American Planning Association
Sustainable Communities Division
Webinar

Award-Winning Sustainability 2020 (Part 1 of 3)

Boston Coastal Flood Resilience Design Guidelines & GeoMicroDistrict Feasibility Study

October 22, 2020
CM | 1.0 (live viewing only)

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2021 Awards Overview

- **Information packet will be posted** on our new website by early November.
- New website will be announced by next week – watch our social media and e-bulletin for updates!

Notice of Award Updates or Clarifications

- More information coming by early November!
- If you would like to be directly notified of any substantial updates, please send an email to the awards coordinator (jenniferk@rhiplaces.com), with the subject line "SCD Award Updates"

Today's Event

Award-Winning Sustainability 2020 (Part 1 of 3)

Boston Coastal Flood Resilience Design Guidelines

- **Matthew Littell** | Principal, Utile
- **Jessy Yang** | Urban Designer, Utile

GeoMicroDistrict Feasibility Study

- **Richa Yadav** | Engineer and Sustainability Consultant
- **Audrey Schulman** | HEET Co-founder and Co-Executive Director

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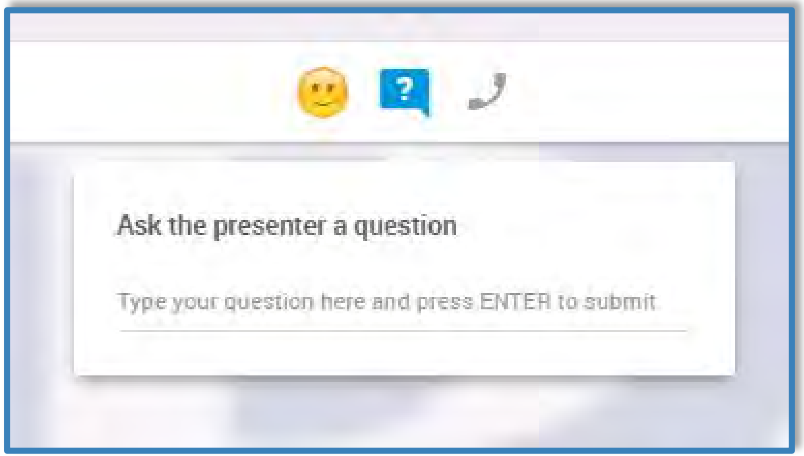
Submit Questions throughout the Session!

- We'll have a Q&A at the end of the webinar, but please feel free to send your questions any time!
- You can use the chat box or the Q&A tool



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Coastal Flood Resilience Design Guidelines

City of Boston

APA SCD Award Webinar, Oct 22, 2020

boston planning & development agency

Boston Climate Action

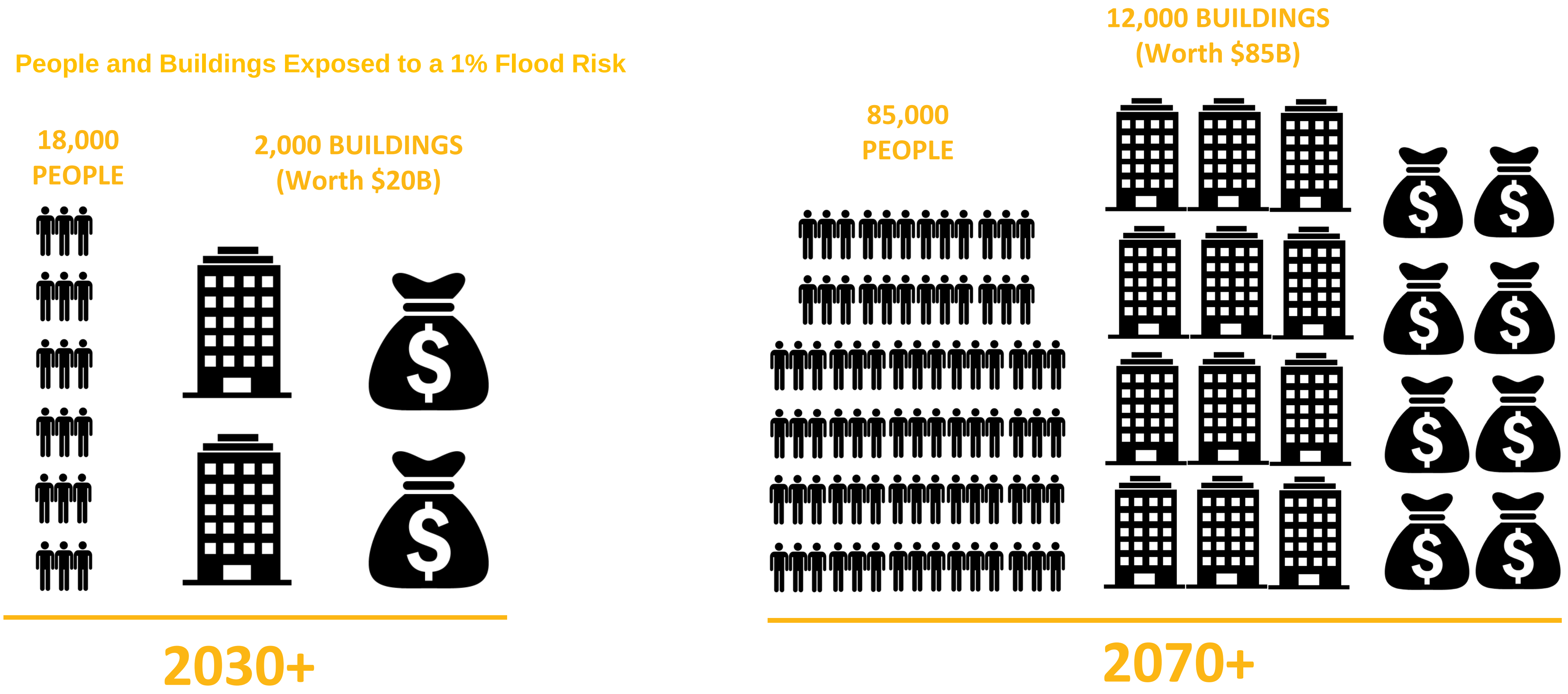
Imagine Boston 2030

Carbon Free Boston

Climate Ready Boston

- Neighborhood Coastal Resilience Plans
- Resilient Boston Harbor
- *Flood Resiliency Zoning Overlay + Resiliency Design Guidelines*

Current and Future Threats



Data source: Climate Ready Boston

Climate Resilience Initiatives

UPDATED CLIMATE PROJECTIONS

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

PREPARED AND CONNECTED COMMUNITIES

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

RESILIENT INFRASTRUCTURE

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

ADAPTED BUILDINGS

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

PROTECTED SHORES

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

Source: Climate Ready Boston

Layered Protections

Climate Ready Charlestown:
Long-term flood protection systems for the Sullivan Square waterfront

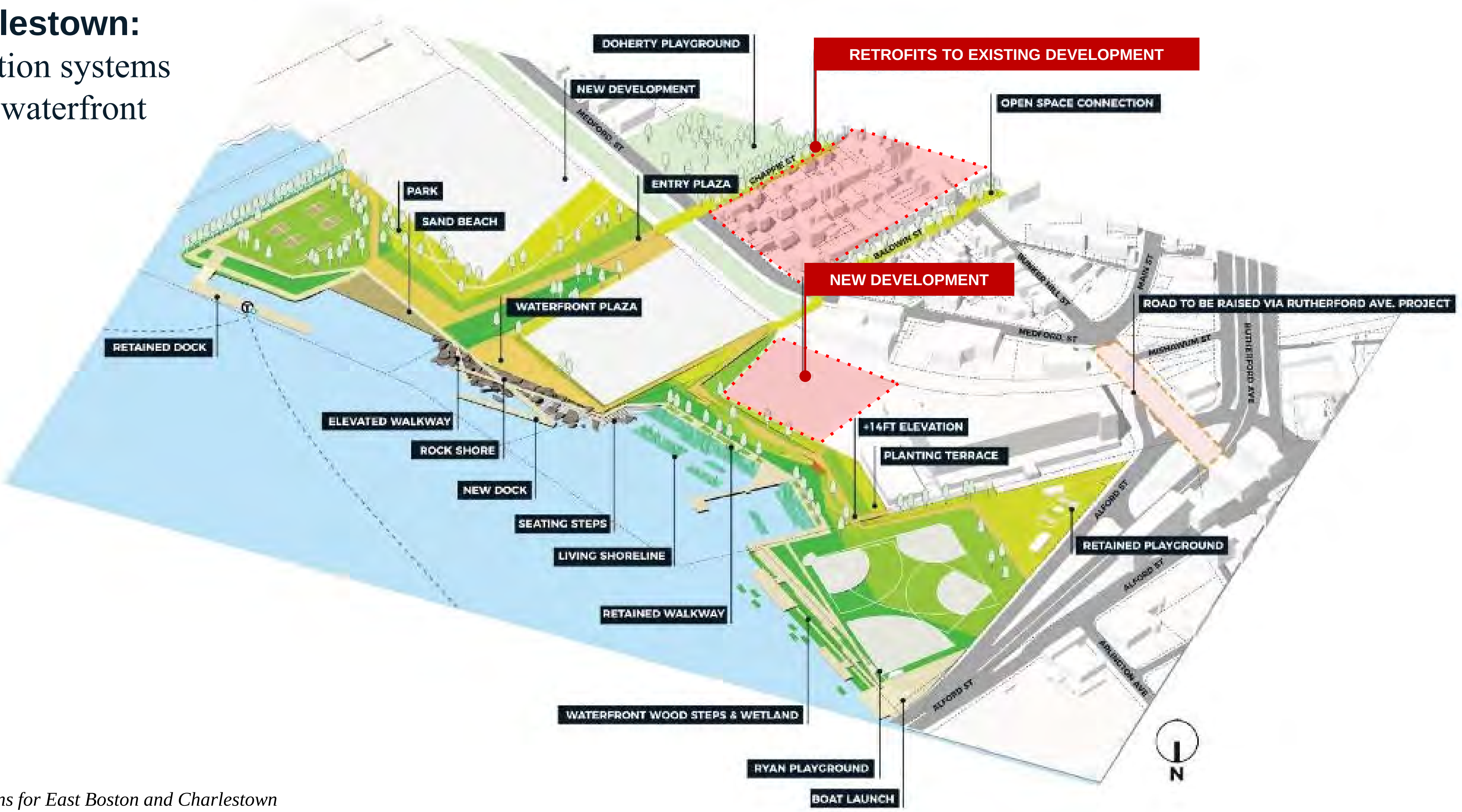


Image Source: Coastal Resilience Solutions for East Boston and Charlestown

Applicability

Existing Buildings **&** **New Construction**

Process

Advisory + Outreach

- *City progress presentations*
- *Advisory Groups / Focus Groups*
- *Community Forums and Consensus Building*

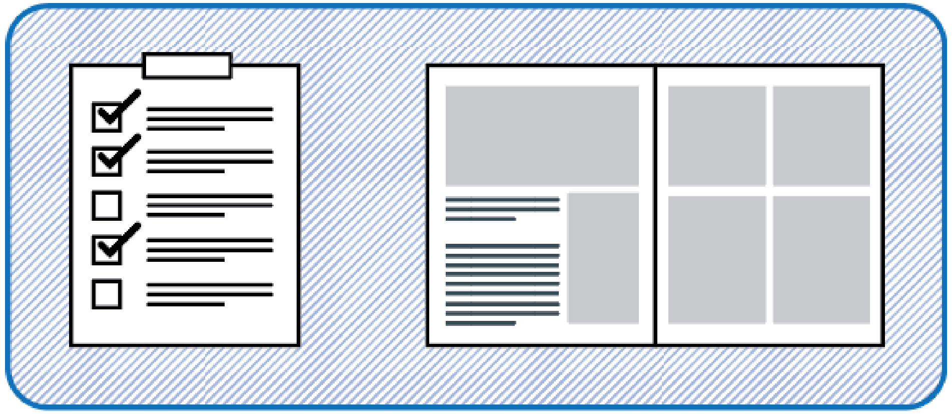
Zoning Research + Recommendations

- *Precedents: National and Regional*
- *Research potential conflicts*
- *Relationships w/ Art. 80 Design Rev.*

Design Guidelines Development

- *Research resiliency best practices (FEMA, local, national)*
- *Identify primary building typologies*
- *Develop illustrative case studies for new construction and retrofits*

Design Guidelines + Review Checklist



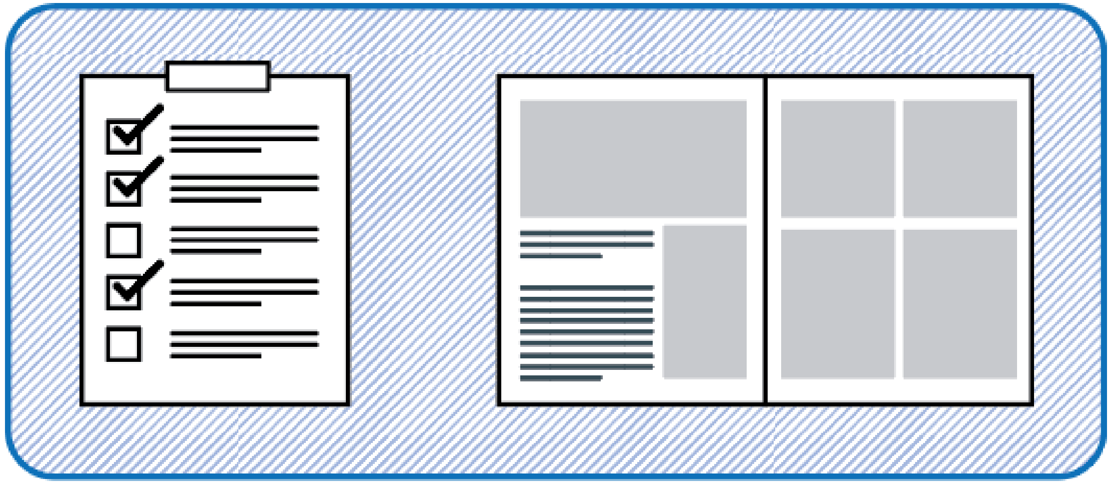
Zoning

Project Scope

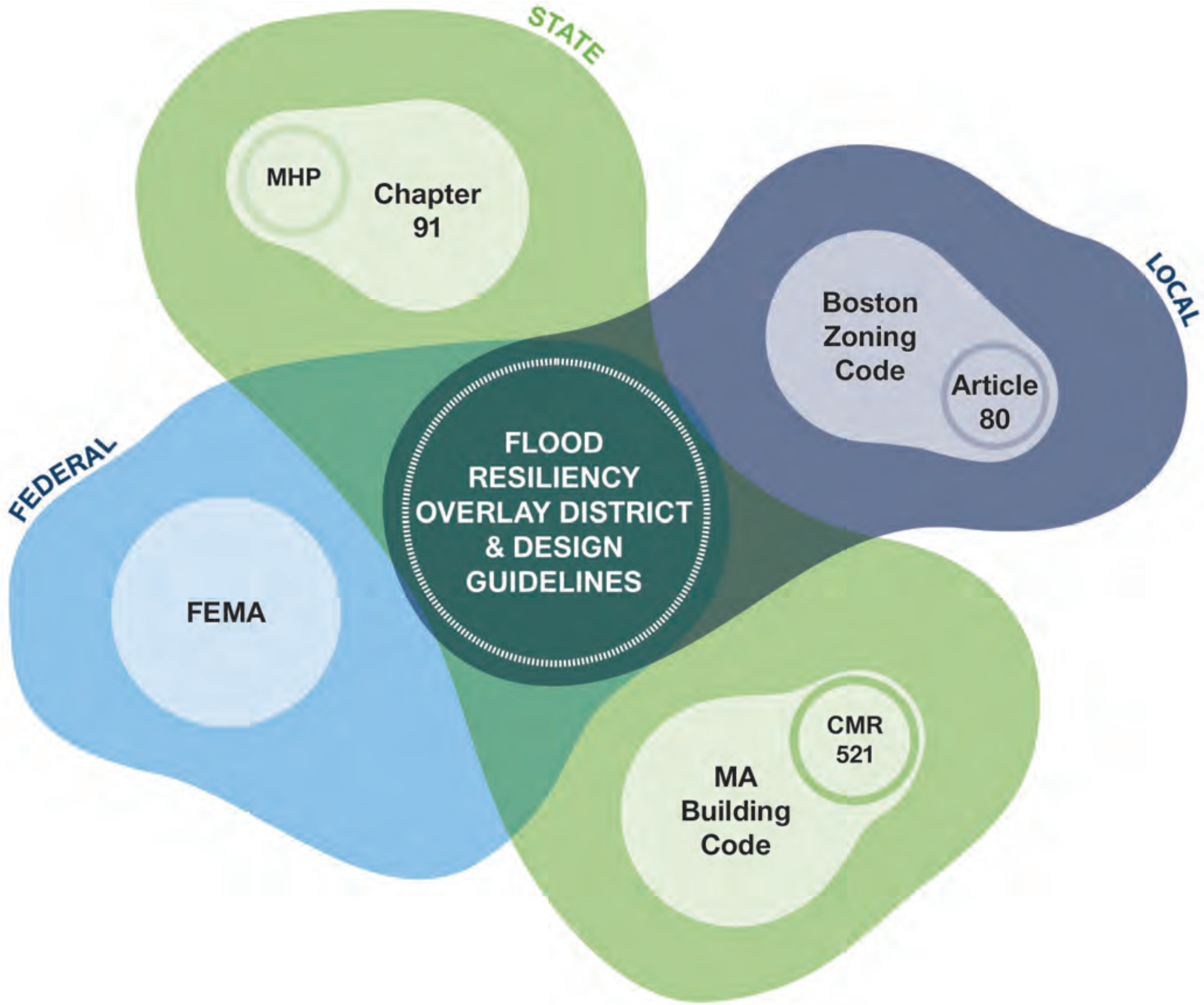
Zoning Recommendations

+

Design Guidelines + Review Checklist

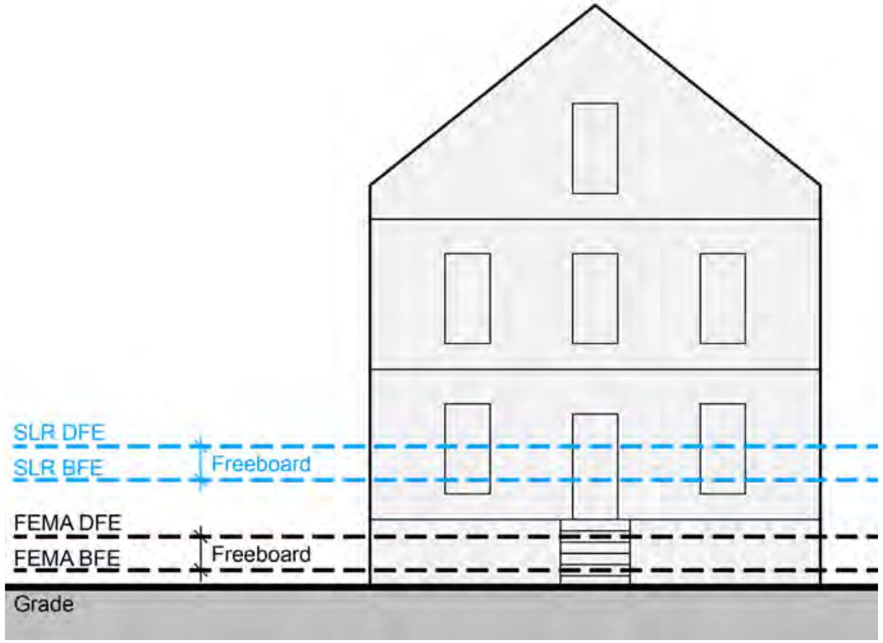


Regulatory Context



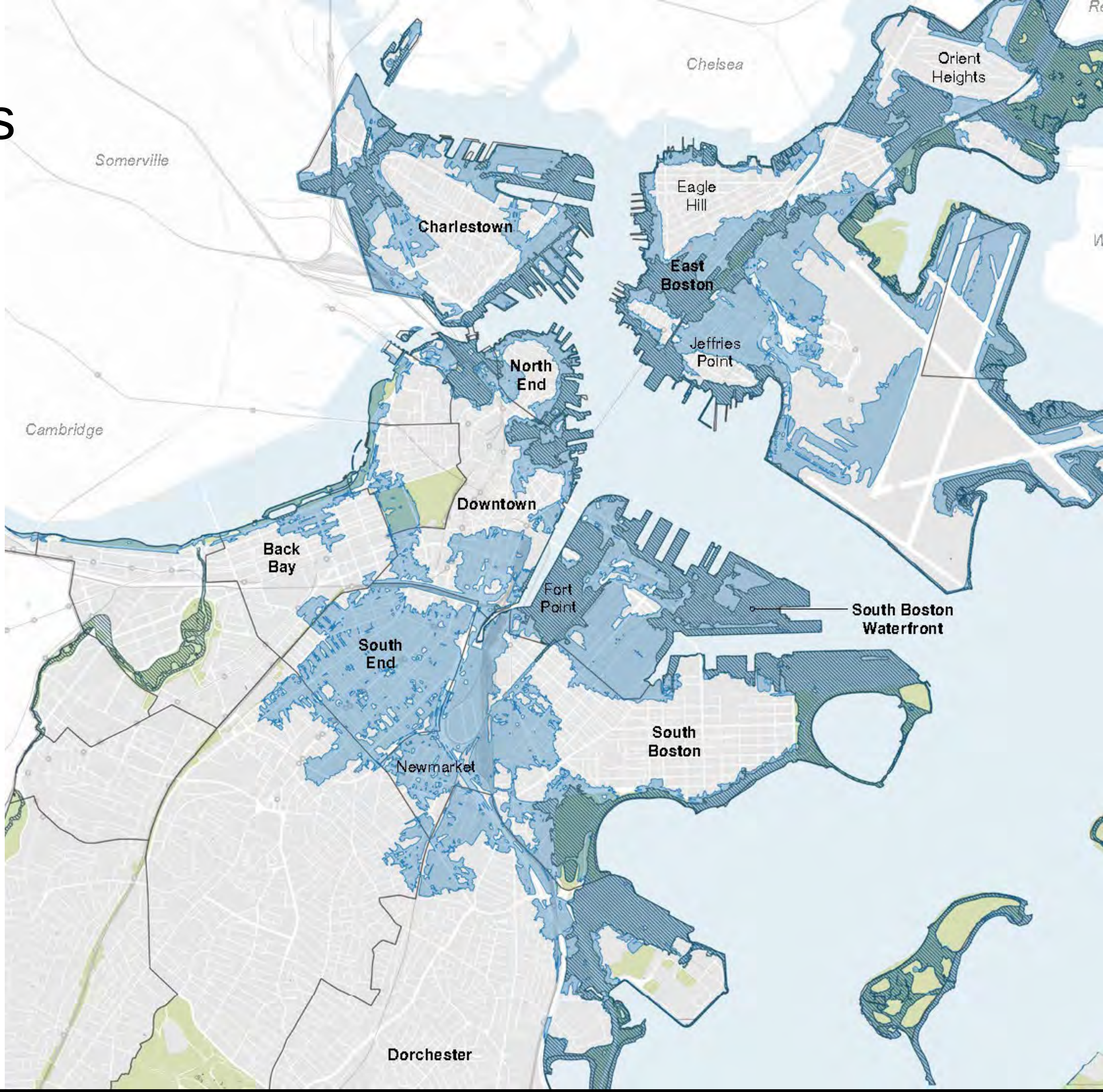
1% Annual Chance Flood - 2070s

Assumes 40” of Sea Level Rise

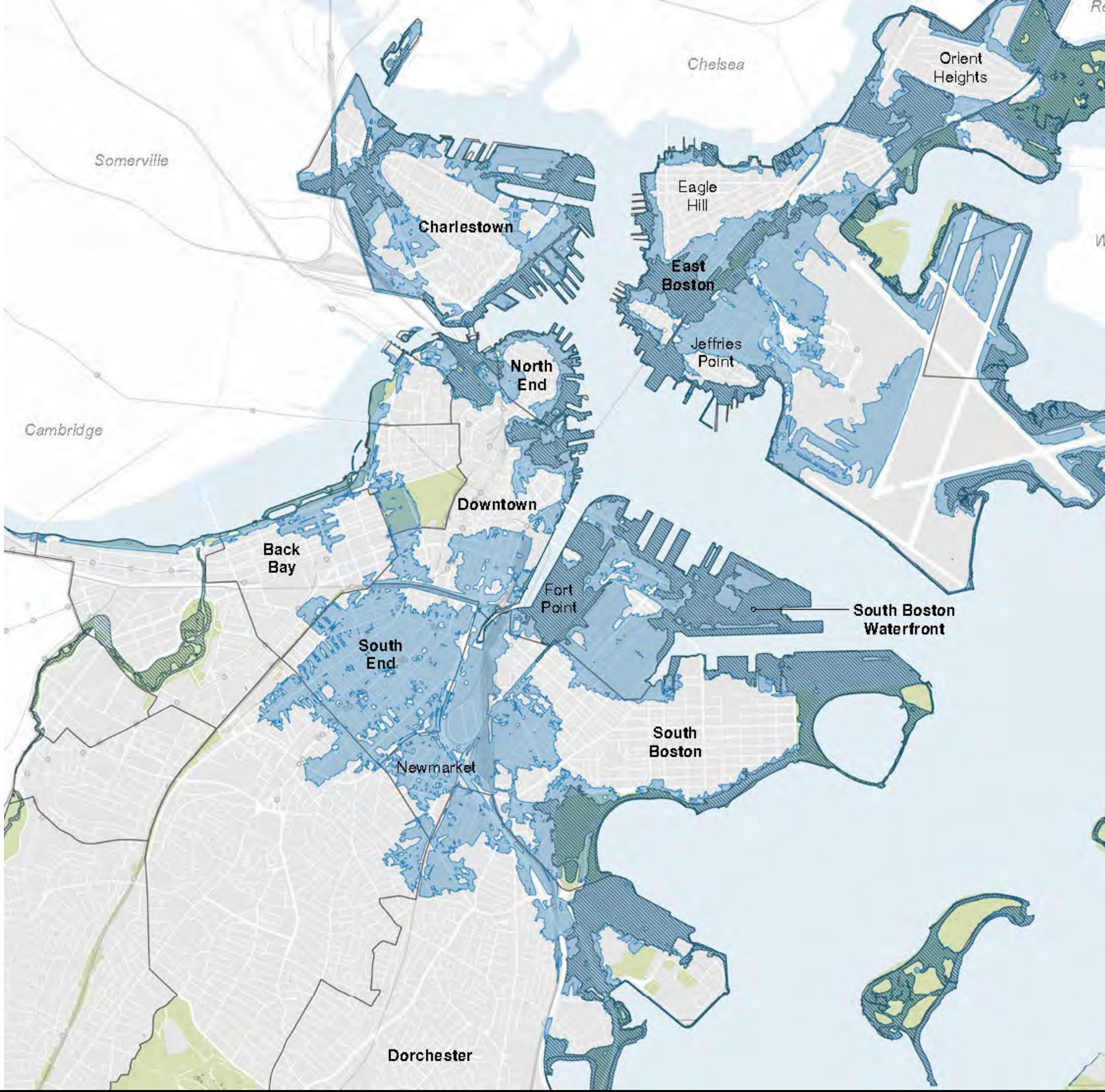


Current Flood Risks (Zoning Article 25)
Areas with a 1% annual chance of flooding

Future Flood Risks (Coastal Flood Resilience Zoning Overlay District)
Areas with a projected 1% annual chance of flooding in the year 2070 with 40 inches of sea level rise



Source: Climate Ready Boston



Zoning: Use and Dimensional Regulations

Zoning | *Policies implemented outside of zoning*

Minimum

Revised Definitions

Modify definitions of height and floor area to allow conformity with guidelines

+

"Hold Harmless"

Modify by-right requirements and allow reuse of lost FAR for non-conforming structures

++

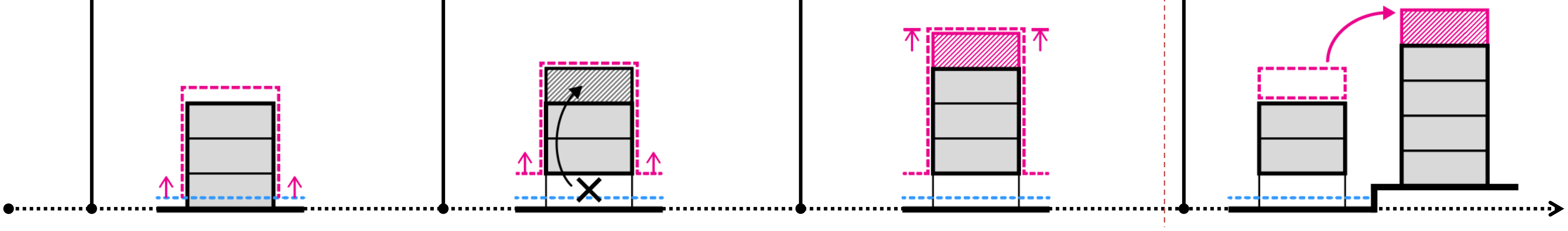
Dimensional Incentives

Provide additional height and density bonuses that exceed by-right standards to preserve building value

+++

Additional Incentives?

Tax incentives or transfer of development rights in lieu of additional on-site density



Revised definitions:

- Height
- Gross Floor Area

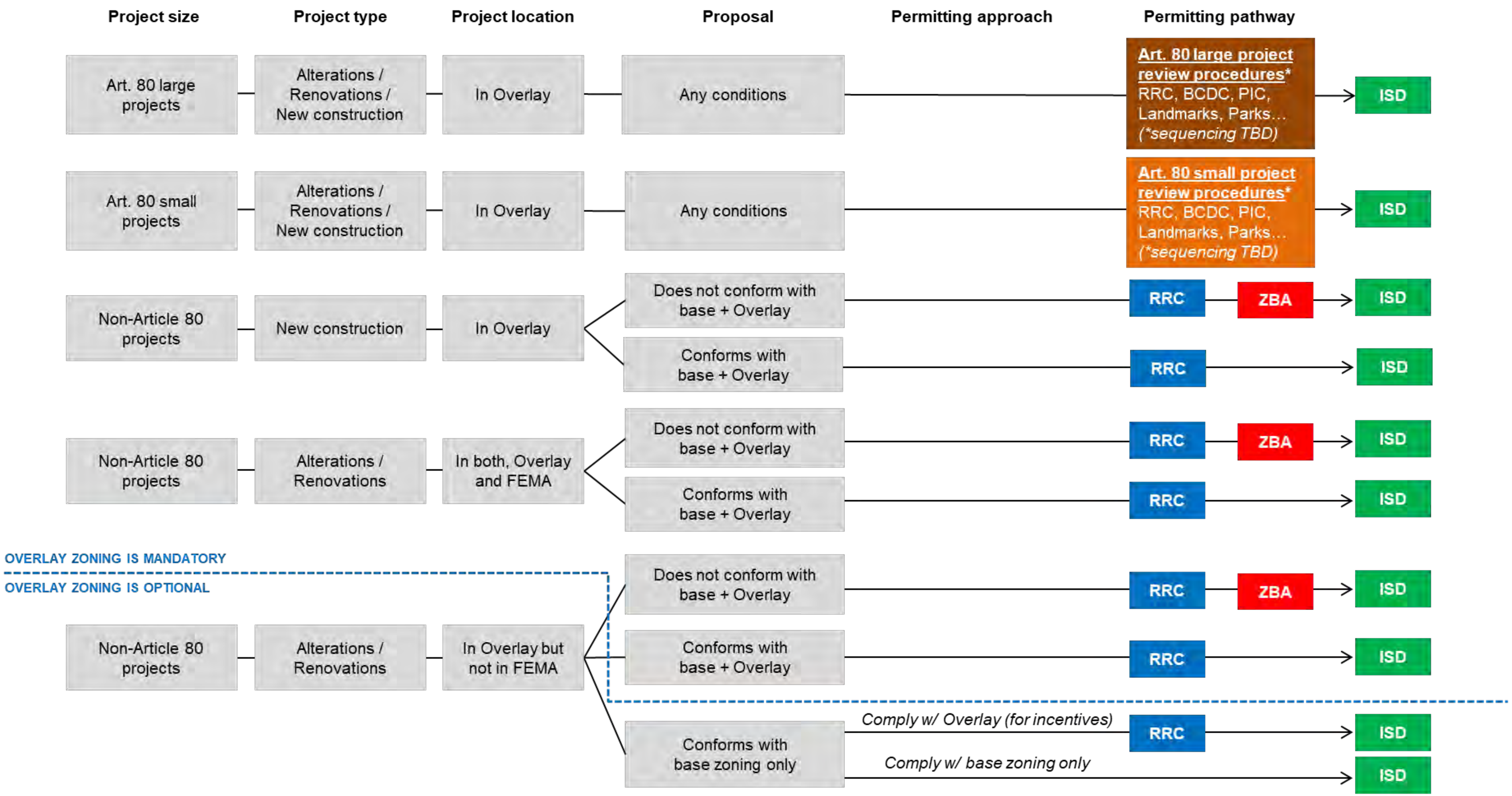
Uses below SLR- DFE:

☑ Parking, Access, Storage
☑ Non-residential (Conditional)
☒ Residential

Potential incentives:

- Parking relief
- Rooftop addition
- Redefining setbacks
- Redefining height from first occupiable story
- Additional FAR

Permitting Pathway Considerations



Resilient Design Principles

Promote Resiliency Best Practices

Proposed designs / renovations should incorporate best practices and standards to reduce or eliminate coastal flood risk or damage resulting from future climate conditions.

Enhance the Public Realm

Resilient measures should support pedestrian connections and, where feasible, enhance the character and pedestrian environment of the Overlay parcels.

Generate Co-benefits

Wherever feasible, proposed flood resiliency upgrades should also enhance a building's energy efficiency, greenhouse gas reduction potential, and passive survivability.

Relate to District Scale Solutions

Enhancements at a plot level, to the extent feasible, should support the resiliency goals and implementation of district coastal resilience plans.

Wet Floodproofing

Wet floodproofing is an adaptation measure that allows flood waters to enter and exit portions of a building not used as living space such as crawl spaces, walk-out basements, or floodable ground floors.

Flood openings are important to allow water to enter and exit the structure and rise and fall at the same rate inside and outside of the building. Therefore, wet floodproofing requires proper planning for the quantity, type, and location of flood openings.

This strategy avoids structural damage by equalizing hydrostatic pressure on walls, as well as damage from buoyancy or uplift forces. In addition to providing openings that allow the entry of flood waters, wet floodproofing requires the use of flood-resistant materials below the flood elevation, the protection of service equipment from flood damage, and the relocation of high value contents. Examples of engineered flood openings include grilles, vents, and hinged panels that automatically open in both directions to allow water to pass.

Top photo: Continuing Education Center / Photo by Smart Vent Products, Inc.
Bottom photo: FEMA. 2013. Floodproofing Non-Residential Buildings.

Applicability

Project Scale	Non-Art. 80 renovations and new construction, Art. 80 renovations and new construction
Building Type	Non-residential spaces within typologies such as the triple decker, townhouse, new mixed use, and general industrial

Cost and Insurance Considerations

$ | **$$** | **$$$** | $$$$

- Wet floodproofing is generally less expensive than dry floodproofing. Additional cost considerations should also include expenses for related measures such as building elevation, providing access to elevated areas, installation of flood-resistant materials, rearrangement of utility systems, and post-flood cleaning to control exposure to pollutants and prevent mold growth.
- Wet floodproofing of structures insured under the NFIP in A Zones may be eligible for flood insurance premium reductions.

Public Realm Considerations

- If combined with providing interior circulation to a raised interior floor, a wet floodproofed lobby or access area can maintain an at-grade connection between sidewalk and building entry.
- Alterations on the facades of buildings in historic districts will need to be reviewed by Landmarks Commission.

Additional Resources

- FEMA P-312, Homeowner's Guide to Retrofitting
- Enterprise Community Partners, Inc., Ready to Respond: Strategies for Multifamily Building Resilience
- FEMA Technical Bulletin 1, Openings in Foundation Walls and Walls of Enclosures
- FEMA Hurricane Sandy Fact Sheet 1, Cleaning Flooded Buildings

Technical Considerations

Materials

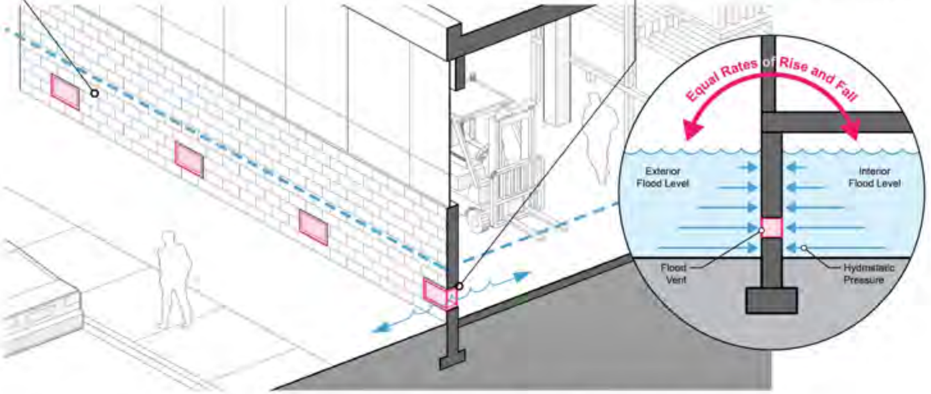
Use flood-damage-resistant materials in wet floodproofed enclosures, such as concrete, stone, masonry block, ceramic and clay tile, pressure-treated lumber, epoxy-based paints, and metal. These materials may require additional treatment to protect against damage from repeated saltwater inundation. Avoid paper-faced gypsum wall board and non-treated wood. (See "Flood-damage Resistant Materials" on p48 for details.)

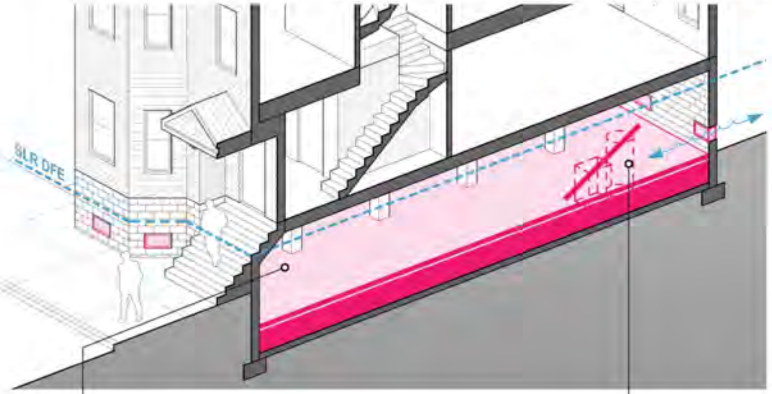
Water from flooding may carry contaminants so post-flooding health risks should be mitigated by contracting certified clean-up professionals. Hazardous household materials should not be stored in wet floodproofed spaces. After flooding, objects and materials that have been exposed to water should be cleaned and dried or disposed of following guidelines from local officials. Affected areas should be allowed to adequately dry with 24 hours to prevent mold growth.

Openings

Per FEMA standards for non-engineered openings, at least two wall openings (one in two different walls) below the base flood elevation in each enclosed area should be provided, at a location of no more than 1' above grade. One square inch of opening for every square foot of enclosed floor area should be provided.

Openings should be carefully maintained to ensure they are not clogged with debris and can be opened if movable parts are part of the system.





Spaces below the DFE

When wet floodproofing a retrofitted building, sub-grade spaces should be filled to the nearest adjacent grade to allow water to drain out of the structure slowly by gravity. Pumping can cause serious structural damage if surrounding soils are still saturated and is not recommended. Spaces below the SLR-DFE are non-habitable and use is limited to storage, parking, and access.

Utilities

Any utility or service equipment such as ductwork, heaters, and electrical lines should be removed from a wet floodproofed space and relocated above the design flood elevation.

Dry Floodproofing

Dry floodproofing is a category of treatments aimed at inhibiting water from entering a structure. This technique is appropriate for low flood elevations and structures that can withstand hydrostatic and hydrodynamic loads imposed by flooding.

Dry floodproofing should be thought of as a system of multiple components working together, including:

- Watertight enclosures for openings, doors, windows, and floors, including shields and barriers, often requiring human intervention prior to a storm event; types of flood shields include sliding, lift-out, modular panel, bolt-on, hinged, and automatic
- Membranes and sealants to reduce seepage of floodwater through walls and utility conduits
- Structural reinforcement to wall assemblies so that they can resist hydrostatic pressure, flotation, or collapse
- Pumping and drainage systems with backup power to control water intrusion
- Backflow or check valves to prevent the entrance of water or waste through plumbing systems
- Flood doors and egress requirements

Cost and Insurance Considerations

$ | $$ | **$$$** | **$$$$**

- Dry floodproofing is generally more expensive than wet floodproofing for new construction. Cost increases for larger structures and for higher design flood elevations. Consider storage requirements and operational elements (time and cost) required to assemble any deployable features.
- For residential buildings, dry floodproofing does not result in NFIP premium rate reductions and is not allowed by the State Building Code for residential spaces below the FEMA BFE plus two feet of freeboard.

Flood panels connected to removable posts.
Photo: Flood Panels LLC

Applicability

Project Scale	Non-Art. 80 renovations, Art. 80 renovations and new construction
Building Type	Non-residential spaces within pre-war mixed use, new mixed use, contemporary commercial

Public Realm Considerations

- Dry floodproofing can allow for active uses such as retail to remain on the ground floor of a building.
- Proponents using dry floodproofing should carefully study how to best integrate any permanent elements such as the mounting and brackets for shields and barriers.
- Buildings in historic and landmarks districts must have hardware reviewed by Landmarks Commission.

Additional Resources

- FEMA P-936, Floodproofing Non-Residential Buildings
- FEMA P-1037, Reducing Flood Risk to Residential Buildings That Cannot Be Elevated
- Boston Public Works Department, Climate Resilient Design Standards & Guidelines For Protection Of Public Rights-Of-Way
- A Better City Report, Enhancing Resilience in Boston: A Guide for Large Buildings and Institutions

Temporary, portable, and deployable flood barriers
Photo: Aquafence

Technical Considerations

Suitability

Dry floodproofing is not allowed to protect residential buildings, except for parts of a building that are used for access, parking, or storage. For all other uses, if utilizing a temporary flood barrier system, consider setting the barriers back to allow for an area of assisted rescue per state building code requirements, as well as a movable code-compliant stair, handrails, and landing. Any temporary barrier or means of egress should not encroach into the public right of way without coordination with the City of Boston (see BPWD Section 7 page 72.)

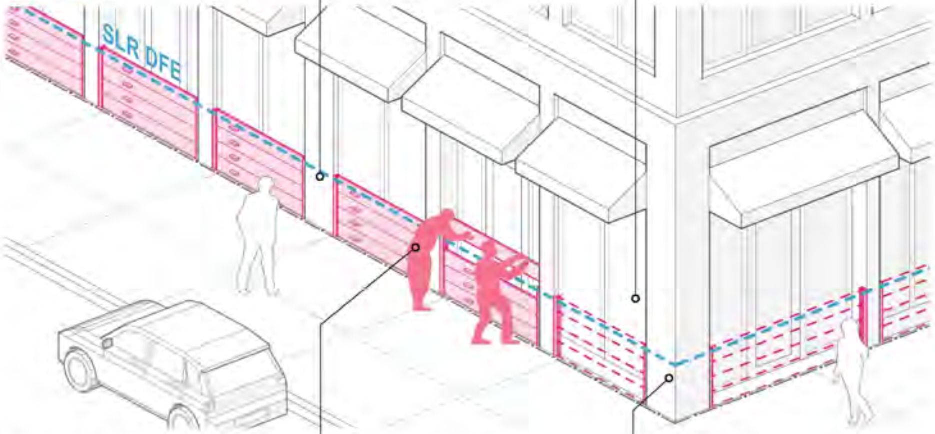
Flooding Depth

Dry floodproofing is most practical where flood depths do not exceed 3' and when flood velocities and durations are low.

Per FEMA standards, dry floodproofing is not allowed in special flood hazard areas with high velocity wave-action (V-zones, Coastal A-Zones) because it does not protect against wave action, erosion, scour, and may make the building subject to greater risk of structural failure.

Means of Egress

Flood barriers cannot block an accessible means of egress. Per ASCE 24-14, a dry floodproofed building must have at least one door satisfying building code egress requirements for an emergency escape above the applicable flood elevation.



Sealants and Interior Drainage

Waterproofing and sealants can be applied either to the exterior or interior side of walls and floors (as shown below) to make them impermeable.

Water may still seep through small openings in a dry floodproofed building. Therefore, a dry floodproofed building requires a drainage system utilizing sump pumps with backup power to remove any leaked water.

Human Intervention

Dry floodproofing often requires human intervention for storage, maintenance, and implementation of shields and barriers, along with training of building owners or facilities personnel to properly deploy and maintain these systems. These dry floodproofing systems should be incorporated into a building's emergency operations plan.

Structural Integrity

Engineering must be performed to ensure the structure can withstand hydrostatic pressure by flood waters and saturated soils. This includes reinforcing above-grade walls and foundations to withstand these flood pressures. Because of the flood pressures imposed by water and saturated soils, dry floodproofing is most appropriate for concrete and load-bearing masonry structures without basements.

Interior waterproofing and structural reinforcing
Source: FEMA. 2013. Floodproofing Non-Residential Buildings.

Drop-in flood shields inserted into brackets
Photo: Flood Panels LLC

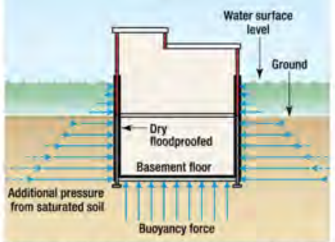


Diagram showing various hydrostatic forces on building
Source: FEMA. 2013. Floodproofing Non-Residential Buildings.

Elevate on Open Foundation

In this flood resilient strategy, a building is elevated on piles, piers, or posts with open foundations so that its first occupiable floor is at or above the SLR-DFE.

In areas subject to wave action, this strategy protects a building from high and moderate-height waves which would otherwise erode fill material placed below a structure or cause structural damage to solid foundation walls.

Applicability

Project Scale	Non-Art. 80 renovations and new construction
Building Type	Detached 1–2 family
Locations	Required in FEMA V Zones, recommended in FEMA Coastal A Zones (see Section 1 for explanation about relationship of FEMA zones within the Overlay)

Elevated home in the Arverne neighborhood of Queens, New York.
Photo source: NYC Housing Recovery Operations

Cost and Insurance Considerations

$ | $$ | **$$$** | **$$$$**

- Elevation of structures insured under the NFIP may be eligible for FEMA Hazard Mitigation Assistance grants and flood insurance premium reductions.
- The design of enclosures below the lowest floor will affect insurance rates. All else being equal, the lowest rates are available for buildings rated as "free of obstruction," which have no enclosure below the lowest floor other than insect screening or open wood latticework (i.e., at least 50% of the lattice construction is open, such as shown in photo).

Public Realm Considerations

- Access from grade to the lowest floor should be carefully considered for design integration into both the building and the public realm. The sidewalk-facing side of an open foundation level should incorporate streetscape mitigation measures (screening, plantings, front porch, etc.).

Sustainability Co-benefits

- When elevating a building on an open foundation, ensure that adequate under-floor insulation is provided to prevent heat loss.

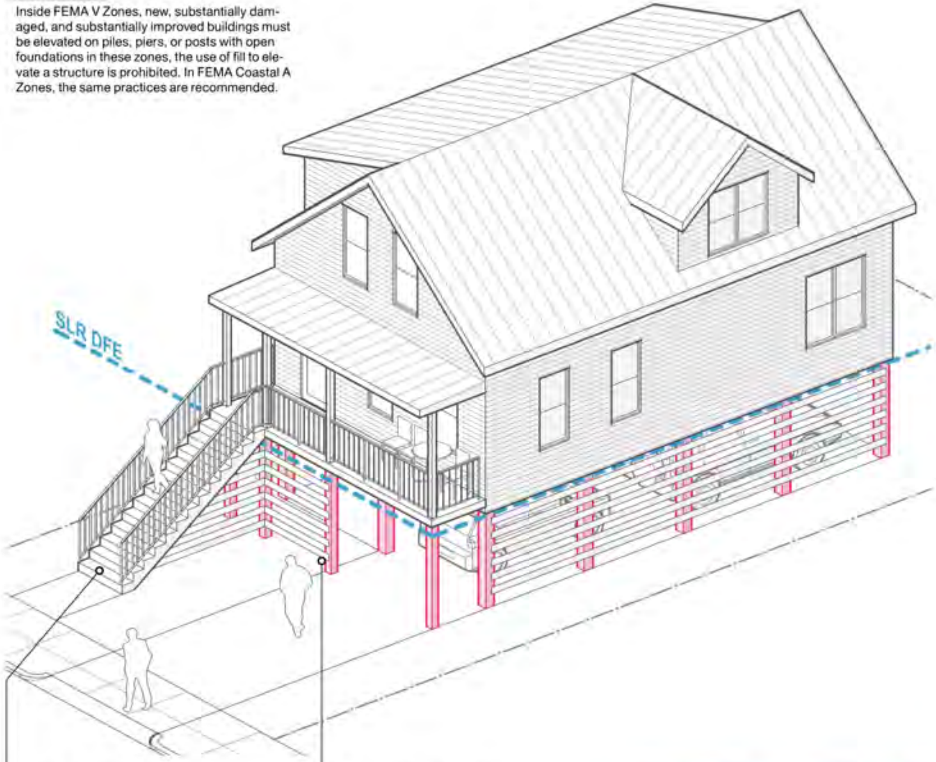
Additional Resources

- FEMA P-312, Homeowner's Guide to Retrofitting
- FEMA P-55, Coastal Construction Manual
- FEMA Technical Bulletin 5, Free-of-Obstruction Requirements
- FEMA Hurricane Sandy Recovery Fact Sheet No. 2, Foundation Requirements and Recommendations for Elevated Homes
- A Better City Report, Enhancing Resilience in Boston: A Guide for Large Buildings and Institutions

Technical Considerations

Suitability

Inside FEMA V Zones, new, substantially damaged, and substantially improved buildings must be elevated on piles, piers, or posts with open foundations in these zones, the use of fill to elevate a structure is prohibited. In FEMA Coastal A Zones, the same practices are recommended.



Stairs, Decks, Porches

Appurtenant structures (e.g., stairs, decks, porches) must be designed either to structurally resist design flood loads or break-away without damaging the building or its foundation. Decks and porches must be designed to allow flooding to pass through them, so as to not adversely affect adjacent or nearby structures by diverting harmful floodwaters and waves.

Materials

Building materials below the DFE should be resistant to water damage.

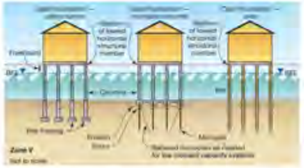
Structural stability

Elevated open pile, pier, or post foundations must be designed to structurally resist site-specific design flood loads, be geotechnically stable, and be protected from scour and erosion. The diagram below illustrates NFIP-compliant foundations.

Below-grade Enclosures

Existing below-grade enclosures (basements, crawlspaces, etc.) should be filled to match the adjacent grade. The fill must be compacted and designed to resist scour and erosion.

Enclosures below the lowest floor should be designed either to be free of obstruction or with breakaway walls and flood openings.



Examples of NFIP-compliant foundations: piers / columns on pier footings, columns on micropiles, and piles.

Source: FEMA. May 2013. Foundation Requirements and Recommendations for Elevated Homes.

Elevate on Solid Foundation Walls and Filled Subgrade Space

In areas not subject to wave action, a building may be elevated by raising the lowest occupiable floor on solid foundation walls to meet the SLR-DFE.

When retrofitting an existing building using this strategy, existing solid foundation walls should be extended to meet the newly-elevated lowest floor. Existing foundations and footings may need to be modified or reinforced to ensure structural stability. See the complementary strategy, Wet Floodproofing, for additional information on protecting the structure.

Applicability

Project Scale	Non-Art. 80 renovations
Building Type	1–2 family detached, triple decker
Locations	Elevation on solid foundation walls is prohibited in FEMA V Zones and not recommended in Coastal A Zones, seaward of the LiMWA.

Cost and Insurance Considerations

$ | $$ | **$$$** | **$$$$**

- Elevation of structures insured under the NFIP may be eligible for FEMA Hazard Mitigation Assistance grants and flood insurance premium reductions.

Public Realm Considerations

- The sidewalk-facing side of an elevated solid foundation wall should incorporate streetscape mitigation measures (plantings, contextual materials, lighting, color, art, see p42 for more details.)

Additional Resources

- FEMA P-312, Homeowner's Guide to Retrofitting
- FEMA Hurricane Sandy Recovery Fact Sheet No. 2, Foundation Requirements and Recommendations for Elevated Homes

House in Meyerland, Houston before elevating.

Construction photo showing house elevating on extended foundations. Spaces below SLR-DFE are not habitable.

House after elevating. Note that the condenser is also elevated at left. Flood vents are not pictured.

Offcite / "Mid-Century Elevated: How an Architecturally Significant House Was Lifted Above the Floodplain" / All photos by Raj Mankad

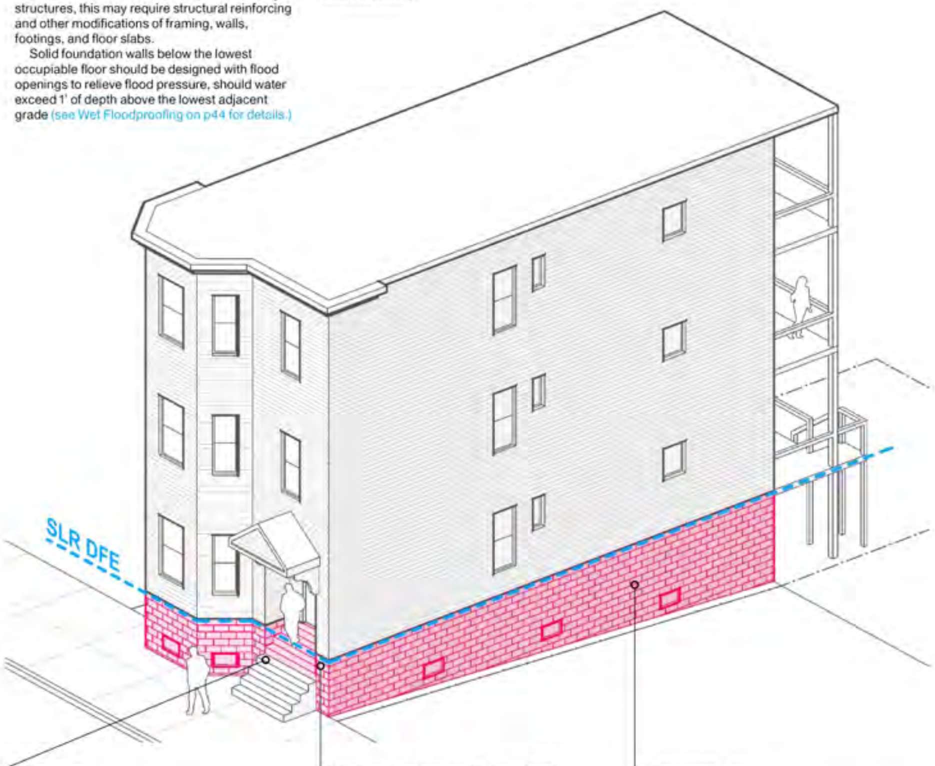
Technical Considerations

Foundations

Elevated solid wall foundations must be designed to structurally resist site-specific design flood loads, be geotechnically stable, and be protected from scour and erosion. For retrofits of existing structures, this may require structural reinforcing and other modifications of framing, walls, footings, and floor slabs.

Solid foundation walls below the lowest occupiable floor should be designed with flood openings to relieve flood pressure, should water exceed 1' of depth above the lowest adjacent grade (see Wet Floodproofing on p44 for details.)

Scour and erosion depths and the need for structural fill should be considered to ensure that the foundation will not be undermined in design flood conditions.



Access

Access from grade to the lowest floor should be carefully considered for design integration into both the building and the public realm. The modification of building access and height may trigger building, accessibility, and other applicable code requirements, and therefore should be coordinated.

Stairs, Decks, and Porches

Appurtenant structures (e.g., stairs, decks, porches) must be designed either to structurally resist design flood loads or break away without damaging the building or its foundation.

Decks and porches must be designed to allow flooding to pass through them, so as to not adversely affect adjacent or nearby structures by diverting harmful floodwaters and waves.

Basements

Existing below-grade enclosures (basements, crawlspaces, etc.) should be filled to match the lowest adjacent grade. The fill must be compacted and designed to resist scour and erosion.

Materials that can be used for fill include compacted soil, crushed stone encased with a concrete slab, and controlled low strength material ("flowable fill"). Consult with a contractor or engineer to determine the most suitable material depending on project requirements.

Building materials below the DFE should be resistant to water damage. (see p48 for details)

Elevate on Fill

Elevate the lowest occupiable floor of a new building on structural fill to meet the design flood elevation (DFE).

Applicability

Project Scale	Non-Art. 80 and Art 80 new construction
Building Type	All new construction
Locations	Elevation on fill is prohibited in FEMA V Zones and not recommended in Coastal A Zones, seaward of the LiMWA.

Sunset Park Material Recovery Facility, Brooklyn, New York. *Photo by Field Condition / "SIMS Sunset Park Material Recovery Facility"*

Cost and Insurance Considerations

$ | $$ | $$$ | $$$$

- Elevation of structures insured under the NFIP may be eligible for FEMA Hazard Mitigation Assistance grants and flood insurance premium reductions.
- Within areas subject to Article 25 and FEMA FIRM's, a building elevated on fill that exceeds the FEMA BFE may be eligible for a Letter of Map Revision based on fill (LOMR-F), which, if approved by FEMA, would eliminate the NFIP requirement for the building to comply with flood resistance standards and to carry flood insurance. However, the elimination of these requirements does not mean the building is not at risk of flooding.

Public Realm Considerations

- Elevation of a building on fill should try to create a positive co-benefit of creating or preserving open space in the form of fill slope with vegetation and other public amenities.
- On the waterfront, elevating a site on structural fill is encouraged where doing so will also serve to prevent flooding from crossing through the site from the waterfront to other properties or public rights-of-way landward of the site. In so doing, elevation of an entire waterfront site, as opposed to just the portion of a site immediately surrounding a building, can support the incremental implementation of district-scale coastal flood protection.

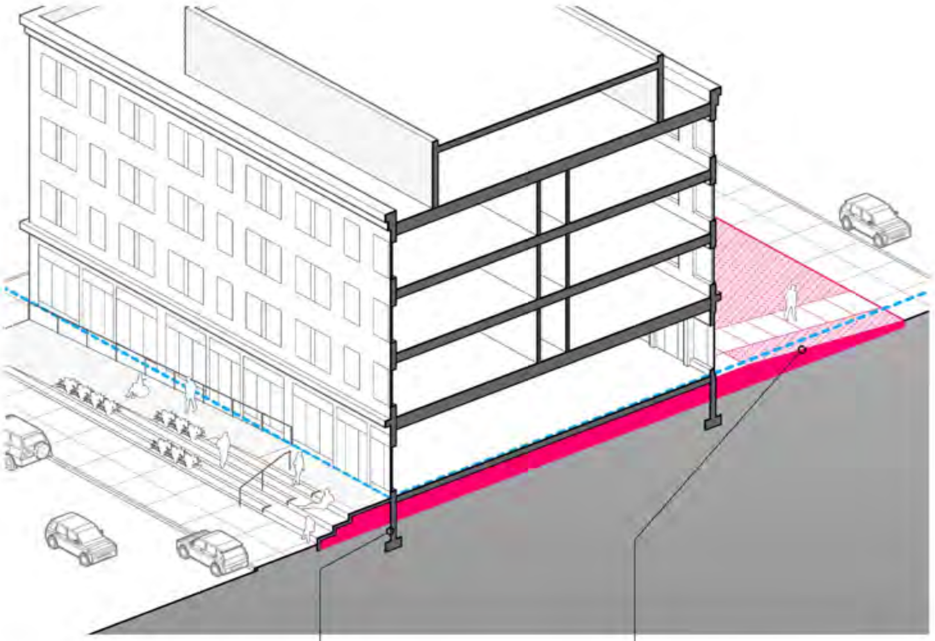
Sustainability Co-benefits

- For large sites, this strategy has the potential to incorporate landscape features into existing or new ground space areas that can provide resilience for additional climate risks such as extreme precipitation and rising temperatures.

Additional Resources

- NYC Planning, Urban Waterfront Adaptive Strategies
- FEMA Hurricane Sandy Recovery Fact Sheet No. 2, Foundation Requirements and Recommendations for Elevated Homes
- A Better City Report, Enhancing Resilience in Boston: A Guide for Large Buildings and Institutions

Technical Considerations



Structural stability

Buildings and sites elevated on fill must be designed to structurally resist site-specific design flood loads, be geotechnically stable, and be protected from scour and erosion.

Foundations

Solid foundation walls below the lowest occupiable floor should be designed with flood openings to relieve flood pressure, should water exceed 1' of depth above the lowest adjacent grade.

Sloping to Adjacent Grade

Fill may be graded to slope up from adjacent ground level or be held in place by retaining structures. The toe and surface of fill slopes must be protected from erosion and scour under design flood conditions, and maximum fill slopes must not be exceeded.

Fill must be designed so as not to adversely affect nearby structures by diverting harmful floodwaters and waves or increasing flow velocity.

Use Restrictions

Use of this strategy should not result in habitable spaces below the SLR-DFE, such as basement units.

Materials

Building materials below the SLR-DFE should be resistant to water damage.

Elevate Lowest Interior Floor with Exterior Circulation to DFE

Circulation to reach the elevated first floor level is provided outside the building through exterior walkways, ramps, or stairs. Design measures like planted areas, seating, lighting, and contextually appropriate materials are used to contribute to visual interest, break up the scale of larger surfaces, and add to neighborhood character.

To avoid disrupting visual connectivity and interest along the streetscape, designers should carefully consider the public realm when elevating a building's first floor above the SLR-DFE for flood protection.

Applicability

Project Scale	Non-Art. 80 renovations, Art. 80 renovations and new construction
Building Type	Triple decker, Townhouse, pre-war mixed use, contemporary mixed use
Location	Buildings outside of FEMA AE zones

Cost and Insurance Considerations

$ | $$ | **$$$** | **$$$$**

- For projects within Article 25 (FEMA zone), the elevation of structures insured under the NFIP may be eligible for FEMA Hazard Mitigation Assistance grants and flood insurance premium reductions.

Public Realm Considerations

- This strategy can enhance the public realm if designed to add visual interest and to incorporate additional amenities such as landscape and seating.
- The design of exterior circulation elements should pay careful attention to universal design and accessibility. For example, ramps should be designed to be appealing to all users.

Additional Resources

- FEMA P-1037, Reducing Flood Risk to Residential Buildings That Cannot Be Elevated

Technical Considerations

Alternatives for Access

If a front yard ramp is not possible, an accessible exterior ramp may be provided within the side yard or rear yard.

Resisting Flood Loads

Stairs, ramps, and walkways must be designed to structurally resist design flood loads.

Floodproofing below the DFE

This strategy should be combined with floodproofing measures below the DFE to protect against flood damage. This would include either wet floodproofing to allow automatic entry and/or exit of floodwaters or dry floodproofing.

Consider the Public Right-of-way

Exterior ramps and stairs may not encroach into the public right-of-way. If a building has intentional setbacks that provided publicly accessible private space, that space may be used for accessible external ramps.

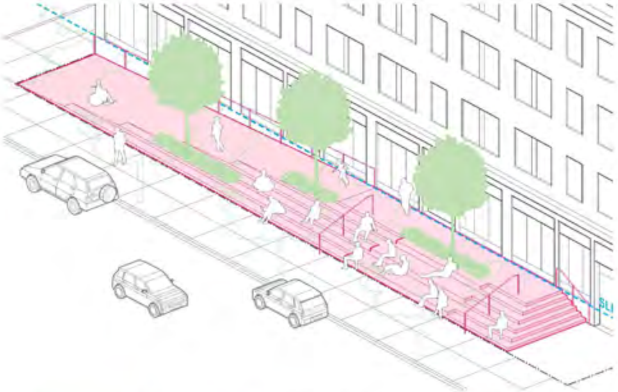
Furthermore, such additions added onto existing historic buildings will need to observe design guidelines within landmark districts.

Exterior Circulation and Vegetation

Saltwater tolerant planting is woven into the edges and railings that flank stairs and ramps, adding to visual interest along the sidewalk and softening the presence of paved areas. The use of vegetated areas also provides additional opportunities for stormwater and temperature mitigation.

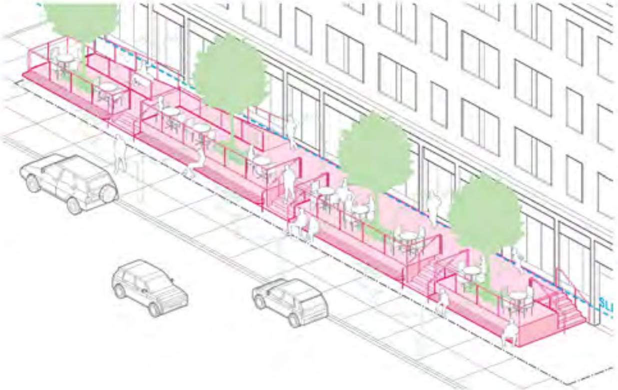
Exterior Circulation and Public Seating

Informal gathering areas can blend seamlessly into stairways and ramps.



Exterior Circulation and Activated Deck

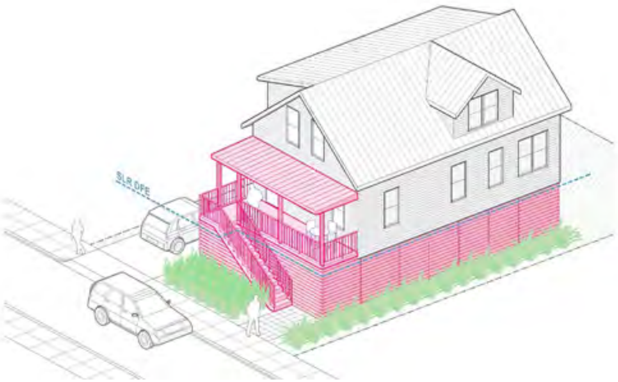
For walkways fronting restaurant or retail spaces, seating areas can activate the elevated areas, contributing to a lively streetscape.



Exterior Circulation for Small-scale Residential Structures

When carefully designed to integrate with context, porches, stair railings, and screens can contribute to the human scale for sidewalk-facing areas.

Note that spaces below the SLR-DFE are non-habitable and uses are limited to parking, access, and storage. Residential structures cannot use dry floodproofing.



Pier 17, Brooklyn. *Photo: https://www.shoparc.com/projects/pier-17/*

Proposal for General Electric buildings, Fort Point. *Photo: https://www.ge.com/reports/boston/*

Bow Market, Somerville. *Photo: https://www.bow-marketsomerville.com/*

Ink Block, South End. *Photo: https://undergroundinkblock.com/neighborhood*

Elevated building in South Boston Waterfront. *Photo: Google Maps*

Elevated houses in Queens, New York Photo: NYC Housing Recovery Operations

Elevate Lowest Interior Floor with Interior Circulation to DFE

For buildings that have high first floor ceilings, a portion of the first floor may be elevated or reconstructed at or above the SLR-DFE to protect that floor from flood risk. Circulation to reach the elevated first floor level from an at-grade entry area may be provided by internal ramps and stairs.

Elevating a new or existing building's ground floor above the DFE can protect against flood damage; however, a change in ground plane may lead to the unintended consequence of disrupting the visual connectivity between pedestrians and building interiors. One way to avoid this disruption is by providing a carefully designed interior circulation area that mediates an at-grade entry area with an elevated main floor.

Cost and Insurance Considerations

$ | $$ | $$$ | **$$$$**

- For projects within Article 25 (FEMA zone), the elevation of structures insured under the NFIP may be eligible for FEMA Hazard Mitigation Assistance grants and flood insurance premium reductions.
- Similarly, if the building is located within a FEMA zone, elevating the lowest floor may trigger a Substantial Improvement declaration.

Applicability

Project Scale	Non-Art. 80 renovations
Building Type	Triple decker, Townhouse, Post-war mixed use, Contemporary mixed use
Locations	Appropriate for buildings located outside of FEMA AE zones

Public Realm Considerations

- In new construction, to maintain visual connection at the sidewalk and an active streetscape, circulation from at-grade lobbies (wet or dry floodproofed) can lead to elevated areas above the DFE.
- This strategy may be an advantageous technique for maintaining the front facade of an historic building while enhancing the resilience of the structure.

Additional Resources

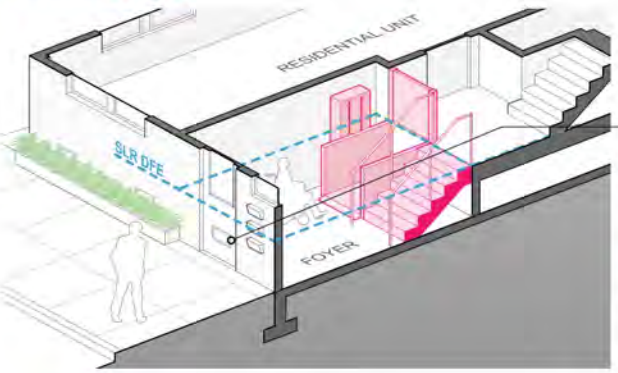
- FEMA P-1037, Reducing Flood Risk to Residential Buildings That Cannot Be Elevated
- FEMA P-467-2, Floodplain Management Bulletin - Historic Structures

Retrofitted stairs lead to an elevated first floor in a retail shop in Darlington, Wisconsin. *Photo: FEMA. 2013. Floodproofing Non-Residential Buildings.*

Floodable entryway with stairs that lead to an elevated lobby at the Querini Stampalia in Venice, Italy. *Photo: Architectours / "The renovation of the Fondazione Querini Stampalia is a great example of how Master Carlo Scarpa integrated the new with the old"*

Technical Considerations

Small Building Strategy



Openings

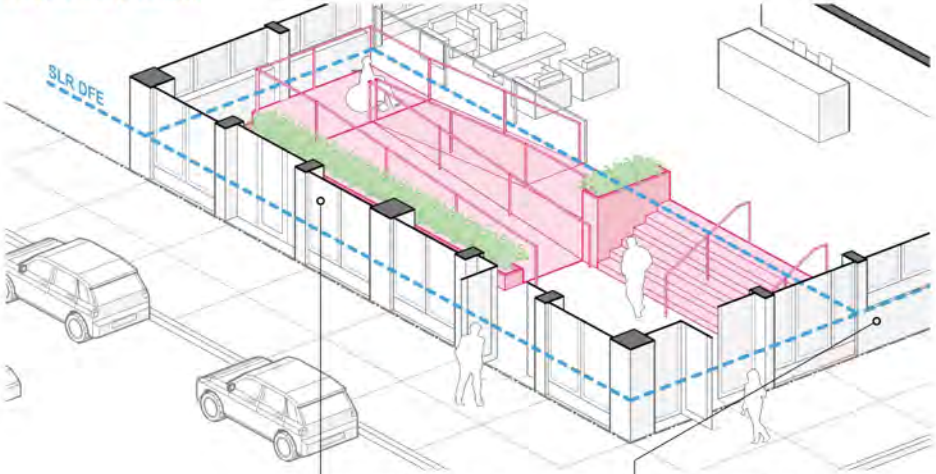
All penetrations, such as openings for HVAC, electrical, and plumbing systems, should be removed and relocated above the design flood elevation.

Floodproofing below the DFE

The resulting space below the elevated interior floor should be filled to create a stem wall or retrofitted with flood openings (see Wet Floodproofing, p44 for details.) Below-grade spaces for storage or parking may be maintained only if dry floodproofed in coordination with review and approval by an engineer for resistance to flood-related loads on the structure (see Dry Floodproofing, p46 for details.) Spaces below the SLR-DFE are non-habitable.

Wet floodproofing of the entry area allows water to enter and exit through vents in the storefront wall or entry door, equalizing hydrostatic pressure. The wet floodproofed vestibule uses flood damage resistant materials.

Large Building Strategy



Ground Floor Height

The floor-to-ceiling height of the ground floor must be high enough to accommodate a reduced ceiling height. While many existing buildings may have this height capacity, an elevated floor may disrupt the way windows and doors relate to the first floor, so this strategy must be coordinated with the character of the existing facades and remain integrated with the public realm.

Dry Floodproofing

Dry floodproofing may be utilized in a limited way to seal and reinforce the interior surfaces of the entry area and/or providing internal flood shields to prevent the seepage of water further into the building. Spaces below the SLR-DFE are non-habitable. This strategy allows for an at-grade connection between the sidewalk and the building to preserve the character of the building's exterior (see Dry Floodproofing, p46, for details).

Protect Critical Systems

Building utility systems, including electrical and mechanical equipment, should be protected from flood risk to avoid costly damage, safety risks, and loss of habitability and other critical building functions during a flood event. This should be among the highest priority resilience actions for property owners.

For all new construction and substantial improvements, electrical, heating, ventilation, plumbing and air-conditioning equipment and other service facilities shall be designed and/or located so as to prevent water from entering or accumulating within the components during conditions of flooding. These systems and equipment include:

Mechanical
- Boilers and furnaces
- Air-handlers, condenser units, and heat pumps
- Ductwork and piping
- Fuel storage tanks
- Water heaters
- Fire-suppression sprinkler controls
- Elevator machine rooms

Electrical
- Electrical panels and switchgear
- Backup generators
- Alarm controls and components
- Service wiring and receptacles
- Building management systems
- Telecommunications equipment
- Electric and gas meters
- Utility shut-off switches

With proper planning, new buildings can easily accommodate the protection of critical systems by locating equipment in upper floors or in a mechanical penthouse. For renovation projects, the three main types of protection are elevation, relocation, and protection in place.
- **Elevate:** Outdoor equipment or ground floor equipment located in spaces with high ceilings can usually be elevated on pedestals or platforms to bring the systems above the flood elevation.
- **Relocate:** Depending on the available space within an existing building, service equipment from a basement or other area below the flood level can be relocated to an upper floor to bring the equipment and distribution systems above the flood elevation.
- **Protect in place:** When elevating and relocating are not practical or feasible, the last option to increase the resilience of critical systems is to protect them in place. This includes elevating to the greatest extent possible and dry floodproofing with low floodwalls and shields and with anchors and tie downs to prevent flotation.

Applicability

Project Scale	Non-Art. 80 renovations and new construction, Art. 80 renovations and new construction

Sustainability Co-benefits Considerations
- When replacing equipment, choosing high-efficiency models can reduce energy use, utility bills, and emissions of greenhouse gases and other pollution. It also reduces strain on the energy grid, making the whole system more resilient. This is exemplified in the case of replacing an old sub-grade furnace with a more fuel-efficient electric heat-pump system, located above the SLR-DFE.
- Electrification of heating systems, in combination with choosing clean sources of electricity and implementing energy efficiency improvements, will support Boston's efforts to achieve carbon neutrality.

Cost and Insurance Considerations:

$ | $$ | $$$ | $$$$

- In FEMA V zones, elevating mechanical equipment is required for NFIP premium reduction.
- Relocating/Replacing critical utilities is also an opportunity to upgrade and increase the energy efficiency of a building's systems, which may lead to a reduction in annual utility costs.

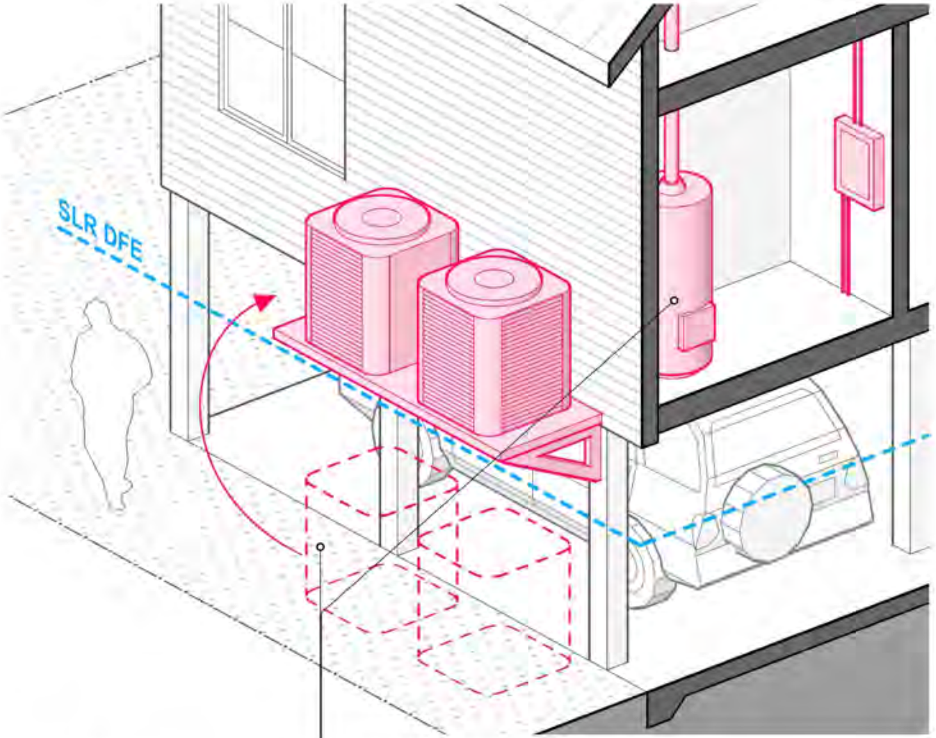
Additional Resources
- FEMA 348: Protecting Building Utilities From Flood Damage
- FEMA P-312, Homeowner's Guide to Retrofitting
- A Better City Report, Enhancing Resilience in Boston: A Guide for Large Buildings and Institutions
- FEMA Recovery Advisory 2: Reducing Flood Effects in Critical Facilities

Technical Considerations

Repair and Replacement
Use natural cycles of repair and replacement as opportunities to improve the flood resilience of building utility systems and equipment. For example, replacing an old furnace in the basement with a more compact mini-split heat pump can improve efficiency, reduce fossil fuel use, and make relocating or elevating heating and cooling systems more feasible in space-constrained buildings.

Energy Audits
Building owners should conduct an energy audit to identify opportunities for improvements in energy efficiency to coincide with resilience upgrades. This is not only limited to replacing old equipment with higher-efficiency models. An energy audit can reveal how upgrades to the building envelope can reduce heating and cooling loads, which can result in equipment down-sizing in addition to added efficiency.

Utility Coordination
Coordinate with the local utility company when planning modifications to the placement of electric and/or gas meters.

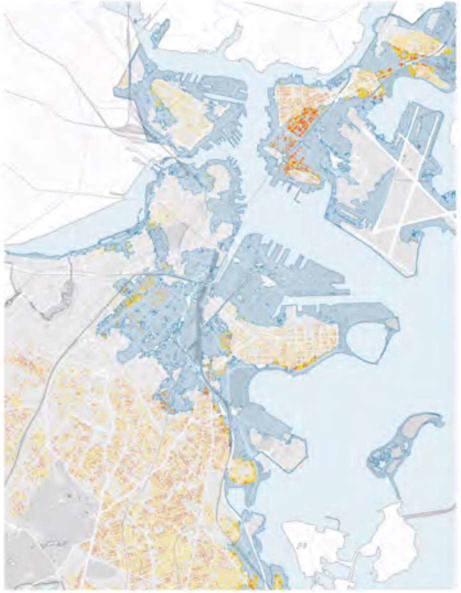


Protecting in Place
If protecting in place is the most feasible option, watertight walls and shields are most practical when flood depths are less than 3'. Utilize a watertight closure panel if a floodwall is too high to step over. Utilize anchors and tie-downs to hold equipment in place.

Elevating Equipment
When relocating or elevating MEP systems, consider horizontal and vertical clearances for routine maintenance; venting requirements for combustion equipment; drain pans for equipment containing water storage to prevent leakage; and provisions to prevent equipment from freezing.

The maps below are an illustration of locations where these types tend to cluster. They have been derived from the City of Boston's Tax Assessors' database using the best available attributes to identify the building types. Because of limitations with the data, these maps are not comprehensive or mutually exclusive. There may be instances where all buildings of a certain type are not represented on the map, or buildings are identified in more than one map.

One- and Two-family Residential, and Triple-deckers



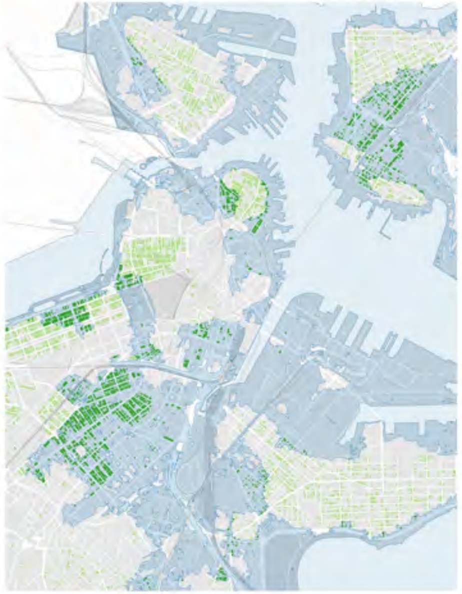
One- and two-family detached residential in the Overlay

Triple-deckers in the Overlay

Other one- and two-family detached residential

Other triple-deckers

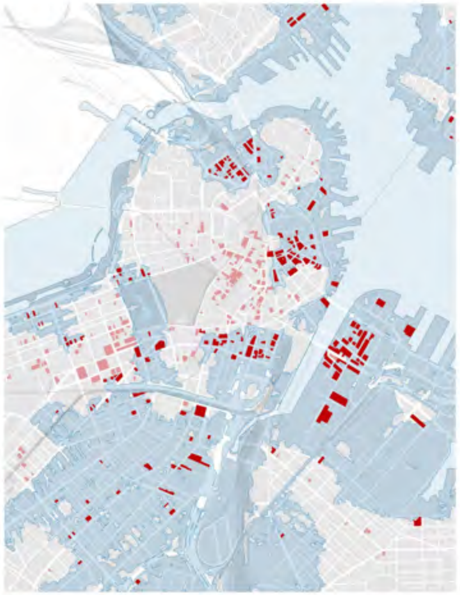
Attached Townhouses



Attached townhouses in the Overlay

Other townhouses

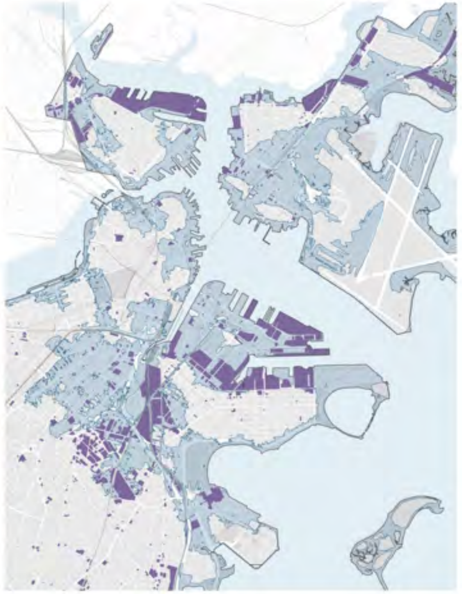
Pre-war Commercial or Mixed Use Buildings



Pre-war commercial or mixed-use buildings in the Overlay

Other pre-war commercial or mixed-use buildings in the Overlay

General Industrial Buildings



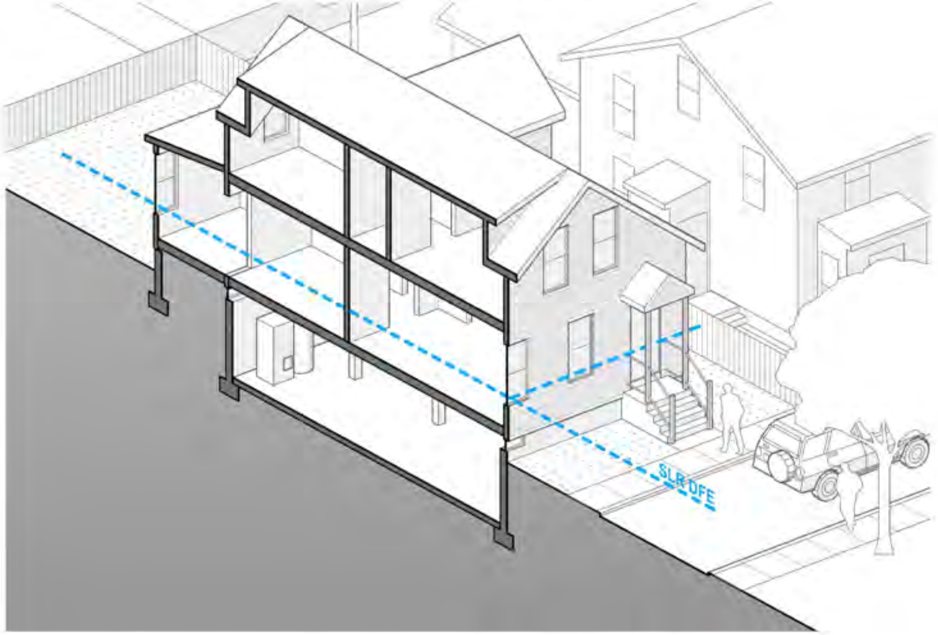
General industrial buildings in the Overlay

Other general industrial buildings

One- and Two-Family Residential

Existing Conditions

This type is commonly found in Dorchester within the Overlay neighborhoods. Structures are typically one or two-story wood-framed structures with pitched roofs and fieldstone foundations. They are commonly free-standing and often set back a few feet from the sidewalk, with porches covering raised stoops. Because of the scale of these buildings and their separation from adjacent structures, elevating the building is a viable adaptation measure.



Case Study Location

Sea Level Rise Conditions

SLR-BFE	19.50' BCB
SLR-DFE	20.50' BCB
FEMA BFE	16.46' BCB

Other Neighborhoods

Dorchester, East Boston

Building Characteristics

Grade elevation	approx. 14.57' BCB
Lowest occupiable floor	approx. 17.57' BCB
Cellar elevation	Unknown
Critical systems location	Basement
Construction type	Wood frame
Year built	Late 19th–early 20th century
Stories	2
Units	1
Sidewalk width	4'
Zoning district	Two-family Residential

Long-term Strategy

Building Systems

Protect Critical Systems

Locate water heater and critical systems above the SLR-DFE.

Evaluate life of systems and upgrade where possible. Consider upgrading heating to high-efficiency mini-split heat pump system with equipment mounted outside and above the SLR-DFE.

Building Form

Elevate on Open Foundation

Elevate house on posts above SLR-DFE on new foundation system. Consider elevating higher to accommodate storage and/or parking. Abandon basement and fill it to the lowest adjacent grade.

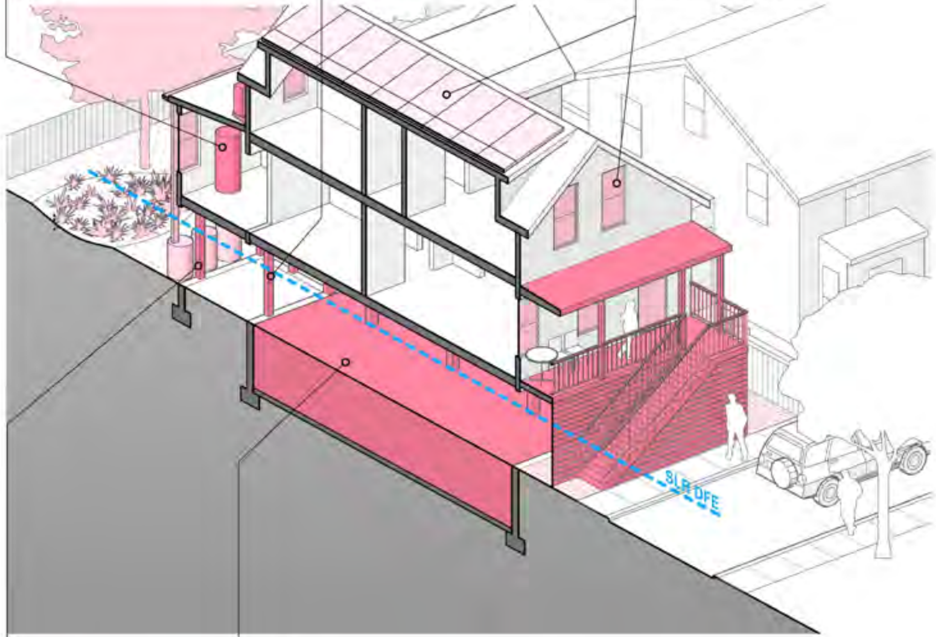
When elevating, incorporate screens, porches, and stairs to integrate with the public sidewalk.

Supporting Strategy

Enhanced Envelope

Conduct energy audit and blower door test. Air-seal at windows, doors, and penetrations. Upgrade windows to low-e, low-U-factor units.

Install blown-in cellulose insulation to wall cavities; add roof insulation outboard of deck. Install islandable, grid-connected solar PV system on the roof for on-site energy generation.



Building Envelope and Access

Flood-Damage-Resistant Materials

Use saltwater-damage-resistant materials below SLR-DFE.

Building Form

Repurpose / Relocate Ground Floor Use

Abandon basement and ground floor. Fill basement to the lowest adjacent grade.

Convert ground floor use to storage, parking, or access. Eliminate any habitable spaces below SLR-DFE. Recuperate lost FAR at roof addition.

When filling basement, consider structure and envelope to prevent wicking of moisture up into building after flooding.

View from the street

Above photo: Landslides Aerial Photography / Alex MacLean

Incremental Strategy

Floodproofing the basement and protecting the components of critical systems are priority short-term measures.

Building Systems

Protect Critical Systems

Locate systems above SLR-DFE. Consider mini-split system with condenser mounted to the side of house above SLR-DFE.

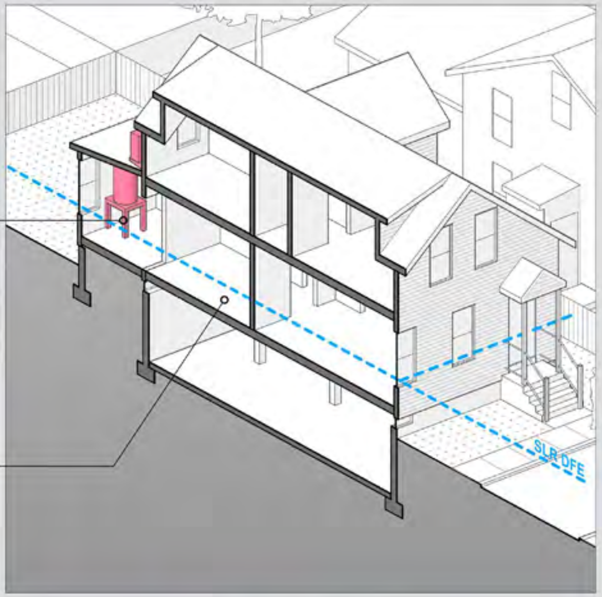
Backup Systems

Install backflow preventers to limit wastewater backup and sump pumps to provide internal drainage.

Building Envelope and Access

Flood-Damage-Resistant Materials

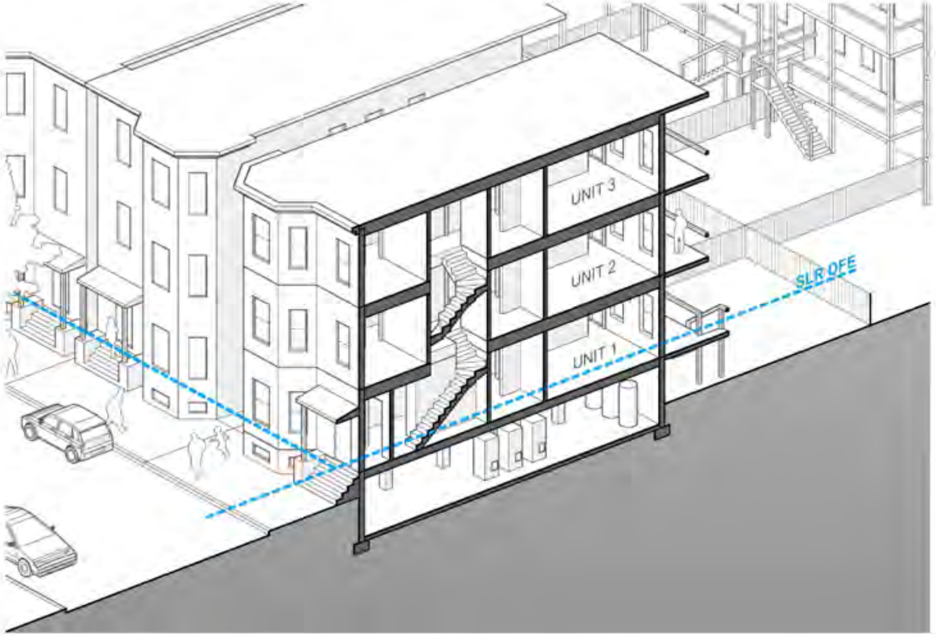
Use flood-damage-resistant materials below SLR-DFE.



Triple-decker

Existing Conditions

One of the most prevalent building types in Boston, triple-deckers are commonly found in the Overlay neighborhoods of East Boston, South Boston, Dorchester, and Charlestown. They are typically free-standing, three-story wood structures commonly supported on fieldstone and brick foundations, with bay windows and covered stoops facing the sidewalk and tiered decks facing the rear yard.



Case Study Location

Sea Level Rise Conditions

SLR-BFE	19.50' BCB
SLR-DFE	20.50' BCB
FEMA BFE	17.46' BCB

Other Neighborhoods

Dorchester, Charlestown

Building Characteristics

Grade elevation	approx. 15.56' BCB
Lowest occupiable floor	approx. 18.75' BCB
Cellar elevation	10.10' BCB
Critical systems location	Basement
Construction type	Wood frame
Year built	Late 19th–early 20th century
Stories	3
Units	3
Sidewalk width	10'
Zoning district	Three-family Residential

Long-term Strategy

Supporting Strategies

Enhanced Envelope

Conduct energy audit and blower door test to identify air leaks.

Install blown-in cellulose insulation to wall cavities; add roof insulation outboard of deck.

Upgrade windows to low-e, low-U-factor casement windows.

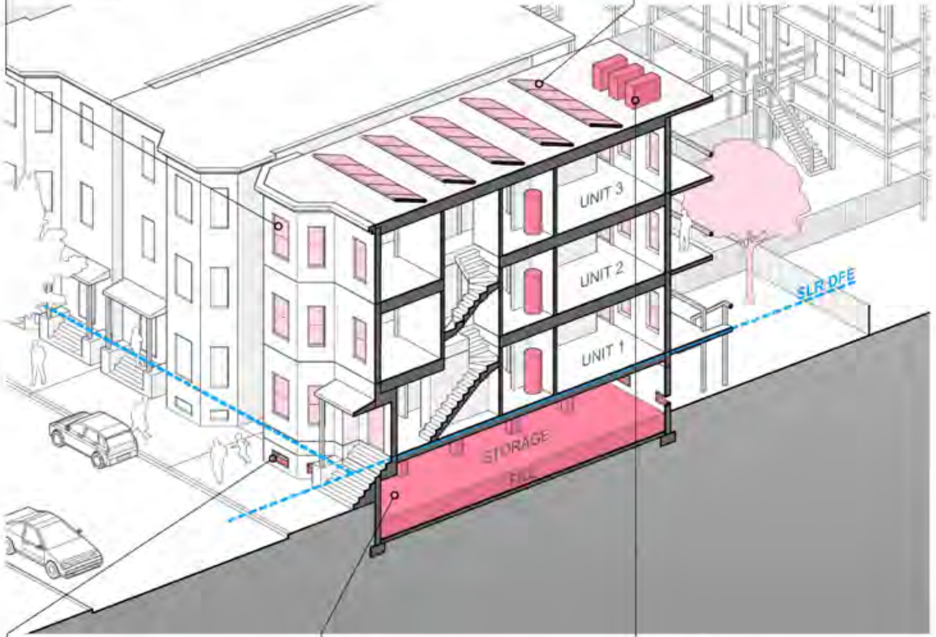
Cool roofing mitigates overheating by reducing roof temperatures

Consider envelope upgrades in conjunction with replacing critical systems for resilience. A better envelope can result in down-sized HVAC systems that are less expensive to operate.

Supporting Strategies

On-Site Energy Generation

Install islandable, grid-connected solar PV system on the roof.



Building Envelope and Access

Wet Floodproof

Install flood vents at foundation walls in order for water to enter and balance hydrostatic forces.

Use saltwater-damage-resistant materials below SLR-DFE.

Eliminate any habitable spaces below SLR-DFE. Limit uses below SLR-DFE to parking, access, and storage.

Building Form

Elevate Building on Extended Foundation Walls

Abandon basement and fill it to the lowest adjacent grade.

Elevate building such that first occupiable floor is above SLR-DFE. Extend foundation walls.

When filling basement, consider structure and envelope to prevent wicking of moisture up into building after flooding.

Building Systems

Protect Critical Systems

Locate water heater and critical systems above the SLR-DFE.

Upgrade heating to high-efficiency mini-split heat pump system with equipment located outside and above the SLR-DFE.

Incremental Strategy

Floodproofing the basement and moving critical systems out of sub-grade space are priority short- and medium- term measures.

Building Systems

Protect Critical Systems

Relocate equipment from sub-grade space.

Backup Systems

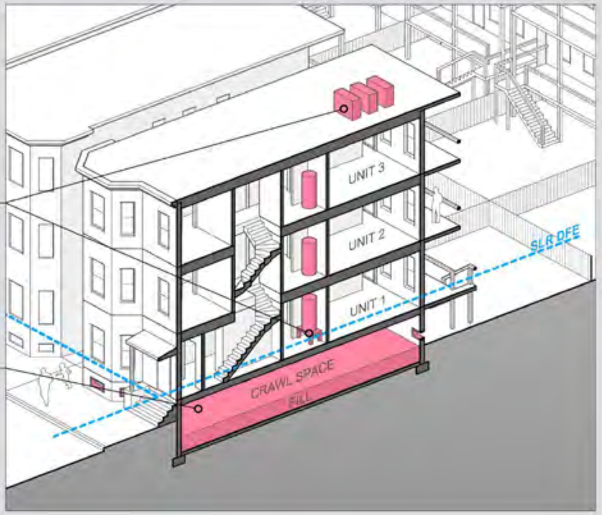
Provide interior drainage system (sump pump and emergency power source). Install backwater preventers.

Wet Floodproofing

Fill the basement slab to the rear yard grade, and provide flood vents at basement windows.

Use flood-damage-resistant materials below SLR-DFE.

When filling basement, consider structure and envelope to prevent wicking of moisture up into building after flooding.



Short-term Strategy

In the interim, it is important to provide component protection and back-up drainage if equipment cannot be moved out of the basement in the short-term.

Building Systems

Protect Critical Systems

Elevate water heaters and heating equipment as high as possible, and create dry floodproofed component protection around the equipment.

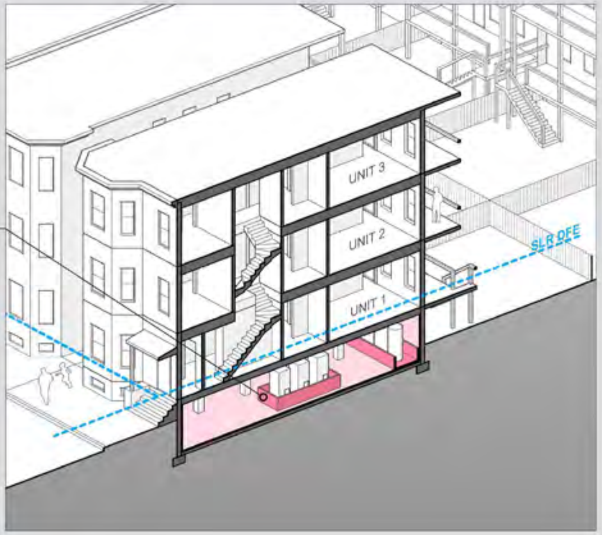
Backup Systems

Provide interior drainage system (sump pump and emergency power source) and install backflow preventers.

Building Envelope and Access

Flood-Damage-Resistant Materials

Use flood-damage-resistant materials below SLR-DFE.



Pre-war Mixed-use

Existing Conditions

Pre-war mixed use buildings are historic multi-story structures commonly found in Downtown, Fort Point, North End and the South End. While structural systems vary, they typically include solid masonry walls with heavy timber post and beam framing or concrete slab and post construction. Ground floor levels often have high ceilings, making it feasible to accommodate resilience adaptations require greater floor-to-floor height on the first floor.

Case Study Location

Sea Level Rise Conditions

SLR-BFE	19.50' BCB
SLR-DFE	20.50' BCB
FEMA BFE	16.46' BCB

Other Neighborhoods

South Boston, Downtown, Charlestown

Building Characteristics

Grade elevation	approx. 15.00' BCB
Lowest occupiable floor	approx. 15.00' BCB
Cellar elevation	Unknown
Critical systems location	Basement / Roof
Construction type	Brick masonry, timber
Year built	Late 19th–early 20th century
Stories	5
Units	45
Sidewalk width	10'
Zoning district	South Boston M-4

Long-term Strategy

Strategies not pictured:
Emergency power
Renewable energy systems
Resilient elevators

Building Systems

Protect Critical Systems

Locate systems for ground floor retail above SLR-DFE.

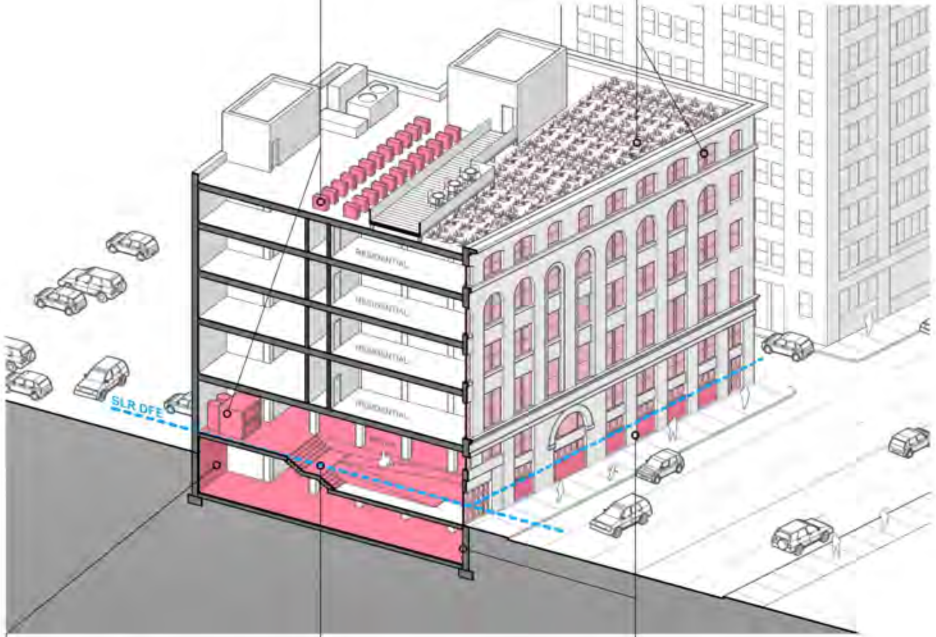
Upgrade residential space conditioning to systems that can be elevated out of basement, such as unitized variable refrigerant flow (VRF) system with energy-recovery ventilation.

Supporting Strategy

Enhanced Envelope

Conduct energy audit and blower door test. Air-seal at windows, doors, and penetrations.

Add roof insulation outboard of deck and use high-albedo or green roofing (shown) to mitigate urban heat islands. Upgrade windows to historically sensitive low-e, low-U-factor units.



Building Systems

Backup Systems

Protect sub-grade areas from the backflow of municipal wastewater by installing backwater valve(s) or flow preventer(s).

Building Envelope and Access

Elevate Lowest Interior Floor + Provide Interior Circulation to DFE

Ramps and stairs mediate an at-grade entry area with an elevated main floor. High ceilings in the existing ground floor can accommodate this adaptation.

Building Envelope and Access

Dry floodproofing

Install historically sensitive brackets for temporary shields at windows and doors below the SLR-DFE.

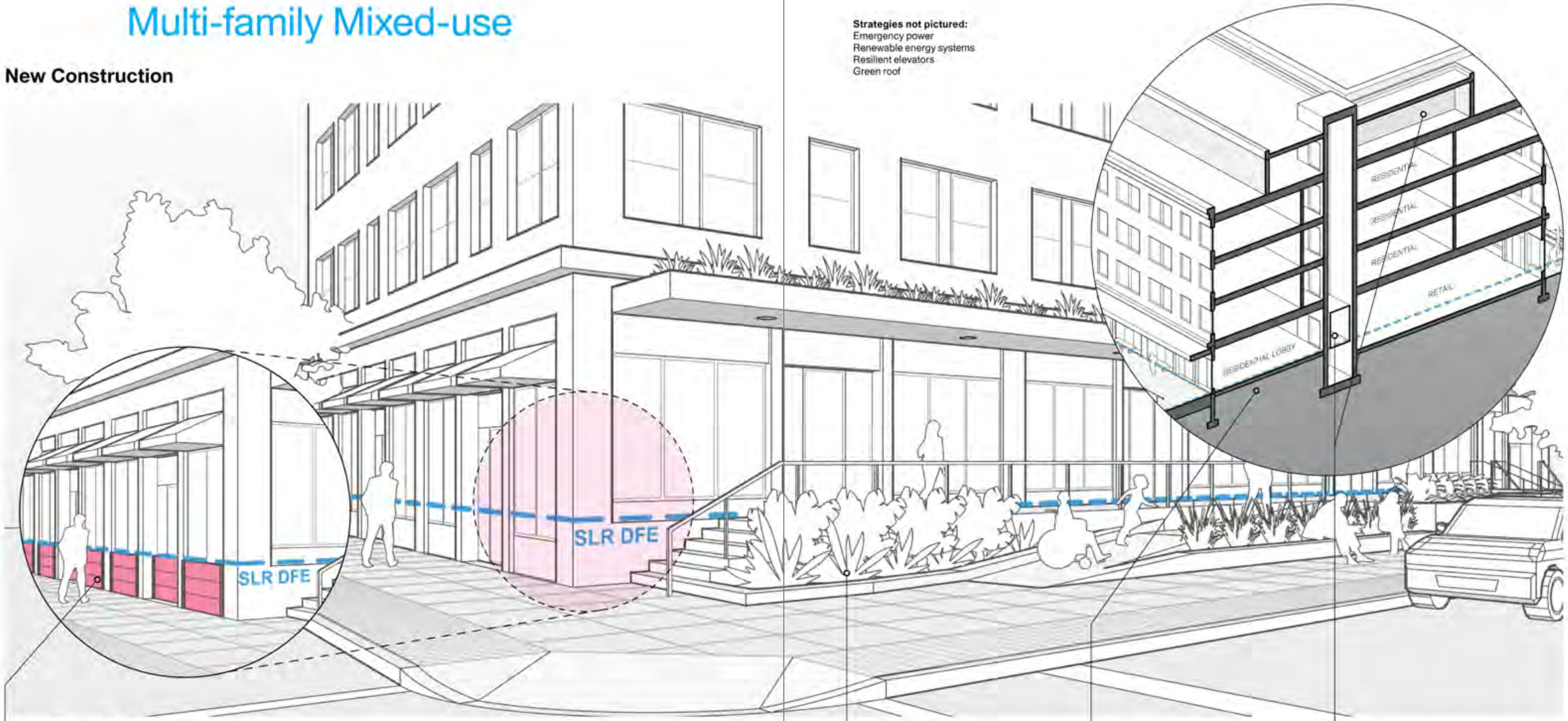
Parge and structurally reinforce stone foundation to resist hydrostatic forces. Historic and older buildings may require fortifying or replacing materials designed to breath and flex.

Install sump pumps for backup drainage.

Multi-family Mixed-use

New Construction

Strategies not pictured:
Emergency power
Renewable energy systems
Resilient elevators
Green roof



Resilient Design Strategy

Building Envelope and Access

Dry Floodproofing

Retail is kept at grade for sidewalk activation. During storm events, storefront doors are fitted with flood shields into built-in brackets. Retail space must be vacated prior to storm event. Walls, glazing supports, and building structure must be engineered to withstand hydrostatic pressure from floodwaters.

Building Envelope and Access

Wet Floodproofing

Residential access doors have flood vents and wet floodproofed lobby has saltwater-resistant materials. Access door and flood vents not shown.

Supporting Strategy

Enhanced Envelope

Exterior insulation and high performance windows allow interior spaces to maintain interior temperatures despite loss of heating during a power outage.

Building Adaptation and Access

Elevate Lowest Interior Floor + Provide Exterior Circulation to DFE

Front facade is set back to allow for elevated walkways, accessible ramps, and stairs. Planters soften the transition between elevated hardscape and sidewalk, contributing to an improved public realm experience.

Building Form

Elevate Building on Fill

Elevate residential lobby on structural fill above SLR-DFE. The fill must be compacted and designed to resist scour and erosion.

Podium construction of first floor is separate from upper levels.

Building Systems

Protect Critical Systems

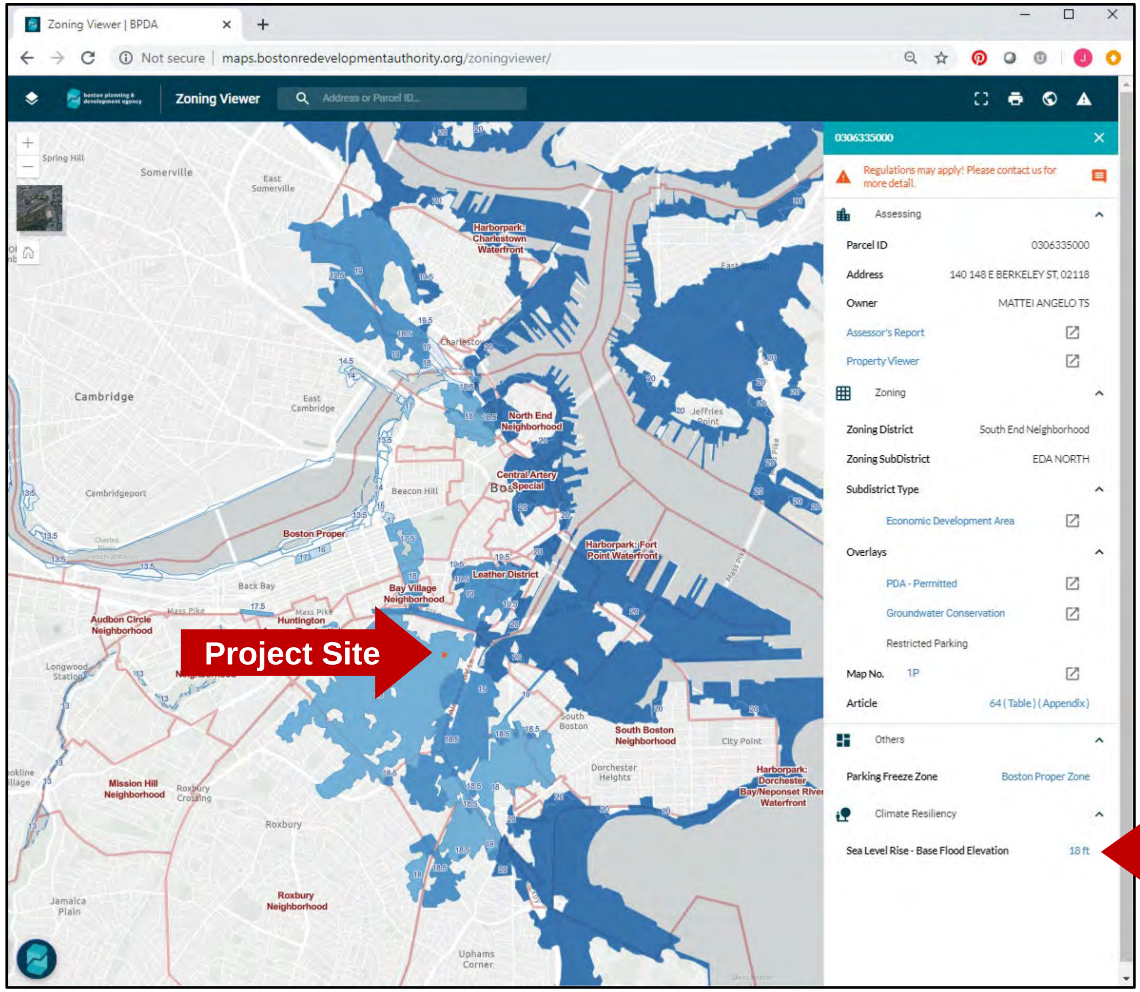
Locate critical systems and backup power generator in mechanical penthouse.

Resilient Elevators

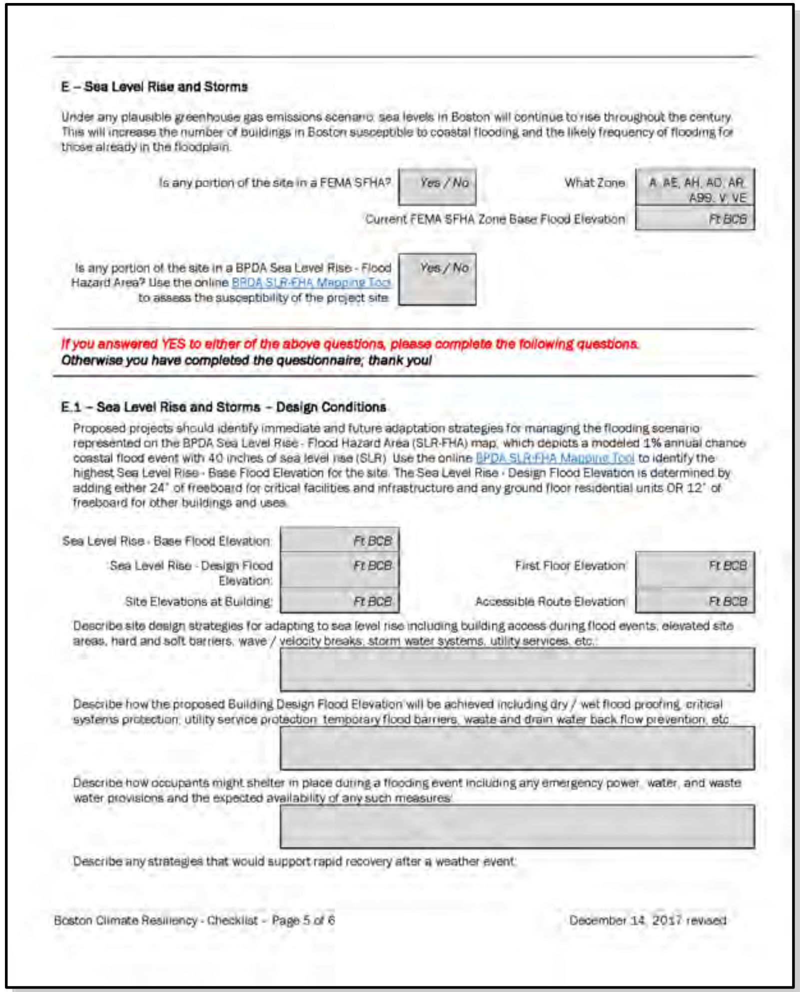
Locate electrical controls and hydraulic pumps above the SLR-DFE. Use NEMA Type 4-rated enclosure for any electrical equipment that must be installed below the SLR-DFE.

Identifying Project Flood Risks and Enforcing the Guidelines

BPDA Online Mapping Viewer



Review Checklist



E – Sea Level Rise and Storms

Under any plausible greenhouse gas emissions scenario, sea levels in Boston will continue to rise throughout the century. This will increase the number of buildings in Boston susceptible to coastal flooding and the likely frequency of flooding for those already in the floodplain.

Is any portion of the site in a FEMA SFHA? Yes / No

What Zone: A, AE, AH, AO, AR, A99, V, VE

Current FEMA SFHA Zone Base Flood Elevation: Ft BCB

Is any portion of the site in a BPDA Sea Level Rise - Flood Hazard Area? Use the online BPDA SLR-FHA Mapping Tool to assess the susceptibility of the project site. Yes / No

If you answered YES to either of the above questions, please complete the following questions.
Otherwise you have completed the questionnaire; thank you!

E.1 – Sea Level Rise and Storms – Design Conditions

Proposed projects should identify immediate and future adaptation strategies for managing the flooding scenario represented on the BPDA Sea Level Rise - Flood Hazard Area (SLR-FHA) map, which depicts a modeled 1% annual chance coastal flood event with 40 inches of sea level rise (SLR). Use the online BPDA SLR-FHA Mapping Tool to identify the highest Sea Level Rise - Base Flood Elevation for the site. The Sea Level Rise - Design Flood Elevation is determined by adding either 24" of freeboard for critical facilities and infrastructure and any ground floor residential units OR 12" of freeboard for other buildings and uses.

Sea Level Rise - Base Flood Elevation: Ft BCB

Sea Level Rise - Design Flood Elevation: Ft BCB

First Floor Elevation: Ft BCB

Site Elevations at Building: Ft BCB

Accessible Route Elevation: Ft BCB

Describe site design strategies for adapting to sea level rise including building access during flood events, elevated site areas, hard and soft barriers, wave / velocity breaks, storm water systems, utility services, etc.:

Describe how the proposed Building Design Flood Elevation will be achieved including dry / wet flood proofing, critical systems protection, utility service protection, temporary flood barriers, waste and drain water back flow prevention, etc.:

Describe how occupants might shelter in place during a flooding event including any emergency power, water, and waste water provisions and the expected availability of any such measures:

Describe any strategies that would support rapid recovery after a weather event:

Boston Climate Resiliency - Checklist – Page 5 of 6 December 14, 2017 revised

Thank You!

GeoMicroDistrict Feasibility Study

October 22, 2020

Audrey Schulman, HEET
audrey.schulman@heetma.org

Richa Yadav, Buro Happold
richa.yadav@burohappold.com

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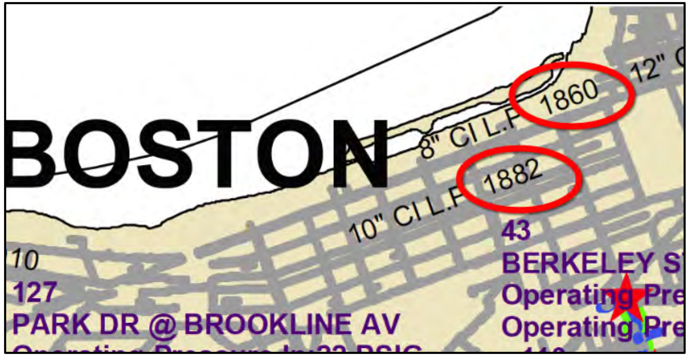
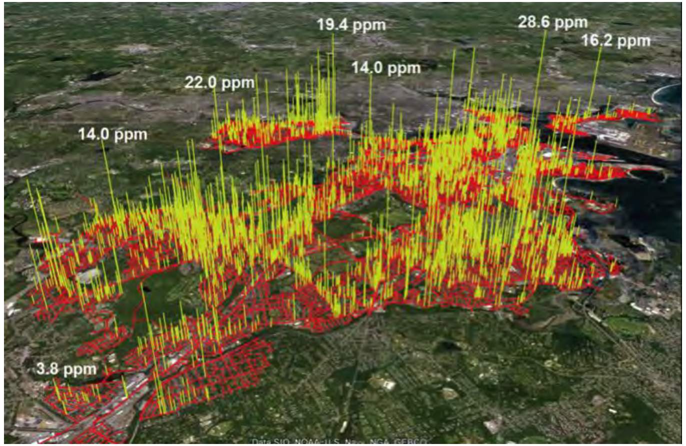
Massachusetts

- **Second oldest** natural gas infrastructure in the United States
- Leaking pipes release **methane**, a potent greenhouse gas
- If unchecked, gas leaks can result in **explosions**



Source: National Grid



Source: Gas leaks in Boston, MA; Nathan Phillips, et al (2013)

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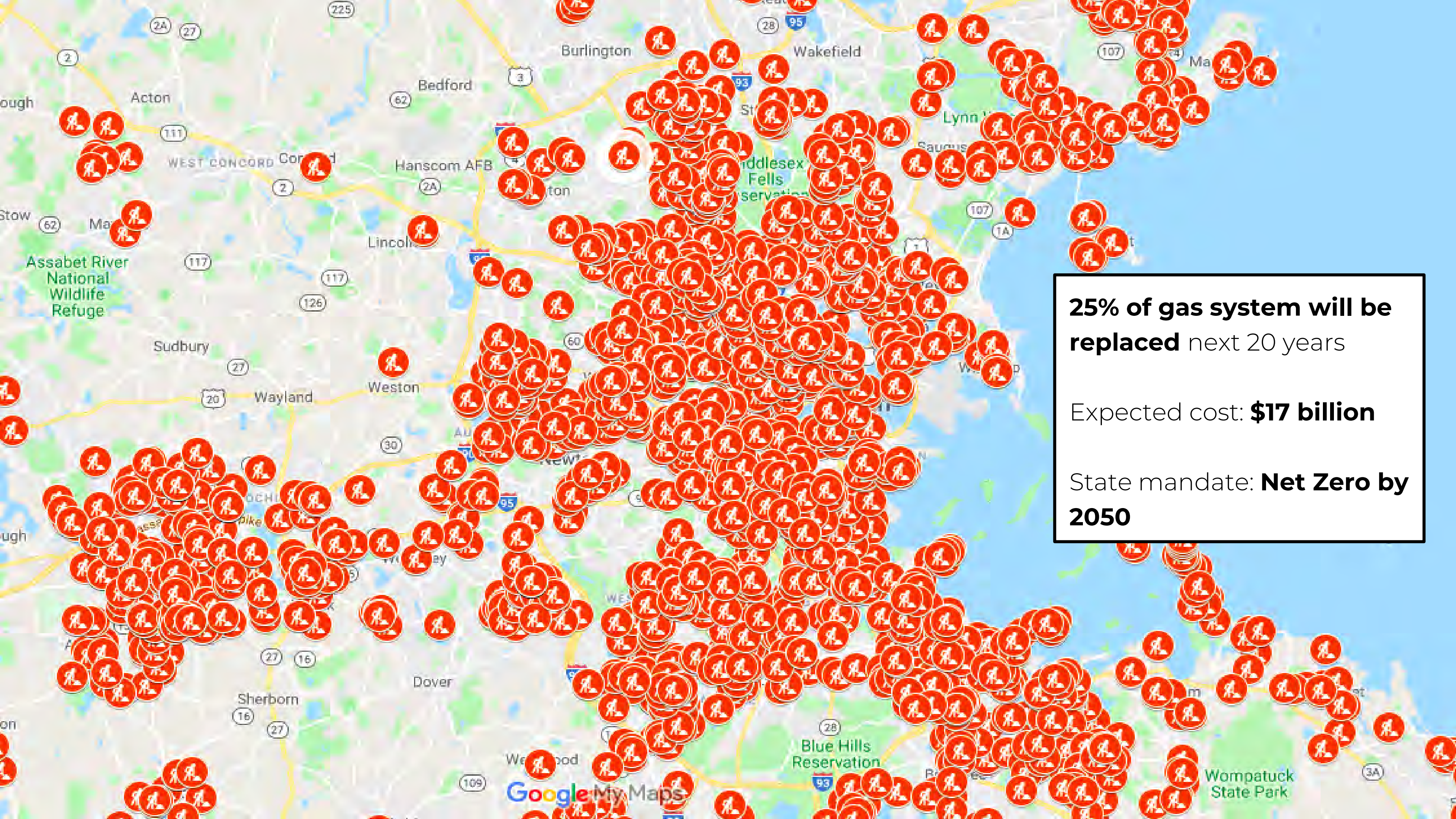

25% of gas system will be replaced next 20 years

Expected cost: **$17 billion**

State mandate: **Net Zero by 2050**

Project Objective:

Explore feasibility of replacing aging gas infrastructure with street-scale geothermal systems

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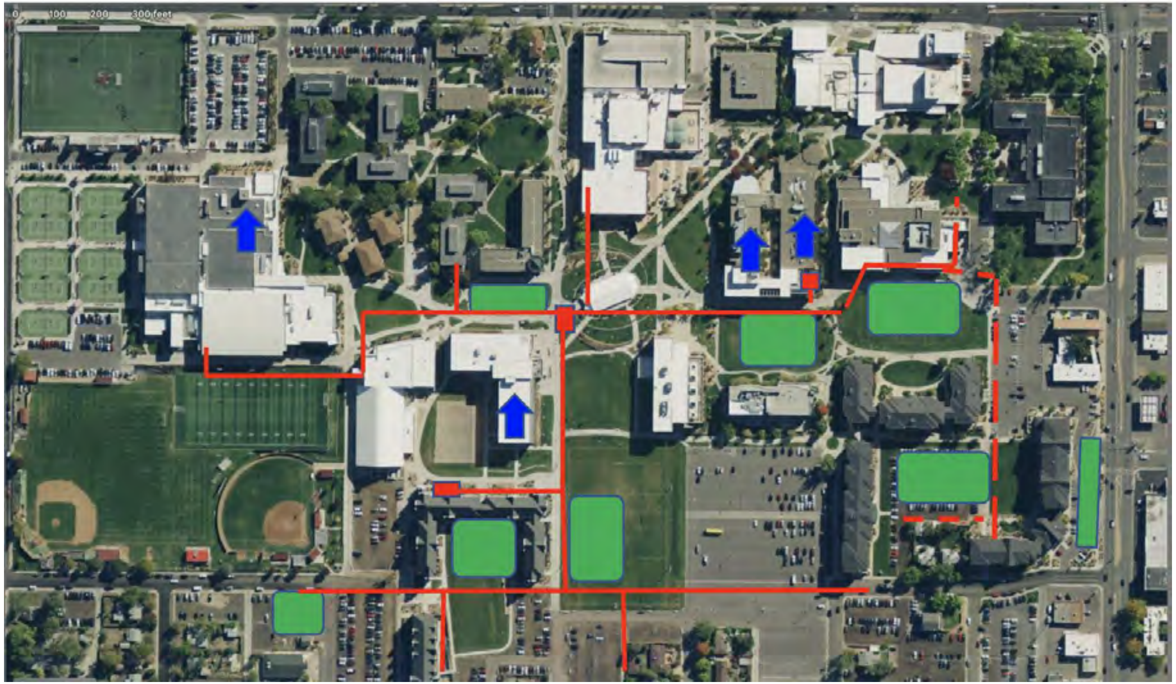
Colorado Mesa University

Capacity = 3,500 Tons
Area = 82 acres

Legend

- Borefields: 121,000 ft
- Vaults and Mechanical Rooms
- Cooling Towers: 750 tons
- 18” Pipes
- 12” & 10” Pipes



Courtesy of the GreyEdge Group

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Preliminary Analysis

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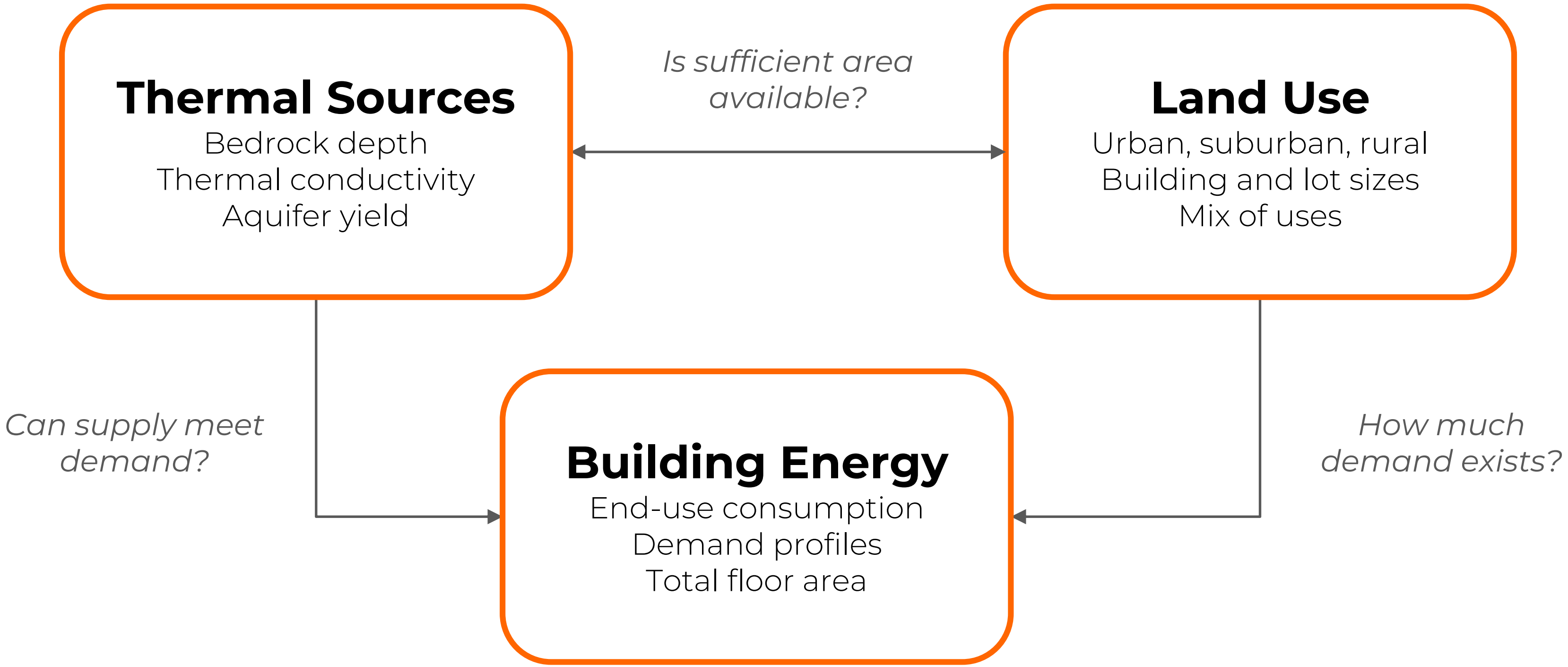
What systems are feasible given the conditions of a certain site?

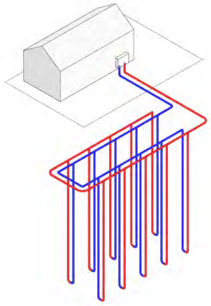


Technologies Considered

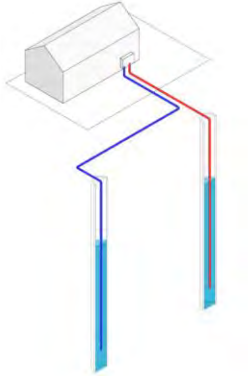
Three ground source heat pump (GSHP) systems evaluated:

1. Ground-coupled heat pump
2. Groundwater heat pump
3. Surface-water heat pump

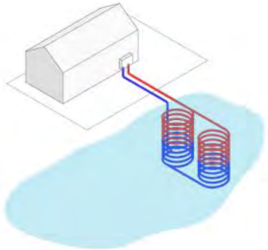
GCHP Closed Vertical



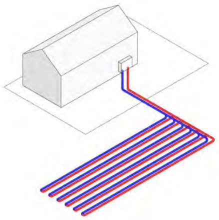
GWHP Open Vertical



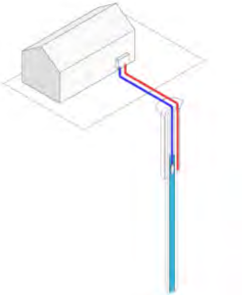
SWHP Closed



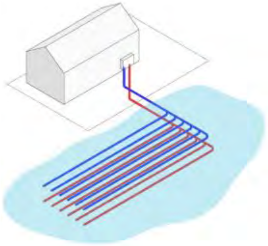
GCHP Closed Horizontal



GWHP Standing Column Well



SWHP Open



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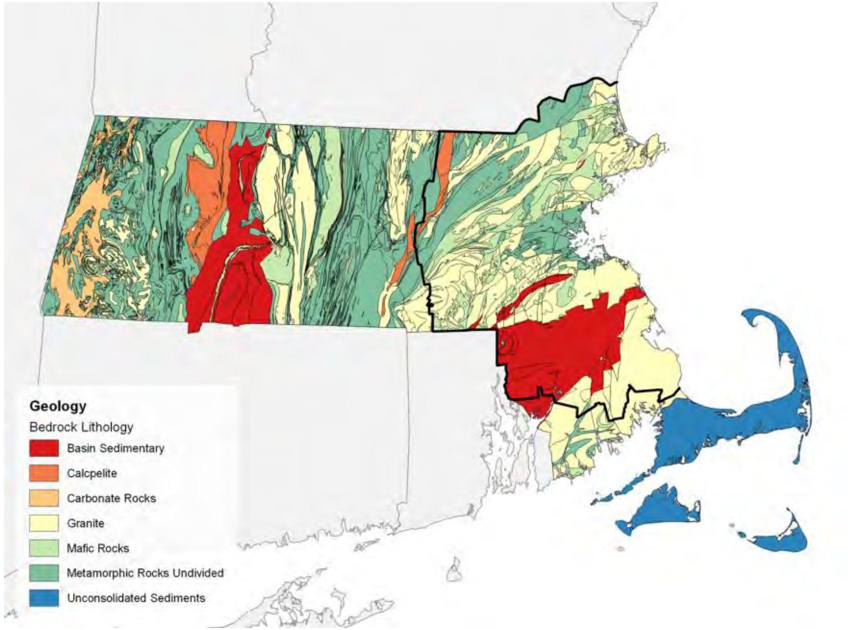
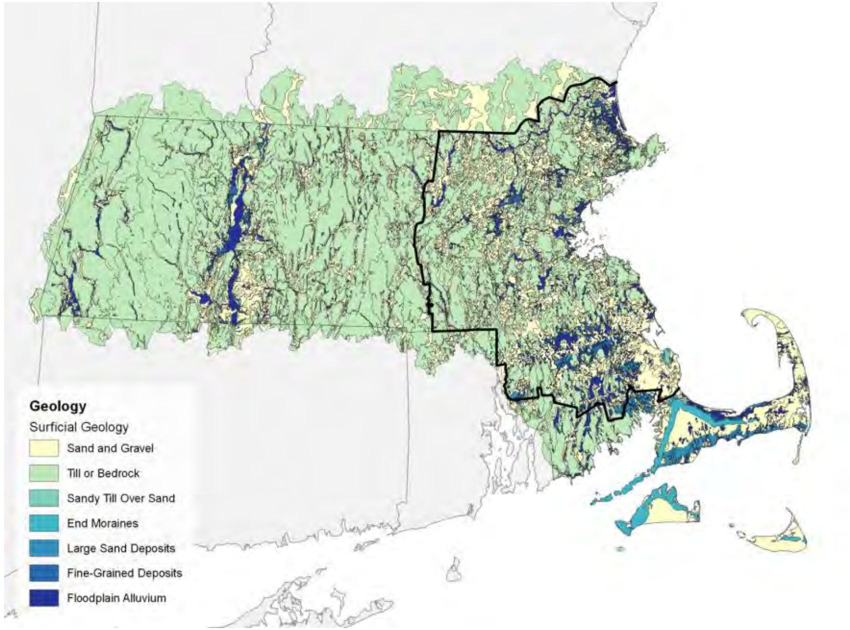


Bedrock Lithology

Source: BuroHappold analysis; MassGIS/USGS



Surficial Geology

Source: BuroHappold analysis; MassGIS/USGS

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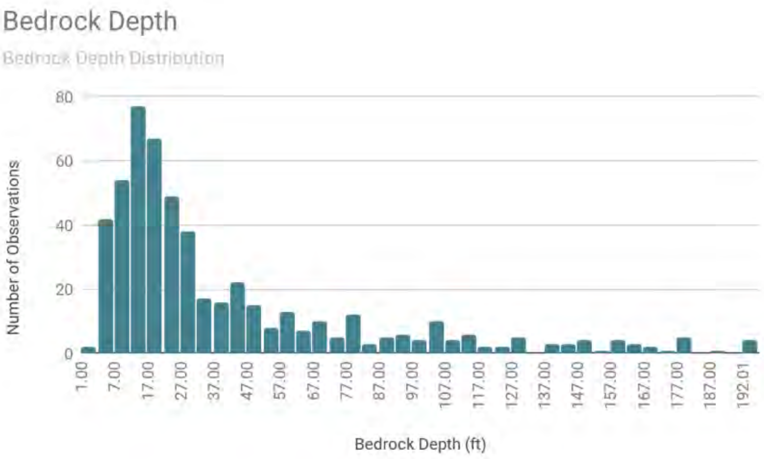

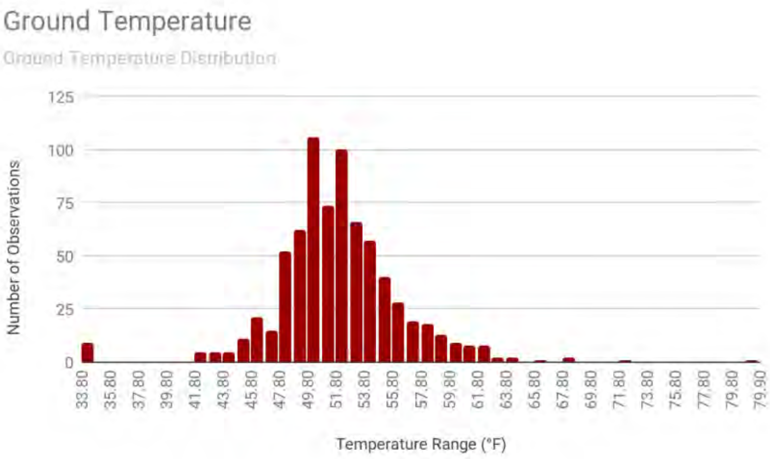

Well Type	Min. Bedrock Depth (ft)	Avg. Bedrock Depth (ft)	Max. Bedrock Depth (ft)
GSHP	1.0	47.5	1,300.0
GSHP Open Loop	*1.0*	*49.7*	*465.0*
GSHP Closed Loop	*2.0*	*45.7*	*1,300.0*
Other	0.1	34.6	1,300.0
Total	**0.1**	**34.7**	**1,300.0**

Source: BuroHappold analysis; Massachusetts Energy & Environmental Affairs; Massachusetts Geological Survey/National Geothermal Data System

Depth (ft)	Count	Min. Temp. (°F)	Avg. Temp. (°F)	Max.Temp. (°F)
0-100	552	34	52	68
100-200	92	34	51	62
200-300	25	42	53	66
300-400	20	34	50	55
400-500	8	48	52	55
500-600	12	49	52	57
600-700	5	46	51	56
700-800	3	49	55	60
800-900	2	51	54	57
1100-1200	2	52	54	56

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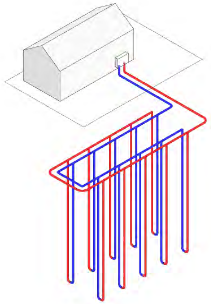
Technologies Considered

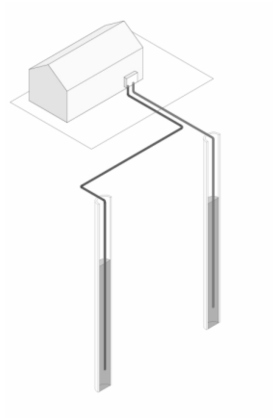
Three ground source heat pump (GSHP) systems evaluated:

1. **Ground-coupled heat pump**
2. Groundwater heat pump
3. Surface-water heat pump

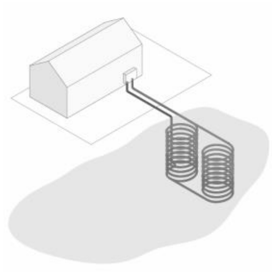
GCHP Closed Vertical



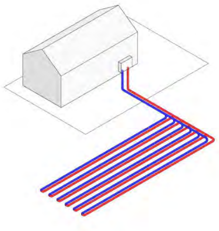
GWHP Open Vertical



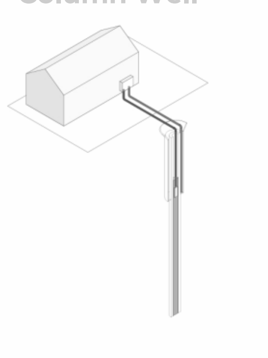
SWHP Closed



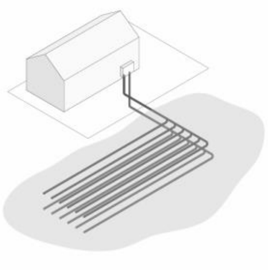
GCHP Closed Horizontal



GWHP Standing Column Well



SWHP Open



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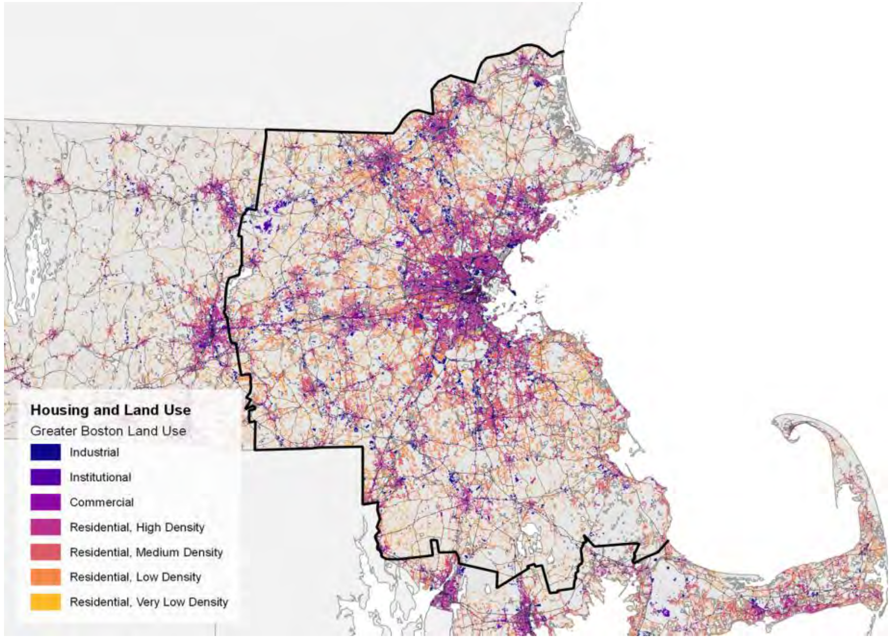
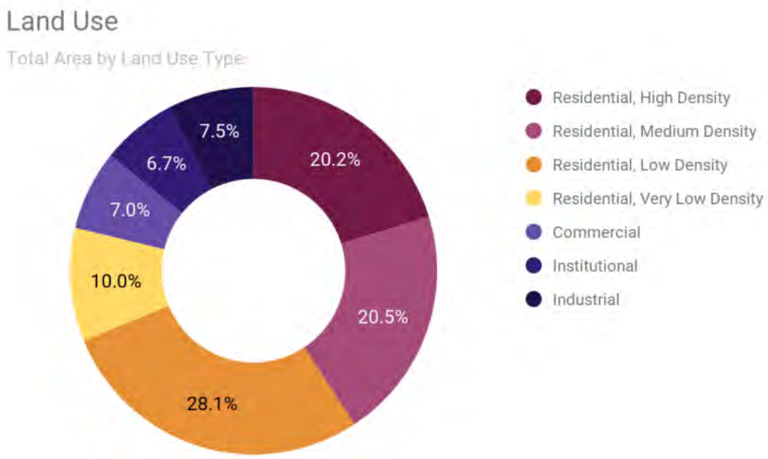
Engineering Feasibility Study

Land Use Density



Source: BuroHappold analysis; MassGIS



LU Category	Total Area (ac)	Pct. Total
Residential, High Density	207,264	20.2%
Residential, Medium Density	209,655	20.5%
Residential, Low Density	287,314	28.1%
Residential, Very Low Density	102,183	10.0%
Commercial	72,055	7.0%
Institutional	68,288	6.7%
Industrial	77,200	7.5%
Total	**1,023,959**	

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Building Energy Profiles

Energy profiles created for six building typologies:

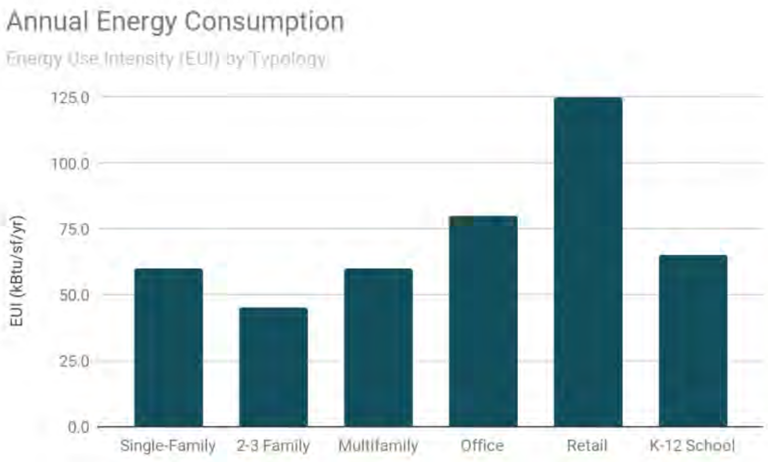
1. Single-family residential
2. 2-3 Family Residential
3. Multifamily Residential
4. Commercial Office
5. Commercial Retail
6. K-12 School

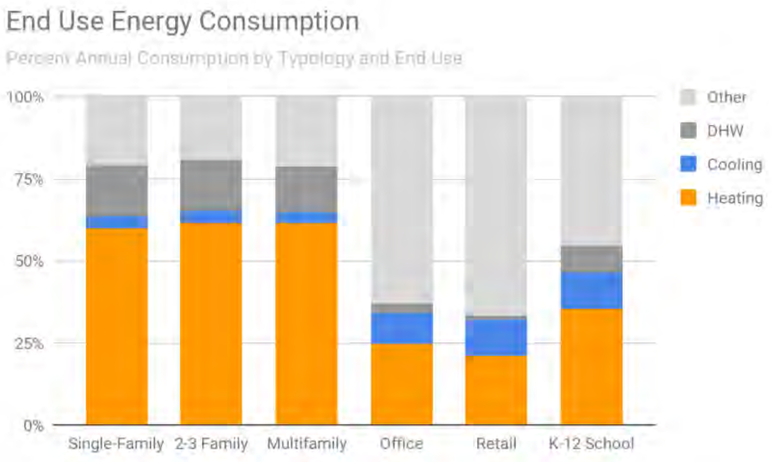
Energy Use Intensity
MA DOER Technical Reference Manual, DOE CBECS and EIA RECS data.

Seasonal Demand Patterns
DOE commercial and residential reference buildings.

End Use Consumption
DOE CBECS and EIA RECS data.

Hourly Load Shapes (Peak Day)
EPRI Load Shape Library





Typology	Typ. Area (sf)	EUI (kBtu/sf/yr)	Energy (kBtu/yr)	Heating	Cooling	DHW	Other
Single-Family	1,500	60.0	90,000	59.8%	3.8%	15.5%	20.9%
2-3 Family	3,000	45.0	135,000	61.7%	3.6%	15.5%	19.2%
Multifamily	20,000	60.0	1,200,000	61.5%	3.5%	13.8%	21.2%
Office	150,000	80.0	12,000,000	24.6%	9.5%	2.8%	63.1%
Retail	25,000	125.0	3,125,000	20.9%	11.0%	1.4%	66.7%
K-12 School	140,000	65.0	9,100,000	35.5%	10.8%	8.1%	45.6%

Source: BuroHappold analysis; U.S. DOE; U.S. EIA

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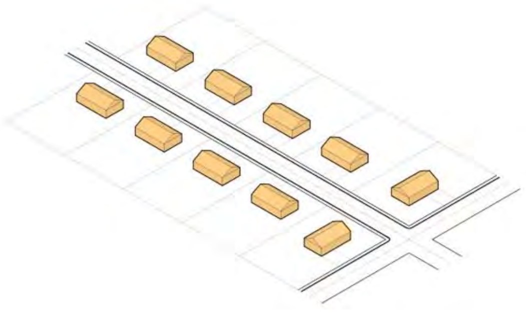
Prototype Street Segments

Four prototype street segments (PSS) created and analyzed:

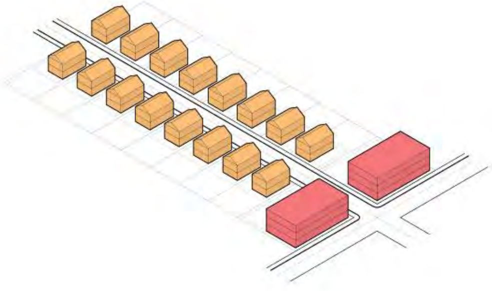
1. Low density residential
2. Medium density residential
3. Medium density mixed-use
4. High density mixed-use

The Right-of-Way is 600 to 650 feet long and 40 feet wide.

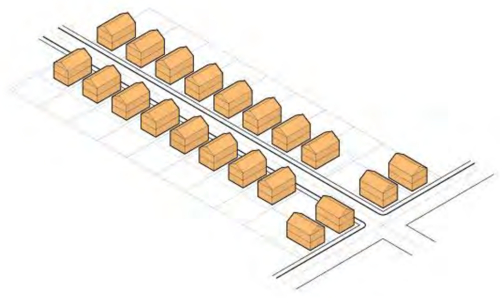
Low density residential



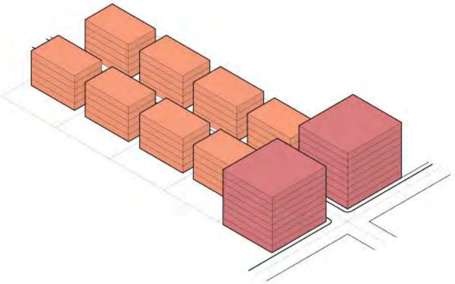
Medium density mixed-use



Medium density residential



High density mixed-use



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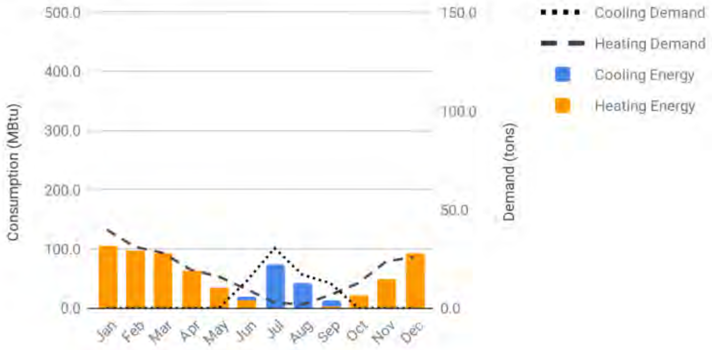
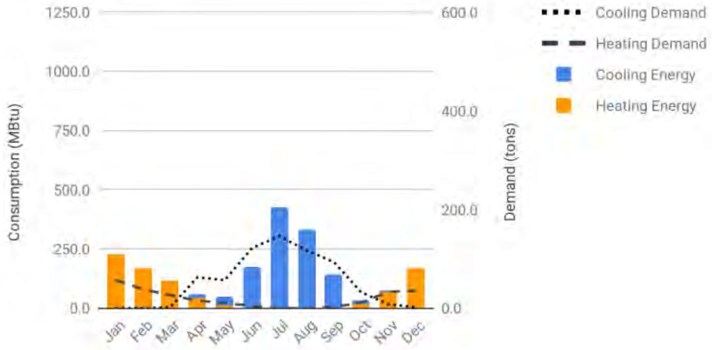
Low Density Residential

Thermal Energy Loads



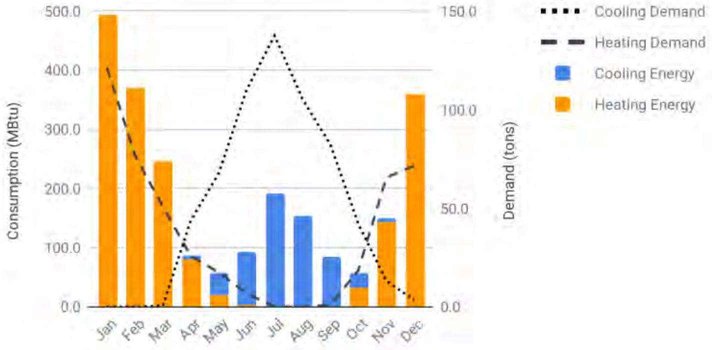
Medium Density Mixed-Use

Thermal Energy Loads



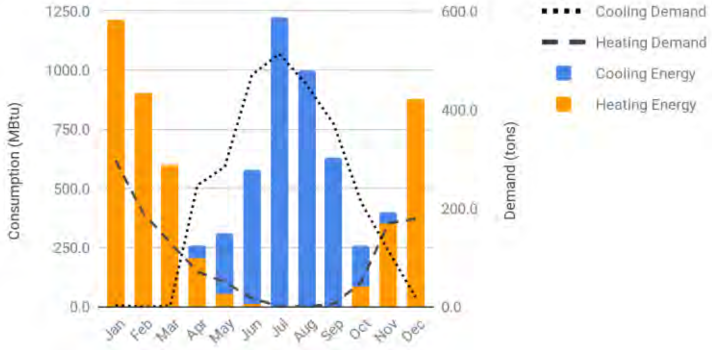
Medium Density Residential

Thermal Energy Loads



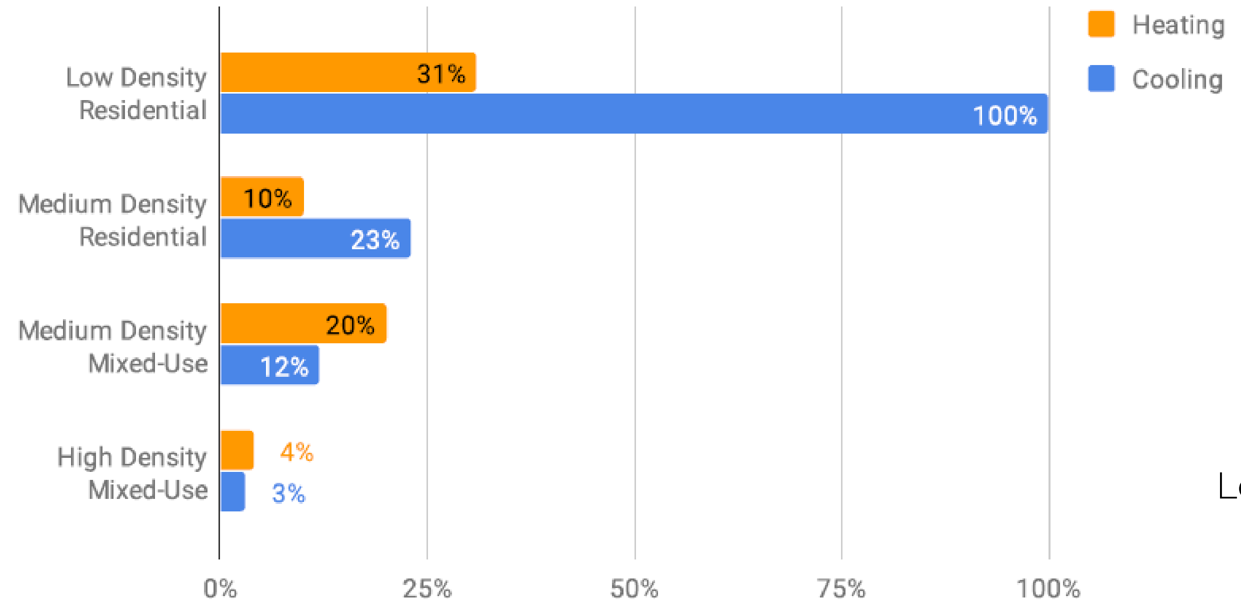
High Density Mixed-Use

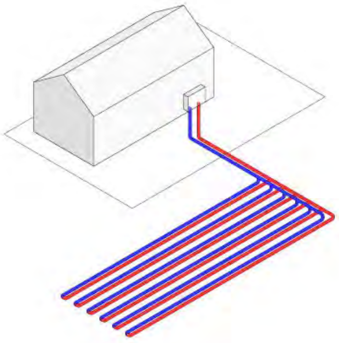
Thermal Energy Loads



Technical Feasibility: GCHP Closed Horizontal

Annual Heating and Cooling Loads Met (Interconnected)





Loop Length = 2000 feet

Closed horizontal systems were unable to meet 100% of heating and cooling loads with the parameters modeled.

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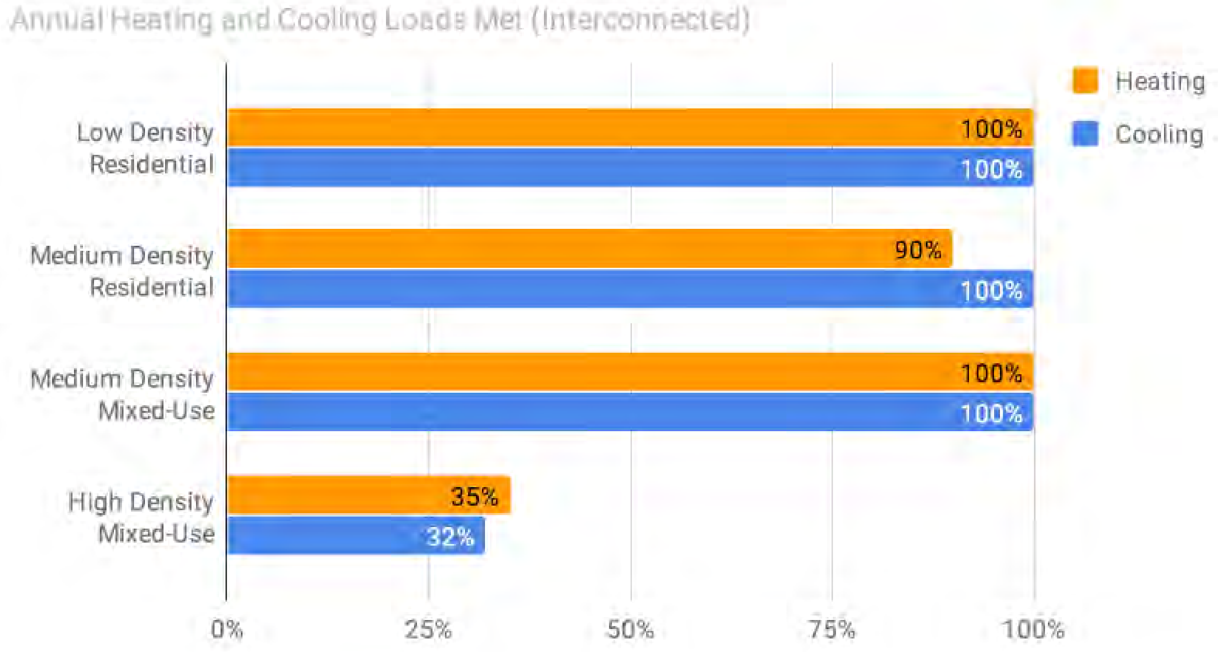
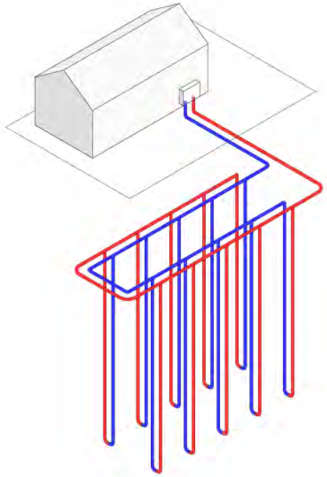
Technical Feasibility: GCHP Closed Vertical





Loop Length = 4000 to 15,000 feet

Closed vertical systems were able to meet 100% of heating and cooling loads for 2 of the 4 PSS modeled.

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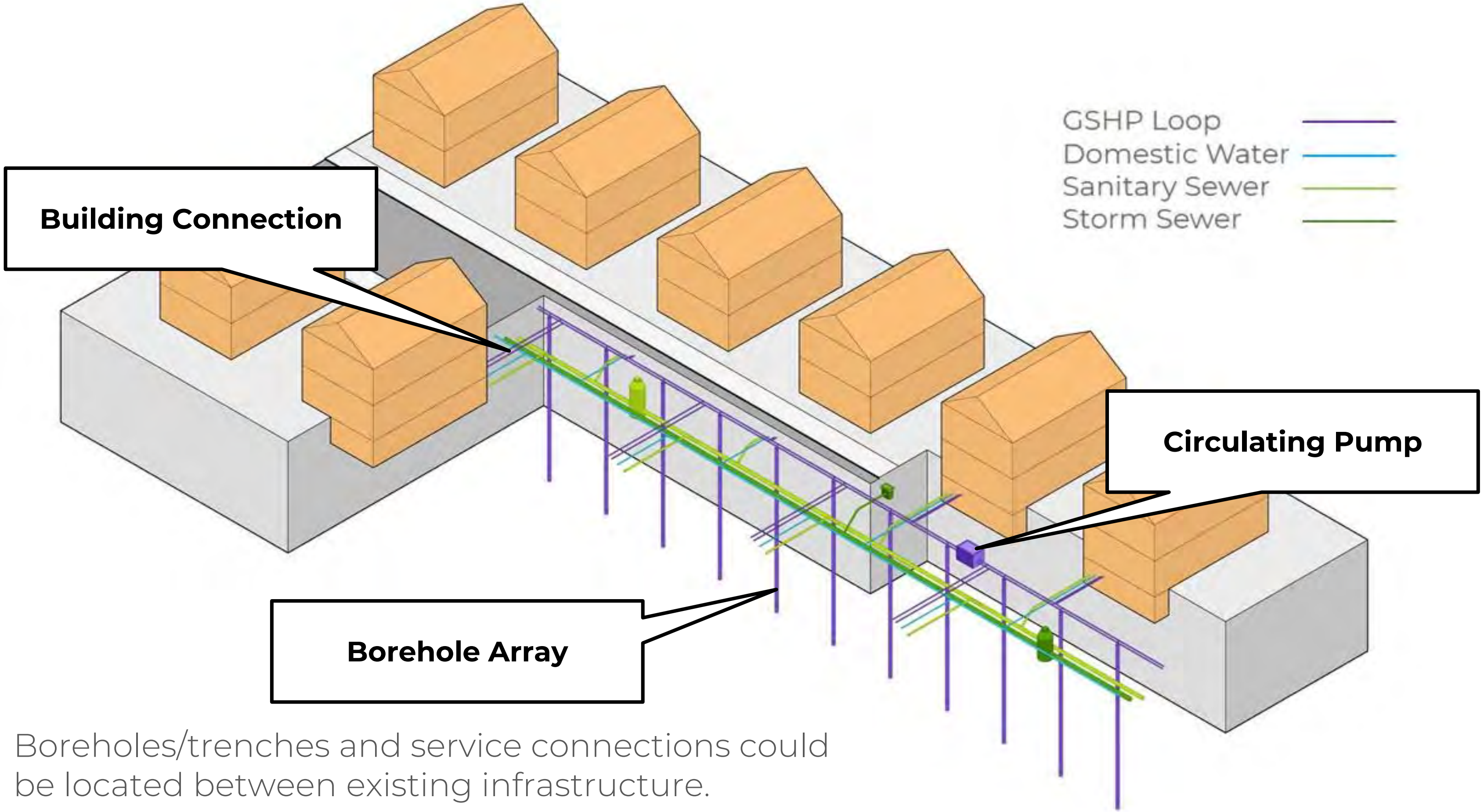

Boreholes/trenches and service connections could be located between existing infrastructure.

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Economic Feasibility Study

Costs

Costs to Utility:

- Equipment and labor
  - Drill rig setup/breakdown
  - Borehole drilling
  - Loop piping and installation
  - Circulating fluid
  - System pumps
- Other allowances:
  - Design and engineering
  - Permits and approvals
  - Overhead, profit, and contingency
  - Economies of scale

Cost to Customer:

- Energy Efficiency Retrofit:
  - Air sealing and Insulation
  - White/cool roof
- GCHP Conversion:
  - Heat pump installation
  - Backup ASHP Installation
  - Gas to electric conversion
- New appliances
  - Electric domestic hot water heater
  - Electric stove/oven
  - Electric dryer

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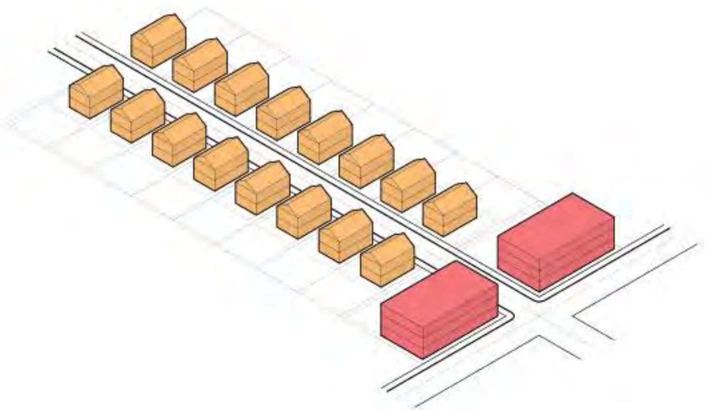
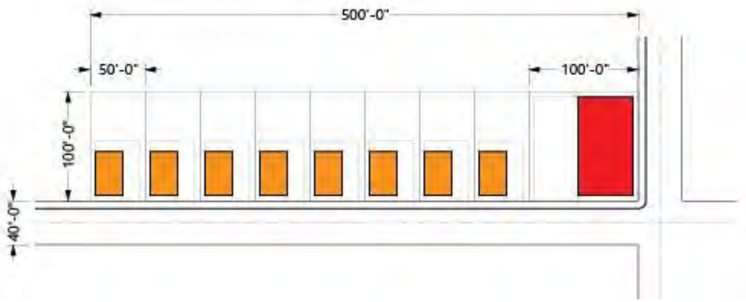
Medium Density Mixed-Use

- **16 2-3 family homes**
- **2 commercial buildings**
- 75,000 gsf total area
- 5,535 MBtu/yr consumption
- 101 tons heating demand
- 39 tons cooling demand
- 500 ft. long ROW
- 2 lines of 30 boreholes





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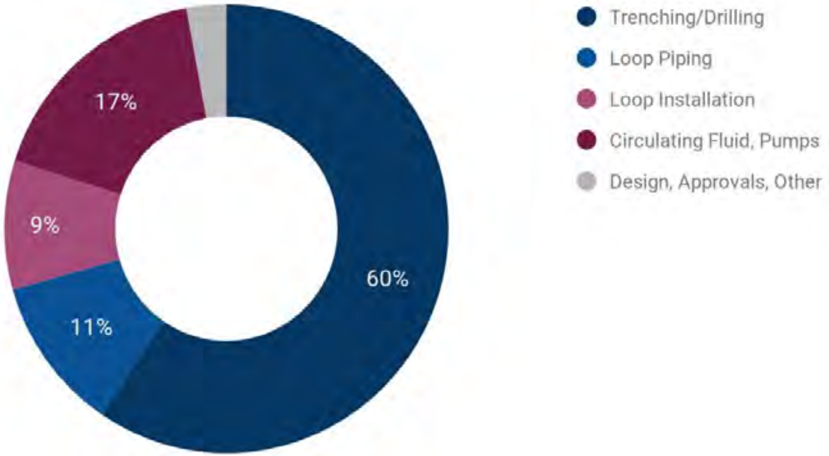
Installation and Conversion Costs

Medium Density Mixed Use

Investment	Estimated Cost
GSHP Installation	$500,000
Residential Conversion	$5,000/unit*
Commercial Conversion	$80,000/building*

* Estimated conversion costs after rebates and financing

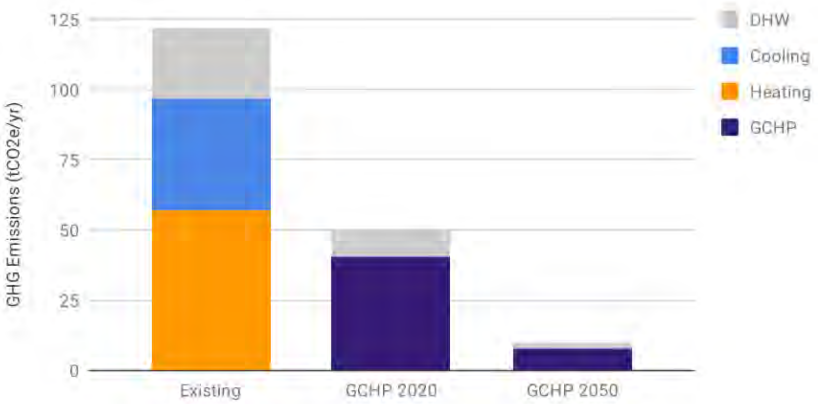
Revenue earned from thermal energy sales have not been evaluated.



Conclusion

Benefits

- Increased safety
- Energy bill savings
- Water bill savings
- Reduced GHG emissions
- Improved indoor air quality
- Equitable electrification



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Potential Pilots

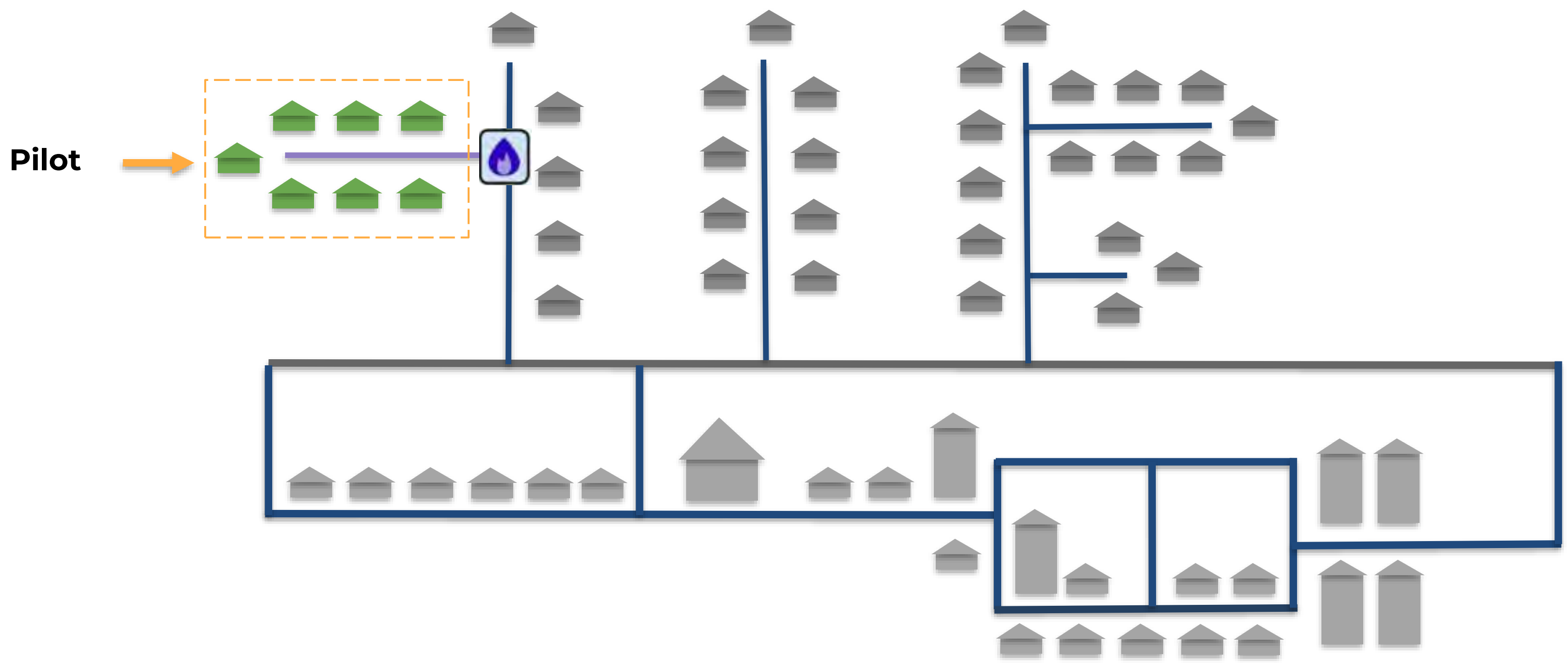
In Massachusetts

- **Columbia Gas Settlement**
  $4 million competitive grant
- **Eversource Gas**
  3 pilots requested, ruling October 30, 2020
- **National Grid**
  Will request permission in November, 2020

Outside of Massachusetts

- Niagara Mohawk
- Con Ed
- NYSERDA
- Bridgeport, Connecticut

The GeoMicroDistrict



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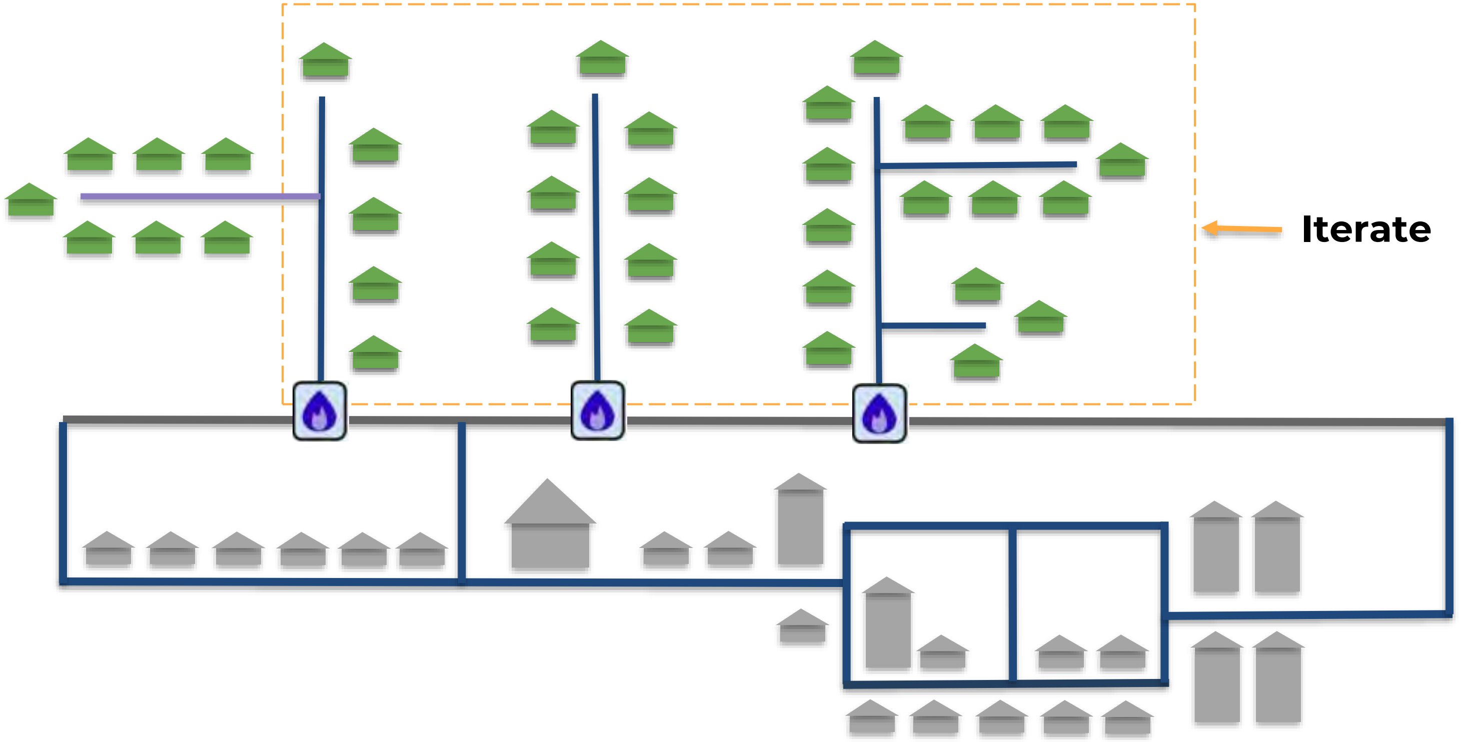
The GeoMicroDistrict



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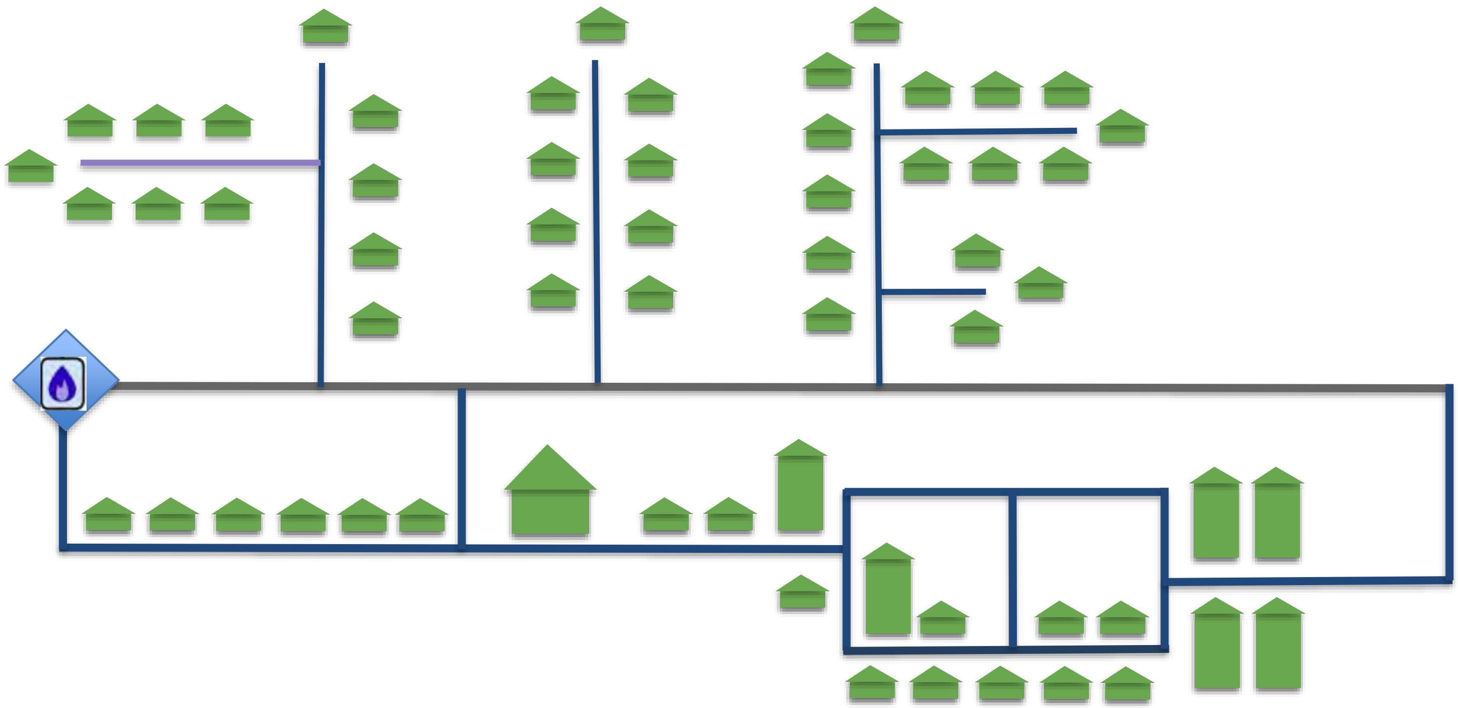
The GeoMicroDistrict



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HEET Pilot Research & Evaluation Team

- **MIT** Sloan School , System Dynamics
- **Harvard** T.H.Chan School of Public Health, C-CHANGE Institute
- **BuroHappold** Engineering
- Massachusetts **DEP** (Department of Environmental Protection)
- **Berkeley National Lab**, Earth and Environmental Science
- University of California, **Berkeley**, Civil & Environmental Engineering
- **National Renewable Energy Laboratories**
- Massachusetts **CEC** (Clean Energy Center)

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Thank You

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REFERENCES & RESOURCES

"GeoMicroDistrict Feasibility Study", Buro Happold & HEET, 2019

Eversource Gas geothermal pilot ratecase DPU 19-120

AG Healey's Petition to Consider the Future of Gas

Applied Economic Clinic policy brief

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Conversation

Boston Coastal Flood Resilience Design Guidelines

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