before relocating. Add landscaping to increase stormwater retention. Consider installing "backup measures," which could include operable windows and toilets and faucets that don't require power to operate.



If the unit has a walkout-on-grade basement (at least one exit is at grade), wet floodproof that space and use it for parking, storage, or building access. Include flood vents and use flood damage-resistant materials. Elevate mechanical equipment to the roof or to a floor above the BFE.

Strategies eligible for NFIP flood insurance reduction: Wet floodproofing using flood openings.



Upgrade mechanical equipment to more efficient models before relocating. Add landscaping to increase stormwater retention. Consider installing "backup measures," which could include operable windows and toilets and faucets that don't require power to operate.

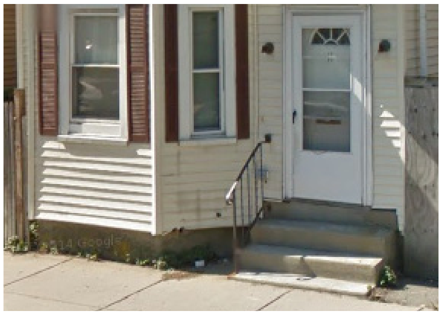
Two Family Detached

Two family homes are a common building typology in Dorchester neighborhoods. Typically wood framed construction with pitched roofs, these homes often have a one or two-story bay, and a porch or overhang sheltering the front door. Two family houses rest on a stone or brick base that raises the first floor 1 to 2 feet above grade. These buildings come in many different variations, with some including decorative molding under eaves and lattice panels under porches.

The building in this case study was modeled based on two family homes along Denny Street and Playstead Road in Dorchester. These structures fall along the edge of Zone AE in FEMA's SFHAs. The BFE shown on the FEMA FIRM is 10 feet, which references NAVD. Property owners should work with a surveyor to determine BFEs from grade. For the purposes of this report, the BFE has been shown at 1.0 foot from grade. Since two family detached buildings are residential homes, which have an increased risk of loss of life during an emergency, the DFE has been shown at 3.0 feet from grade, separated from the BFE by two feet of freeboard.

Two family home massing in North Dorchester

Two family homes along Mohawk Street in North Dorchester, composite image
Image capture ©2016 Google

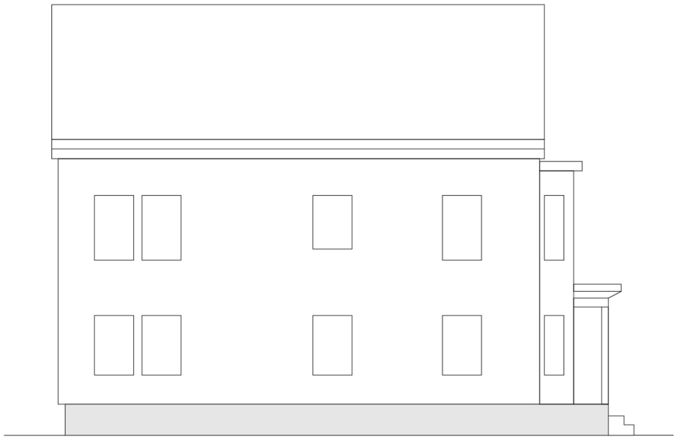


Two family detail
Image capture ©2016 Google

Two Family Detached

SFHA Zone: AE
BFE: 1' from grade
Freeboard: 2'
DFE: 3' from grade

Existing Conditions: residential building with mechanical equipment in the basement



FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

Retrofi+

Retrofitting strategies that incorporate additional design recommendations

Infill the basement and move mechanical systems to a cantilevered platform, or to a floor above the BFE.

Strategies eligible for NFIP flood insurance reduction: Infilling basement

Relocate lost square footage from the basement to the back of the building. Add landscaping to increase stormwater retention. Consider installing "backup measures," which could include operable windows and toilets and facuets that don't require power to operate. Cover mechanical systems with a screen and consider locating the cantilever in the backyard, or move mechanical systems to a floor above the BFE.

FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

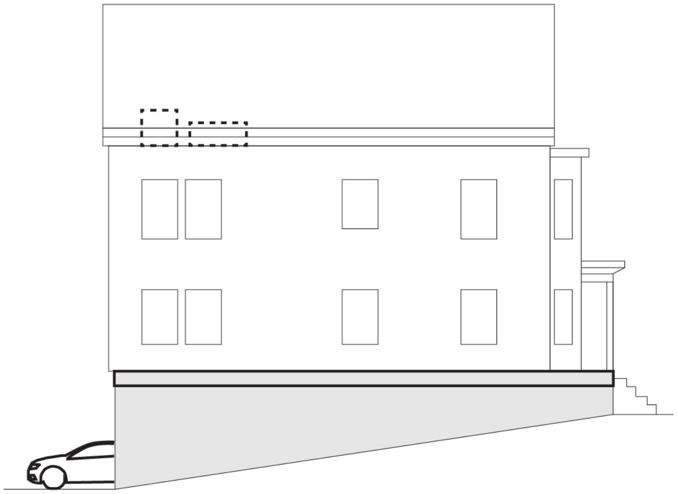
Retrofi+

Retrofitting strategies that incorporate additional design recommendations

Infill the basement and move mechanical systems to a cantilevered platform, or to a floor above the BFE. Elevate the building.

Strategies eligible for NFIP flood insurance reduction: Infilling basement and elevating the lowest interior floor

Add a front porch, a staircase, and landscaping to help connect the raised building with the street. Consider installing "backup measures," which could include operable windows and toilets and facuets that don't require power to operate. Cover mechanical systems with a screen and consider locating the cantilever in the backyard, or move mechanical systems to a floor above the BFE.



If the unit has a walkout-on-grade basement (at least one exit is at grade), wet floodproof that space and use it for parking, storage, or building access. Include flood vents and use flood damage-resistant materials.   Elevate building and move mechanical systems to a cantilevered platform, or to a floor above the BFE.

Strategies eligible for NFIP flood insurance reduction: Wet floodproofing using flood openings

Add landscaping to increase stormwater retention. Consider installing "backup measures," which could include operable windows and toilets and facuets that don't require power to operate.

19th and 20th Century Industrial Loft

Industrial loft buildings are a common sight in the Fort Point Channel Landmark District (FPCLD). These structures were designed and built by the Boston Wharf Company between the 1880s and 1920s. At the time of their construction, the Fort Point Channel was the center of a booming import and export industry. The industrial lofts along the waterfront were used to make and store goods like molasses, sugar, wool, and other fabrics. They were later appropriated by artists during the 20th century. These buildings are easily recognizable, with masonry construction, flat roofs, and classical details around doors and cornices.

The building in this case study was modeled based on industrial loft buildings along Summer and Melcher Street in the Fort Point Channel Landmark District. These structures fall within Zone AE of FEMA's SFHAs. The BFE shown on the FEMA FIRM is 10 feet, which references NAVD. Property owners should work with a surveyor to determine BFEs from grade. For the purposes of this report, the BFE has been shown at 1.0 foot from grade. Since these buildings are historic structures, the DFE has been shown at 3.0 feet from grade, separated from the BFE by two feet of freeboard.

FEMA

Historic buildings are exempt from the NFIP's requirements for post-FIRM buildings, as long as the alterations or repair of a substantially improved or substantially damaged structure does not end its designation as a historic building.

Historic buildings include those that are listed in the National Register of Historic Places, a state inventory of historic places, a certified local inventory of historic places, or that have been certified by the Secretary of the Interior as contributing to an area's historic significance.

Industrial loft massing

Industrial loft buildings along Summer Street in the Fort Point Channel Landmark District

Industrial Loft detail

19th / 20th Century Industrial Loft

SFHA Zone: AE
BFE: 1’ from grade
Freeboard: 2’
DFE: 3’ from grade

Existing Conditions: first floor retail, apartments above, mechanical equipment in the basement and on the first floor

FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

If ceiling height allows, raise the level of the first floor to the DFE. Keep the lobby at grade and wet floodproof that space. Add interior stairs and an ADA compliant ramp. Incorporate deployable flood shields in the design of access elements. Raise mechanical systems to the level of the raised first floor or to the roof. Wet floodproof the lobby that leads to the upstairs apartment. Use flood damage-resistant materials in all wet floodproofed spaces. Infill the basement.

Strategies eligible for NFIP flood insurance reduction: Infilling basement, raising lowest interior floor, wet floodproofing using flood openings

Retrofi+

Retrofitting strategies that incorporate additional design recommendations

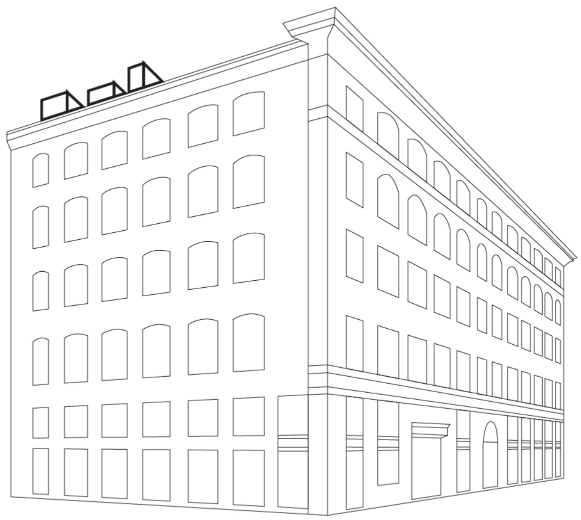
Add landscaping along the street level. Consider installing “backup measures,” like emergency lighting in residential hallways and stairwells, solar panels, and operable windows.

FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

Retrofi+

Retrofitting strategies that incorporate additional design recommendations



Abandon lowest floor and use the space for storage and as a lobby. Wet floodproof the first floor and use flood damage-resistant materials in that space. Infill the basement and elevate mechanical systems to a floor above the BFE or to the roof.

Strategies eligible for NFIP flood insurance reduction: Infilling basement, abandoning lowest interior floor, wet floodproofing using flood openings

Use the first floor space for temporary programming, including pop-up retail, indoor markets, art exhibitions and performances, and community facilities and meetings. Add landscaping along the street level and on the roof. Add a unit to the roof to replace some of the square footage lost by abandoning the first floor.

Dry floodproof the first floor, up to the level of the DFE, and install sump pumps. Dry floodproof the mechanical room. Elevate the mechanical systems that are the easiest to move, as a precaution. Infill the basement. Work with an engineer to reinforce structural systems in anticipation of hydrostatic pressure.

Strategies eligible for NFIP flood insurance reduction: Infilling basement

Add landscaping along the street level. Install backup generators to power sump pumps during a blackout. Consider installing "backup measures," like emergency lighting in residential hallways and stairwells, solar panels, and operable windows.

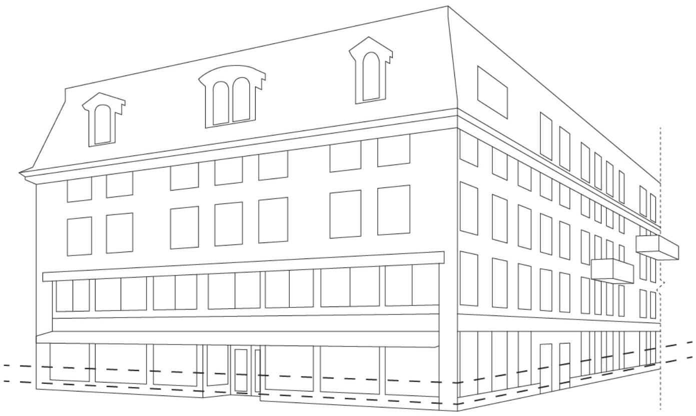
18th and 19th Century Wharf Building

18th and 19th century wharf buildings were built to support Boston's busy shipping industry. At the time, Boston was a leading colonial port. The length of the wharves allowed ships to unload their goods directly, rather than having to use smaller boats to shuttle their wares to shore. The goods were then stored and sold to merchants from the masonry buildings constructed on the wharves. These structures have since been converted to accommodate a mix of different uses, including apartments, stores, and office space.

The building in this case study was modeled based on buildings on Commercial and Lewis Wharf along the Downtown waterfront. These structures fall within Zone AE of FEMA's SFHAs. The BFE shown on the FEMA FIRM is 10 feet, which references NAVD. Property owners should work with a surveyor to determine BFEs from grade. For the purposes of this report, the BFE has been shown at 1.0 foot from grade. Since these buildings include residential spaces, which have a higher risk of loss of life during an emergency, the DFE has been shown at 3.0 feet from grade, separated from the BFE by two feet of freeboard.

Wharf buildings along the Downtown Waterfront

Historic wharf buildings near Lewis Wharf along the Downtown Waterfront



18th / 19th Century Wharf Building

SFHA Zone: AE
BFE: 1' from grade
Freeboard: 2'
DFE: 3' from grade

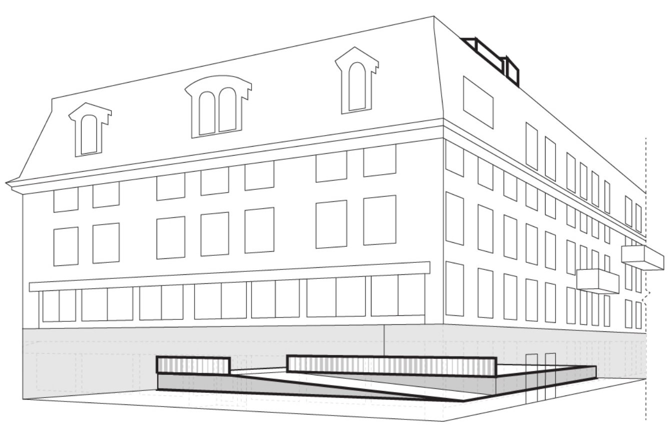
Existing Conditions: first floor retail, apartments above, mechanical equipment on the first floor

FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

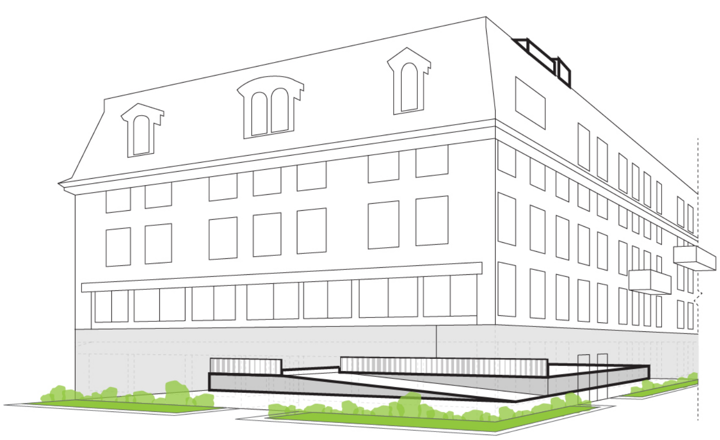
Retrofi+

Retrofitting strategies that incorporate additional design recommendations



If ceiling height allows, raise the level of the first floor to the DFE. Keep the lobby at grade and wet floodproof that space. Add interior stairs and an ADA compliant ramp. Incorporate deployable flood shields in the design of access elements. Raise mechanical systems to the level of the raised first floor or to the roof. Wet floodproof the lobby that leads to the upstairs apartment. Use flood damage-resistant materials in all wet floodproofed spaces. Infill the basement.

Strategies eligible for NFIP flood insurance reduction: Infilling basement, raising lowest interior floor, wet floodproofing using flood openings



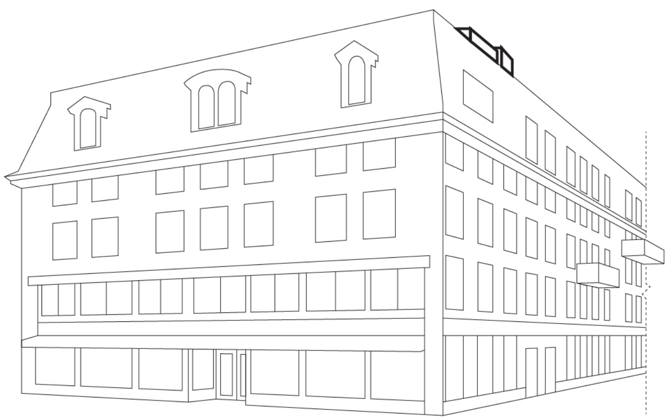
Add salt-tolerant landscaping to increase stormwater retention. Consider installing "backup measures," like emergency lighting in residential hallways and stairwells, solar panels, and operable windows.

FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

Retrofi+

Retrofitting strategies that incorporate additional design recommendations



Abandon lowest floor and use the space for storage and as a lobby. Wet floodproof the first floor and use flood damage-resistant materials in that space. Infill the basement and elevate mechanical systems to a floor above the BFE or to the roof.

Strategies eligible for NFIP flood insurance reduction: Infilling basement, abandoning lowest interior floor, wet floodproofing using flood openings

Use the first floor space for temporary programming, including pop-up retail, indoor markets, art exhibitions and performances, and community facilities and meetings. Add landscaping along the street level and on the roof. Add a unit to the roof to replace some of the square footage lost by abandoning the first floor.

Dry floodproof the first floor, up to the level of the DFE, and install sump pumps. Dry floodproof the mechanical room. Elevate the mechanical systems that are the easiest to move, as a precaution. Infill the basement. Work with an engineer to reinforce structural systems in anticipation of hydrostatic pressure.

Strategies eligible for NFIP flood insurance reduction: Infilling basement

Add landscaping along the street level. Install backup generators to power sump pumps during a blackout. Consider installing "backup measures," like emergency lighting in residential hallways and stairwells, solar panels, and operable windows.

Contemporary High Rise

Post-FIRM structures must comply with floodplain management regulations. The following strategies illustrate resiliency measures for contemporary high rise buildings, some of which go above and beyond FEMA's baseline standards.

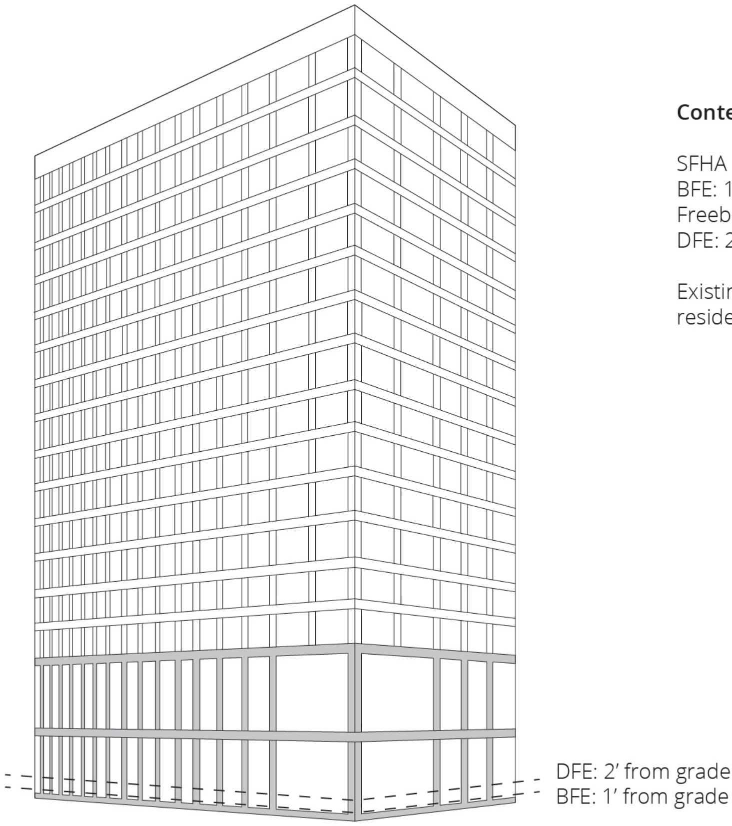
Designers and developers should consider a structure's lifespan when building in the 100-year floodplain. FIRMs are based on historical data, so the listed flood projections do not include factors related to future sea level rise or future coastal erosion. When planning new construction, imagine how a building's site could be impacted by climate change by mid-century or by 2100. The most resilient projects go above and beyond today's requirements in anticipation of tomorrow's risks.

The building in this case study was modeled based on contemporary high rise buildings along the South Boston Waterfront. These structures fall within Zone AE of FEMA's SFHAs. The BFE shown on the FEMA FIRM is 10 feet, which references NAVD. Property owners should work with a surveyor to determine BFEs from grade. For the purposes of this report, the BFE has been shown at 1.0 foot from grade and the DFE has been shown at 2.0 feet from grade.

Building massing

Buildings near Northern Ave in South Boston
Image capture ©2016 Google

Buildings along Seaport Blvd in South Boston
Image capture ©2016 Google



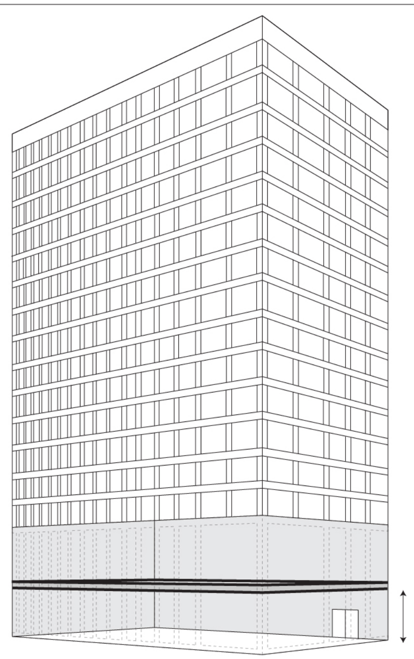
Contemporary High Rise

SFHA Zone: AE
BFE: 1’ from grade
Freeboard: 1‘
DFE: 2‘ from grade

Existing Conditions: contemporary mixed-use building with no basement and non-residential uses on the first two floors

FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

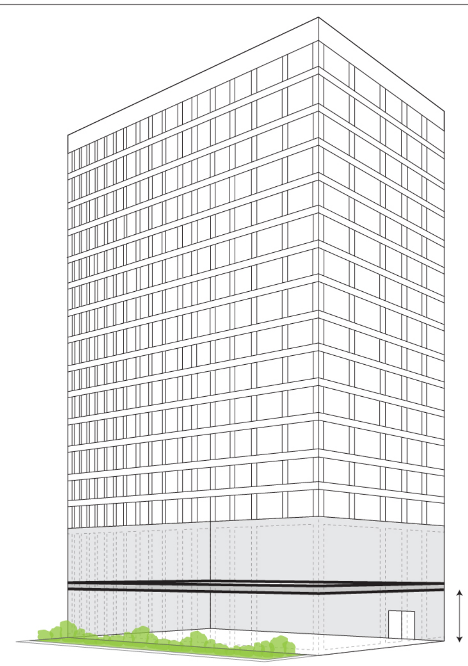


Incorporate large ceiling heights in the first two floors to accommodate retailand allow for the floor to be elevated later. Alternatively, first-floor stores could eventually retreat to the second floor.

Strategies eligible for NFIP flood insurance reduction: Raising lowest interior floor, abandoning lowest interior floor

Retrofi+

Retrofitting strategies that incorporate additional design recommendations



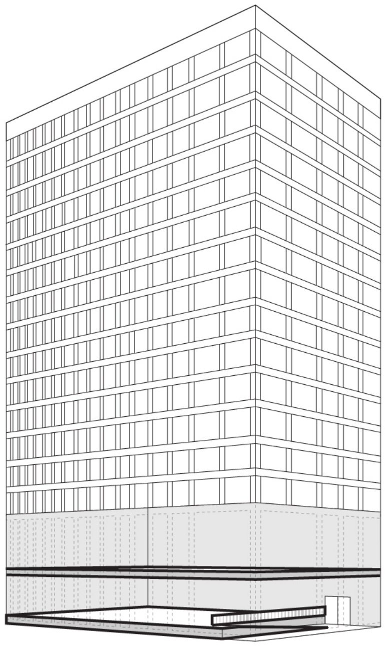
Elevate the level of the site and incorporate porous landscape strategies, like a berm. Add landscaping along the street level. Consider incorporating “backup measures,” like backup generators and operable windows.

FEMA

Retrofitting strategies that are required or encouraged by FEMA and the NFIP

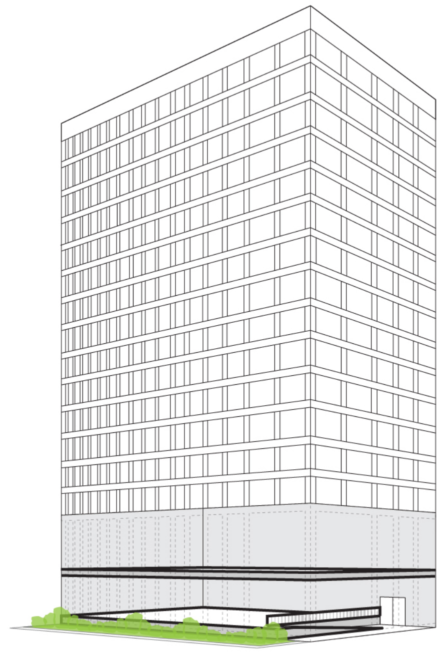
Retrofi+

Retrofitting strategies that incorporate additional design recommendations

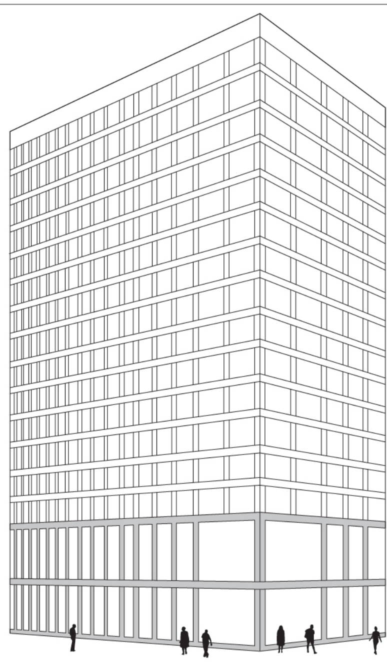


Elevate the ground floor and provide access elements in an interior, wet floodproofed vestibule.

Strategies eligible for NFIP flood insurance reduction:
Raising lowest interior floor

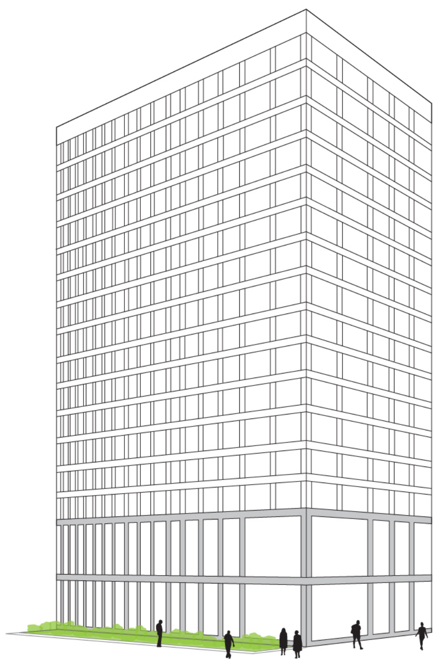


Elevate the level of the site and incorporate porous landscape strategies. Add landscaping along the street level. Consider incorporating "backup measures," like backup generators and operable windows.



Design for a wet floodproofed first floor space that can be used for storage, parking, or building access. Other temporary uses for the first floor could include markets and exhibitions.

Strategies eligible for NFIP flood insurance reduction:
Wet floodproofing using flood openings



Wet floodproof the first floor and use space for semi-permanent uses that can help activate the street level of the building and be quickly evacuated before a major flood. For example, a first floor retail space with all of their equipment on wheels. Add landscaping along the street.

PART III: POSSIBLE POLICY OR REGULATORY INTERVENTIONS

Photo: Melcher Street

Possible Policy or Regulatory Interventions

Retrofitting strategies for buildings in the 100-year floodplain can conflict with current zoning codes, causing encroachment and exceedance issues related to lot coverage, setbacks, and height restrictions. Granting variances and making exceptions for buildings that retrofit in preparation for flooding is in the public interest. Retrofitted, resilient neighborhoods will be better prepared for the next devastating flood. There are also opportunities for the city of Boston to incentivize or require certain floodplain management regulations that can go above and beyond FEMA's baseline requirements. Some examples of these potential policy and regulatory interventions are included below.

Exceptions to height restrictions in Special Flood Hazard Areas (SFHA), including:

· Measuring building height from the lowest occupiable floor or from the base flood elevation (BFE) rather than from grade, for retrofits that involve elevating an entire building.

· Minimizing floor area loss for retrofits that create a wet floodproofed or sacrificial first floor, by allowing all or part of the lost square footage to be added as a new floor to the top of the building. These buildings may need to be structurally reinforced.

Changes to floor area calculations, including:

· Removing uninhabitable spaces below the BFE (for example, a floodable first floor) from a building's total floor area.

· Removing relocated mechanical equipment and relocated mechanical rooms from a building's total floor area.

· Removing the space needed for stairs and ramps in an interior vestibule leading to a raised first floor, from total floor area.

· Removing the floor area of a wet floodproofed first floor entryway and display space, for businesses that relocate to a building's second floor.

Incentives for freeboard levels that go above ASCE 24-14 requirements. For example, ASCE 24-14 requires one foot of freeboard for most residential, commercial, and industrial buildings in A Zones and V Zones, but NYC's 2008 Building Code requires two feet of freeboard for 1-2 family homes.

The Facilities of Public Accommodation (FPAs) required by Chapter 91 for new buildings or redevelopment projects could be expanded to encourage temporary public programming under buildings that are elevated to address flood risk. This programming could include mobile community facilities, markets, pop-up retail, outdoor art exhibitions, and performances.

Variances for retrofitted buildings, including:

· Allowing buildings that have been improved with resiliency measures like higher freeboard levels to retain some noncompliant aspects of the original building. For example, a two-family home with pre-existing lot coverage that doesn't comply with current zoning codes, that undergoes a substantial alteration as part of a flood retrofit, could retain its original building footprint.

· Variances for streetscape mitigation strategies that conflict with current requirements. For example, adding a front porch to an elevated building would help to connect that property to the public realm, but could also conflict with setback requirements.

Support for building retrofits, including:

· Financial support for building retrofits in the 100-year floodplain, the 500-year floodplain, and the Flood Resiliency Overlay District (if implemented).

· The City could start a pilot program that would pay a certain percentage of the costs of an eligible retrofit. The pilot program could eventually lead to a formal grant program with federal funding.

· Support for low-income tenants who would have to vacate their home during a retrofit.

· Support for "partial mitigation measures" for those who are financially unable to complete a full retrofit, or for property owners with buildings that are structurally unable to accommodate certain retrofits. For example, the City could subsidize the cost of installing backwater valves and sump pumps on household sewer connections.

· Incentives for increasing a property's stormwater retention rate.

· Incentives for relocating a building outside of SFHAs.

· Including information on flood resilience in the public planning processes occurring in SFHA neighborhoods.

Programs that encourage property owners to move their mechanical equipment at or above the design flood elevation (DFE), including:

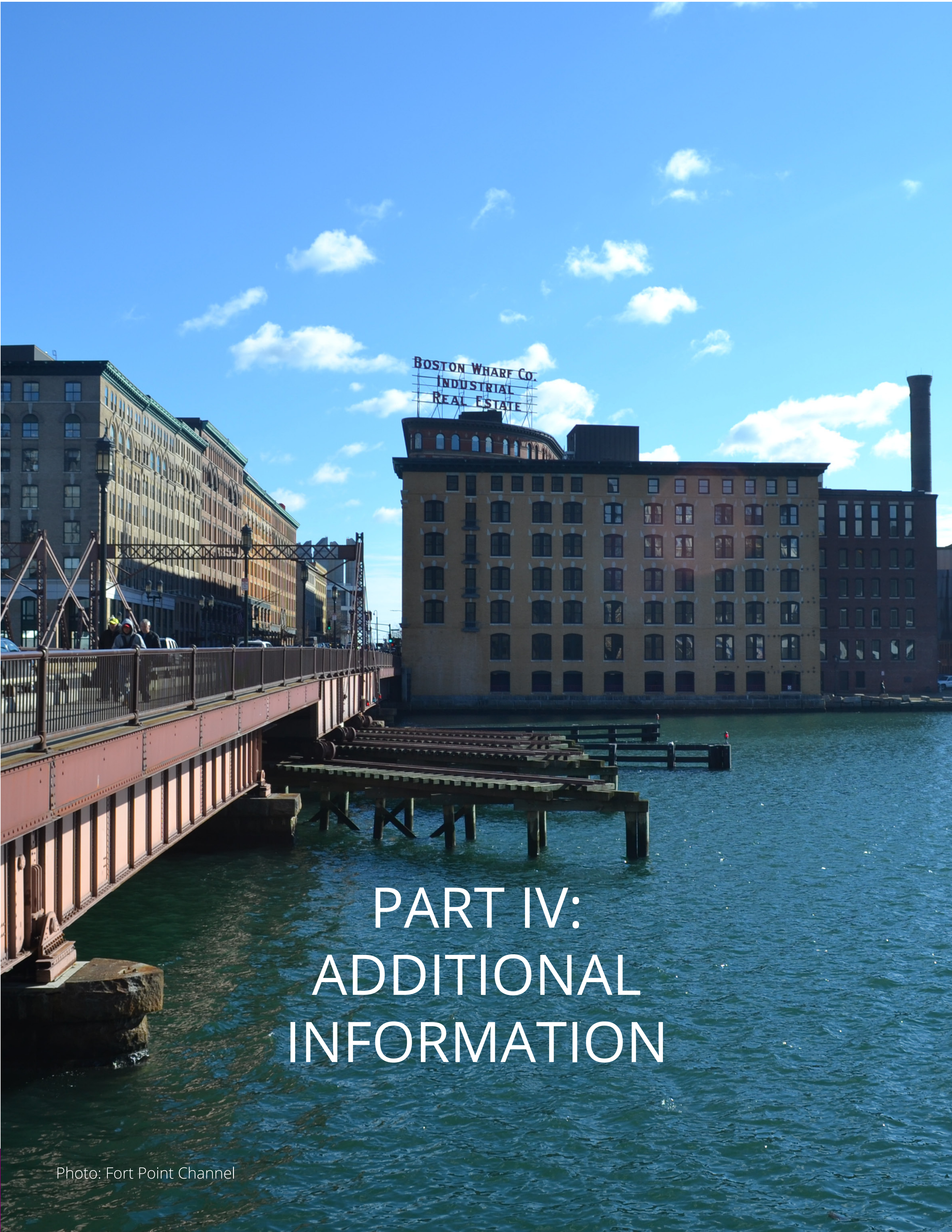
· A utility retrofit program that provides incentives for moving your mechanical equipment above the BFE. This program could be linked to standard energy assessments used to determine whether or not a property's mechanical systems should be updated. Property owners could upgrade their equipment to smaller, more efficient models that could more easily be located above the BFE.

· A standard that encourages property owners who are selling a building in a FEMA SFHA to elevate their mechanical systems at or above the BFE.

Prohibiting pre-FIRM buildings from remodeling basements into livable space. The only allowable uses could include storage, parking, and building access.

Boston's participation in the Community Rating System (CRS). By joining the CRS and adopting floodplain management regulations that go beyond FEMA's baseline requirements (for example, higher freeboard levels), the City could be eligible for community-wide discounts on flood insurance premiums. Participating in the CRS could also help Boston develop a comprehensive approach to building and retrofitting in the floodplain.

Allowing semi-permanent uses below the BFE, especially for post-FIRM commercial and mixed-use buildings that can help activate the street level. Currently, the NFIP restricts permanent uses for spaces below the BFE of post-FIRM buildings. Semi-permanent uses could include retail spaces with equipment on wheels, allowing a store to evacuate quickly and efficiently before a flood. The spaces for these semi-permanent uses could be wet floodproofed.



PART IV: ADDITIONAL INFORMATION

Photo: Fort Point Channel

Retrofitting Precedents

Darlington, Wisconsin
Historic Downtown

Darlington is bordered on three sides by the Pecatonica River. The river has a history of flooding but a particularly devastating inundation in 1993 led to resilient retrofits in the historic downtown area. Some structures at a high risk for flooding were demolished and the land along the river was turned into a community green space. Other buildings were floodproofed by infilling basements and raising building utilities.

Property owners also raised first floors to the base flood elevation while preserving at least an eight foot ceiling height. They added interior floodwalls to dry floodproof an additional two feet of freeboard. Access to the raised floor was provided in an interior vestibule that separated the building's wet floodproofed entrance from the elevated first floor.

ADA compliant ramps were constructed behind the buildings, allowing for access to several structures and providing an additional floodwall. The wet floodproofed vestibules used flood damage-resistant materials like brick and ceramic tile, and will help equalize hydrostatic pressure during floods. This strategy has allowed Darlington's historic storefronts to remain in place, helping to preserve the area's character.

Twenty-two commercial buildings and fifty-two residential buildings underwent some degree of retrofitting. The project, completed in 2008, cost more than twelve million dollars. The funding and expertise for the work came from various federal, state, and local agencies; including FEMA, the NFIP, and Wisconsin Emergency Management.

Darlington downtown after floodproofing
Photo credit: Phil Risseeuw, 2015
Image courtesy of the City of Darlington

Installation of temporary exterior flood shield
Photo credit: FEMA
Image courtesy of the City of Darlington

Flooding prior to floodproofing, 1993
Image courtesy of the City of Darlington

Combined ADA ramp and flood wall behind buildings in downtown Darlington
Photo credit: Phil Risseeuw, 2015
Image courtesy of the City of Darlington

Steps leading from the interior vestibule to the raised first floor. The walls were designed to accommodate a temporary flood shield at the top of the stairs.
Photo credit: Bev Anderson
Image courtesy of the City of Darlington

Red Hook, Brooklyn

This residential building was damaged during Hurricane Sandy in 2012. After the storm, the homeowners infilled the basement with gravel, elevated utilities, elevated the level of the first floor 2" above the BFE, and installed subgrade flood vents in what used to be the basement access. After applying these retrofits, the homeowners received a discount on their flood insurance.

Utilities were elevated more than six feet above grade

The first floor was elevated 2" above the BFE

Flood vents were installed where the basement access used to be

The basement was infilled with gravel

Photo source: FEMA P-1037, inside cover photo, image courtesy FEMA

Strategies for Future Flooding: Thinking Outside the Box

This report outlines potential strategies for retrofitting buildings for today's 1% annual chance flood. New approaches will be needed by 2050, when Boston could be dealing with 1.5 feet of sea level rise, and by 2070, when sea level rise could reach 3 feet. There will certainly be a need for new approaches by the end of the century, when today's 100-year flood could be as frequent as the twice-daily high tide. Some additional strategies for living with water are listed below. Many of these concepts are applicable at the landscape and infrastructural scale. These ideas are not included as part of FEMA's recommendations and are not eligible for NFIP flood insurance premium reductions.

The 2015 Boston Living With Water competition generated a number of innovative strategies for designing for the rising tide. These ideas included turning streets into canals, developing oyster reefs, and elevating major roads and coastal properties. Participants also proposed turning land along the shoreline into wetlands that could act as public spaces during clement weather and buffer zones during flooding and storm surges. Similar ideas involved creating water retention systems incorporated into the city as blue roofs and public water parks. Several projects also suggested expanding public transport and adopting renewable energy systems that harness wind, wave, and solar energy.

An image from the "Re De Boston" proposal by Architerra, winner of the neighborhood category of the Living With Water design competition. This rendering imagines an active, public waterfront along the Fort Point Channel in South Boston.
Image courtesy of Architerra

There are also a number of inventive resilient design strategies being used internationally. Floating buildings have become a popular design challenge, and architects have developed proposals and prototypes for floating schools, single family homes, and even entire apartment complexes.

Image at top of next page: A floating house designed by Baca Architects in Marlow, Buckinghamshire. The building rests in a fixed foundation similar to a shipping dock. When the site floods, the building rises along four guide posts. This system can accommodate up to about 8 feet of flooding.
Photo ©Oliver Pohlmann, courtesy of Baca Architects

Larger-scale strategies have also been tested. The Dutch government is managing an ongoing project called the Sand Motor, sited along the coast near Ter Heijde. Started in 2011 and projected to last 20 years, the project involves depositing a large amount of sand along the shoreline. The amount of sand and the location were carefully chosen to allow ocean currents to redistribute the material along the coast, creating a large-scale, publicly accessible flood barrier.

An image of the Sand Motor, which stretches along the Dutch coast.
Image courtesy of Rijkswaterstaat

APPENDIX

Photo: Downtown Waterfront

Suggested Resources

Some addition resources that may be of use in understanding flood risk, retrofitting, and NFIP regulations include the reports listed below. This is not intended as an exhaustive list of resilience and retrofitting literature.

A Better City's 2015 report, Enhancing Resilience in Boston: a Guide for Large Buildings and Institutions

Presents a detailed "building resilience toolkit" that describes the benefits and drawbacks of various strategies, equipment, and materials.

Boston Society of Architect's *Building Resilience in Boston*, 2013

A comprehensive collection of best practices for climate change adaptation and retrofitting strategies for existing buildings.

BostonLivingWithWater.org

An online archive of information related to resiliency and the Boston Living With Water design competition.

Enterprise Green Communities' 2015 report, Ready to Respond: Strategies for Multifamily Building Resilience

A thorough comparison of retrofitting strategies and other considerations (for example, building a community's collective resilience) and how they might apply to various multifamily structures. Includes a relative sense of cost and images of real-world case studies.

FEMA's *Homeowner's Guide to Retrofitting*, 2014

A comprehensive explanation of retrofitting options and hazard mitigation.

FEMA's *Reducing Flood Risk to Residential Buildings that Cannot be Elevated*, 2015

A clearly outlined and well illustrated set of strategies for retrofitting buildings that cannot be elevated.

FEMA's *Quick Reference Guide: Comparison of Select NFIP and Building Code Requirements for Special Flood Hazard Areas,* 2012

A quick and easily digestible comparison of standards between the National Flood Insurance Program (NFIP), the American Society of Civil Engineers' Flood Resilient Design and Construction (ASCE 24), and the International Code Series (I-Codes).

New York City Department of City Planning, *Coastal Climate Resiliency: Retrofitting Buildings for Flood Risk*, 2014

A thorough guide to retrofitting buildings in flood-prone areas. This report also applies design guidelines to ten case studies in New York City.

New York City Department of City Planning, *Coastal Climate Resilience: Designing for Flood Risk*, 2013

An explanation of the standards, recommendations, and urban design principles surrounding flood resilient construction.

Acknowledgments

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Photo: Harborwalk in the South Boston Waterfront