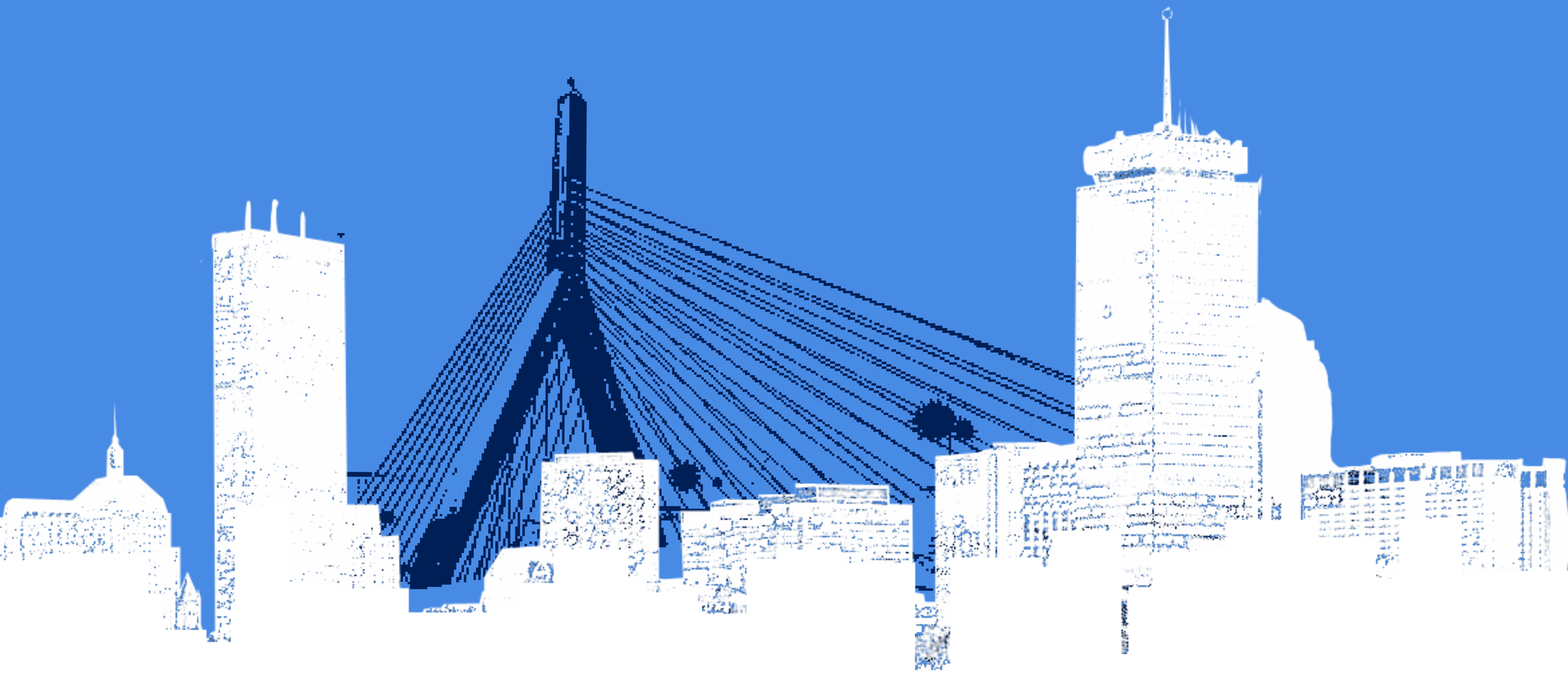
BUILDING RESILIENCE IN BOSTON

"Best Practices" for Climate Change Adaptation and Resilience for Existing Buildings



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Building Resilience in Boston

A Project for the **Boston Society of Architects**

Prepared for the **Boston Green Ribbon Comission Climate Preparedness Working Group**

Submitted July 2013

The Barr Foundation has provided funding to the Boston Society of Architects (BSA) to "provide the Boston Society of Architects, the Boston Green Ribbon Commission, and the City of Boston a better understanding of the strategies and specific measures that property owners can use to reduce their vulnerability to climate change, and the policies and programs that government and other public bodies can establish to spur such efforts." The scope of this report includes a review of national and international programs, initiatives, and activities related to improving the resilience of existing buildings in Boston to climate change impacts.

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SCOPE OF THIS STUDY

The scope of this report includes a review of national and international programs, initiatives, and activities related to improving the resilience of existing buildings to climate change impacts. The Barr Foundation has provided funding to the Boston Society of Architects (BSA) to "provide the Boston Society of Architects, the Boston Green Ribbon Commission, and the City of Boston a better understanding of the strategies and specific measures that property owners can use to reduce their vulnerability to climate change, and the policies and programs that government and other public bodies can establish to spur such efforts." This report fulfills one part of the goals of Climate Preparedness Working Group of the Green Ribbon Commission.

Resilience can be defined as the ability to recover from or adjust easily to misfortunate or change. For cities like Boston, which was settled over 350 years ago, a critical aspect is adapting existing buildings to improve resilience to natural hazards, particularly in light of pending climate change impacts.

OVERVIEW

This report includes a review of national and international research, publications, planning documents, and related materials to establish the state-of-knowledge and identify "best practices" related to the improvement of existing buildings to better withstand climate change impacts. The report is focused on the City of Boston and its specific geologic, population, cultural, and natural environmental context, related to vulnerability and risk from natural hazards (including extreme temperatures, rain and coastal flooding, high wind, and seal level rise and storm surge) and their secondary impacts. Several recent major reports focusing on disaster resilience for cities and regions are key reference sources for the City of Boston and the Green Ribbon Commission as they consider actions to improve the resilience of the existing building stock.

It is clear from reviewing actions and reports from around the United States and the world that planning – and acting – to increase resilience of buildings that there is a lot of work to do. Building owners will be facing multiple hazards of various levels of severity at any time. Resilience needs to be included in capital planning and maintenance schedules right away.

The compilation of strategies to inform building owners about ways to improve the resilience of existing buildings draws upon numerous reference sources. Strategies are organized by the region of intervention, such as the site and specific building systems. Each strategy includes specific references for detailed technical or implementation information.

A section of this report describing municipal strategies for spurring efforts to upgrade existing buildings is illustrated with examples from cities across the U.S. and internationally. These strategies include mandatory building retrofits, mandatory actions for new construction and major retrofits, incentives for voluntary actions, financing mechanisms and grants to facilitate upgrades, and education and outreach programs. By drawing upon examples in other cities and regions, the City of Boston and public and private organizations are prepared to implement effective actions to improve the resilience of its existing buildings.

BOSTON CONTEXT

Boston is an old city. Over 50% of Boston's housing units were built before 1940 (MAPC, 2008, p. 3), with the highest proportion of pre-WWII housing among the major cities in the U.S. (Cox, 2013). Commercial buildings, on the other hand, saw a major surge of new construction after 1960, with over 25 million square feet added between 1960 and 1998 (BRA, 1999, p. 12).

The most common natural hazards in the Boston area are floods (including both rain events and coastal flooding with storm surge), severe storms (which include both rain and high wind conditions), and extreme temperatures (both hot and cold). In addition, a common secondary impact from extreme weather events is the loss of critical infrastructure services, including energy, water, wastewater, transportation, and communications.

Climate change will exacerbate these extreme weather events, increasing both the frequency of the events as well as the magnitude of the impacts. For example, sea level rise will increase the incidence of coastal flooding, especially with storm surges, and the magnitude of the flooding will increase with the rising tides. More severe storms will likewise increase rain floods and extreme wind conditions, and increased ambient temperatures will increase the number of high heat degree days.

The vulnerable populations in Boston (including the very old and very young, physically or mentally impaired, lower income, and without English language proficiency) appear in certain clusters throughout the neighborhoods of the City. For instance, East Boston has a higher proportion of vulnerable populations than downtown Boston.

While local emergency response (police, fire, EMTs) may be cognizant of the locations of assisted living facilities, daycare and elder care centers, and other officially designated places of refuge for vulnerable populations, experience in other cities has indicated that unofficial centers may need to be monitored during extreme events to protect these vulnerable populations; as an example, in New York City, certain apartment buildings have become de facto retirement communities with high concentrations of elder populations, and many of these buildings are located within close proximity to coastal regions. Therefore, additional attention may needed to identify these informal centers and to explicitly incorporate the upgrade of these facilities with respect to their higher density of vulnerable persons.

A majority of Boston's residential buildings are 1, 2, and 3 story wood-framed (the classic "triple-deckers"), which are especially vulnerable to floods, heat waves, and storms. Multi-story steel or concrete residential buildings exist across the city, and are generally less vulnerable to wind damage from storms, but may be vulnerable to flooding in low lying areas of the City. All of Boston's buildings are vulnerable to loss of critical services to different degrees, depending on specific locations in Boston. Extreme temperatures become a critical factor in public health and safety particularly when critical services (especially energy) are lost in these residential buildings.

STRATEGIES FOR IMPROVING RESILIENCE IN BUILDINGS

Improving the resilience of existing buildings for climate change impacts requires a multi-hazard approach. As noted above, expected climate change will increase the frequency and magnitude of extreme events in Boston throughout the seasons, and prudent planning will consider all relevant hazards for each location and building type.

Many of the adaptation strategies for buildings identified in this study improve resilience for several hazards at once and also provide additional benefits during normal conditions. A recent study found that, for each dollar invested in mitigation, over $4 of benefits are returned (MMC, 2006). An example adaptation strategy might be increasing the shading on a site to reduce stormwater flow, lower ambient temperatures, and lessen wind impacts as well as improve air quality and quality of life.

The adaptation strategies identified in this research work at different scales, from the site to specific building systems. The compiled list includes both smaller or incremental improvements that can be implemented over time and larger or major improvements that may require significant investments and coordination with the building occupants.

MUNICIPAL STRATEGIES TO IMPROVE RESILIENCE OF EXISTING BUILDINGS

Communities often develop and rapidly implement strategies to improve the resilience of existing buildings primarily after extreme events. California instituted major code and standard changes, and required the retrofit of existing buildings for seismic loads (earthquakes) after the Loma Prieta earthquake in 1989. Florida instituted major changes in building performance requirements for hurricane loads after Hurricane Andrew in 1992 and Hurricane Katrina in 2005.

Most cities have taken a multi-pronged approach, using a combination of mandatory upgrades, incentive programs, funding mechanisms, and education/outreach programs to enact change. Depending on the vulnerability to specific hazards, the cities may employ smaller or more incremental programs to gradually improve resilience or institute a larger-scale coordinated program to respond to critical deficiencies. New York City has proposed a significant investment program to upgrade its critical infrastructure systems and buildings to withstand a storm similar to Hurricane Sandy. Faced with limited resources, most cities have developed upgrade programs that can be changed over time to respond most effectively to climate trends; for instance, the acceleration of sea level rise may induce major East Coast U.S. cities to move more quickly on their coastal adaptation plans than was originally budgeted.

POTENTIAL NEXT STEPS FOR BOSTON

Cities across the U.S. and internationally are increasingly incorporating disaster resilience and specifically climate change adaptation into their comprehensive community plans and operations. Boston has the opportunity to learn from some of the strategies employed by these cities for its potential next steps, which include:

- convening members of the community, including business leaders, civic leaders, and representatives from organizations responsible for major segments of the building stock to identify and prioritize potential resilience strategies;

- developing the capacity of local organizations to develop and implement specific actions;

- coordinating among federal, state and local public and private organizations to mitigate vulnerabilities and improve community resilience; and

- leveraging current and emerging state, and federal regulations and local assets to accelerate the resilience improvement of existing Boston buildings.

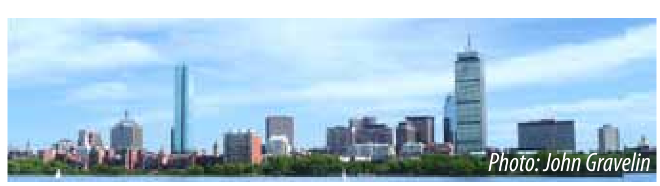


Photo: John Gravelin

Section 1:

Scope and Context of This Study

Photo: John Gravelin

Section 1: **Scope and Context of this Study**

Scope of Study

The focus of this study is on strategies for improving the resilience of existing buildings in Boston. Specifically, this study compiles a selection of "best practices" to improve the resilience of buildings to current and emerging hazards related to climate change. This report focuses on enhancing the resilience of existing buildings because newly designed buildings can easily adapt to new building standards, but adapting existing buildings takes more effort and different strategies.

Much of Boston's building stock is over 50 years old. Over 50% of Boston's housing units were built before 1940 (MAPC, 2008, p. 3); the highest proportion of pre-WWII housing among the major cities in the U.S. (Cox, 2013). Commercial buildings saw a major surge of new construction after 1960, with over 25 million square feet added between 1960 and 1998 (BRA, 1999, p. 12). .

This study includes:

A review of literature and planning documents:

Annotated selected bibliography of relevant published reports and unpublished planning efforts around the U.S. and the world;

- Interviews with selected relevant agencies and organizations on goals, processes, and best practices for resilience planning;
- A compilation of resilience-focused best practices from around the U.S. and internationally regarding upgrading existing buildings to improve disaster resilience;
- A review of municipal and regional resilience planning steps and elements from around the U.S. and internationally;
- A review of potential goals and processes for effective building resilience planning by the City of Boston, the BSA, and the Green Ribbon Commission's Climate Preparedness Workgin Group (CPWG).

Section 1 includes a brief description of the City of Boston, including the natural resources and populations, as well as relevant hazards. This section includes descriptions of the current building stock, by building type and location, mapped to the relevant hazards.

Section 2 provides a summary of selected major reference reports, with a full annotated bibliography in Appendix A.

Section 3 provides the compilation of resilience-focused "Best Practices" for existing buildings, based on multiple resources. Each "Best Practice" includes a brief description and reference to detailed technical sources.

The final sections provide a framework for future actions. Section 4 discusses the range of current municipal actions for resilience planning and implementation, with specific examples from currently implemented programs across the U.S. and internationally.

Section 5 provides a mapping of current resources and opportunities for collaboration within the Boston area for resilience planning and implementation.

Context

> ***A few leading companies are taking steps to address climate risks where they see significant opportunities to become more efficient, reduce costs, or provide greater value to customers - in other words, where there is a clear business case to do so. By and large, however, the business response thus far is largely a continuation of existing practices based on a historical picture of past risks, and often fails to adequately consider changing climate and weather conditions.***
>
> *Crawford and Seidel, 2013 page IX*

Resilience

The Merriam-Webster definition of resilience is "the ability to recover from or adjust easily to misfortune or change" (Merriam-Webster, 2013).

The recent National Research Council report defines resilience as "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse effects." (NRC, 2012, p.16)[1]

The Resilient Design Institute defines resilience as "the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance" (Wilson, 2013).

For many communities and organizations, resilience planning requires a detailed assessment of the exposure of critical community assets to natural and man-made hazards, and an evaluation of the risk of loss or failure from these hazard exposures. The relative risk of failure or loss from these exposures is related to the frequency and magnitude of the incidence of extreme events.

Current projections for climate change impacts indicate that, for Boston, both the frequency and magnitude of extreme events will increase in the future. Therefore, resilience planning for Boston should include projected trends in relevant hazards and the related vulnerability for the city.

Resilience and Community Viability

The recent NRC report provides an analogy for the resilience of a community by comparing it to a healthy human body.

> ***"Communities can be viewed as a set of interrelated systems that share a common vision, and the overall resilience of communities may be viewed in much the same way as the overall health of the human body. A human body relies on the integrated functioning of its shared systems—like the skeletal, nervous, and immune systems—to maintain health and resist disease and injury. Similarly, communities depend on a number of interrelated systems for economic stability and growth, commerce, education, communication, population wellness, energy, and transportation. The relative "health" of community systems will determine how well a community can withstand disruptive events. If a community has weakened infrastructure, like a human body with a compromised immune system, it will not withstand trauma as well as one in good health."***
>
> ***(NRC, 2012)***

Healthy Ecosystems

Resilience is also a key factor in healthy ecosystems. Analysis of responses of natural systems to disruptions, and particularly resilience as "the measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973, p. 14), has been studied in the field of applied ecology. In this framing, increased resilience improves the chances that a system will continue to exist over time despite changes in its environment and other interdependent systems. For example, the appearance of caterpillar moths may damage a particular tree species during an infestation, but if the moths destroy all of the foliage in that location, they will then starve and die, and a portion of the trees will recover and repopulate the area until the next infestation. Several ecological studies have demonstrated that species diversity in an ecosystem increases its resilience (Holling, 1973, p. 19).

Recent research indicates that the resilience of natural systems that provide critical resources for human communities can be enhanced through "adaptive management" approaches, specifically through community-based programs that respond to changes over time (Tompkins and Adger, 2004).

1 The NRC report further notes that "(a)lthough resilience with respect to hazards and disasters has been part of the research literature for decades (White and Haas, 1975; Mileti, 1999), the term first gained currency among national governments in 2005 with the adoption of The Hyogo Framework for Action by 168 members of the United Nations to ensure that reducing risks to disasters and building resilience to disasters became priorities for governments and local communities (UNISDR, 2007). The literature has since grown with new definitions of resilience and the entities or systems to which resilience refers (e.g., ecological systems, infrastructure, individuals, economic systems, communities) (Bruneau et al., 2003; Flynn, 2007; Gunderson, 2009; Plodinec, 2009; Rose, 2009; Cutter et al., 2010). Disaster resilience has been described as a process (Norris et al., 2008; Sherrieb et al., 2010), an outcome (Kahan et al., 2009), or both (Cutter et al., 2008), and as a term that can embrace inputs from engineering and the physical, social, and economic sciences (Colten et al., 2008). (NRC, 2012, p. 18)

Boston

Growth of the City of Boston (1630-Present)

In 1630, Boston was a small isthmus within a rich delta of the three major rivers (the Charles, Mystic, and Neponset Rivers), and a perfect sheltered harbor (Figure 1.1). Travelers to the city noted its beauty and abundance; in 1614, John Smith noted that the harbor was "the Paradise of all these parts" (Mitchell, 2008).

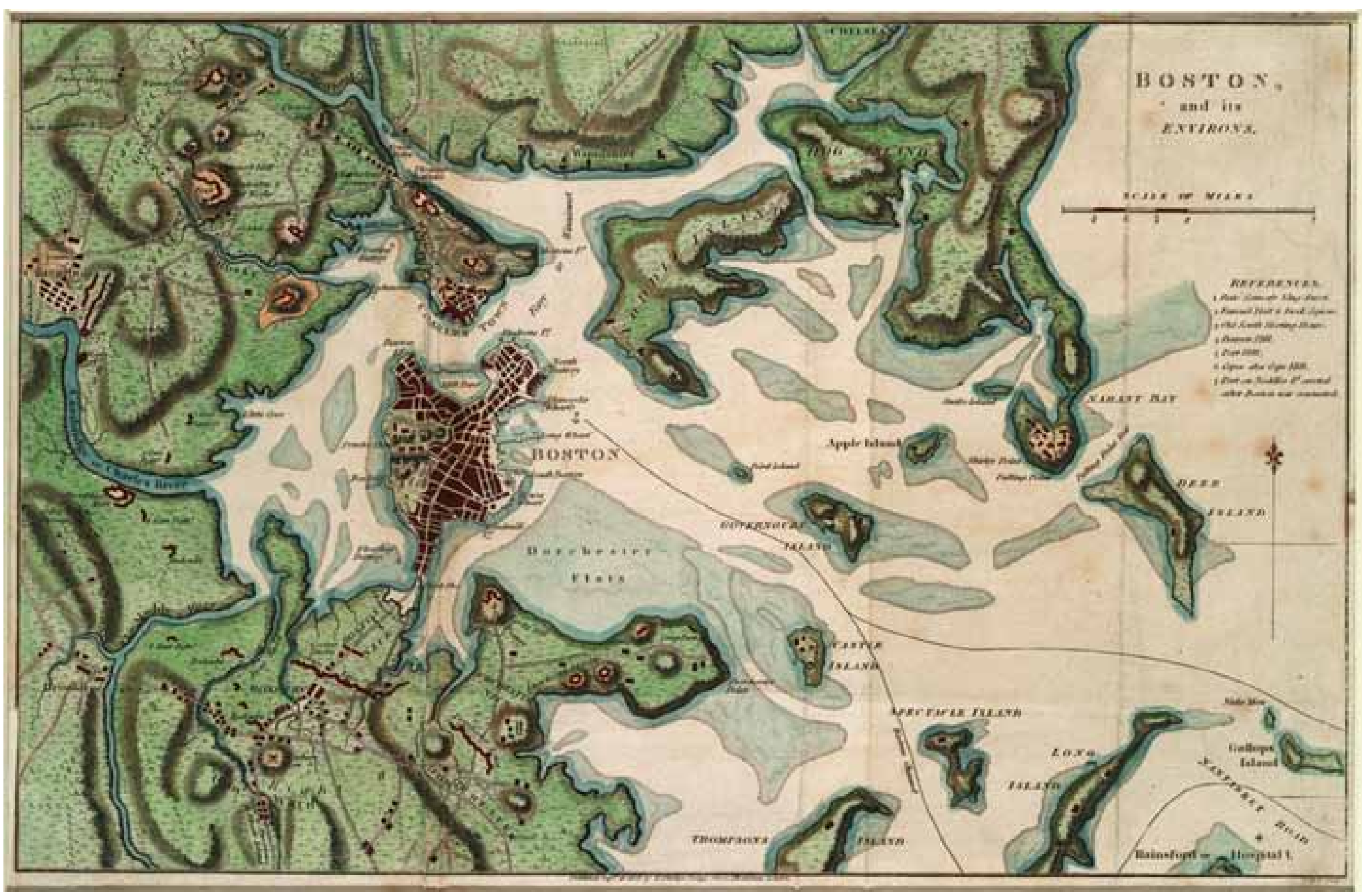
Four hundred years later, Boston is a vibrant city in a changed harbor. Over the centuries, the city has expanded through filling in the coastlines and river shorelines to create new land area that has been developed into residential, commercial, and retail areas. Starting in the early 1800s, new areas of the city were created through filling in selected marshes and ponds, culminating in the massive program that created the Back Bay and the South End in the mid to late 19th century. The docks along the harbor have also been filled in, creating the South End, portions of downtown Boston, and the Seaport district.

Greater Boston's historical, cultural, educational, environmental and pedestrian appeal, as the heart of the American Revolution and a haven of world-renowned attractions — Old North Church, Museum of Fine Arts, Harvard University, Harbor Islands, walkable shopping at Faneuil Hall Marketplace — remains a principal draw for international tourists, who constitute 10 percent of Boston's visitors and generate 15 percent of its estimated $12 billion in annual tourist revenue, according to Patrick Moscaritolo, president and CEO of the Greater Boston Convention and Visitors Bureau.

(http://www.bizjournals.com/boston/print-edition/2012/06/29/tourism-seeing-steady-growth.html?page=all)

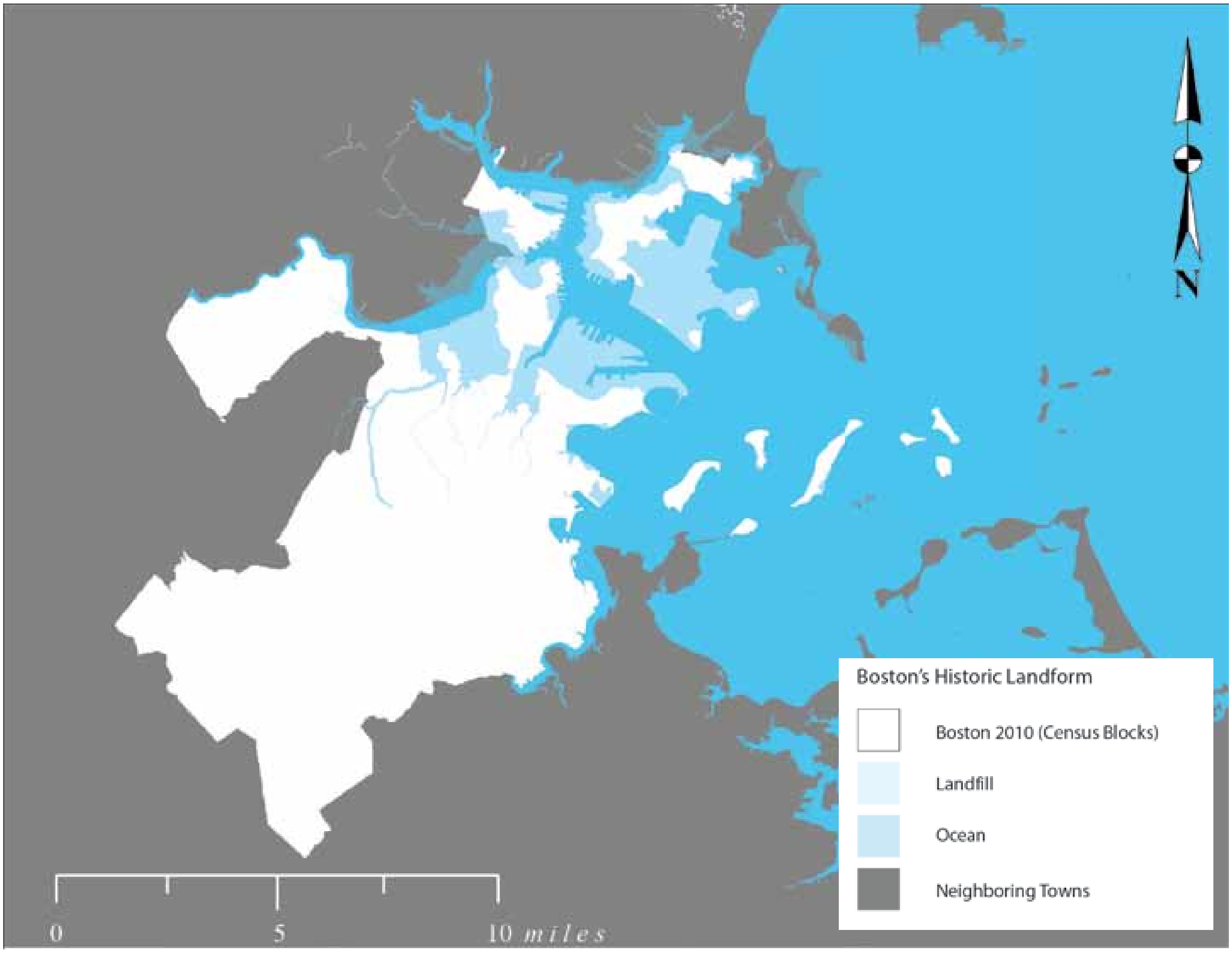
The dam was built on the Charles River (originally in 1910 and revised in 1978) to protect the Back Bay and other contiguous areas from the impacts of the changing tides and potential flooding (US Army Corps, 2013a). The dam on the Mystic Rivers (in 1966) was created to enhance shipping (US Army Corps, 2013b).

Figure 1.1: Early Boston (1806)



Source: Phillips, 1806.

Figure 1.2: Overlay of Historic Boston and Current City Land



The city boundaries have extended over time to include the historic towns of Dorchester and South Boston (in 1804), East Boston (in 1836), Roxbury (in 1868), West Roxbury, Jamaica Plains, Roslindale, Allston, Brighton and Charlestown (in 1874) and Hyde Park (in 1912) (Bacon, 1891) (Figure 1.2).

Current City of Boston Population

The City of Boston in 2011 covers 48 square miles, with a population of 626,000, and ranks as the 21st largest city in the U.S., but the Greater Boston Metropolitan Area ranks as the fifth-largest in the U.S. (US Census, 2011). The population in Boston increased by 3% between 2010 and 2012, and approximately one-third of the population is under 18 or over 65 (Table 1.1).

Photos: John Gravelin

Table 1.1: Boston Population Statistics

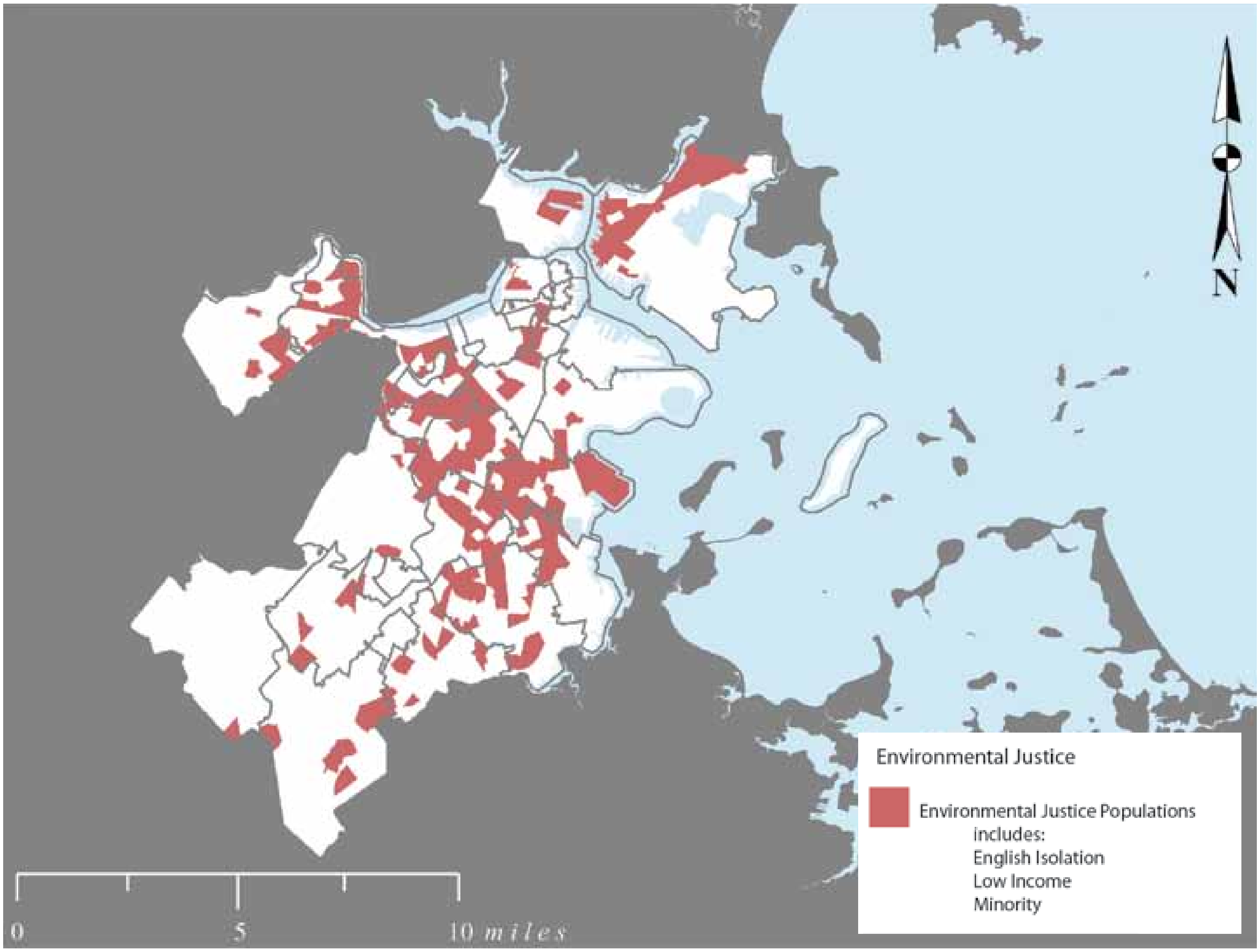
Population, 2012 estimate	636,479
Population Percent change (2010 to 2012)	3.1%
Persons under 18 years (percent), 2010	17%
Persons over 65 years old (percent), 2010	10%
Persons white alone, not Hispanic or Latino (percent), 2010	47%
Foreign-born persons (percent), 2010	27%
Language other than English spoken at home, age 5+ (percent), 2007-2011	36%
Median household income, 2007-2011	$51,739
Persons below poverty level (percent), 2007-2011	21%
Persons per square mile, 2010	12,793

Source: US Census, 2012

Figure 1.3: Boston Neighborhoods

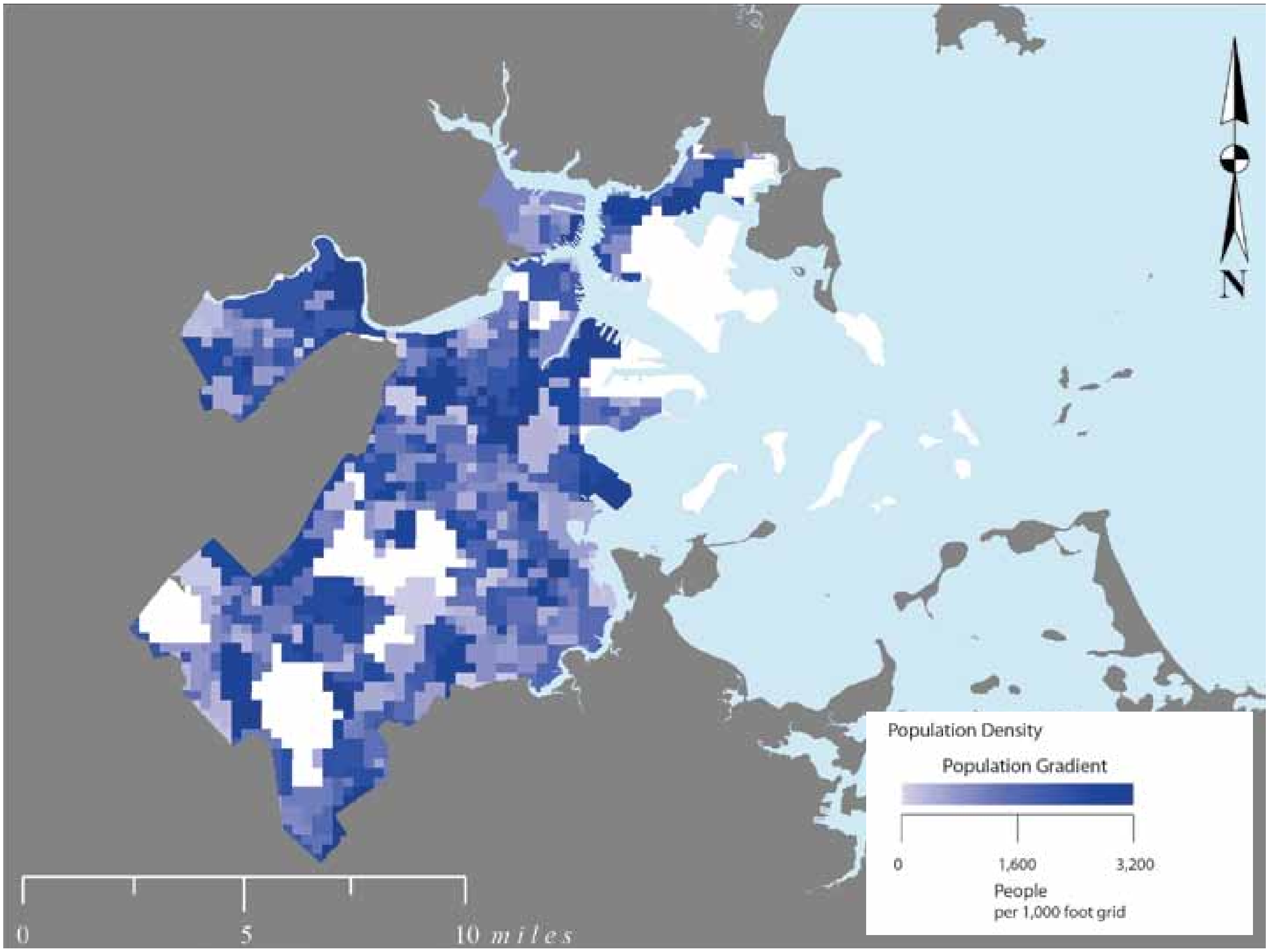
Source: City of Boston

Figure 1.4 Boston Environmental Justice Populations



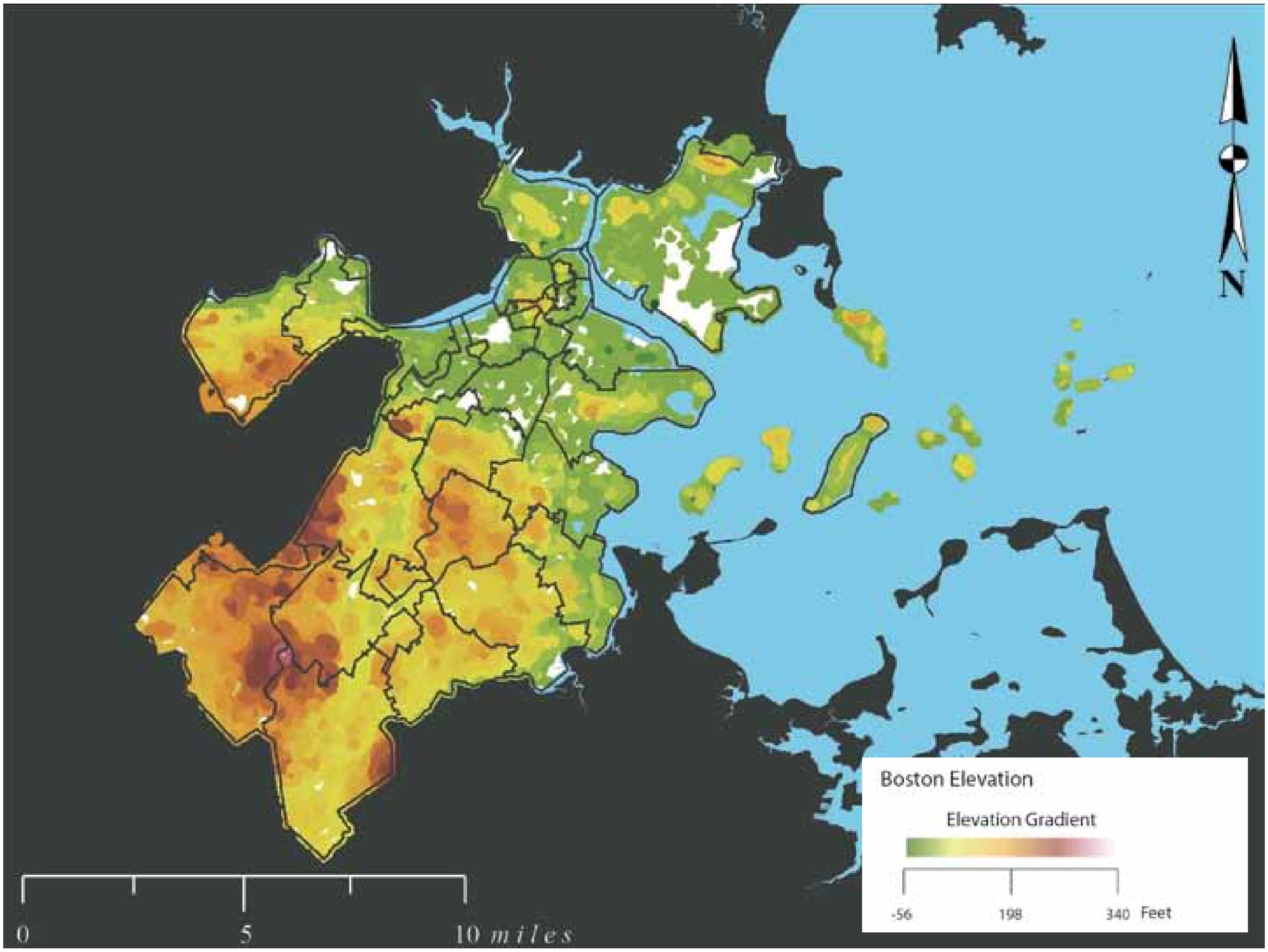
The neighborhoods of Boston are very different in the relative types and percentages of buildings, the different populations, the differences in the vulnerability of populations, and the exposure to different hazards. One useful way to understand the varying vulnerabilities to hazards of the different neighborhoods of Boston is to look at a mapping of neighborhoods with respect to income, relative English language proficiency, and minority status (Figure 1.4).

Figure 1.5 Boston Population Densities



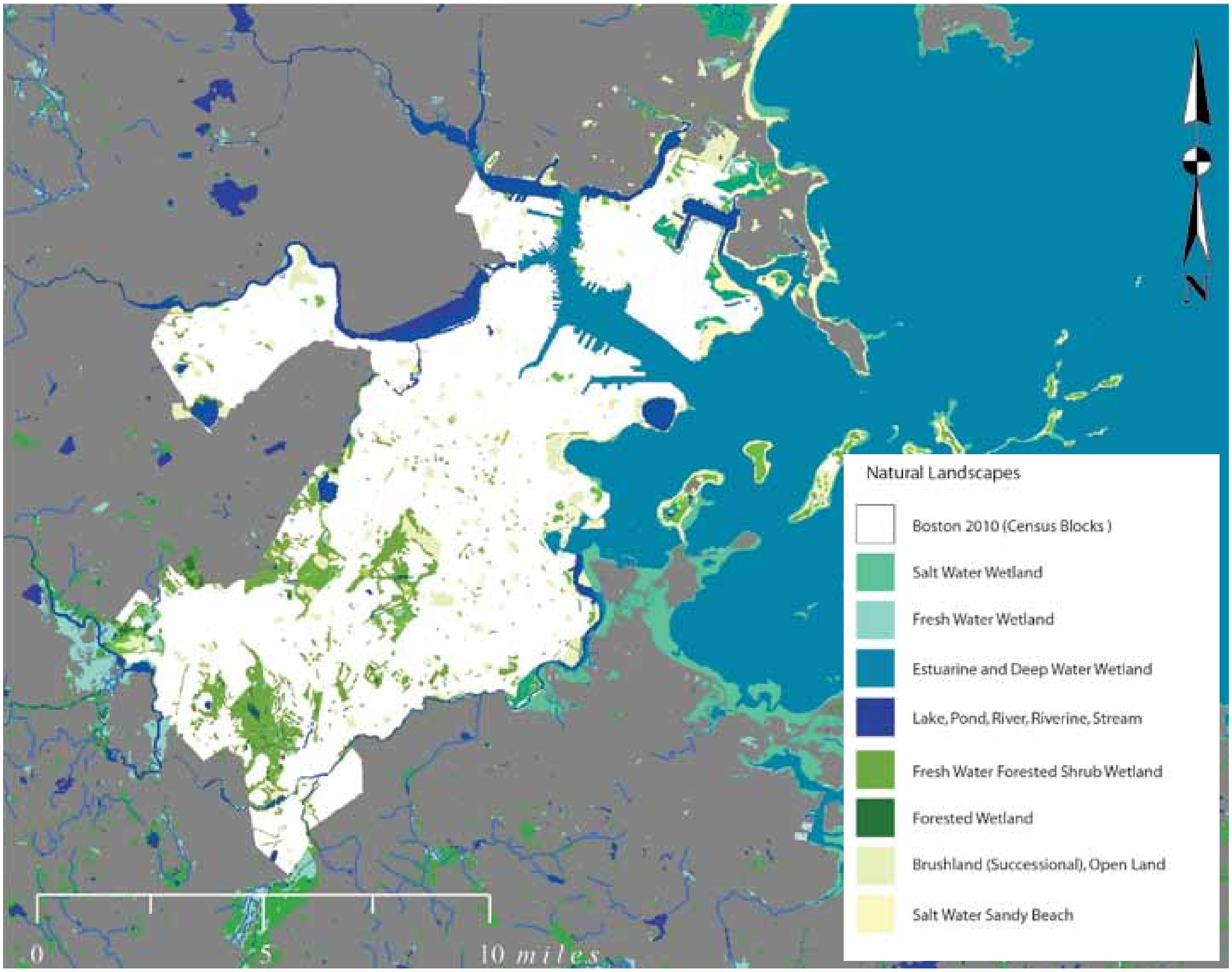
The population density is also an important indicator of the vulnerability of a neighborhood. Some of the highest-density neighborhoods are in the downtown areas, East Boston, and Dorchester, with some of the lowest population densities in Jamaica Plain, West Roxbury, and Hyde Park (Figure 1.5).

Figure 1.6: Topography of Boston



The city's official elevation is 46 ft. (14 meters) above sea level (USGS, 1974), with the lowest portions of the city at sea level (Figure 1.6) and the highest point in the city in Bellevue Hill at 330 ft. above sea level. Among the lowest elevations in the city are the areas created by landfills during the 1800s along the coastline and river banks.

Figure 1.7 Boston Natural Landscapes and Wetlands



Natural Resources in Boston

The City of Boston is located within the Boston Basin eco-region, part of the Southern New England Coastal Plains. Three rivers bound the city. Several large freshwater ponds (including Jamaica Pond and Chandler Pond) and tidal estuaries provide rich, productive ecosystems. The National Wetland Inventory shows existing marine wetlands, particularly in East Boston, and emergent freshwater wetlands in the southwestern portion of the city.

The City of Boston also possesses world-famous parks, including the Emerald Necklace, Forest Hills, the Boston Commons and Public Garden (Figure 1.7), and the Esplanade along the Charles River. The Charles was once designated as the country's dirtiest urban river but has recently been awarded the 2011 International River Prize as one of the cleanest urban rivers in the U.S.

Boston's Existing Building Stock

Everyone is familiar with the iconic building types of Boston; Dorchester's triple-deckers, the stately brick townhouses of Beacon Hill, the modern office towers of the Financial District.

> *One of America's oldest continuously occupied cities, Boston is made up of buildings constructed in many different ways over a period of more than three centuries. New architectural styles appeared while others became old-fashioned and died out, but sometimes buildings in different styles were built at the same time.*
>
> *(http://www.bostonpreservation.org/advocacy/architectural-style-guide.html)*

Understanding the city's vulnerability to climate change and other hazards, and crafting adaptive responses, means understanding the range of building types in the city, as well as understanding how different building types are distributed around Boston and around Boston's neighborhoods.

The range of building types in Boston is both a vulnerability and a source of strength. It is a vulnerability because crafting city-wide responses to hazards is more complicated for a more complex building stock. On the other hand, the range of building types is a strength because different building types have different vulnerabilities, so any one type of hazard will not devastate the whole city , thereby providing strength through diversity.

Buildings in Boston are dominated by small scale housing. 1 to 3 story housing – single family houses, two-family houses, and triple-deckers – make up over 30% of the total square footage of built space in Boston. The next biggest category of buildings is mid scale residential buildings – residential buildings with less than 30 units or less than 7 stories. Together, low and mod-rise residential buildings make up almost half of the built square footage in Boston.

Boston's commercial building stock also shows a large range of both age and size.

> *The Boston commercial property market is comprised of a diverse mix of property types, from large multi-million square foot office towers owned by global real estate investment firms, to small one- and two-story properties owned by local family trusts.*
>
> *(Energy Efficiency and Commercial Real Estate, A Better City)*

According to Energy Efficiency and Commercial Real Estate, put out by A Better City, 65% percent of the city's commercial buildings were built before 1930, though these represent mostly class B and class C office space. The class A office buildings are generally newer and larger than their class B and C neighbors.

We have defined 11 building types for this study, based on the building types defined in the City of Boston Assessor's Database. The Assessor's database lists over 250 different types of buildings for Boston. A breakdown is provided in Appendix C of how building types are aggregated into the 11 main building types used in this analysis. Our list is as follows:

- **Small Scale Residential** – 1 to 3 units per Building
- **Mid Scale Residential** – less than 30 units or less than 7 stories
- **High Rise Residential** – greater than 30 units or higher than 7 stories
- **Residential/Commercial Mixed Use** – a popular type, mostly low-rise
- **Small to Mid-Scale Commercial** – less than 5 stories
- **High-Rise Commercial** – Office buildings greater than 5 stories
- **Industrial** – buildings classified as industrial uses, mostly low-rise
- **School/Daycare/Church** – includes academic buildings
- **Medical/Laboratory** – hospitals, labs, and health care facilities
- **Government** – non-school locations classified as government use
- **Other/Land** – parks, open land, and a host of other uses.

Figure 1.8. Boston Property Gross Area Summary (in square feet)

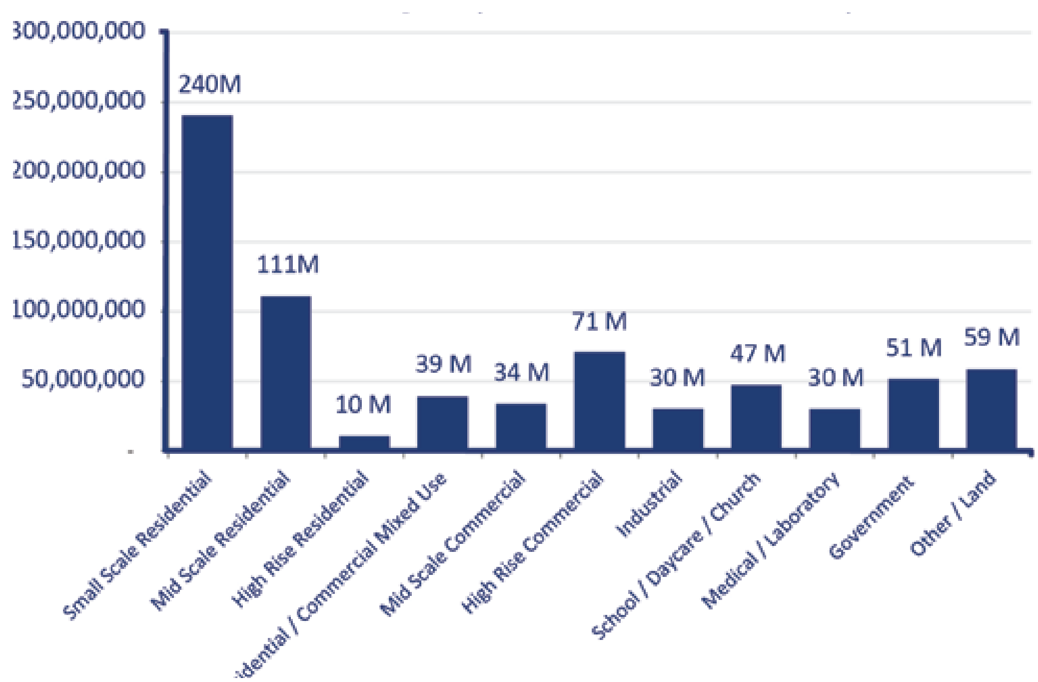


Figure 1.8. Approximately half of the built square footage in Boston is residential, especially if you consider that the Residential/Commercial Mixed Use category primarily describes shops in low-rise commercial districts with housing on top. Industrial space is not a large proportion of built square footage in Boston, but can be highly vulnerable to hazards. (Data from Boston Assessing Department.)

Figure 1.9. Boston Property Count Summary (in no. buildings)

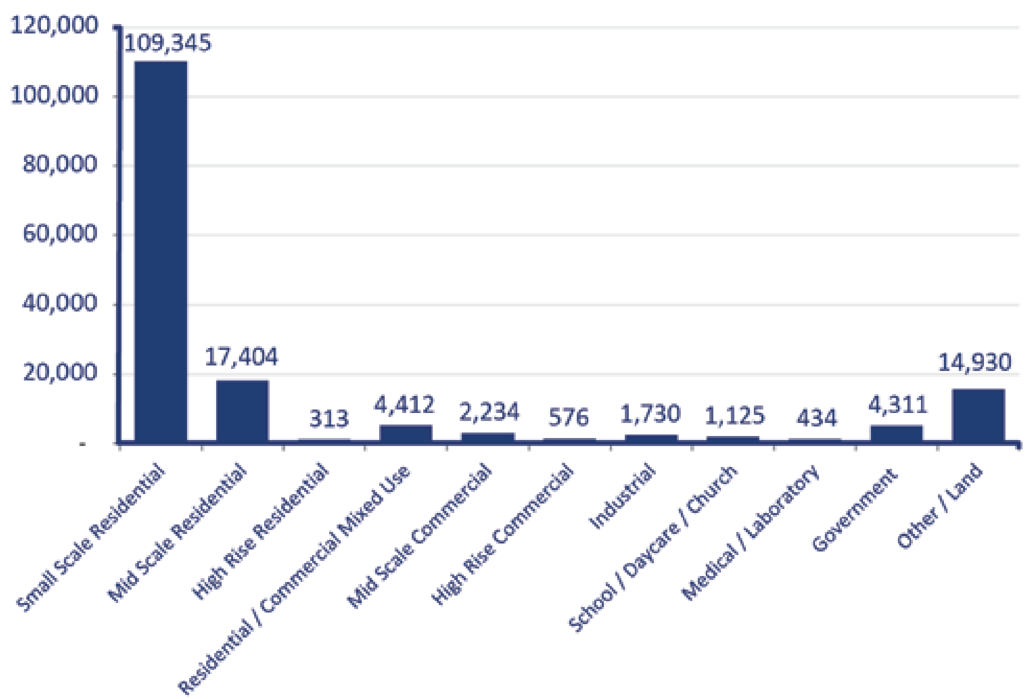
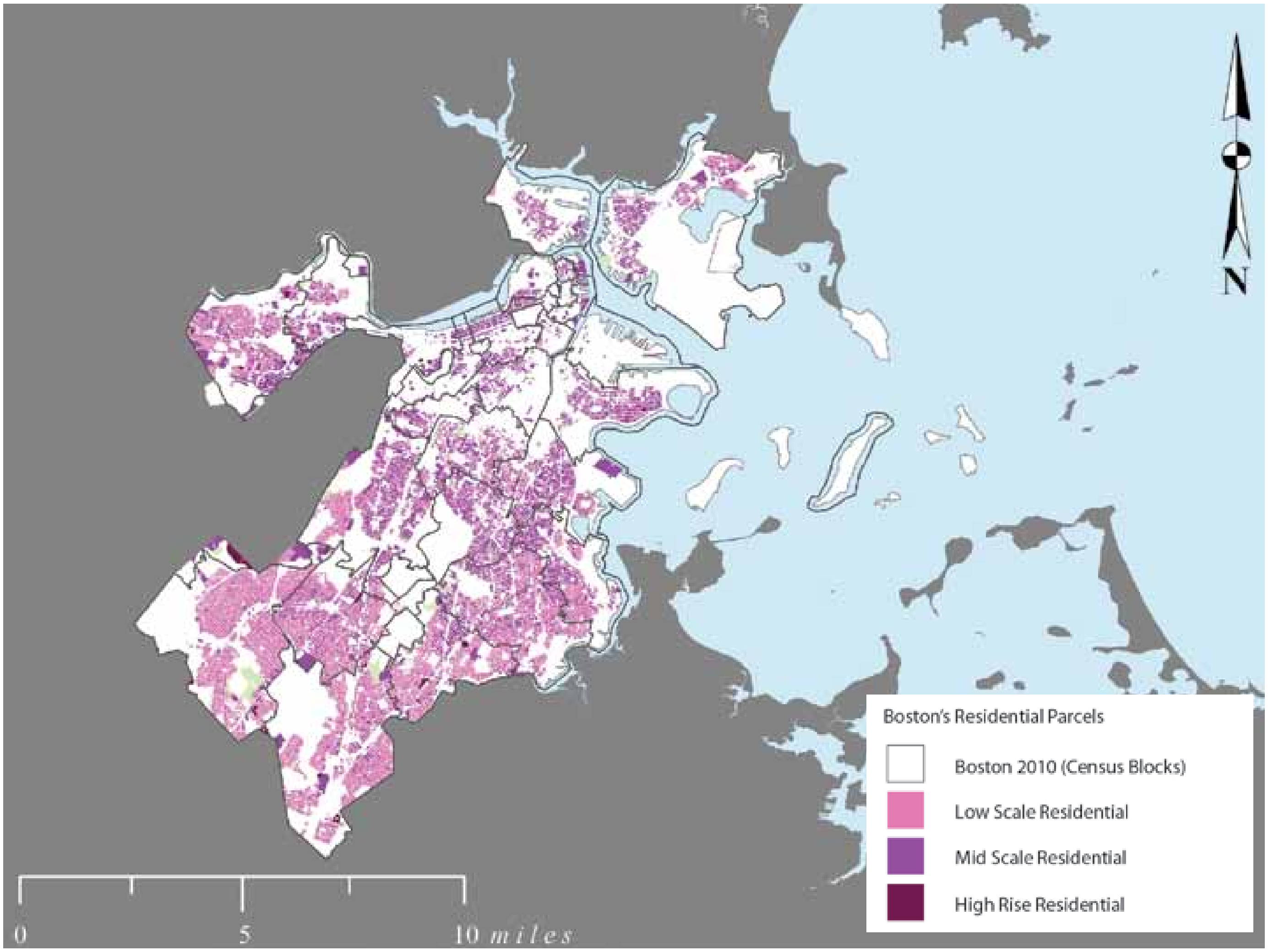


Figure 1.9. The number of small-scale residential buildings far outstrips the number of other types of buldings. Similarly, the number of small and mid-sized commercial buildings is much larger than the number of high-rise commercial buildings. (Data from Boston Assessing Department.)

Buildings in Boston can also be grouped by age and density. As noted before, Boston has some of the oldest housing stock in a major city in the US, with over 50% of Boston's housing units built before 1940. Taller buildings, both residential and commercial, are much newer, in general. However, industrial properties also tend to be older and less well prepared, with many industrial properties originally built in the 1950's.

Figure 1.10. Density of Living Spaces in Boston



Note that Downtown and parts of Charlestown show very low densities of residential space. (Data from the Boston Assessing Department.)

While different building types are distributed throughout the city, some neighborhoods are more dense in specific categories of buildings than others. Sometimes this neighborhood grouping is a result of building age and history, sometimes it is a result of zoning by the city, and in many cases, results from a confluence of forces.

For example, comparing the Allston neighborhood with the Leather District/Chinatown neighborhood, the differences in both building type and age across the city are apparent. Figures 1.11 and 1.12 show comparisons of building type and age of buildings in the two neighborhoods. Nearly 85% of buildings in Allston were built before 1950, and over 75% of buildings are residential. However, in the Leather District/Chinatown neighborhood over 20% of buildings are commercial in nature, and there are more newer buildings than in Allston.

Figure 1.11. Property Counts of Allston and Chinatown - Leather District

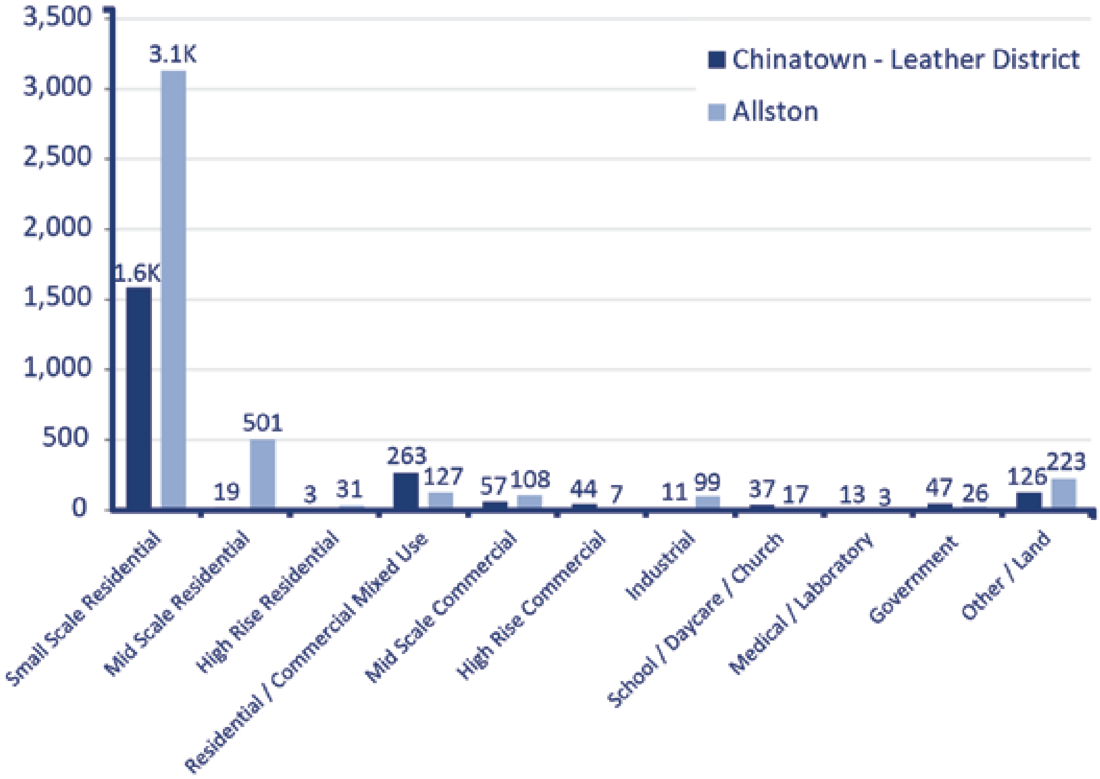


Figure 1.11. Comparison of building type distributions in the Allston neighborhood versus the Leather District/Chinatown neighborhood. Allston has more small scale residential and fewer commercial buildings.

Figure 1.12. Building Year Built of Allston and Chinatown - Leather District

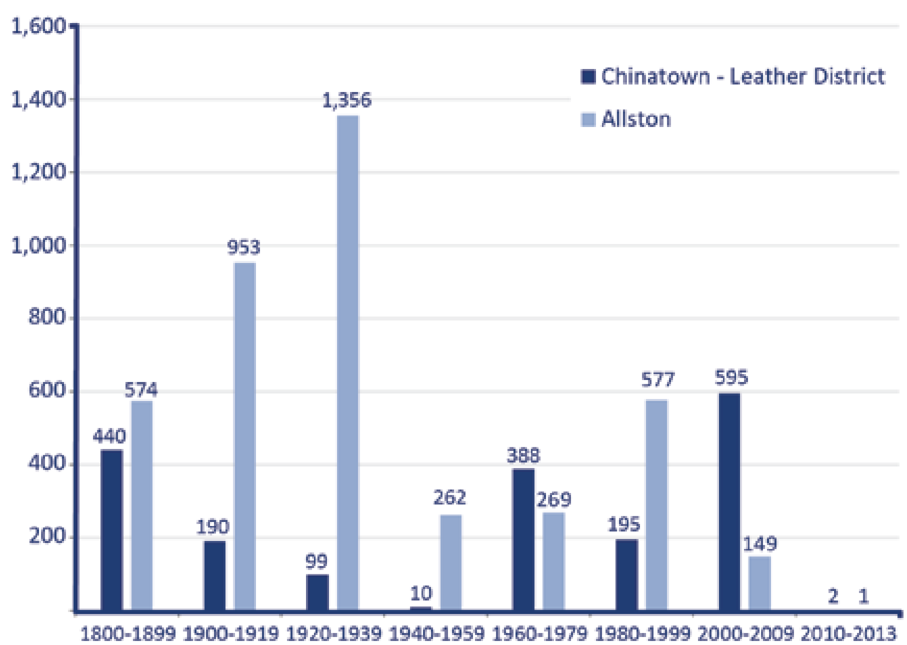


Figure 1.12. Comparison of building year of origin in Allston versus Chinatown/Leather District. The two neighborhoods show very different patterns of building age, with a larger percentage of buildings in Chinatown/Leather District built both earlier and later than buildings in Allston.

Hazards in Boston

Definitions of Hazard, Risk and Vulnerability

The U.S. Department of Homeland Security defines a hazard as a "natural or man-made source or cause of harm or difficulty", and notes that a hazard can be actual or potential. It also defines vulnerability as a "physical feature or operational attribute that renders an entity open to exploitation or susceptible to a given hazard" (DHS, 2008). "Risk", in the DHS lexicon, is defined as "the potential for an unwanted outcome resulting from an incident, event or occurrence, as determined by its likelihood and the associated consequences" (DHS, 2008).

The National Research Council report notes that:

> *We refer to disaster risk as the potential for adverse effects from the occurrence of a particular hazardous event, which is derived from the combination of physical hazards, the exposure, and vulnerabilities ...Similarly, we use the term disaster risk management (or simply risk management) to include the suite of social processes engaged in the design, implementation, and evaluation of strategies to improve understanding, foster disaster risk reduction, and promote improvements in preparedness, response, and recovery efforts*
>
> *(NRC, 2012, p. 27)*

Hazards Relevant to Massachusetts and Boston

The Massachusetts State Hazard Mitigation Plan includes a full assessment of the state's vulnerability to current and potential future hazards (MEMA, 2010). The hazards with the highest expected frequency across the state are floods, coastal hazards, high winds, thunderstorms, Nor'easters, and snow/blizzard, while hurricanes, tornados, ice storms, wildland fires, and extreme temperatures are expected to have a medium frequency (Figure 1.13).

	Frequency				Severity				Area of Impact				Area of Occurrence		
	Very Low	Low	Medium	High	Minor	Serious	Extensive	Catastrophic	Isolated	Local	Regional	Widespread	Isolated	Regional	Statewide
Flood				X		X		P			X				X
Dam Failure	X						X	P		X				X	
Coastal Hazards				X		X	P				X			X	
High Wind				X	X		P				X				X
Hurricane/ Tropical storm			X			X		P				X			X
Thunderstorm				X	X		P				X				X
Tornado			X			X	P			X					X
Nor'easter				X	X		P					X			X
Snow and Blizzard				X	X		P					X			X
Ice Storm			X		X		P				X				X
Major Urban Fires		X			X	P			X						X
Wildland Fire			X		X		P			X				X	
Drought		X			X	P						X			X
Extreme Temperature			X		X	P						X			X
Earthquake	X					X		P			X				X
Landslide		X			X		P			X					X
Tsunami	X						X	P				X		X	

Potential vulnerability to natural hazards. The symbol X represents the vulnerability ranking established for this hazard mitigation plan update. The symbol P denotes the worst case scenario potential for a given hazard.

Figure 1.13 Massachusetts Potential Vulnerability to Future Natural Hazards
MA State Hazard Mitagion Plan, 2010, page 120

Table 1.2 Frequency and Severity of Natural Hazards in the State and Boston

Hazard	Frequency	Severity
Flood	High	Serious to extensive
Dam Failure	Low	Extensive
Hurricanes	Medium	Extensive to catastrophic
Severe Storms	Medium	Serious
Tornados	Medium	Extensive to catastrophic
Winter Storms	High	Serious
Earthquakes	Low	Catastrophic
Landslides	Low	Minor
Brush Fires	Medium	Serious

Source: MAPC, 2008, p. 10

Compared to the State plan, the Boston Hazard Mitigation Plan uses a condensed list of hazards, and identifies floods and winter storms as the hazards with expected high frequency, with hurricanes, severe storms, tornados, and brush fires with an expected medium frequency (Table 1.2).[1]

Despite Boston's sheltered location within the greater Boston Harbor, shielded by Cape Cod and the islands from major Atlantic storms, the city is vulnerable to extreme weather events. The Boston Area Hazard Mitigation Plan (MAPC, 2008) lists eleven major storms (excluding hurricanes) over the past 50 years that caused major flooding in the Boston area (Table 1.3), including the October 1991 "Perfect Storm," which combined a nor'easter, a subtropical storm, and a hurricane (NOAA,2013).

Hurricanes occur relatively frequently in the Boston area, and "nor'easters" (winter storms that generate winds from the northeast) are particularly dangerous for the Boston Harbor with the high winds that often bear directly down on the coastal areas.

Table 1.3: Major Storms and Hurricanes in the Boston Area

Major Storms (excl. hurricanes, since 1950s)*	Hurricanes**	Winter Storms**
August 1954	September 1938 (Cat 3)	February 1978 (27")
March 1968	September 1944 (Cat 3)	February 1960 (26")
January 1979	September 1950	March 1997 (25")
April 1987	August 1954 (Cat 3)	January 1978 (21")
October 1991	September 1954 (Cat 3)	March 1960 (20")
October 1996	October 1954	February 1958 (19")
June 1998	August 1955	February 1994 (19")
March 2001	September 1960	December 1975 (18")
April 2004	September 1985	January 1996 (18")
October 2005	August 1991	February 1920 (17")
May 2006		February 1921 (16")

*Source: MAPC, 2008. * p. 12, ** p. 13*

1 The Metropolitan Area Planning Commission is currently updating the Boston Hazard Mitigation Plan, expected to be complete in the Fall of 2013. It is likely that temperature extremes or heat waves will be added.

The expected property damages from a hurricane (Category 2 to Category 4) range from $125 million to $14 billion, respectively (MAPC, 2008, p. 43). Many portions of Boston are also vulnerable to liquefaction under earthquake conditions, with the expected total property damage from an earthquake (magnitude 5.0 to 7.0) ranging from $26 million to $3 billion, although the study notes that most new planned development (as of 2008) is within zones that are susceptible to earthquake liquefaction (MAPC, 2008, p. 45).

The primary natural hazards can also cause secondary hazard effects; for example, a hurricane can cause structural damage, utility outage, chemical releases or spills, commodity shortages, emergency communications outages, erosion, mold, carbon monoxide poisoning, disease, flooding, storm surge, and tornados (Figure 1.14). These secondary effects can pose dangers to human health and safety as well as lead to additional property loss, economic loss, and environmental losses.

Figure 1.14. Secondary Hazard Effects Matrix

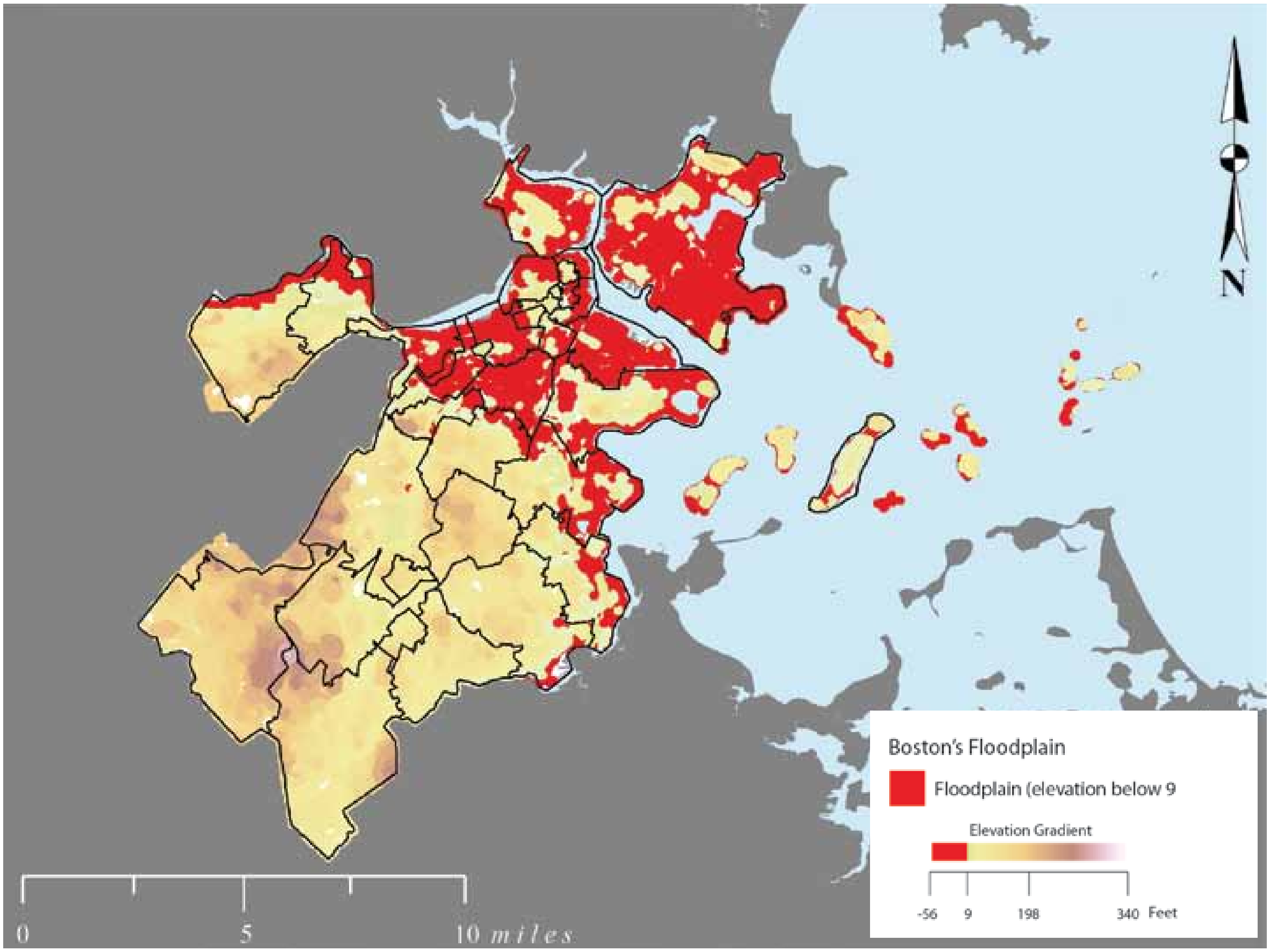
Primary Hazards	Structural Damage	Utility Outage	Chemical Release/ Spill	Commodity Shortages	Emergency Comm. Failure	Erosion	Structural Fire	Mold	Carbon Monoxide Poisoning	Disease	Flooding	Landslide	Dam Failure	Storm Surge	Tornado	Wildfire	Hail	Tsunami
Coastal Erosion	x										x	x						
Coastal Flooding	x		x			x		x		x		x						
Inland Flooding	x	x	x			x		x		x		x	x					
Hurricane/ T.S.	x	x	x	x	x	x		x	x	x	x			x	x			
Tornado/ Downburst	x	x	x					x										
Major Thunderstorm/ lightning		x					x								x	x	x	
Earthquake	x	x	x	x	x		x		x			x	x					x
Winter Storms/nor'easters	x	x		x		x	x		x		x			x				
Ice Storms	x	x		x	x		x		x									
Ice Jam	x										x		x					
Landslide	x					x												
Wildfires	x						x											
Tsunami	x	x	x	x		x		x		x	x							
Major Urban Fire	x	x	x															
Drought				x												x		
Epidemic / Pandemic Disease				x														

Source: MA Hazard Mitigation Plan (2010) p. 117 Table 14

Boston Hazard Maps

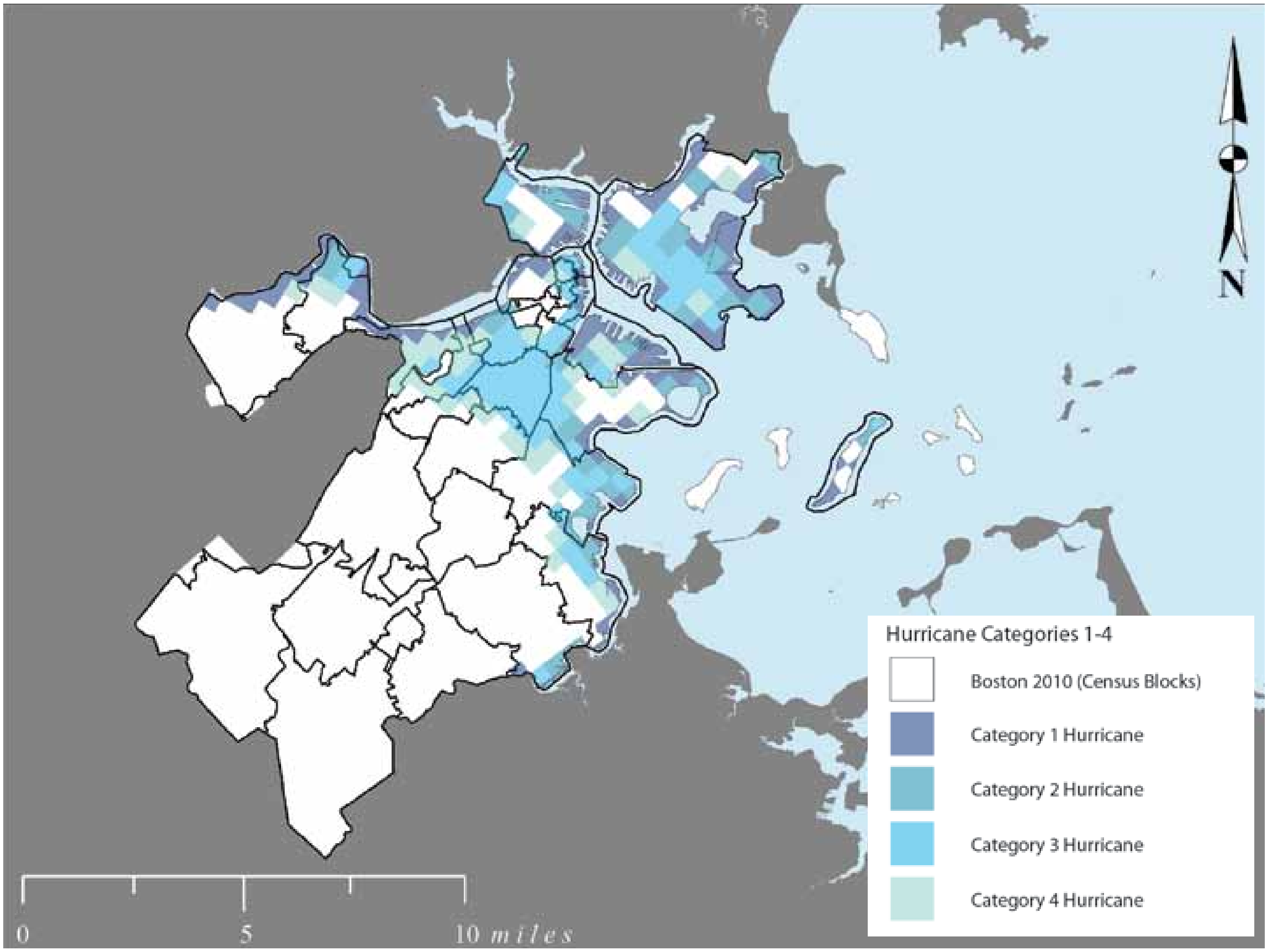
The Federal Emergency Management Administration (FEMA) floodplain maps for Boston and the surrounding areas are in the process of being updated. The map of current elevation readings provides an indication of the regions of the city that are most vulnerable to flooding under extreme precipitation events (Figure 1.15). As noted earlier, major portions of Boston were built on filled-in land and are vulnerable to earthquake liquefaction.

Figure 1.15. Flood levels in Boston, based on a water level 9 feet above current levels.



This corresponds to highest Mean Higher High Water level of a 2050 sea level rise scenario in the Preparing for the Rising Tides (BHA,

Figure 1.16. Boston Storm Surge Vulnerability, based on NOAA SLOSH models.



The National Oceanographic and Atmospheric Administration (NOAA) has constructed models to calculate the extent of storm surge in coastal areas (the SLOSH models). Current analysis using the SLOSH models indicate that over 30% of properties in the City of Boston would be significantly inundated under a Category 3 hurricane due to storm surge (Figure 1.16).

Figure 1.17.1. Category 1 Hurricane Storm Surge

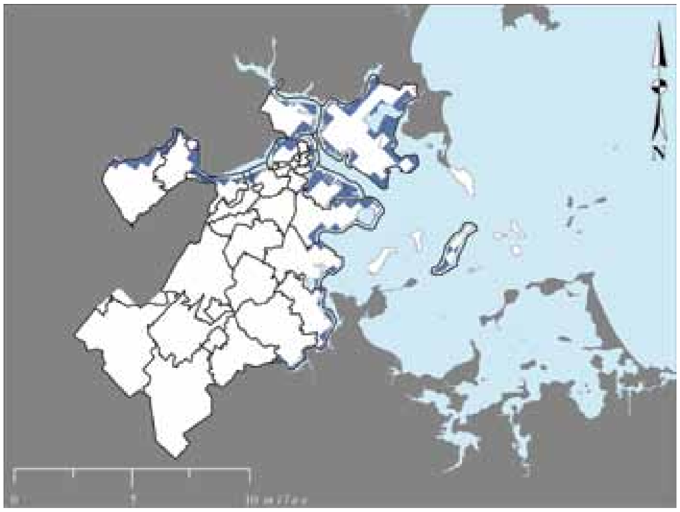


Figure 1.17.3. Category 3 Hurricane Storm Surge

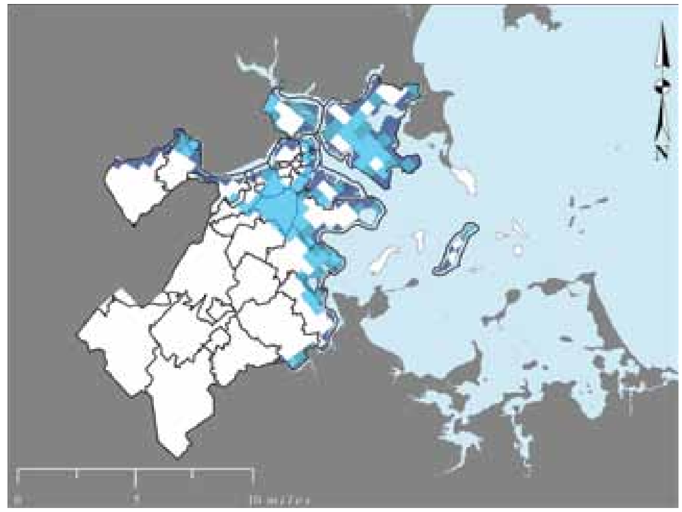


Figure 1.17.2. Category 2 Hurricane Storm Surge

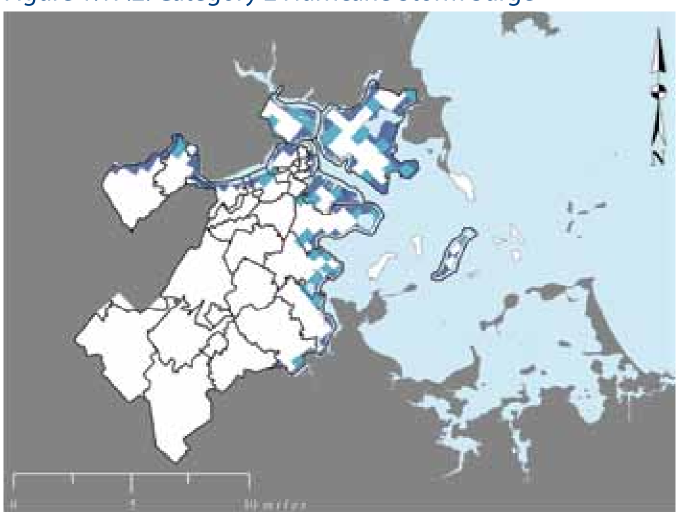
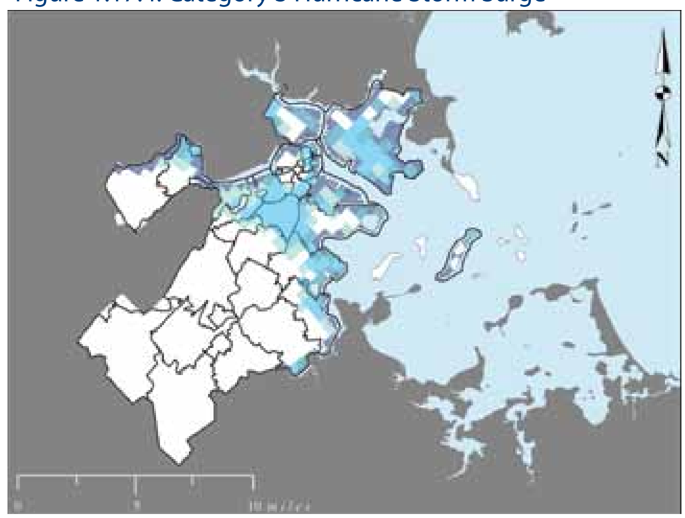


Figure 1.17.4. Category 3 Hurricane Storm Surge



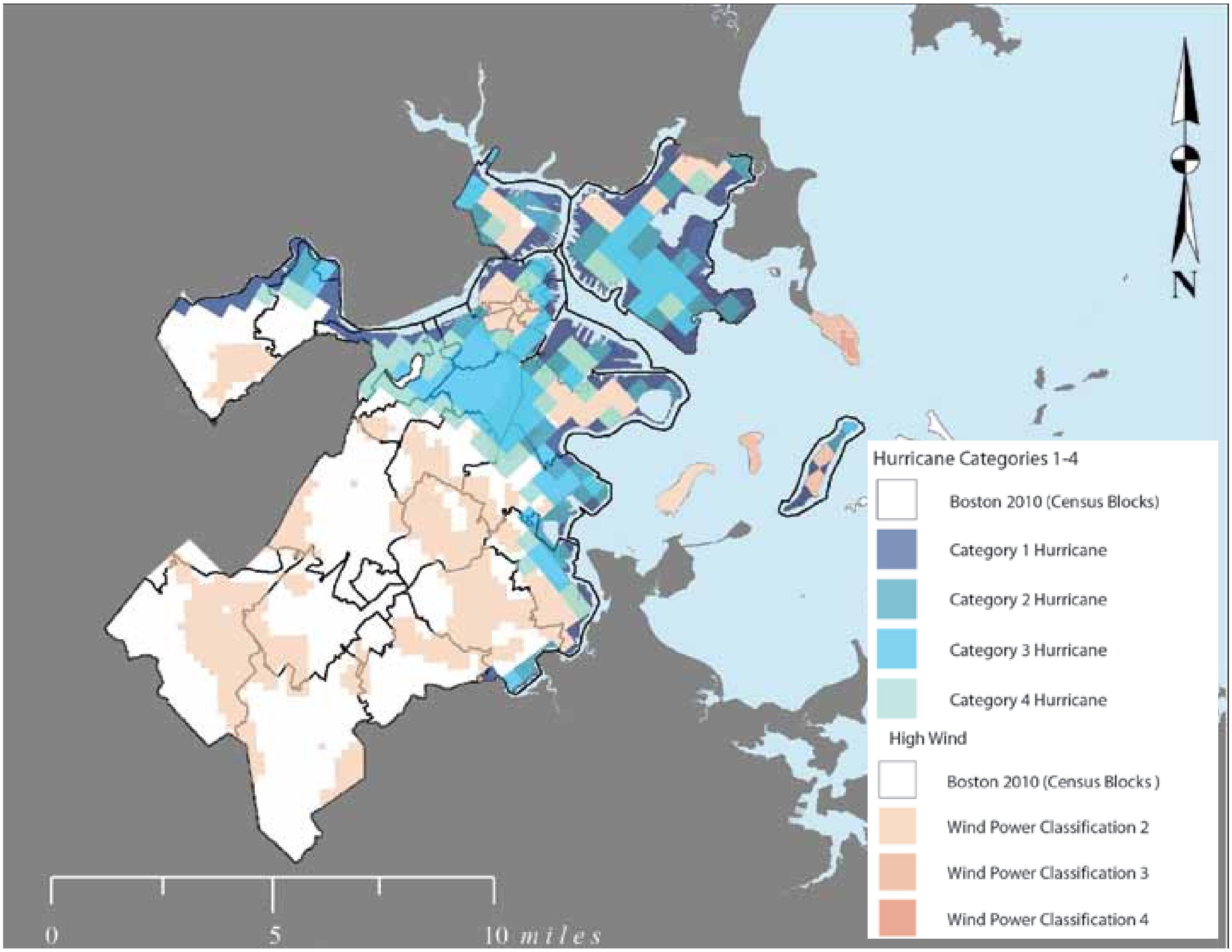
Figures 1.17.1 through 1.17.4 Storm surge predictions for Boston, based on category 1 through 4 hurricane events. Approximately 6% of Boston shows flooding in the Category 1 model, while almost 30% of Boston shows flooding in the category 4 model.

Table 1.4 Flood Inundation Model Results

NOAA SLOSH Model				
Hurricane Flooding Scenario	**Elevation Datum Nomenclature**			
Category Hurricane	**NAVD 88 (ft) Mean**	**NAVD 88 (ft) Min**	**NAVD 88 (ft) Max**	**Percent Boston Flooded**
1	6.2	4.9	7.7	9%
2	11.1	9	13.3	15%
3	14.9	12	17.1	26%
4	19.3	16.3	24.4	33%

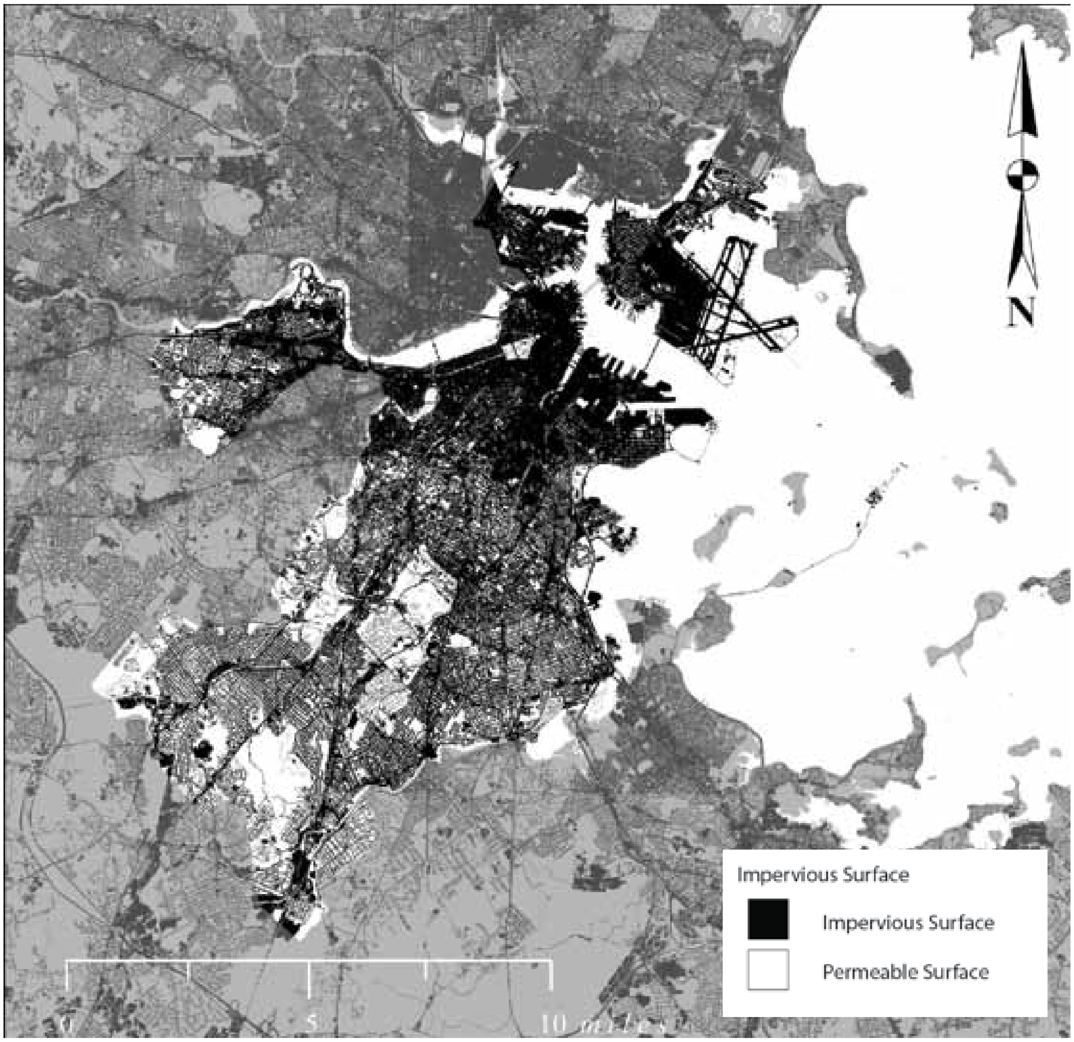
Preparing for the Rising Tides				
Sea Level Rise Scenario		**Elevation Datum Nomenclature**		
Scenario Year	Projected Sea Level Rise (ft)	MHHW (+ft)	NAVD 88 Total (ft)	Percent Boston Flooded
2050	1-2 ft	5	9.8	6.6%
2100	3-6 ft	7.5	12.3	30.1%

Figure 1.18. Wind and Hurricane Hazards, based on combining wind resource maps and NOAA SLOSH models for Boston.



Mapping of wind and hurricane hazards for Boston reveals the highest wind speeds in East Boston, with high wind also in downtown Boston and in exposed elevations around the city.

Figure 1.19. Impermeable Surfaces in Boston. .



Areas with a high percentage of impermeable surface are more prone to flooding and correlate with strong heat island effects

Boston boasts of many extensive park systems, and overall the city has a relatively low percentage of its surface area covered with impermeable surfaces (Figure 1.19). However, certain neighborhoods have much higher percentages of impermeable surface, and are therefore more vulnerable to flooding from rain and storm events.

The impermeable surfaces not only increase the incidence and amount of stormwater runoff (rather than soaking into the ground and recharging the groundwater), but can also increase the ambient temperature neighborhoods with high percentages of exposed pavement, especially during heat waves and other high-temperature events. The map of impervious surfaces Boston shows the neighborhoods of the city that are most vulnerable to extreme heat days and, in some cases, reveal neighborhoods that may significantly benefit from interventions that reduce heat retention and capture.

Climate Change Impacts – Projected Changes in the Frequency and Magnitude of Extreme Events in Boston

The *Massachusetts Climate Change Adaptation Report* notes that ambient temperatures have already increased in the state by almost 2 degrees (Fahrenheit) since 1970 and that sea surface temperatures have increased by 2.3 degrees (Fahrenheit) (EEA, 2011). The sea levels have also risen, by 8.6 inches between 1921 and 2006, while the state is experiencing more extreme heat days per year, with less snowpack and earlier snow melt.

Future climate change impacts are expected to continue this trend, with more extreme heat days per year, more extreme precipitation events – by 12 to 30 percent.

The rise in sea levels – and the related hazards for storm surge, where the waves are driven up higher on the land due to wind and wave power, is a particular concern for Boston. Recent sea level rise projections indicate that flood water will regularly cover the 100-year flood plain by 2040, and the 500-year flood plain by 2070 (Kirshen et al., 2008; Beaulieu et al., 2011).

Hurricane Sandy, if it had hit at high tide, might have flooded up to 6% of Boston and, if there is a sea level rise of 2.5 feet, the proportion could be over 30% of Boston flooded in a similar storm (BHA, 2013, p. 5).

Recent research suggests that sea level rise is accelerating, based on current readings from over 16 tide stations along the eastern U.S. seashore (Boon, 2012). Although the direct cause has not been determined, some evidence exists that the reduction and/or redirection of the Gulf Stream could be responsible for the acceleration, and could lead to higher estimated sea levels more quickly than previously believed.

The Interaction of Hazards and Buildings in the Allston Neighborhood: An Example

The Allston neighborhood is home to a range of building types, from modest single family homes to large institutional and commercial office buildings. There are several bustling commercial areas in the neighborhood, as well as the Harvard Business School campus and a large Harvard athletic campus. (Harvard campus buildings are not included in Boston Assessing Department data.) The Massachusetts Turnpike crosses through the heart of the neighborhood, accompanied by rail tracks leading to a large freight yard.

The Charles River forms the north and west border of Allston. Most of the storm sewers that serve the neighborhood empty into the Charles, along the Allston shore. During the famous Blizzard of '78, much of the snow plowed from the Boston streets was put in the large parking lots in Lower Allston to melt. Unfortunately, these same large parking lots contribute to both flooding hazards in severe rain events and heat island effect on very warm days.

Figure 1.20. Impervious Surfaces in the Allston neighborhood

This map of impervious surfaces in the Allston neighborhood shows the extent of paving and building density.

The maps included here illustrate the two hazards that the Allston neighborhood is most vulnerable to: heat waves, and flooding. The potential flooding from a severe hurricane or rain storm could inundate the Harvard Business School and athletic facilities, as well as a substantial number of residential and commercial properties.

Recent Local Studies

The City of Boston's *Climate Action Plan* specifically focuses on mitigation actions for buildings, transportation, solid waste, and city operations (City of Boston, 2011) and recommends developing detailed adaptation plans working with local communities.

The *Massachusetts Climate Change Adaptation Report* (EEA, 2011) details specific "no regrets" strategies as well as longer term planning and coordination efforts.

The recently released *Preparing for the Rising Tide* report by the Boston Harbor Association assessed the vulnerability of various portions of Boston to sea level rise and storm surges, and identified several potential strategies, such as increasing the height of sea walls (BHA, 2013).

The Metropolitan Area Planning Council is currently developing a Regional Climate Change Adaptation Strategy, which will include assessing the vulnerabilities of critical assets and developing adaptation goals and general strategies.

This report is complementary to the previous studies in its specific focus on the opportunities to improve existing buildings to improve disaster resilience.

Figure. 1.21. Allston Category 4 Hurricane Flood Risk

Allston building types shown with the predicted extent of flooding from a category 4 hurricane as determined from a NOAA SLOSH model for Boston.

Section 2:
Key Resources for this Study

Photo: © Astro Ltd. 2013

Section 2: Key Resources for this Study

Several recent reports focusing on disaster resilience for cities and regions are key reference sources for the City of Boston as it considers actions to improve the resilience of its existing building stock. This section provides a brief summary of the most important reports. Additional publications and references are included in the annotated bibliography in Appendix A.

New York City Reports Post-Sandy

Hurricane Sandy in October 2012 wrought such damage on New York City that Mayor Bloomberg formed a special committee to assess the city's recovery and resilience opportunities. In addition, the Mayor and the City Council Speaker Quinn worked with the New York City chapter of the US Green Building Council, Urban Green, to convene a panel of experts to develop recommendations specifically focused on improving buildings resilience.

The PlaNYC Report, *A Stronger More Resilient New York*, details the impact of Hurricane Sandy on the City, and evaluates the potential for future damage given climate change impacts. It then details the opportunities for improvement to the citywide infrastructure and built environment, specifically coastal protection, buildings, and critical services (including utilities, energy, telecommunications, transportation, water and wastewater) as well as healthcare, insurance, and natural environments such as parks. The final section of the report describes the community rebuilding and resilience plans for different neighborhoods in the city.

The PlaNYC Report chapter on buildings notes that, while the coastal protection measures will be a critical part of the improvement in resilience for buildings, they will be insufficient to meet the immediate needs and larger impacts from climate change. The recommendations therefore include initiatives to facilitate upgrading existing buildings (Table 2.1). Appendix G in the report outlines flood-resistant techniques for new construction and major renovations, which augments the Green Codes Task Force's recommendations to change the building codes to ensure "passive survivability" in the event of utility outages.

Hurricane Sandy's impact on buildings differed by building height and structural characteristics. One and two story buildings were much more likely to be damaged by flood waters than larger residential or commercial buildings.

The *Building Resiliency Task Force* report was prepared by a large and inclusive group of stakeholders in the city. The report includes 33 proposals to improve disaster resiliency of buildings in New York City, and provides a costing methodology for new construction and existing buildings. Several implementation approaches are presented for the proposals, including: *required upgrade*, *new code*, *remove barrier*, *recommended*, and *further actions*. Each proposal is described by:

- Summary – including issue and brief description of the recommendation
- Proposed legislation, rule, or study
- Supporting information – including expanded descriptions of the issues and benefits, specific actions on building systems (such as foundations, structure, windows and doors, and mechanical systems), cost estimates, and additional references.

The proposals are grouped under the headings of: 1) stronger buildings; 2) backup power; 3) essential safety; and 4) better planning. The specific applications of the proposals differs by the building type, whether it is a commercial building, multifamily residential, or home. For example, the required retrofits for commercial buildings are to safeguard toxic materials stored in flood zones, and keep gas stations open during blackouts, while required upgrades for multifamily residential buildings are to safeguard toxic materials stored in flood zones, supply drinking water without power, and create emergency plans. (There are no required upgrades for homes.)

Very significantly, the *Building Resiliency Task Force* report raises the critically important issue maintaining habitable conditions in buildings in the event of loss of power. This concept, also known as *passive survivability* is defined in the report as "requiring further action".

Federal Government Reports

The US Federal Government has recently released several important reports related to improving disaster resilience.

The Federal Emergency Management Administration (FEMA) compiled a summary report of mitigation actions for reducing risk to natural hazards (FEMA, 2013). The report is organized by category of natural hazard (such as extreme temperatures, flooding, severe wind, tornado), and the miti-

Table 2.1: PlaNYC Initiatives for Increasing Resilience in Buildings

Initiative #	Title
1	Improve regulations for flood resiliency of new and substantially improved buildings in the 100-year flood-plain
2	Rebuild and repair housing units destroyed and substantially damaged by Sandy
3	Study and implement zoning changes to encourage retrofits of existing buildings and construction of new resilient buildings in the 100-year floodplain
4	Launch a competition to encourage development of new, cost-effective housing types to replace vulner-able stock
5	Work with New York State to identify eligible communities for the New York Smart Home Buyout Program
6	Amend the Building Code and complete studies to improve wind resiliency for new and substantially improved buildings
7	Encourage existing buildings in the 100-year floodplain to adopt flood resiliency measures through an incentive program and targeted requirements
8	Establish Community Design Centers to assist property owners in developing design solutions for recon-struction and retrofitting, and connect them to available City programs
9	Retrofit public housing units damaged by Sandy and increase future resiliency
10	Launch a sales tax abatement program for flood resiliency in industrial buildings
11	Launch a competition to increase flood resilience in building systems
12	Clarify regulations relating to the retrofit of landmarked structures in the 100-year floodplain
13	Amend the Building Code to improve wind resiliency for existing buildings and complete studies of poten-tial retrofits
14	Amend the Construction Codes and develop best practices to protect against utility service interruptions

gation actions are grouped by focus area, specifically: 1) local planning and regulations; 2) structure and infrastructure projects; 3) natural systems protection; and 4) education and awareness programs.

For example, for earthquake hazards, a mitigation action related to structure and infrastructure projects is to implement structural mitigation techniques, with specific activities including strengthening and retro-fitting non-reinforced masonry buildings. Most of the actions include specific references to FEMA technical reports.

At the request of multiple US Federal Agencies (including the U.S. Army Corps of Engineers, and U.S. Departments of Agriculture, Energy, Commerce and Interior), the National Academies convened a committee under the National Research Council to develop a national agenda for disaster resilience (NRC, 2012). The report presents the state of knowledge on understanding, managing, and reducing disaster risks, and provides the case for investments to improve resilience. It also identifies current activities to measure improvements in resilience, and assesses the current practice at the community level and from the federal, state, and regional levels that can improve resilience, including a research agenda to address gaps in current knowledge and practice.

The *National Climate Assessment (USGCRP, 2013)* compiles the state of the nation with respect to climate change, compiling research, data, and information across the country on the current status of climate change and its impacts. It focuses specifically on the sectors of human health, water, energy, transportation, agriculture, forests, and ecosystems and biodiversity, and the interdependencies of several sectors at the national level. The report examines the impacts for the regions of the United States (such as Northeast and Southeast) and summarizes the status of climate adaptation activities.

"Proactively preparing for climate change can reduce impacts, while also facilitating a more rapid and efficient response to changes as they happen."

(USGCRP, 2013, p. 7)

The US Government Accountability Office (GAO) was asked to examine decision-making for infrastructure investments, which are supplemented by federal funds, with respect to climate-change impacts, building on the NRC report (GAO, 2013). The GAO report found that most government agencies are not currently incorporating potential climate change impacts into their decision making processes, despite the magnitude of the possible disruption and damage to critical assets.

Based on specific cases, the GAO found that decision makers were enabled to consider climate change impacts when: 1) local circumstances were conducive to addressing climate-related risks (such as recent disasters), 2) decision makers learned to use available information, 3) decision makers had access to local assistance, and 4) decision makers considered climate impacts within existing planning processes.

The key GAO recommendation is for the Federal Government to facilitate and coordinate resources to provide the best critical climate-related information needed by local decision makers, and to regularly update that information as needed.

City Adaptation Planning Reports

The Cities of London and Toronto have completed extensive adaptation reports several years ago, that focus specifically on upgrading existing building to improve disaster resilience.

The Toronto report, *Ahead of the Storm*, included planned and proposed actions that could be implemented immediately to address adaptation as well as a process to develop a comprehensive adaptation strategy (Toronto, 2008). A recent progress update describes the progress in implementing the 76 proposed actions (Toronto, 2011), including:

- Toronto Green Standard – mandatory building performance targets (effective 1/31/10);
- Green Roof Bylaw – requires green roofs on new developments or additions (effective 1/31/10);
- Deep Lake Water Cooling – pumps cold lake water for cooling downtown office buildings;
- Commitment to Double Tree Canopy – increase tree canopy cover from 17% to 30-50%;
- Spatial Heat Vulnerability Assessment – create spatial heat-related vulnerability assessment tool to improve effectiveness of hot weather response plan.

The City of Toronto also compiled the expected benefits from these actions, including expected quantities of greenhouse gas emission reduction, financial savings, and other benefits (Toronto, 2008).

The City of London developed its adaptation plan in 2007, focusing on the risks from floods, extreme heat and air pollution, as well as managing water resources and ground conditions. The adaptation options are grouped into: research and monitoring, policy, and practical actions, and they are further grouped into categories ("no regrets," "low-regrets," "win-win", and "flexible"). The progress report describes the current climate change trends, as well as the current status for each subject area and the stage of implementation of the adaptation strategies at the national and city levels. It also provides links to specific information resources for specific actions, such as fact sheets on improving flood resistance for homes and businesses (London, 2011).

Section 3:
Strategies for Resilient Buildings in Boston


Photo: © Astro Ltd. 2013

Section 3: Strategies for Improving Resilience of Existing Buildings

This section provides detailed strategies for improving the resilience of new and existing buildings, drawn from multiple reference sources including publications, reports, and interviews. These "best practice" strategies represent current knowledge, experience, and expertise to improve the resilience of existing buildings for multiple hazards.

The strategies are categorized by the portion of the building that is the focus of the improvement: 1) General Actions; 2) Site; 3) Building Structure; 4) Building Enclosure; 5) Building Systems; 6) Building Operations; and 7) People.

Within those general categories, the strategies are further grouped under specific topics, such as "Create places of refuge" or "Identify vulnerable populations."

Each strategy includes a link to a report or publication for additional detailed information. The exception is strategies from interviews (which represent experience-based knowledge).

Most strategies are applicable across all building types, although some specific strategies (as noted in the description) are most applicable to one building type (such as residential buildings). Most strategies address multiple hazards, although some strategies are most applicable to a specific hazard (such as floods).

Table 3.1: Resilience Strategies for Existing Buildings

General Actions	Assess Vulnerability and Risk
	Create Places of Refuge
Site	Build for Higher Rainflow
	Create Cool Ground Surfaces
	Floodproof Building Site
	Floodproof Industrial Buildings
	Use Hard Infrastructure to Prevent Flooding
	Use Hazard Resilient Landscape Design
	Protect Entrances from Snow and Ice
	Provide Shade
	Reduce Vulnerability to Wind Damage
	Use Soft/Green Infrastructure to Prevent Flooding
	Stabilize Slopes Susceptible to Erosion, Landslide, Fire
Building Structure	Enhance Structural Elements for Extreme Loads
Building Enclosure	Use Cool Roofing
	Enhance Building Insulation
	Increase Resistance to High Winds
	Manage Heat Gain
Building Systems	Resilient Back-up Power and Systems
	Resilient Heating, Cooling and Ventilation Systems
	Resilient Water Systems During Outages
	Extend Emergency Lighting and Services
Building Operations	Have Emergency Communications Plans
	Protect Records and Inventory
	Secure Interior Environment
	Train Building/Facility Teams for Resilience Upgrades
People	Educate Households
	Partner with Local Community Organizations to Enhance Resilience
	Locate Vulnerable Populations
	Plan for Tenant Needs

GENERAL ACTIONS

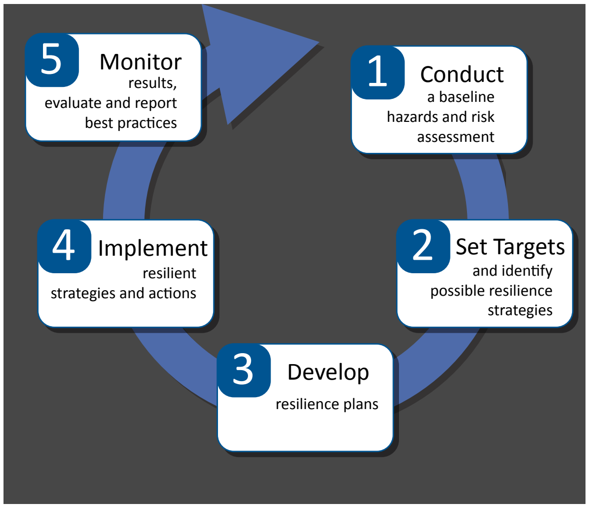
Photo: John Gravelin

GENERAL ACTIONS

ASSESS VULNERABILITY AND RISK

"Regardless of whether downscaled local climate change predictions are available, additional work may be needed to assess neighborhood and site-level vulnerability. One strategy is to use local knowledge of recent events. When combined with regional climate change predictions, local historical accounts enable governments to envision how prepared they would need to be to respond to similar future events that are more frequent or more severe. Green building professionals should follow a similar process but tailor their approach to the specific concerns at the neighborhood or building level."

Green Buildings and Climate Change, p. 20



STRATEGIES

- **Collect and analyze data on hazards and exposure**
    - Collect data on relevant local hazards using local historical data and expected climate change impacts
    - Use GIS to map the hazard exposure across locations

Identifying Hazards and Estimating Losses[1]

- **Create scenarios of potential outcomes**
    - Use hazard data and exposure data with expected climate change data to develop several scenarios
    - Use GIS to map scenario outcomes across locations

Identifying Hazards and Estimating Losses[2]

- **Monitor current conditions in response to hazards and risks**
    - Update hazard and exposure data with current events
    - Use GIS to map recent and current events across locations

Identifying Hazards and Estimating Losses[3]
Visual Screening of Buildings for Potential Seismic Hazards[4]

- **Develop inventory of buildings vulnerable to each risk**
    - Use GIS to map buildings by location with respect to hazard maps
    - Incorporate expected climate change data into inventory of buildings potentially at risk

Identifying Hazards and Estimating Losses[5]

- **Assess potential deaths/injuries and property loss**
    - Use HAZUS and other systems to calculate potential losses

Identifying Hazards and Estimating Losses[6]

- **Develop checklist for vulnerability assessment**
    - Use a checklist that summarizes the main 'climate-proofing' principles that should be considered when developing policies and projects.

City of London Corporation: Rising to the Challenge APP 15[7]

ASSESS VULNERABILITY AND RISK (CONT'D)

1 Understanding Your Risks: Identifying Hazards and Estimating Losses- State and Local Mitigation How to Guide. FEMA 386-2. August 2001. Accessed 7/11/2013. http://www.fema.gov/library/viewRecord.do?id=1880

2 Understanding Your Risks: Identifying Hazards and Estimating Losses- State and Local Mitigation How to Guide. FEMA 386-2. August 2001. Accessed 7/11/2013. http://www.fema.gov/library/viewRecord.do?id=1880

3 Understanding Your Risks: Identifying Hazards and Estimating Losses- State and Local Mitigation How to Guide. FEMA 386-2. August 2001. Accessed 7/11/2013. http://www.fema.gov/library/viewRecord.do?id=1880

4 Rapid Visual Screening of Buildings for Potential Seismic Hazards, A Handbook, Second Edition. FEMA 154. March 2002. Accessed 7/11/2013. https://www.fema.gov/library/viewRecord.do?id=3556

5 Understanding Your Risks: Identifying Hazards and Estimating Losses- State and Local Mitigation How to Guide. FEMA 386-2. August 2001. Accessed 7/11/2013. http://www.fema.gov/library/viewRecord.do?id=1880

6 Understanding Your Risks: Identifying Hazards and Estimating Losses- State and Local Mitigation How to Guide. FEMA 386-2. August 2001. Accessed 7/11/2013. http://www.fema.gov/library/viewRecord.do?id=1880

7 City of London Corporation: Rising to the Challenge. The City of London Climate Adaptation Strategy, 2010 Update. City of London. January 2010.

GENERAL ACTIONS

CREATE PLACES OF REFUGE

Facilities designated as shelters are given the responsibility of protecting the lives of those taking refuge within them. Yet damage to these "shelters" or "hardened areas" continues to be observed, which undermines public confidence. Often, there is a general lack of understanding of effects of exposing buildings not designed to provide life-safety protection from extreme-wind events. A variety of different types of "shelters" that are used before, during, and after storm events, provide different levels of protection. If the building or structure selected for use as a shelter cannot withstand the effects of hurricane winds, the results can be devastating.

Guidance for Community Saferooms, 1-9

We are beginning to think of designating one building within a group as a "Safe Haven" for the community, instead of just one room.

Edward Connolly, New Ecology

STRATEGIES

- **Build sheltered spaces**
  - Use design specifications FEMA-361, which includes structural, siting, and human factors design guidelines.

Design and Construction Guidance for Community Safe Rooms[1]

- **Harden structure and windows in schools against natural disasters**
  - Use best practices for building systems to harden the structure and windows against natural disasters.

Kansas School Shelter Initiative[2]

1 Design and Construction Guidance for Community Saferooms. FEMA P-361. Second Edition. August 2008. Accessed 7/11/2013. http://www.fema.gov/library/viewRecord.do?id=1657
2 Protecting School Children from Tornadoes. State of Kansas School Shelter Initiative. Mitigation Case Studies. FEMA 2002. http://www.fema.gov/library/file?type=publishedFile&file=ks_schools_cs.pdf&fileid=6d363790-53b4-11db-8645-000bdba87d5b

SITE

Photo:John Gravelin

Vegetation for Urban Heat Island mitigation

By Luce Trouche

Extreme heat, particularly in cities, can pose dangerous hazards to the population. For example, during the 15-day heat wave in 2003, 14,800 people, often elderly and frail, died in France, and 70,000 deaths across Europe are attributed to that heat wave (Ledrans, 2006). Recent research indicates that, when average temperatures are above 21.5°C (71°F), for each couple of degrees increase in temperature there is a 3% increase in deaths (Hajat et al., 2002). Energy use also increases with temperature, and one study estimated that each two degrees increase in temperature increases peak electricity demand for air conditioning by 2-4% (Akbari et al., 1992).

Vegetated surfaces (such as tree canopy, parks, and lawns) can help reduce localized heat island effects in urban areas. Evapotranspiration is the process by which plants release moisture in the form of water vapor, and the solar energy expended for evapotranspiration instead of directly heating the air lowers the temperature increase during the day. Evapotranspiration and shading effects together can reduce air temperatures by as much as 9°F (Akbari et al., 1992).

Recent analysis indicates that a row of trees along a street could decrease air temperature by several degrees (Dimoudi et al., 2003). For example, temperatures in suburban Davis, CA and Sacramento, CA with mature tree canopies were 3-6°F cooler than developments without trees, and simulations predicted that increasing tree cover by 25% in Sacramento, CA and Phoenix, AZ would decrease air temperatures by 6-10°F (Akbari et al., 1992).

Even more pronounced cooling effects have been measured in large urban parks, where the temperature can be up to 7°F lower than surrounding neighborhoods through the combination of evapotranspiration and wind (Akbari et al., 1992). One analysis calculated that creating a block park within a densely settled area could reduce temperatures by 4-11°F (2-6 °C), and doubling the park size could increase its cooling effect by another 3-5°F (1.5-3°C) (Dimoudi et al., 2003). The cooling effects of the parks have been measured to extend beyond park boundaries, reducing ambient air temperatures in the adjacent neighborhoods. Large parks have a greater cooling impact than smaller parks, although multiple smaller parks within close proximity can have a similar urban cooling effect on neighborhoods (Dimoudi et al., 2003; Shashua-Bar et al., 2009; NCRA 2007; Cao et al., 2010).

These approaches can also be applied to specific building sites. Field measurements have found that shade trees and shrubs planted immediately adjacent to buildings can directly reduce summer air-conditioning costs by 40 percent and directly shading the air conditioning condenser unit can increase its efficiency by up to 10 percent during the warmest periods (Akbari et al., 1992). Additional research indicates that shade trees and grass can reduce daytime temperatures in a building courtyard by 4-5°F (2.5°C) (Shashua-Bar et al., 2009).

Parking lots shaded by trees are 2-4°F (1-2°C) cooler than paved parking lots, and shaded fuel tanks were 4-8°F (2-4°C) cooler than unshaded tanks (Scott, 1999). Unshaded grass and lawns do not appear to have the same cooling effects as shade trees and shrubs, and often have unusually high watering requirements (Cao et al., 2010). Therefore, trees provide by far the most efficient means of reducing outdoor air temperature, as measured by water consumption (Shashua-Bar, 2009).

References

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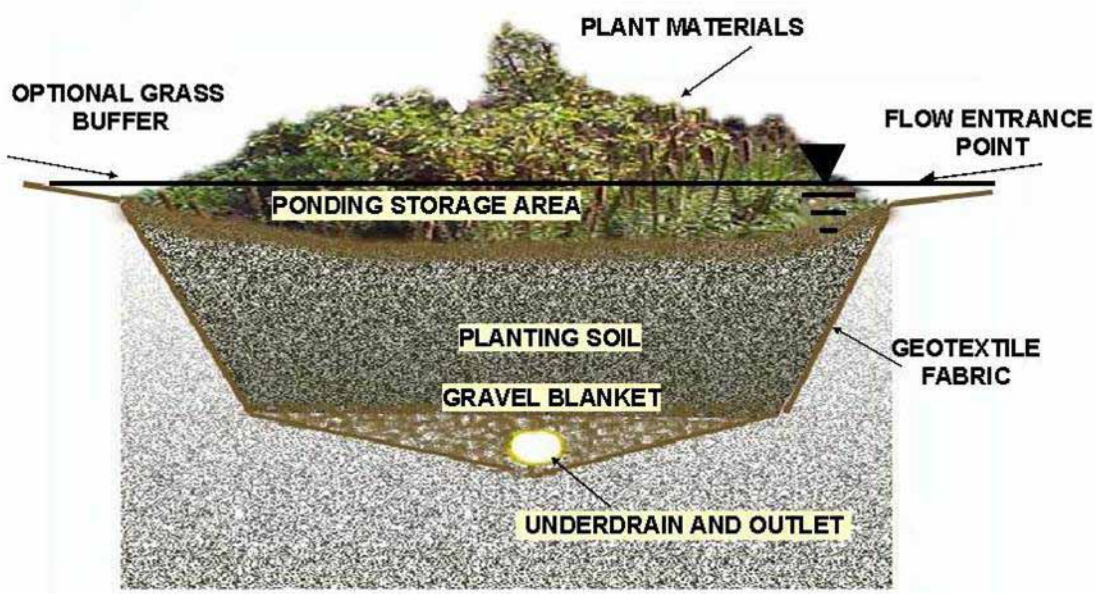
SITE

BUILD FOR MORE RAINFLOW



Soft infrastructure such as rain gardens (shown here) and hard infrastructure, such as enlarged drainage pipes can help reduce flooding during severe rain events. Image: Keith Giampotone.

[I]f a city's combined sewer and stormwater system is already overloaded and climate change impacts include increased precipitation, onsite stormwater management should be considered to increase a project's resilincey to storm events.

Green Building and Climate Resilience, P 11

Heavy downpours are increasing and are projected to increase further. These can lead to flooding and related impacts on water quality, infrastructure and agriculture.

ClimAID Synthesis Report

STRATEGIES

- **Use pervious pavement**
  - Using pervious pavements in parking lots enhances groundwater infiltration and reduces stormwater runoff.

Wet Weather Flow Management Guidelines. P 5[1]
NYC Stormwater Management Systems[2]

- **Use underground storage tanks**
  - Underground storage tanks can provide emergency water supplies and can be used for landscape watering, which enhances groundwater infiltration.

Wet Weather Flow Management Guidelines. P 5[3]
NYC Stormwater Management Systems[4]

- **Grade site to slow runoff and enhance infiltration**.

Wet Weather Flow Management Guidelines. P 5[5]
NYC Stormwater Management Systems[6]

BUILD FOR MORE RAINFLOW (CONT'D)

- **Use on-site retention and detention ponds**
  - On-site ponds collect stormwater from a site or defined area in order to prevent flooding, and can be used as emergency fire protection water supplies.

Green Building and Climate Resilience, C-65[7]

- **Perform regular drainage improvements and maintenance**
  - Drainage improvements and maintenance, such as sediment and debris clearance, and inspection and detection prevent localized flooding and discharges into stormwater and sewer systems.

FEMA Mitigation Ideas. P 27[8]

- **Build infiltration galleries and french drains**
  - Building foundation drainage systems, such as infiltration galleries and french drains, are pits or trenches that are filled with rubble or gravel to allow for groundwater infiltration and reduce water pressure against foundation walls that lead to leaks and potential to failure.

Green Building and Climate Resilience, C-67

- **Use bioswales and other vegetated on-site water capture systems**
  - Vegetated on-site systems prevent erosion with by slowing the flow of stormwater, filter pollutants, and promote groundwater infiltration.

Green Building and Climate Resilience, C-69
Biofiltration Swale Design Guidance, CA Dept. of Transportation[9]

Quote: NYSERDA. "ClimAID Synthesis Report." 2011. http://www.nyserda.ny.gov/climaid

1 Wet Weather Flow Management Guidelines, November 2006, Toronto Water, City of Toronto. http://www.toronto.ca/water/protecting_quality/wwfmmp/pdf/wwfm_guidelines_2006-11.pdf
2 Guidelines for the Design and Construction of Stormwater Management Systems. New York City Dept. of Environmental Protection. 2012. Online resource accessed 7/15/2013. http://www.nyc.gov/html/dep/pdf/green_infrastructure/stormwater_guidelines_2012_final.pdf
3 Wet Weather Flow Management Guidelines, November 2006, Toronto Water, City of Toronto. http://www.toronto.ca/water/protecting_quality/wwfmmp/pdf/wwfm_guidelines_2006-11.pdf
4 Guidelines for the Design and Construction of Stromwater Management Systems. New York City Dept. of Environmental Protection. 2012. Online resource accessed 7/15/2013. http://www.nyc.gov/html/dep/pdf/green_infrastructure/stormwater_guidelines_2012_final.pdf
5 Wet Weather Flow Management Guidelines, November 2006, Toronto Water, City of Toronto. http://www.toronto.ca/water/protecting_quality/wwfmmp/pdf/wwfm_guidelines_2006-11.pdf
6 Guidelines for the Design and Construction of Strormwater Management Systems. New York City Dept. of Environmental Protection. 2012. Online resource accessed 7/15/2013. http://www.nyc.gov/html/dep/pdf/green_infrastructure/stormwater_guidelines_2012_final.pdf
7 Larsen et al. "Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions." University of Michigan; U.S. Green Building Council, 2011.
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9 Biofiltration Swale Design Guidance. Caltrans Storm Water Quality Handbook. California Department of Transportation, Division of Environmental Analysis. 2011. Last accessed 7/15/2013. http://www.dot.ca.gov/hq/LandArch/ec/stormwater/guidance/DG-Biofiltration%20Swale-060111.pdf

SITE

CREATE COOL GROUND SURFACES

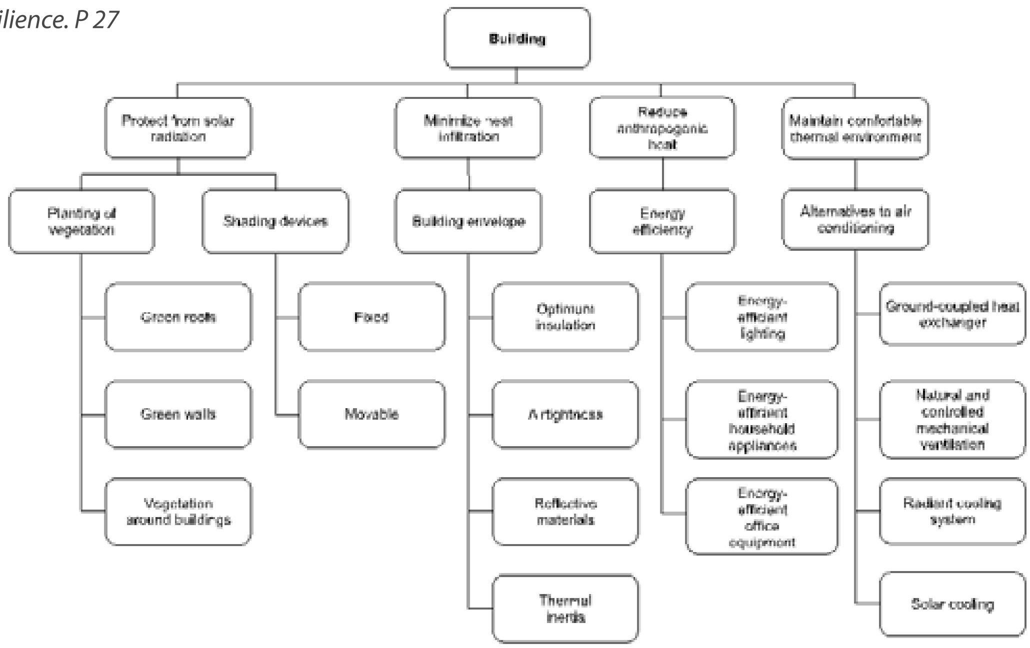
Urban neighborhood patterns have a distinct effect on the thermal comfort of the local inhabitants during high heat events. Research on the [Urban Heat Island] effect shows that higher density development exacerbates extreme heat events, resulting in additional stressors in urban areas. The design of urban neighborhoods, including large areas of impervious surfaces, lack of shade-producing vegetations, lower albedo materials, and higher concentrations of waste heat sources all magnify the impact of heat events.

Green Building and Climate Resilience. P 27

One concern is that a lot of attention is paid to catastrophic events, but slow creeping impacts, such as longer heat waves or altered precipitation patterns, are just as important from a public health standpoint.

Paul Shoemaker, Boston Public Health Commission

Schematic diagram of urban heat island mitigation strategies involving buildings. Source: Institut national de sante' publique du Quebec



STRATEGIES

- **Use light color (high albedo) paving, or paving that has the ability to reflect solar wavelengths**. High albedo paving includes light color materials and surface treatments on existing asphalt and pavement.
  - Conventional asphalt pavements can be modified with high albedo materials or treated after installation to raise reflectance
  - Several examples of high albedo paving include:
    - Conventional concrete pavements
    - Resin based pavements which use clear tree resin in place of petroleum based elements to bind an aggregate
    - Colored asphalt and colored concrete which added pigments or seals to increase reflectance

Green Building and Climate Resilience. C-75

- **Use nonvegetated permeable pavements**
  - Permeable pavements allow water to drain through the surface into sublayers and the ground below. These include porous asphalt, rubberized asphalt, pervious concrete, and brick or block pavers. Typically used in lower traffic areas, with some experimental highway use.

Cool Pavements Compendium. P 12[i]

CREATE COOL GROUND SURFACES (CONT'D)

- **Use vegetated permeable pavements**
  - Vegetated permeable pavements include grass pavers and concrete grid pavers that allow grass or other vegetation to grow in their interstices. These are most often used in areas where lower traffic volumes would minimize damage to the vegetation, such as alleys, parking lots, and trails.

Cool Pavements Compendium. P 12[2]

- **Use surface topping to resurface roadways to enhance reflectivity.** Examples include:
  - Chip seals consist of aggregate bound in liquid asphalt, and are often used to resurface low-volume asphalt roads and sometimes highways.
  - Whitetopping is a layer of concrete greater than 4 inches thick, for resurfacing road segments, intersections, and parking lots, which can incorporate a light color surface that reflects solar wavelengths.
  - Ultra-thin whitetopping is similar to whitetopping and can be used in the same applications, but is only 2-4 inches thick.
  - Microsurfacing is a thin sealing layer used for road maintenance.

Cool Pavements Compendium. P 13

- **Use woody trees and shrubs for shade and cooling**
  - Trees and shrubs lessen urban heat island effects through evapotranspiration, and providing shade. Increasing vegetative cover also provides soil stability, allows groundwater recharge, and can maintain humidity in the air in dryer regions.

Green Building and Climate Resilience. C-59[3]

1 Reducing Urban Heat Islands: Compendium of Stratgies- Cool Pavements. U.S. Environmental Protection Agency. Last Accessed 7/11/2013. http://www.epa.gov/hiri/resources/pdf/CoolPavesCompendium.pdf

2 Reducing Urban Heat Islands: Compendium of Stratgies- Cool Pavements. U.S. Environmental Protection Agency. Last Accessed 7/11/2013. http://www.epa.gov/hiri/resources/pdf/CoolPavesCompendium.pdf

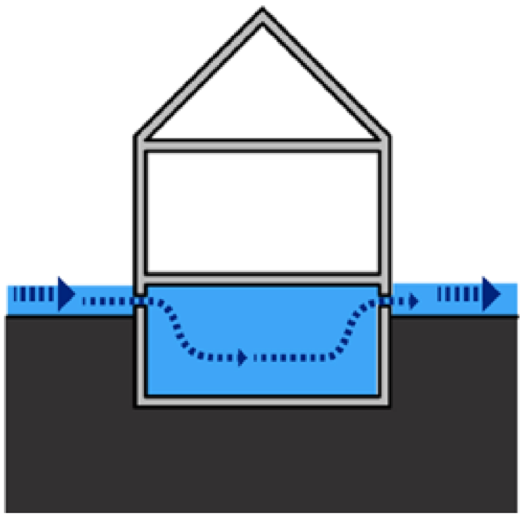
3 Larsen et al. “Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions.” University of Michigan; U.S. Green Building Council, 2011.

SITE

FLOOD PROOF CONSTRUCTION- HOMES AND BUSINESSES

One nightmare scenario in a major flood is floodwaters entering people's basements which can float and tip heating oil tanks. Spilled heating oil mixed with flood waters and backed up sewage is a devastating tragedy for homeowners and tenants alike.

Paul Shoemaker, Boston Public Health Commission



Vents that direct flood waters through buildings, instead of around them, can be useful in keeping first floor spaces and basements from structural failure. (Image: Marcus Springer.)

STRATEGIES

- **Utilize FEMA's home and commercial building retrofitting guides,** which include analysis measures, mitigation measures, and funding sources.

  Homeowner's Guide to Retrofitting, 5-1 [1]
- **Elevate residential structure above Design Flood Elevation** as a retrofit project or in design of new buildings.

  Homeowner's Guide to Retrofitting, 5-1 [2]
- **Flood-proof building**
  - Wet flood-proofing includes
    - Provide openings in the envelope to ensure that floodwaters enter and exit the home, which prevents structural failure.
    - Protect service equipment inside and outside the home

    Homeowner's Guide to Retrofitting, 6-1
  - Dry flood-proofing includes
    - Seal the exterior walls of the home, covering openings below the flood level, protecting the interior of the home from seepage, and protect service equipment outside the home.

    Homeowner's Guide to Retrofitting, 7-3
- **Relocate the building structure.**

  Homeowner's Guide to Retrofitting, 7-1
- **Protect Service Equipment** including HVAC, fuel systems, electrical systems, sewage management systems and potable water systems from floodwaters through barriers or elevating equipment.

  Homeowner's Guide to Retrofitting, 8-1
- **Install back-water flow valves and sump pumps.**
  - The City of Toronto is subsidizing the costs of installing back-water valves and sump pumps on household sewer connections in order to provide additional protection against flooding from sanitary sewers.

  Toronto's Adaptation Actions. P 2 [3]
  FEMA Mitigation Ideas, P 31 [45]

FLOOD PROOF CONSTRUCTION- HOMES AND BUSINESSES (CONT'D)

- **Secure external and interior objects.**
    - External items, including debris, propane tanks, and yard items, and interior items, such as furniture and stored objects, should be secured to prevent the being swept away in floodwaters and causing additional damage.

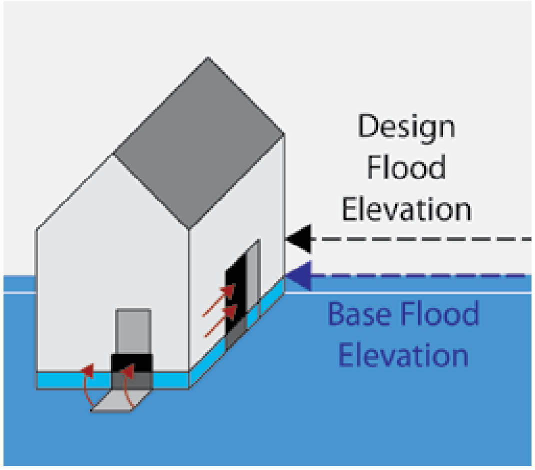
FEMA Mitigation Ideas, P 31[6]

1 Homeowner's Guide to Retrofitting: Six Ways to Protect Your Home from Flooding. Second Edition. FEMA. 2009. Last Accessed 7.10.2013 http://www.fema.gov/library/viewRecord.do?id=1420
2 Homeowner's Guide to Retrofitting: Six Ways to Protect Your home from Flooding. Second Edition. FEMA. 2009. Last Accessed 7.10.2013 http://www.fema.gov/library/viewRecord.do?id=1420
3 "Toronto's Adaptation Actions." Update April 2011. Link to the Basement Flooding Protection Program. http://www.toronto.ca/water/sewers/pdf/brochure.pdf
4 Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." FEMA Risk Analysis Division. Jan 2013.
5 Detailed backflow valve installation and cost data can be found on FEMA's website: Last accessed 7/10/2013 http://www.fema.gov/library/viewRecord.do?id=3262
6 Ibid.

SITE

FLOOD PROOFING INDUSTRIAL BUILDINGS

Industrial properties are particularly vulnerable to flood damage because they tend to be concentrated in coastal areas of the city. This vulnerability is heightened since many industrial businesses are located in 1- to 2-story structures and ordinarily store expensive equipment and inventory at ground level.



This diagram illustrates how a building that has water tight doors and cover plates to create a water tight exterior in case of flood. The doors and covers can be deployed in anticipation of a severe storm. (Image: John Gravelin)

STRATEGIES

- **Safeguard toxic materials**
    - All toxic materials in industrial buildings located in floodzones should be stored in a floodproof area.

Building Resiliency Task Force. 7. [1]
Building Resiliency Task Force 7, P 40 [2]

- **Deploy water tight construction,** including:
    - Closures and flood shields
    - Sealants, and membranes.

Floodproofing Non-Residential Structures. P 48-73. [3]

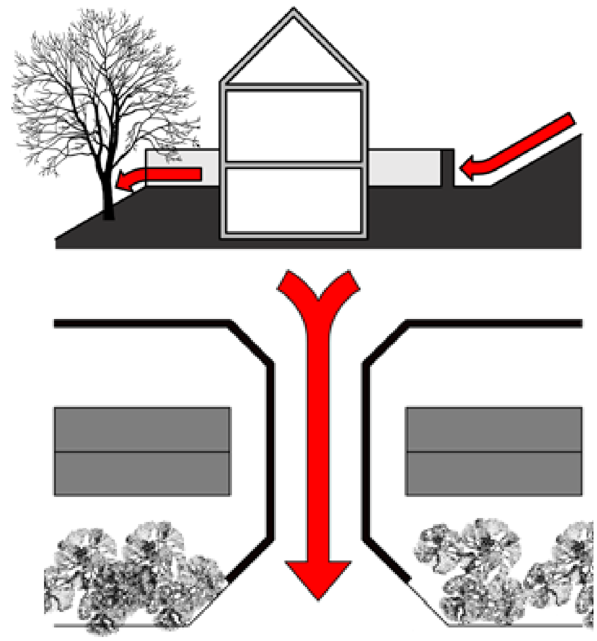
- **Flood-proof building**
    - Wet flood-proofing includes
        - Provide openings in the envelope to ensure that floodwaters enter and exit the home, which prevents structural failure.
        - Protect service equipment inside and outside the home
    - Dry flood-proofing includes
        - Seal the exterior walls of the home, covering openings below the flood level, protecting the interior of the home from seepage, and protect service equipment outside the home.
- **Consider sidewalk or exterior flood protection**
    - If appropriate on site, use sidewalk flood protection, which entails the temporary installation of dry floodproofing sandbags, gates, or fencing around a property. These barriers may encroach onto public right of ways.

Building Resiliency Task Force Report. 5-I [4]

1 Building Resiliency Task Force Full Proposals. Urban Green Council. June 2013. Accessed 7/10/2013. http://www.urbangreencouncil.org/servlet/servlet.FileDownload?file=015U0000001EyaR
2 Building Resiliency Task Force Full Proposals. Urban Green Council. June 2013. Acceded 7/10/2013. http://www.urbangreencouncil.org/servlet/servlet.FileDownload?file=015U0000001EyaR
3 "Floodproofing Non-Residential Structures." FEMA 102. May 1986. Accessed 7/10/2013. http://www.fema.gov/library/viewRecord.do?id=3581
4 Building Resiliency Task Force Full Proposals. Urban Green Council. June 2013. Accessed 7/10/2013.

SITE

HARD INFRASTRUCTURE TO PREVENT FLOODING



"Many existing buildings located in flood zones have adjacent street grades with elevations below the Design Flood Elevation. Buildings often have exterior perimeter walls and egress doors at the property lines, presenting significant challenges to building owners that wish to voluntarily incorporate dry floodproofing (flood barriers and/or shileds) around the building perimeter.

Building Resiliency Task Group, p. 2

Barriers can be effective for re-directing flood waters around residential and industrial properties. (Image: Marcus Springer.)

STRATEGIES

- **Assess flood-based vulnerability and risk to properties**

  Homeowner's Guide to Retrofitting Properties, 4-1[1]

- **Consider sidewalk or exterior flood protection**
  - If appropriate on site, use sidewalk flood protection, which entails the temporary installation of dry floodproofing sandbags, gates, or fencing around a property. These barriers may encroach onto public right of ways.

  Building Resiliency Task Force Report. 5-I[2]

- **Consider levees or floodwalls,** if appropriate.

  Homeowner's Guide to Retrofitting Properties, 3-32

1 Homeowner's Guide to Retrofitting: Six Ways to Protect Your Home from Flooding. Second Edition. FEMA. 2009. Last Accessed 7.10.2013 http://www.fema.gov/library/viewRecord.do?id=1420

2 Building Resiliency Task Force Full Proposals. Urban Green Council. June 2013.

SITE

HAZARD RESILIENT LANDSCAPE DESIGN

Climate change, including changes in precipitation and temperature patterns, will affect landscape design, including native plants. Climate change will also shift plant hardiness zones northward, affecting plant selection.

Green Buildings and Climate Resilience P 10

A drought is a period of unusually constant dry weather that persists long enough to cause deficiencies in water supply (surface or underground). Droughts are slow onset hazards, but, over time, they can severely affect crops, municipal water supplies, recreational resources, and wildlife. If drought conditions extend over a number of years, the direct and indirect economic impacts can be significant. High temperatures, high winds, and low humidity can worsen drought conditions and also make areas more susceptible to wildfire. In addition, human actions and demands for water resources can accelerate drought-related impacts.

FEMA Mitigation Ideas P 5

STRATEGIES

- **Implement flood and wind resistant landscape design,** such as:
    - Selection and planting of trees that fit increased rain and wind events

      U.S. Department o f Agriculture Plant Database[1]
    - Prune and maintain trees and other site vegetation to improve health and reduce windblown debris

      Building Resiliency Task Force 9[2]
- **Implement drought tolerant landscape design**, such as:
    - Incorporating drought tolerant or xeriscaping practices into landscape to reduce dependence on irrigation
    - Using permeable driveways and surfaces to reduce runoff and promote groundwater recharge

      FEMA Mitigation Ideas P 7[3]

      Landscaping Water Conservation Tips[4]
- **Identify and plant appropriate trees and shrubs for climate zone.**

  Landscaping to Conserve Water, UMASS Amherst[5]

Quote: Larsen et al. “Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions.” University of Michigan; U.S. Green Building Council, 2011.

1 PLANTS database Characteristics. U.S. Department of Agriculture. Online resource accessed 7/15/2013. http://plants.usda.gov/characteristics.html

2 Building Resiliency Task Force Full Proposals. Urban Green Council. June 2013. Accessed 7/10/2013. http://www.urbangreencouncil.org/servlet/servlet.FileDownload?file=015U0000001EyaR

3 “Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards.” Federal Emergency Management Agency Risk Analysis Division. Jan 2013.

4 Garden and Landscaping Water Conservation Tips. Massachusetts Water Resources Authority. Online resource accessed 7/15/2013. http://www.mwra.state.ma.us/04water/html/gardening.htm

5 Landscaping to Conserve Water Fact Sheet. University of Massachusetts. UMASS Amherst. Online Resource. Accessed 7/13/2013. http://extension.umass.edu/landscape/fact-sheets/landscaping-conserve-water

SITE

PROTECT ENTRANCES FROM SNOW AND ICE

It is also expected that there will be more freeze-thaw cycles, which can cause extensive damage to road surfaces and create potholes, create rooftop ice dams, and damage trees and plants.

Climate Change and Healthy Equity, 2009

Heavy snows and ice storms in the Boston area can render many unprotected buildings difficult to enter or leave and dangerous for disabled or older people. (Photo: Jim Newman.)

STRATEGIES

- **Protect entrances of buildings from unseasonal presence of ice** due to irregular freeze and thaw cycles.

Interview with David MacLeod [1]

Quote: Pinto,E., Penney,J. , Ligeti,E., Gower,S. and Mee,C. Climate Change Adaptation and Health Equity Background Report. City of Toronto. 2009.

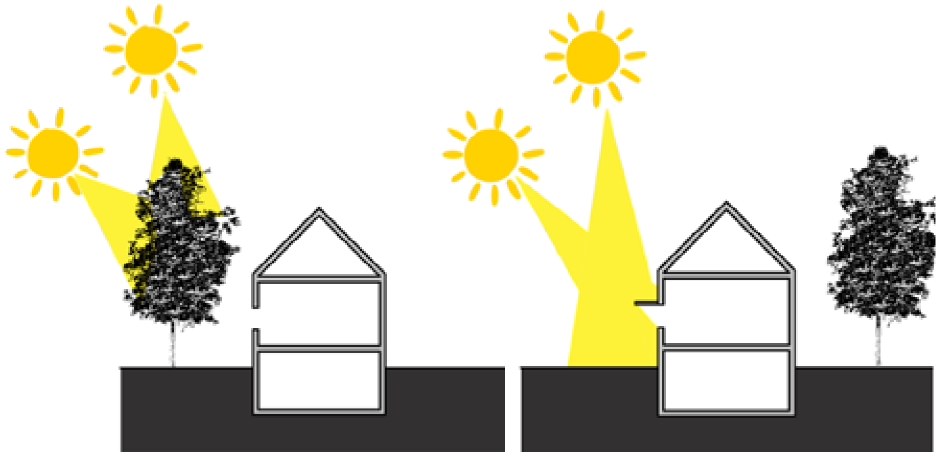
1 MacLeod, David- Senior Environmental Specialist- Environment and Energy Office, City of Toronto. Interview by Jim Newman. Phone interview. Cambridge, MA. June, 2013. (Appendix B)

SITE

PROVIDE SHADE

" Trees and vegetation lower surface and air temperatures by providing shade and through evapotranspiration. Shaded surfaces, for example, may be 20–45°F (11–25°C) cooler than the peak temperatures of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 2–9°F (1–5°C)."

EPA, Heat Island Mitigation



(Image: Marcus Springer)

STRATEGIES

- **Shade building with woody trees**
  - Shelter Eastern and Western windows and walls with woody trees.
  - Prune branches high enough to provide shade while maintaining views and breezes around the windows.
  - Prune branches to a height that allows winter sun through (in cooler latitudes)
  - Plant trees at least 5 to 10 feet but no more than 30 to 50 feet away from the building.
- **Shade air conditioner condenser units and other building cooling equipment with trees, vines, or shrubbery.**
- **Shade parking lots.**

Reducing Urban Heat Islands P 12[1]

- **Use bushes, shrubs, or vines to shade windows and walls** in places where trees do not fit.

Green Building and Climate Adaptation Strategies[2]

Quote: Climate Adaption Strategies- Implementation Plans. City of Chula Vista. 2011. Page 8. Last Accessed 7/8/2013 http://www.chulavistaca.gov/clean/conservation/Climate/documents/ClimateAdaptationStrategiesPlans_FINAL_000.pdf

1 Reducing Urban Heat Islands: Compendium of Strategies, U.S. Environmental Protection Agency . Online resource accessed 7/8/2013. http://www.epa.gov/heatisland/resources/pdf/GreenRoofsCompendium.pdf

2 Larsen et al. "Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions." University of Michigan; U.S. Green Building Council, 2011.

SITE

REDUCE VULNERABILITY TO HIGH WINDS

"High winds and windblown debris can easily break unprotected windows and then enter your house. Once inside, wind and debris can cause more damage."

Louisiana Governor's Office of Homeland Security and Preparedness, "Protecting your property from wind," (http://www.ohsep.louisiana.gov/factsheets/windshutter&windowcovers.htm)

STRATEGIES

- **Secure external items**
  - Secure debris, propane tanks, yard items, and stored objects.
  - Educate tenants about the dangers of windblown items and the techniques for securing their site.

FEMA- Unanchored Fuel Tanks, Homes and Businesses[1]

- **Prune vegetation to remove dead limbs and provide clearance from other structures**
  - Prune vegetation, including dead branches and material close to building or point of building entry for utility lines to reduce damage from windblown debris
  - Establish agreements with utilities about pruning around power lines.

Trim Your Risk of Tree Problems[2]
FEMA Mitigation Ideas. SW-4[3]

- **Assess vegetation in wildfire-prone areas to prevent landslides after fires**.
  - Encourage plants with strong root systems.

The Landslide Handbook, Section 3, Part A[4]
FEMA Mitigation Ideas. LS-1

1 "Anchor Fuel Tanks." FEMA online resources under Protect Your Property from Flooding homepage. http://www.fema.gov/library/viewRecord.do?id=3262 April 2011. Last accessed 7/10/2013. http://www.fema.gov/library/file?type=publishedFile&file=how2005_fuel_tanks_4_11.pdf&fileid=77216bb0-6374-11e0-b6f6-001cc4568fb6
2 Still Standing: Trim Your Risk of Tree Problems. Institute for Business and Home Safety. Online Resource accessed 7/15/2013. http://www.alfaaic.net/PDFs/Tree%20Trimming%20before%20Storm.pdf
3 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.
4 The Landslide Handook- A Guide to Understanding Landslides Circular 1325. U.S. Geological Survey, Reston, Virginia: 2008. Online Resource. Accessed 7/13/2013. http://pubs.usgs.gov/circ/1325/pdf/C1325_508.pdf

SITE

SOFT/GREEN INFRASTRUCTURE TO PREVENT FLOODING

Green infrastructure is an approach that communities can choose to maintain healthy waters, provide multiple environmental benefits and support sustainable communities…By weaving natural processes into the built environment, green infrastructure provides not only stormwater management, but also flood mitigation, air quality management, and much more.

EPA, Green Infrastructure (http://water.epa.gov/infrastructure/greeninfrastructure/index.cfm)

Rain gardens are an example of soft infrastructure that enhances natural water management on a building site. Image: Keith Giamportone.

STRATEGIES

- **Build grassy swales or bioswales** along roadsides to enhance ground water infiltration and reduce erosion.
  Biofiltration Swale Design Guidance, CA Dept. of Transportion[1]
- **Provide on-site stormwater retention and detention basins, natural and constructed wetlands**.
  - Both natural and constructed wetlands collect stormwater and prevent erosion during severe storm events. Wetland vegetation also provides cooling effect through evapotranspiration.
    Green Building and Climate Resilience C 71[2]
  - On-site ponds collect stormwater from a site or defined area in order to prevent flooding, and can be used as emergency fire protection water supplies.
    Green Building and Climate Resilience, C-65[3]
- **Plant and preserve more trees near building.**
  FEMA Mitigation Ideas. P 24
- **Plant vegetative buffers and vegetative islands in parking areas.**
  National Menu of Stormwater Best Management Practices[4]
- **Use permeable pavements, driveways, and surfaces** to reduce runoff and increase groundwater recharge
  National Menu of Stormwater Best Management Practices[5]
  FEMA Mitigation Ideas. P 24[6]
- **Before development, inquire about environmental programs (e.g. easement or development rights) to keep property vacant.**
  FEMA Mitigation Ideas P 30[7]

SOFT/GREEN INFRASTRUCTURE TO PREVENT FLOODING (CONT'D)

- **Explore experimental and Innovative coastal protection options,** including:
  - Sand engines, which are a means of nourishing beaches and supplementing dunes by utilizing natural ocean currents
  - Shallowing or reducing the depth of bays for flood and wave risk reduction
  - Living shorelines reefs and constructed wetlands to retain storm water (2)
  - Floating Islands / Breakwaters and Constructed barrier Islands (2)

A Stronger More Resilient New York. P 65[8]
(2) A Stronger More Resilient New York. P 53

1 Biofiltration Swale Design Guidance. Caltrans Storm Water Quality Handbook. California Department of Transportation, Division of Environmental Analysis. 2011. Last accessed 7/15/2013. http://www.dot.ca.gov/hq/LandArch/ec/stormwater/guidance/DG-Biofiltration%20Swale-060111.pdf
2 Larsen et al. "Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions." University of Michigan; U.S. Green Building Council, 2011.
3 Larsen et al. "Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions." University of Michigan; U.S. Green Building Council, 2011.
4 National Menu of Best Management Practices. Stormwater Management. U.S. Environmental Protection Agency, National Pollutant Discharge Elimination System (NPDES). Online resource accessed 7/15/2013. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse
5 National Menu of Best Management Practices. Stormwater Management. U.S. Environmental Protection Agency, National Pollutant Discharge Elimination System (NPDES). Online resource accessed 7/15/2013. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse
6 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.
7 [New York] City will evaluate opportunities for collaboration with the State in connection with its home buyout program, using an objective set of criteria developed by the City, including extreme vulnerability, consensus among a critical mass of contiguous local residents, and other relevant factors. It is anticipated that these criteria will be met in a limited number of areas citywide. *A Stronger More Resilient NewYork. New York City Mayor's Office. 2013.p 386*
8 A Stronger More Resilient New York Report. Mayor's Office of Long Term Planning and Sustainability. 2013.

SITE

STABILIZE SLOPES SUSCEPTIBLE TO EROSION, LANDSLIDE, FIRE

Increased precipitation and drought events will change the likelihood of erosion, landslide and fire on properties.

Short-term erosion typically results from periodic natural events, such as flooding, hurricanes, storm surge, and windstorms, but may be intensified by human activities. Long-term erosion is a result of multi-year impacts such as repetitive flooding, wave action, sea level rise, sediment loss, subsidence, and climate change… Landslides occur when the slope or soil stability changes from stable to unstable, which may be caused by earthquakes, storms, volcanic eruptions, erosion, fire, or additional human-induced activities. Potential impacts include environmental disturbance, property and infrastructure damage, and injuries or fatalities.

FEMA Mitigation Ideas P 15, P 37

Most of Boston is classified as a moderate landslide risk. Those parts of Boston furthest from the coast are classified as low risk.

Boston Hazard Mitigation Plan 2008 P 15

Photo: Sarah Slaughter

STRATEGIES

- **Assess steep slope and high risk areas.**

Seattle Department of Planning and Development Tip 324[1]

- **Use proper site stabilization techniques to prevent erosion**, including
    - Bank stabilization, sloping or grading techniques, planting vegetation on slopes, terracing hillsides, or installing riprap boulders or geotextile fabric.
    - Retaining walls
    - Hybrid of hard/soft engineering techniques, such as
        - Low-profile rock, rubble, oyster reefs
        - Wood structures with vegetative planting or other soft stabilization techniques).

FEMA Mitigation Ideas. ER-5 P 17[2]
Seattle Department of Planning and Development Tip 324[3]
The Landslide Handbook P 76-96

- **Stabilize cliffs** with terracing or plantings of grasses or other plants to hold soil together.
- **Prohibit removal of natural vegetation** from dunes and slopes.
- **Plant mature trees and other vegetation in the coastal and riverine riparian zones** to assist in dissipation of the wind force in the breaking wave zone.
- **Use a rock splash pad** to direct runoff and minimize the potential for erosion.

FEMA Mitigation Ideas. ER-5 P 17[4]

STABILIZE SLOPES SUSCEPTIBLE TO EROSION, LANDSLIDE, FIRE (CONT'D)

- **Direct runoff to a catch basin or holding area to reduce erosion.**
  - Confine waterflow into drainpipe or through an approved discharge point such as a drainage ditch, drywell, gutter, or natural drainage holding pond.

Seattle Department of Planning and Development Tip 324[5]

- **Use debris-flow mitigation techniques**, including
  - Strengthening slopes for erosion and debris flows, and structures to mitigate debris flow.

    The Landslide Handbook P 109-124[6]
  - Debris-flow protective structures, such as wooden deflectors and engineered block walls.

    The Landslide Handbook P 113-122

Quote: Metro-Boston Multi-Hazard Mitigation Plan. Metropolitan Area Planning Council. 2008. Online resource. Accessed 7/13/2013. http://www.cityofboston.gov/environment/mitigationplan.asp

1 Seattle Permits Tip 324. Department of Planning and Development. Online Resource. January 2002. Accessed 7/13/2013. http://www.seattle.gov/dpd/publications/cam/cam324.pdf
2 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.
3 Seattle Permits Tip 324. Department of Planning and Development. Online Resource. January 2002. Accessed 7/13/2013. http://www.seattle.gov/dpd/publications/cam/cam324.pdf
4 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.
5 Seattle Permits Tip 324. Department of Planning and Development. Online Resource. January 2002. Accessed 7/13/2013. http://www.seattle.gov/dpd/publications/cam/cam324.pdf
6 The Landslide Handook- A Guide to Understanding Landslides Circular 1325. U.S. Geological Survey, Reston, Virginia: 2008. Online Resource. Accessed 7/13/2013. http://pubs.usgs.gov/circ/1325/pdf/C1325_508.pdf

BUILDING STRUCTURE

Photo: John Gravelin

BUILDING STRUCTURE

ENHANCE STRUCTURAL ELEMENTS FOR EXTREME LOADS

Construction type, which tends to correlate with building height, also served as a predictor of Sandy-related damage for buildings. As stated above, low-rise structures suffered the most severe damage. Though such structures are often of combustible construction, not all are. However, where low-rise structures were also of combustible construction, the damage tended to be even more severe. In fact, while 85 percent of the 1-story buildings in the area inundated by Sandy were combustible structures, 99 percent of 1-story buildings receiving red DOB December Tags (including those further tagged as destroyed) were of a combustible construction type. Conversely, high-rise structures, which often are of a non-combustible construction type, tended to experience less severe structural damage.

A Stronger, More Resilient New York. P 75

Meltwater from ice dams can cause significant damage to roof sheathing and structure. As warmer temperatures may cause increased freeze/thaw cycles, detailing the roof-eave assembly and insulation to prevent ice dams will become more important.

Green Building and Climate Resilience C-23

Many different types of pests, especially termites, do damage to buildings and wooden structures. Because of warmer winters, the ranges of these pests may expand and cause increased damage to buildings. Designing in termite resistance, performing integrated pest management, or avoiding wood construction all can prevent damage to buildings from pests such as termites.

Green Building and Climate Resilience C-47

Change in soil moisture or winter freeze/thaw cycles may cause damage to existing building foundations. Anticipating changes in soil moisture may help to precent damage over the long term to a building's structure.

Green Building and Climate Resilience. C-49

STRATEGIES

- **Enhance/retrofit building structural elements (connectors, members, systems) to withstand extreme loads.**
    - Bracing strategies
    - Retrofit non reinforces masonry buildings and non-ductile concrete
    - Modify gable walls and roofs for wind and snow loads

Seismic Rehabilitation of Existing Buildings Ch1, Part 3[1]
FEMA Protect Your Property From High Winds[2]

- **Retrofit building with load-path connectors to strengthen the structural frames**

Wind Retrofit Guide for Residential Buildings[3]

- **Enhance/retrofit building foundation to minimize structural damage**
    - Raise building up above hazard level
    - Create open foundations or deep foundations

Homeowner's Guide to Retrofitting, 5-1 [4]
Seismic Rehabilitation of School Buildings[5]
FEMA Mitigation Ideas EQ-6 P 12[6]

- **Retrofit roofing system to minimize structural and collateral damage**
    - Secure built up and single ply roofs
    - Secure metal siding and metal roofs
    - Secure composition shingle roofs

FEMA Protect Your Property From High Winds[7]

    - Improve roof coverings to reduce windblown debris
        - Remove pebbles and other ballast roof systems

FEMA Mitigation Ideas P 48[8]

ENHANCE STRUCTURAL ELEMENTS FOR EXTREME LOADS (CONT'D)

- **Construct masonry chimneys greater than six feet above a roof with continuous reinforced steel bracing**

FEMA Mitigation Ideas EQ-6[9]

- **Elevate structure above Design Flood Elevation**
- **Backfill basement to grade**
- **Rebuild or reinforce foundation to address flood loads,**
    - Add interior piers
    - Add bracing or tensile strengthening
- **Provide foundation flood openings or open foundations**
- **Provide anchorage between superstructure and substructure**

Building Resiliency Task Force Section 1 P 5[10]

- **Use materials that are more resistant to pests** to meet expanding pest territories

Green Building and Climate Resilience[11]

Quote: A Stronger More Resilient New York Report. Mayor's Office of Long Term Planning and Sustainability. 2013.
Quote: Larsen et al. "Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions." University of Michigan; U.S. Green Building Council, 2011.

1 Techniques for the Seismic Rehabilitation of Existing Buildings. Federal Emergency Management Agency. FEMA 547. 2006. Online resource accessed 7/15/2013.

2 "Protect Your Property from High Winds" website contains details construction and cost information on all listed strategies. Last accessed 7/10/2013. http://www.fema.gov/library/viewRecord.do?id=3263

3 "Wind Retrofit Guide for Residential Buildings." FEMA P-804. December 2010.

4 Homeowner's Guide to Retrofitting: Six Ways to Protect Your home from Flooding. Second Edition. FEMA. 2009. Last Accessed 7.10.2013 http://www.fema.gov/library/viewRecord.do?id=1420

5 Incremental Seismic Rehabilitation of School Buildings (K-12): Providing Protection to People and Buildings. Federal Emergency Management Agency. FEMA 395. 2003. Online resource accessed 7/15/2013. https://www.fema.gov/library/viewRecord.do?id=1980

6 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.

7 "Protect Your Property from High Winds" website contains details construction and cost information on all listed strategies. Last accessed 7/10/2013. http://www.fema.gov/library/viewRecord.do?id=3263

8 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.

9 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.

10 Building Resiliency Taslk Force Full Proposals. Urban Green Council. June 2013. Acceded 7/10/2013. http://www.urbangreencouncil.org/servlet/servlet.FileDownload?file=015U0000001EyaR

11 Larsen et al. "Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions." University of Michigan; U.S. Green Building Council, 2011.

BUILDING ENCLOSURE

BUILDING ENCLOSURE

COOL ROOFING

Rising temperatures and urban heat islands increase the risk of illness and even death; the most vulnerable populations are the elderly, young children, and low-income residents. In addition to public health problems, urban heat islands increase energy use and costs as well as pollution levels in cities, causing additional illness.

Adapting to Urban Heat, P 1

A high solar reflectance—or albedo—is the most important characteristic of a cool roof as it helps to reflect sunlight and heat away from a building, reducing roof temperatures. A high thermal emittance also plays a role, particularly in climates that are warm and sunny. Together, these properties help roofs to absorb less heat and stay up to 50–60°F (28–33°C) cooler than conventional materials during peak summer weather. Building owners and roofing contractors have used cool roofing products for more than 20 years on commercial, industrial, and residential buildings. They may be installed on low- slope roofs (such as the flat or gently sloping roofs typically found on commercial, industrial, and office buildings) or the steep-sloped roofs used in many residences and retail buildings.

EPA Cool Roofs Website

Vegetated, or green roofs are a popular strategy to reduce Heat Island Effect in urban settings. The vegetation absorbs heat and uses it for evapotranspiration, reducing temperature rise associated with impermeable surfaces, like roofs. (Photo: Luce Trouche)

STRATEGIES

- **Use Cool Roofing techniques**, including:
  - Low slope roofs: paints and surface treatments, single ply light color or reflective membranes
  - Steep sloped roofs: cool colored tiles, cool metal roofing

EPA Cool Roofs[1]

- **Use Green Roofing techniques**, including:
  - Extensive (Low-Profile/Ecoroofs) are green-roof options that are usually less expensive ($5-$-25/sf) with low water requirements, low maintenance, and are usually non-accessible and non-recreational.
  - Intensive (High-Profile/ Roof Gardens) are green-roof options that range from $25-$40/sf), designed for relatively flat roofs, and can facilitate trees, shrubs, and vegetables.

EPA Green Roofs[2]

COOL ROOFING (CONT'D)

Quote: Hoverter, S. "Adapting to Urban Heat: A Tool Kit for Local Governments." Georgetown Climate Center. August 2012.
Quote: EPA Cool Roofs Website. Last Accessed 7/10/2013. http://www.epa.gov/hiri/mitigation/coolroofs.htm

1 Reducing Urban Heat Islands: Compendium of Strategies- Cool Roofs. U.S. Environmental Protection Agency. Last Accessed 7/10/2013. http://www.epa.gov/hiri/resources/pdf/CoolRoofsCompendium.pdf
2 Reducing Urban Heat Islands: Compendium of Strategies- Green Roofs. U.S. Environmental Protection Agency. Last Accessed 7/10/2013. http://www.epa.gov/hiri/resources/pdf/GreenRoofsCompendium.pdf

BUILDING ENCLOSURE

ENHANCE BUILDING INSULATION

Utility failures often disable heating and cooling systems, leaving interior building temperatures dependent on whatever protection is provided by the insulation and air sealing of a building's walls, windows, and roof.

Building Resiliency Task Force. 27 P 150.

Well designed insulation systems reduce conduction through the thermal envelope. During the summer, this can reduce interior air temperature, peak electrical demand, and annual cooling requirements. By controlling conductive gains and losses, the building also relies less on heating and cooling systems, further reducing cooling requirements and electrical demand.

Green Buildings and Climate Resilience. C-13.

Installing Johns Manville "Spider" insulation: a spray-applied fiberglass for cavity-fill applications. A small amount of acrylic binder holds the insulation in place even without netting in overheat applications. This type of insulation fills cavities entirely and does a superb job at blocking sound and reducing air leakage in residential and light commercial settings. (Photo: Alex Wilson)

STRATEGIES

- **Add insulation** in the ceiling, walls and basement.

  Overview- Adding Insulation to an Existing House[1]
  Wall Insulation FactSheet[2]
  Basement Insulation Factsheet[3]

- **Insulate crawlspaces.**

  Crawlspace Insulation FactSheet[4]

- **Use advanced wall framing techniques that reduce energy loss**, including:

  Wall Insulation FactSheet[5]

  - Insulating concrete forms that can be used to construct walls for new homes.

    Insulating Concrete Forms[6]

  - Structural insulated panels (SIPS) for new building projects or exterior retrofits.

    Structural Insulated Panels- TechSpecs[7]

  - Exterior insulation Finish Systems (EIFS), also called synthetic stucco, which are available in drainable or barrier systems that resemble traditional masonry stucco finishes.

    Exterior insulation and Finish Systems (EIFS)[8]

1 "Adding insulation to an Existing House (Smart Approaches)." Oak Ridge National Labs Webpage. Last accessed 7/10/2013. http://www.ornl.gov/sci/roofs+walls/insulation/ins_06.html
2 Wall Insulation- Technology Factsheet. Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy U.S. Department of Energy. Last accessed 7/10/2013. http://www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/wall%20insulation%20technology.pdf

ENHANCE BUILDING INSULATION (CONT'D)

3 Crawlspace Insulation- Technology Factsheet. Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department of Energy. Last accessed 7/10/2013. http://www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/basement%20Insulation%20Technology%20fact.pdf
4 Crawlspace Insulation- Technology Factsheet. Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department of Energy. Last accessed 7/10/2013. http://www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/crawlspace%20insulation%20technology.pdf
5 Wall Insulation- Technology Factsheet. Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department of Energy. Last accessed 7/10/2013. http://www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/wall%20insulation%20technology.pdf
6 Insulating Concrete Forms. Toolbase.org webpage. Last Accessed 7/10/2013 http://www.toolbase.org/Technology-Inventory/walls/Insulating-Concrete-Forms
7 Structural Insulated Panels. Toolbase.org webpage. Last Accessed 7/10/2013. http://www.toolbase.org/Technology-Inventory/Whole-House-Systems/structural-insulated-panels
8 Exterior insulation and Finish Systems (EIFS). Toolbase.org webpage. Last Accessed 7/10/2013. http://www.toolbase.org/Techinventory/TechDetails.aspx?ContentDetailID=988&BucketID=6&CategoryID=54

BUILDING ENCLOSURE

INCREASE RESISTENCE TO HIGH WINDS

Protecting your property from high winds can involve a variety of actions, from inspecting and maintaining your building to installing protective devices. Most of these actions, especially those that affect the exterior shell of your building, should be carried out by qualified maintenance staff or professional contractors licensed to work in your state, county, or city.

FEMA Protect Your Property From High Winds

Metal roofing demonstrated high resistence to wind damage. (Photo by Alex Wilson)

STRATEGIES

- **Protect windows, doors, and openings from wind loads and windblown debris.**
    - Reinforce or replace garage doors
    - Protect windows and doors with covers

      FEMA Protect Your Property From High Winds[1]
    - Install hurricane shutters or other protective measures

      Building a Safe Room for Your Home or Small Business[2]
    - Install window film to prevent injuries from shattered glass

      FEMA Mitigation Ideas EQ-6[3]

- **Strengthen wall systems for wind loads and windblown debris.**
    - Brace gable end roof framing
    - Maintain EIFS (Exterior Insulation Finishing System) walls

      FEMA Protect Your Property From High Winds[4]
    - Retrofit building veneers/cladding system to prevent failure

      FEMA Mitigation Ideas EQ-6[5]

- **Strength roof systems for wind loads**
    - Brace gable end roof framing
    - Secure built up and single ply roofs
    - Secure metal siding and metal roofs
    - Secure composition shingle roofs

      FEMA Protect Your Property From High Winds[6]

INCREASE RESISTENCE TO HIGH WINDS (CONT'D)

- Improve roof coverings (remove pebbles and other ballast roof systems)
- Anchor roof mounted heating, ventilation, and air conditioning units
- Upgrade and maintain existing lighting protection systems to prevent roof damage

Design and Construction Guidance for Community Safe Rooms[7]
Homebuilder's Guide to Coastal Construction[8]
Recommended Residential Construction or Coastal Areas[9]
FEMA Mitigation Ideas P 48[10]

- **Prepare site for high wind conditions.**
  - Remove dead tree branches and potential windborne projectiles

FEMA Protect Your Property From High Winds[11]

  - Anchor roof mounted heating, ventilation, and air conditioning units
  - Avoid placing flagpoles or antennae near buildings

Design and Construction Guidance for Community Safe Rooms[12]
Homebuilder's Guide to Coastal Construction[13]
Recommended Residential Construction or Coastal Areas[14]
FEMA Mitigation Ideas P 4

1 "Protect Your Property from High Winds" website contains details construction and cost information on all listed strategies. Last accessed 7/10/2013. http://www.fema.gov/library/viewRecord.do?id=3263
2 "Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business" FEMA P-320. Third Edition. August 2008. http://www.fema.gov/library/viewRecord.do?id=1536
3 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.
4 "Protect Your Property from High Winds" website contains details construction and cost information on all listed strategies. Last accessed 7/10/2013. http://www.fema.gov/library/viewRecord.do?id=3263
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7 "Design and Construction Guidance for Community Saferooms." FEMA P-361, Second Edition/August 2008.
8 "Homebuilder's Guide to Coastal Construction." FEMA P-499. Technical Fact Sheet Series. December 2010. http://www.fema.gov/library/viewRecord.do?id=2138
9 "Recommended Residential Construction for Coastal Areas: Building on Strong and Safe Foundations." FEMA P-550. Second Edition, December 2009. http://www.fema.gov/library/viewRecord.do?id=1853
10 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.
11 "Protect Your Property from High Winds" website contains details construction and cost information on all listed strategies. Last accessed 7/10/2013. http://www.fema.gov/library/viewRecord.do?id=3263
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13 "Homebuilder's Guide to Coastal Construction." FEMA P-499. Technical Fact Sheet Series. December 2010. http://www.fema.gov/library/viewRecord.do?id=2138
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BUILDING ENCLOSURE

MANAGE HEAT GAIN

With their layered transparency, connection to the outdoors, and daylighting—maybe even higher productivity—all-glass buildings have their appeal. But the energy penalty of such buildings cannot be ignored.

Building Green, 2010

Exterior shading at the Burton Barr Central Library in Phoenix. (Photo: Alex Wilson)

STRATEGIES

- **Use energy efficient windows and shading devices** to maximize the insulating qualities of the building openings.
    - For homeowners
      Efficient Window Collaborative[1]
    - For large commercial structures
      Efficient Windows Collaborative [2]
    - For all buildings, consider participating in the U.S. Department of Energy's High Performance Windows Volume Purchase Program[3]
- **Use thermal mass, or building materials that absorb heat energy.**
    - Correct use of thermal mass moderates internal temperatures by averaging day/night (diurnal) extremes. This increases comfort and reduces energy costs.
      Thermal Mass- Yourhome.gov.au[4]

Quote: Wilson, Alex. Rethinking the All-Glass Building. Environmental Building News. June, 2010.

1 Design Guidance for New Windows in a Cold Climate. Efficient Windows Collaborative. 2013. Online resource accessed 7/15/2013. http://www.efficientwindows.org/downloads/ColdDesignGuide.pdf
2 Energy Efficient Windows for Mid-& High-rise Residential Buildings. Efficient Windows Collaborative. 2011. Online resource accessed 7/15/2013. http://www.efficientwindows.org/MidHighRiseResidential.pdf
3 http://www1.eere.energy.gov/buildings/windowsvolumepurchase/
4 4.9 Thermal Mass- Australia's guide to environmentally sustainable homes. Yourhome.gov.au webpage. Last Accessed 7/10/2013 http://www.yourhome.gov.au/technical/fs49.html

BUILDING SYSTEMS

Photo: John Gravelin

BUILDING SYSTEMS

RESILIENT BACKUP POWER AND SYSTEMS

Companies are beginning to look at renewable systems and renewable systems backup as part of their resilience plan.

Interview with Boston Properties

Two Sunny Island inverters from SMA Americas and a battery bank for providing electricity from grid-connected solar-electric systems during power outages. With this system, the specialized inverters regulate electricity flow into and out of the battery bank, and they allow electricity to flow from the standard solar inverters to loads in the building. (Photo: Alex Wilson)

STRATEGIES

- **Elevator system.**
    - Elevator systems should be designed with a back-up power source or automatic return so that they return to the first floor in the event of a power outage. In case of flooding, elevator machinery should be located above flood level in order to prevent permanent damage to the system. The elevator tower should also be sealed to prevent water contamination to the hydraulic fluid or it could be equipped with a water detector that allows the elevator to stop above the flood level.

Green Building and Climate Resilience p.227[1], Reference work (Ministere de l'Ecologie) p.53[4]

- **Choose reliable backup power and prioritize needs.**
    - Prioritize which electrical equipment will run on backup power so buildings can remain habitable during extended blackouts. Because cogeneration and solar power systems are always in use, they can be more reliable than generators that are only turned on during emergencies.

Building Resiliency Task Force P 80[3]

- **Design cogeneration and solar power to run during blackouts.**
    - This "islanding" may require regulatory approval.

Building Resiliency Task Force P 84

- **Consider natural gas generators.**
    - Natural gas generators provide cleaner power than diesel generators that can be used for lighting, fire safety, elevators, and other building systems.

Building Resiliency Task Force Summary P 7

- **Install easy hookups for temporary generators and boilers.**
    - Under extended service disruptions, it is much easier to use electricity and heat from temporary emergency generators and boilers if convenient hookup points are installed in advance.

Building Resiliency Task Force P 108

RESILIENT BACKUP POWER AND SYSTEMS (CONT'D)(1)

- **Prioritize critical system backup maintenance.**
    - The maintenance and operation of critical systems in the event of a power outage should be prioritized in the design of the building as well as in the operations and maintenance plans. Critical systems should be backed up with renewable power generation, a generator, or a battery backup system.

Green Building and Climate Resilience p.229

- **Ensure system redundancy.**
    - Design building systems to provide overlapping services, so that when a system is damaged, some of its services can be provided by a different system.

Green Building and Climate Resilience p.231

- **Insulate refrigeration equipment.**
    - Refrigeration systems that have higher insulation levels will preserve food and other goods at critical temperatures for longer periods of time.

Green Building and Climate Resilience p.235

- **Raise utility hookups and other mechanical devices above expected flood levels.**
    - Electrical, mechanical and HVAC equipment, fuel oil tanks and supply, medical and compressed gas storage tanks, elevators, fire command stations and alarm systems, fire pumps and associated fire protection equipment, reduced pressure zone backflow preventers, fresh air intakes for sewer piping, etc. should be places above expected flood levels.

FEMA Mitigation Ideas p. 28, Building Resiliency Task Force P 17-21[2]

- **Raise electrical service panel to a readily accessible location above expected flood levels.**

Building Resiliency Task Force P11

- **Raise IT services above expected flood levels.**

Building Resiliency Task Force P17

- **Raise tankless water heaters above expected flood levels.**
    - In residential settings, tankless water heaters should be located above flood level.

FEMA Mitigation Ideas p. 28

- **Build a permanent water-resistant barrier around equipment.**
    - In cases where raising equipment is not possible, build a permanent flood proof barrier to protect equipment.

(Ministere de l'Ecologie) p. 40

- **Separate electrical circuits between levels under and above expected flooded levels**.

(Ministere de l'Ecologie) p. 49

- **Protect service equipment.**
    - Including HVAC, fuel systems, electrical systems, sewage management systems and potable water systems from floodwaters through barriers or elevating equipment.

Homeowner's Guide to Retrofitting, 8-1

- **Replace existing non-ductile utility connectors with ductile-utility connectors to reduce breakage during hazardous events (e.g., seismic, high flood).**

Design and Construction Guidance for Community Safe Rooms

- **Upgrade and maintain existing lighting protection systems to prevent and equipment roof damage.**

FEMA Mitigation Ideas P 48

RESILIENT BACKUP POWER AND SYSTEMS (CONT'D)(2)

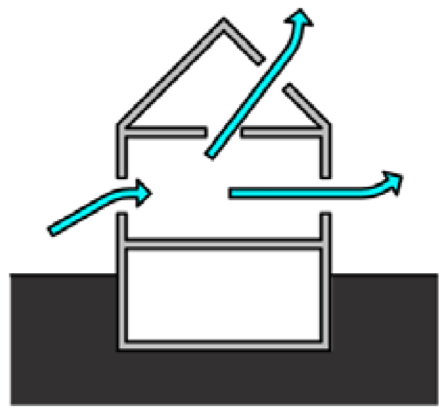
1. Larsen et al. "Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions." University of Michigan; U.S. Green Building Council, 2011.
http://www.usgbc.org/Docs/Archive/General/Docs18496.pdf
2. Federal Emergency Management Administration. Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards. 2013
http://www.fema.gov/library/viewRecord.do?id=6938
3. Building Resiliency Task Force. Report to Mayor Michaël R. Bloomberg & Speaker Christine C. Quinn: full proposals. 2013.
http://www.urbangreencouncil.org/BuildingResiliency
4. Ministère de l'Ecologie, du Développement Durable, des Transports et de l'Habitat. (French Ministry of Ecology, Sustainable Development, Transport and Housing). Référentiel de travaux de prévention de l'inondation dans l'habitat existant (Reference work to prevent flooding in the existing housing). 2012.
http://www.developpement-durable.gouv.fr/Referentiel-de-travaux-de.html

BUILDING SYSTEMS

RESILIENT HEATING, COOLING, AND VENTILATION SYSTEMS

Recommendation: Undertake a comprehensive study of passive survivability and dual-mode functionality, then propose code changes to incorporate these concepts into the city's building codes.

Building Resiliency Task Force page BR-6 1



Passive ventilation strategies are equally important in residential and commercial properties of all scales, to help ensure continued usability of buildings during extended system outages. (Image: Marcus Springer)

STRATEGIES

- **Use cross ventilation for passive cooling.**
    - Cross ventilation relies on the air pressure from the wind to remove heat from a space. Designing spaces to allow for cross ventilation provides a passive method of cooling the building on warm days. In the event of a power failure, cross ventilation may allow the building to continue to be occupied even if there is no mechanical cooling present.

Green Building and Climate Resilience p.177[1]

- **Use stack ventilation for passive cooling.**
    - Designing spaces to allow hot air to rise up and out of the space provides a passive method to cool the building on warm days. In the event of a power failure, stack ventilation may allow the building to continue to be occupied even if there is no mechanical cooling present.

Green Building and Climate Resilience p.181

- **Install ceiling fans.**
    - Electric fans increase indoor air speeds, helping to provide thermal comfort. When used in conjunction with air conditioning, they can help to reduce energy use if the thermostat set point temperature is raised. This can reduce electrical energy demand and usage through the cooling season.

Green Building and Climate Resilience p.185

- **Consider thermal energy storage.**
    - Thermal energy storage can reduce energy demand during the daytime by producing chilled water at night to reduce the load on mechanical systems and electrical grid. This approach can help a building to respond to increased temperatures by reducing peak daytime demand, allowing existing systems to respond greater demand for cooling without reconfiguration.

Green Building and Climate Resilience p.187

- **Insulate Water System.**
    - Insulating pipes helps to minimize heat loss and to protect cold water lines from freezing in the event of extended loss of heating capability.

Green Building and Climate Resilience p.209

RESILIENT HEATING, COOLING, AND VENTILATION SYSTEMS (CONT'D)

- **Power cooling systems using local renewable energy sources.**
  - For example, solar energy is most available when cooling is most needed, and local energy supplies will increase both the development's and the region's resilience to power shortages and outages.

Adapting to Climate Change p.27, Urban Heat Island Mitigation Strategies p. 40[2]

- **Anchor roof mounted heating, ventilation, and air conditioning units.**

FEMA Mitigation Ideas P 48[3]

1 Larsen et al. "Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions." University of Michigan; U.S. Green Building Council, 2011. http://www.usgbc.org/Docs/Archive/General/Docs18496.pdf
2 Institut National de Santé Publique du Québec (Quebec Public Health National Institute). Urban Heat Island Mitigation Strategies. 2009 http://www.inspq.qc.ca/pdf/publications/1513_UrbanHeatIslandMitigationStrategies.pdf
3 Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards. Federal Emergency Management Agency Risk Analysis Division. Jan 2013.

BUILDING SYSTEMS

RESILIENT WATER SYSTEMS DURING OUTAGES

The first step that New York City will take will be to require, by 2014, common access to potable water in high-rise multi-family buildings during emergency situations. This will be done to help upper-floor residents who may lose access to such water in their units in the event of the failure of building electric pumps.

A Stronger, More Resilient New York, plaNYC page 86

STRATEGIES

- **Use water catchment systems/cistern.**
  - Use water catchment systems include cisterns, storage tanks, and ponds. Tanks can be located above or below ground to store water. Storage should be sized based on projected precipitation volumes in order to maximize the volume of water that can be captured during a storm event.

Green Building and Climate Resilience p.217[1]

- **Enhance building water reserves.**
  - Water towers can provide potable water by gravity during power losses.

Building Resiliency Task Force P 143[3]

- **Develop agreements for secondary water sources.**
  - Secondary water sources can provide critical water supplies during emergencies or drought conditions.

FEMA Mitigation Ideas p.6[2]

- **Supply drinking water without power.**
  - During a power failure, residential buildings using electric pumps lose their supply of potable water. Water may be present below the sixth floor, but in some cases remains unavailable if a non-operating pump blocks the water supply. Buildings need to designate one or more common areas on lower floors for potable water distribution.

Building Resiliency Task Force P 132

- **Ensure toilets & sinks work without power.**
  - Some toilets and faucets need electricity to function. To avoid a sanitation risk during an extended power outage, use at least one non-electric toilet and faucet per bathroom, or Lavatory faucet sensors and toilet sensors with the required battery life or flushometer toilets with sensors providing a manual override.

Building Resiliency Task Force P 139

1. Larsen et al. Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions. University of Michigan; U.S. Green Building Council, 2011. http://www.usgbc.org/Docs/Archive/General/Docs18496.pdf
2. Federal Emergency Management Administration. Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards. 2013 http://www.fema.gov/library/viewRecord.do?id=6938
3. Building Resiliency Task Force. Report to Mayor Michaël R. Bloomberg & Speaker Christine C. Quinn: full proposals. 2013. http://www.urbangreencouncil.org/BuildingResiliency

BUILDING SYSTEMS

EXTEND EMERGENCY LIGHTING AND SERVICES

There is a notion of providing enough onsite power generation in a neighborhood to keep residents able to stay. That may be possible by lighting stairwells, lobbies, and front porches longer than 90 minutes, helping to maintain public safety in buildings and on streets.

Interview with Robin Guenther, Perkins + Will

STRATEGIES

- **Keep residential stairwells and hallways lit during blackouts.**
  - Use extended energy efficient lighting.

Green Building and Climate Resilience P199
Building Resiliency Task Force P 119[1]

- **Add backup wireless fire communication systems.**
  - All large buildings in flood zones should consider having a backup wireless fire communication system, and new large critical buildings must have backup phone and data connections.

Building Resiliency Task Force P 36

1 Building Resiliency Task Force. 2013. http://www.urbangreencouncil.org/BuildingResiliency

Photo Alex Wilson

BUILDING OPERATIONS

HAVE EMERGENCY COMMUNICATIONS PLAN

Careful planning, effective communication and targeted training will improve the level of building and occupant protection while minimizing panic.

Building Resiliency Task Force 28 P 163

STRATEGIES

- **Print hardcopies of tenant listings** to assist in evacuation and outreach services before, during and after disasters.
- **Print notices to update building tenants on emergency preparedness and building recovery efforts.**
    - Plan to provide a reliable power source to that printer.
    - *"One building put out flyers the day before the storm about setting a time to meet tenants to answer questions. This turned out to be very valuable. They also printed notices every day about what was going on…But printers were dead. They needed to print off site."*

Enterprise Community Partners Interview[1]

- *"It is very useful, in a multi-family building, to know who lives where, and what units are empty and can take refugees from elsewhere in the building."*

Enterprise Community Partners Interview[2]

- **Have emergency supply plans for water, energy, transportation, communications, and food.**
- **Monitor demand and supply of contingency stock for each resource**.

FEMA Mitigation Ideas D-1, D-3 P 6[3]

1 Olatoye, Shola. Enterprise Community Partners. Interview by Jim Newman. June 2013. Telephone interview.
2 Swenson, Katie. Vice President, National Design Initiatives, Enterprise Community Partners. Interview by Jim Newman. June 2013. Telephone interview.
3 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.

BUILDING OPERATIONS

PROTECT RECORDS AND INVENTORY

Most businesses keep on-site records and files (both hard-copy and electronic) that are essential to normal operations. Some businesses also store raw materials and product inventory. The loss of essential records, files, and other materials during a disaster is commonplace and can not only add to your damage costs but also delay your return to normal operations. The longer your business is not operating, the more likely you are to lose customers permanently to your competitors. To reduce your vulnerability, determine which records, files, and materials are most important; consider their vulnerability to damage during different types of disasters (such as floods, hurricanes, and earthquakes) and take steps to protect them.

Protecting Your Property from Natural Hazards p 1

STRATEGIES

- **Print hardcopies of electronic files critical to facility operations such as building floor plans, evacuation egress routes, and electrical schemes.**
    - *"When the power was out in NYC, we had our building teams standing around paper copies of the plans, figuring out how to get the buildings back up and running…We now recommend keeping 2 sets of paper plans – one on-site and one at the engineers' office."*

Boston Properties Interview[1]

- **Protect business records and inventory.**
    - Move heavy and fragile objects to low shelves
    - Store vital documents (plans, legal papers, etc.) in a secure off-site location
    - Regularly back up vital electronic files (such as billing and payroll records and customer lists) and store backup copies in a secure off-site location
    - When you identify equipment susceptible to damage, consider the location of the equipment. For example, equipment near a hot water tank or pipes could be damaged if the pipes burst during an earthquake, and equipment near large windows could be damaged during hurricanes.

FEMA Protect Business Records and Inventory[2]

1 Koop,Bryan, Senior Vice President and Regional Manager of the Boston Office, Boston Properties. Interview by Jim Newman. June 2013. Telephone interview.

2 Protecting Your Property from Natural Hazards: Protect Business Records and Inventory Worksheet. Online Resource accessed 7/15/2013. http://www.fema.gov/library/viewRecord.do?id=3259

BUILDING OPERATIONS

SECURE INTERIOR ENVIRONMENT

Without the appropriate precautions, even enclosed hazardous substances in the city's 100-year floodplain could be disturbed by storm surge, resulting in undesirable impacts.

A Stronger, More Resilient New York P 203

STRATEGIES

- **Secure interior furnishings and equipment.**
  - Facilities operations and maintenance staff should secure furnishings, storage cabinets, and utilities to prevent injuries and damage. Examples include anchoring tall bookcases and file cabinets, installing latches on drawers and cabinet doors, restraining desktop computer and appliances, using flexible connections on gas and water lines, mounting framed picture and mirrors securely, and anchoring and bracing propane tanks and gas cylinders

FEMA Mitigation Ideas EQ-9, P 14[1]

- **Conduct regular maintenance and inspection of resilience-related equipment**
  - Conduct regular maintenance on drainage systems, back-up generators, and flood protection systems.

FEMA Mitigation Ideas F 14, P27

- **Safeguard on-site hazardous and toxic materials** within flood zones beyond normal code requirements.

Building Resiliency Task Force 7, P 40 [2]

1 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.
2 Building Resiliency Task Force Full Proposals. Urban Green Council. June 2013. Acceded 7/10/2013. http://www.urbangreencouncil.org/servlet/servlet.FileDownload?file=015U0000001EyaR

BUILDING OPERATIONS

TRAIN BUILDING/FACILITY TEAMS FOR RESILIENCE UPGRADES

Careful planning, effective communication and targeted training will improve the level of building and occupant protection while minimizing panic.

Building Resiliency Task Force 28 P 163

Generally, multifamily buildings weathered the storm pretty well. In many cases, it wasn't until after the storm that problems arose, particularly long term service disruption. Housing groups were prepared for a couple of days of disruption, but not 2 -3 weeks.

Shola Olatoye - Enterprise Community Partners

STRATEGIES

- **Train building and facility management staff to operate any backup systems in the building**, including:
  - Generators, battery lighting in stairwells
  - Common area drinking water.

    Building Resiliency Task Force 28 P 162
  - Utilize the local chapter of building professionals (e.g. AIA or USGBC chapter) to help in creating a training program around new building standards, energy requirements, etc.

    Building Resiliency Task Force 27 P 154
  - Attend citywide events that train individuals on resource, communication and procedures that are provided by the city.

    Building Resiliency Task Force 28 161
- **Assess upgrade priority lists.**
  - *"Enterprise has set up a two-year learning collaborative to understand first-hand the challenges facing the region's families and affordable housing organizations. Called the"Learning Collaborative for Multifamily Affordable Housing Resilience". Through this work, Enterprise will create tools and protocols for disaster preparedness in the multifamily affordable housing sector, extending the benefits of this program to all housing owners in the region and beyond. "*

    Enterprise Community Partners Interview [2]
- **Plan for emergency repairs**.
  - *"One especially well-prepared group stockpiled parts for mechanical systems as standard operational procedure and had a team at the ready to deal with repairs. As a result, when Sandy struck, they were able to repair existing systems on their own or with local professional help, while other organizations faced long delays waiting for back-ordered parts or new mechanical systems to become available."*

    Enterprise Community Partners Interview [2]
- **Participate in outreach to builders, architects, engineers and inspectors.**
  - Attend information sessions or other forms of outreach on seismic [or other hazard] code provisions for new and existing buildings to enhance code use and enforcement personnel
  - Building department staff and officials should be trained on form ATC-20 for post-earthquake building evaluation. The ATC-20 report and addendum, prepared by the Applied Technology Council, provide procedures and guidelines for making on-the-spot evaluations and decisions regarding continued use and occupancy of earthquake-damaged buildings.

    FEMA Mitigation Ideas EQ-7,EQ-8 P 13[3]

1 Building Resiliency Taslk Force Full Proposals. Urban Green Council. June 2013. Acceded 7/10/2013. http://www.urbangreencouncil.org/servlet/servlet.FileDownload?file=015U0000001EyaR
2 Olatoye, Shola. Enterprise Community Partners. Interview by Jim Newman. June 2013. Telephone interview.
3 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.

PEOPLE AND BUILDING USE

Photo: Travis Sheehan

PEOPLE AND BUILDING USE

EDUCATE HOUSEHOLDS

STRATEGIES

- **Develop and distribute general information and technical assistance to households**, including:
    - Emergency preparedness, evacuation, and recovery protocol.
    - Structural and non-structural retrofitting of vulnerable homes to encourage retrofit.

FEMA Mitigation Ideas EQ-9, P 14

- **Improve Household Disaster Preparedness**
    - Encourage homeowners to prepare by stocking up the necessary items and planning for how family members should respond during a disaster. Publicized information about household preparedness can be found at www.ready.gov
    - Utilize hazard vulnerability checklists for homeowners to conduct their own inspections.
    - Promote purchase and use of NOAA weather radios by residents
    - Encourage citizens to secure loose items (i.e., patio furniture)
    - Participate in National Weather Service Storm Ready Program
- **Improve community disaster preparedness.**
    - Purchase and install NOAA weather radios in schools, government buildings, parks, etc.
    - Store digital or hard copies of public records in low risk, offsite locations.

FEMA Mitigation Ideas MU-15, P 82

1 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.

PEOPLE AND BUILDING USE

PARTNER WITH LOCAL COMMUNITY ORGANIZATIONS TO ENHANCE RESILIENCE

STRATEGIES

- **Participate in existing programs for local communities by working with pre-established networks that promote community resilience.**
  - FEMA's Citizen Corps was developed to build individual capacity to respond to any disaster scenario, with a focus on terrorism and public health. As of 2011, the program enrolled over one thousand local, county and tribal Citizen Corp Councils that represent 178 million citizens.

    Citizens Corps[1]
  - As a neighborhood-level effort, San Francisco's Neighborhood Empowerment Network (NEN) is leveraging every day concerns from citizens to create a routine of dialogue and community action. NEN's Empowering Communities Program offers tool kits, university collaboration, and increased access to city government.

    Neighborhood Empowerment Network[2]
- **Partner with existing clubs and ethnic communities to enhance resilience.**
  - Social Aide and Pleasure Clubs (SAPCs) were instrumental in providing services for disadvantaged and excluded communities during Hurricane Katrina. SAPCs are associations of mostly lower to middle income African Americans who trace their heritage to cultural institutions created in response to racial discrimination and segregation. The SAPC Task Force worked to ease tensions among internal constituents and addressed external difficulties faced by their members including city relations and regulations and relations with the police.

    Rick Weil, P 14[3]
  - The New Orleans Vietnamese community and Mary Queen of Vietnam (MQVN) Catholic Church leveraged their high collective resources to return from evacuation, build new housing, and build workforce opportunities.

    Rick Weil, P 12
  - Partner with existing coalitions and networks devoted to emergency response and community benefit.
    - In Gulfport Mississippi, Non-Governmental Organizations and Faith Based Organizations filled gaps in government response and recovery efforts, such as child care, pet care and transportation. Cities and Counties typically have Emergency Operations Centers (EOC) that don't include these valuable stakeholders. Formed in 2007, the South Mississippi VOAD (Voluntary Organizations Active in Disaster) provides a structured relationship among member organizations and has seats at state and county EOC meetings and committees

      Lessons from Gulfport, MS.[4]
    - The East Cooper Community Outreach (ECCO) is a faith-based coalition formed to provide disaster recovery capacity for the Charleston Tri-County Area. Through partnerships with local governments, the ECCO member churches serve as places of refuge, distribution centers, and mobilize a force of trained volunteers in disaster scenarios. Their charge has grown and they operate year round to help alleviate situational and generational poverty.

      East Cooper Community Outreach[5]

PARTNER WITH LOCAL COMMUNITY ORGANIZATIONS TO ENHANCE RESILIENCE (CONT'D)

1 Citizen Corps Councils Registration and Profile Data. FY 2011 National Report. September 2012. Accessed June 13 2013. http://www.ready.gov/about-citizen-corps

2 Empowering Communities Program website. Accessed June 13 2013. http://empowersf.org/ecp/

3 Weil, Frederick. "The Rise of Community Organizations, Citizen Engagement, and New Institutions." Draft Report. July 2010. Accessed June 13 2013. http://www.lsu.edu/faculty/fweil/lsukatrinasurvey/ReconstitutingCommunityDraftSummary.pdf

4 Lyons, Adele. "Getting NGOs and Faith-Based Organizations to the Table: A Community Resilience Lesson from Gulfport, MS". Presentation at the CARRI Partner Community Forum, April 28, 2009. Accedded June 13 2013. http://www.resilientus.org/wp-content/uploads/2013/03/Lyons_CARRI_Forum_09_FINAL_1242520031.pdf

5 Rev. Jack Little, East Cooper Community Outreach. "Outreach, Capacity Building, and Post-Disaster Distribution of Goods and Services to Low-Income Populations." Presentation at the CARRI Partner Community Forum, April 28, 2009. Accedded June 13 2013. http://www.resilientus.org/wp-content/uploads/2013/03/Little_CARRI_Forum_09_FINAL_1242519926.pdf

PEOPLE AND BUILDING USE

LOCATE VULNERABLE POPULATIONS

Vulnerable populations, also called "special needs" populations or "at-risk" populations, are those that are particularly "at risk of poor physical, psychological, or social health" after a disaster. They have "additional needs before, during, and after an incident in functional areas, including but not limited to: maintaining independence, communication, transportation, supervision, and medical care." Different groups are traditionally recognized as vulnerable in different contexts. During disasters, several population segments are potentially vulnerable. These include (1) individuals with physical and mental disabilities, (2) elderly persons, (3) pregnant women, (4) children, (5) prisoners, (6) economically disadvantaged minorities, (7) undocumented workers, and (8) those with language barriers.

Protecting the Most Vulnerable in Emergencies. P 1498.

STRATEGIES

- **Make provisions for populations particularly vulnerable to heat waves**, such as children and the elderly.
  A Stronger, More Resilient New York. P 26[1]
- **Organize outreach to vulnerable populations**, including:
  - Establish and promote accessible heating and cooling centers in the community.
- **Create a database to track those individuals at high risk of death**, such as the elderly, homeless, etc.
  FEMA, Mitigation Idea. WW-6/ ET3. P 53[2]
- **Coordinate with Urban Housing Authority for evacuation of vulnerable populations**.
  A Stronger, More Resilient New York. P 85
- **Improve access to limited but critical information about vulnerable populations**, including the name, address, age, and medical conditions of these individuals.
  A Stronger, More Resilient New York. P 159
- **Protect residential buildings and their vulnerable populations from building system outages.**
  A Stronger, More Resilient New York. P 380
- **Identify and mitigate hazards for food pantries**, often located in basements of churches and other buildings, that experience flooding.
  A Stronger, More Resilient New York. P 18
- **Identify Naturally Occurring Retirement Communities** (NORC) to perform emergency preparedness and resilience outreach and education.
  Robin Gunther Interview[3]
- **Address affordability issues** related to reform of flood plains and low income populations.
  A Stronger, More Resilient New York. Initiative 1 P 101

Quote: Hoffman, Sharona. Preparing for Disaster: Protecting the Most Vulnerable in Emergencies. University of California Davis Vol. 42:1493-1546. Accessed 7/11/2013. http://lawreview.law.ucdavis.edu/issues/42/5/articles/42-5_Hoffman.pdf

1 A Stronger More Resilient New York Report. Mayor's Office of Long Term Planning and Sustainability. 2013.
2 "Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards." Federal Emergency Management Agency Risk Analysis Division. Jan 2013.
3 Gunther, Robin. Sustainable Healthcare Design Leader- Perkins+Will. Interview by Jim Newman. June 2013.

PEOPLE AND BUILDING USE

PLAN FOR TENANT NEEDS

"One building put out printed flyers the day before the storm to set a time to meet with tenants and answer questions. Arranging to meet with tenants in advance turned out to be critical to keeping the lines of communication open amidst the confusion . They also printed notices every day to keep tenants informed. However, since there was no power, they had to print off site."

Shola Olatoye, VP and Market Leader, New York, Enterprise Community Parters Inc.

STRATEGIES

- Know building occupants and know who needs help in an emergency.

  Interview with Enterprise Community Partners[1]
- Plan for business continuity
  - Educate tenants about local hazard risks and the insurance implications. Many businesses only carry enough insurance for physical retrofits after a disaster, not gap funding for lost revenues and reinstituting operations.

    RedCross Ready Rating System[2]
    Business Civic Leadership Center[3]
  - Climate and the economy are inextricably linked. For instance, in the UK this year's cold spring has impacted the DIY and outdoor seasonal product sales such as plants, hose pipes and outdoor furniture. However, this was followed by a belated arrival of warm weather which drove improved trading in clothes and shoes as the seasonal sales started. There are also the recent impacts on the commuter travel as train tracks buckle and the health of vulnerable persons.

    Guy Battle, Deloitte dcarbon8 Interview[4]

1 Olatoye, Shola. Enterprise Community Partners. Interview by Jim Newman. June 2013.
2 Red Cross Ready Rating System, http://readyrating.org/
3 Business Civic Leadership Center, US Chamber of Commerce, http://bclc.uschamber.com/
4 Battle, Guy, Lead Partner for Sustainability Services, Deloitte. Interview by Jim Newman. June 2013.

Section 4:

Survey of Municipal Strategies for Enhancing Resilience

Photo © Astro Ltd. 2013

Section 4: **Survey of Municipal Strategies for Enhancing Resilience**

Municipalities have a wide range of tools at their disposal for enhancing resilience. In this section of the report, an overview of these options will be provided, along with a sampling of examples from around the country—and a few outside of the U.S.

This section is organized by types of municipal actions and, under each of those major categories, by the hazard category. Links are provided to explore these measures in detail.

Mandatory building retrofits

In extraordinary situations, municipalities may require retrofit actions for existing buildings. Given the burden on property owners, such actions are rare and typically limited to extraordinary safety needs—such as fire codes relating to nightclubs or seismic retrofits when new earthquake hazards become known.

New York, NY – Safe Storage of Toxics.

The Buildings Resiliency Task Force (BRTF) is recommending that the City mandate safeguards for storage of toxic materials stored in a flood zone. There already exist requirements for filing a risk management plan for facilities that store hazardous materials, but special protections are not currently required for such materials in flood zones.

Miami, FL – Hurricane Mitigation.

Miami-Dade County has a mandatory hurricane mitigation program that requires more secure attachment of roofs to walls and installation of secondary waterproofing and whenever single-family, sloped-roof residences (including townhouses and duplexes) are re-roofed. The mandatory mitigation measures are capped at 15% of the re-roofing cost.
http://www.miamidade.gov/development/permits/hurricane-mitigation.asp

Chico, CA – Retrofit on Resale.

A Retrofit on Resale law in Chico, California requires various energy conservation and water conservation measures to be carried out at the time of a property transfer for any house built prior to 1983. First enacted in 1991 and updated in 2010 with new energy efficiency mandates, the law requires such measures as bringing attic insulation levels up to R-30, carrying out air sealing practices, and replacing older showerheads and faucets with water-efficient models. Energy retrofits help to ensure that habitable temperatures will be maintained in a building in the event of an extended power outage.
http://www.ci.chico.ca.us/building_development_services/building_services/documents/chicoRECOInfoFlyer.pdf

San Francisco, CA – Seismic Retrofits.

The City of San Francisco adopted the Mandatory Seismic Retrofit Program for Soft Story Wood Frame Buildings in April, 2013, and it went into effect June 18, 2013. This law applies to wood-frame multi-family residential buildings of three stories or more (or two stories with basement). Costs of these retrofits are expected to be passed on to tenants, but both building owners and tenant advocacy groups are concerned.
http://www5.sfgov.org/sf_news/2013/04/seismic-safety-mayor-signs-new-seismic-retrofit-legislation.html

> *We need something like a "Marshall Plan" for inspection after a storm. A plan for how to relax regulation and inspection so that building owners could get properties up and running faster.*
>
> *Bryan Koop, Boston Properties*

Mandatory actions (building codes) for new construction or major renovations

Building codes have traditionally been the primary mechanism for addressing safety in buildings. Fire codes were adopted following the Great Chicago Fire of 1871; seismic codes were adopted following the San Francisco Earthquake in 1906. So, in the wake of various storms that have left millions of customers affected, it makes sense that building codes should be a primary mechanism for addressing resilience in the wake of other hazards.

Myrtle Beach, SC – Elevating Buildings.

The small city of Myrtle Beach on the coast of South Carolina, like many other coastal municipalities, requires that all new residential structures in the regulatory floodplain be elevated no less than three feet above the base flood elevation.
http://www.cityofmyrtlebeach.com/flood.html

Toronto, Ontario – Vegetated Roofs.

Since January 31, 2010, Toronto has required that vegetated roofs be installed on all new commercial, institutional, and residential buildings over 2,000 m2 (22,500 ft2) in size. Roof coverage requirements vary from 20% to 60%, depending on building size: minimum 20% for buildings up to 5,000 m2; 30% for buildings 5,000 – 9,999 m2; 40% for buildings 10,000 – 14,999 m2; 50% for buildings 15,000 – 19,999 m2; and 60% for buildings 20,000 m2 and larger. Residential buildings less than six stories or 20 m in height are exempt from the requirement. For industrial buildings, a less stringent vegetated roof requirement took effect April 30, 2012. More information available online.
http://www.toronto.ca/greenroofs/overview.htm

State of Maryland – Elevating Buildings and Equipment.

Statewide regulations in Maryland explicitly require that buildings located in floodplains and mechanical and electrical equipment in those buildings be elevated. According to the state, "To be compliant, an elevated building must be elevated to the Flood Protection Elevation (100-year flood elevation plus additional freeboard specified by the community) and have proper water equalizing venting. All electrical and mechanical equipment, including ductwork and HVAC equipment, must also be elevated. Fuel tanks must be elevated or anchored."

Omaha, NE – Safe Rooms.

The City of Omaha has required that safe rooms be incorporated into all new schools, public housing, and certain other facilities since 1980.

New York, NY – Wind Resistance.

The Buildings Resiliency Task Force is recommending a new building code to require equipment and structures be added to existing buildings during renovations to meet the same wind-resistance standards that are in effect for new buildings. Examples of specific measures currently required include the use of heavy pavers on rooftops and installation of impact-resistant windows in high-wind zones.
http://www.urbangreencouncil.org/BuildingResiliency

New York, NY – Ensuring Habitable Temperatures.

The Buildings Resiliency Task Force has identified the need to maintain "habitable temperatures" in buildings in the event of power outages, though specific recommendations on how to do that have not been presented. The Task Force is seeking an extension to produce that guidance. If such policies emerge, they would be the first in the country.
http://www.urbangreencouncil.org/BuildingResiliency

Bioswale in Rose Quarter, Portland, OR

Photo: Travis Sheehan

Dekalb County, GA – Water Conservation.

When older buildings in Dekalb County, Georgia are sold, older plumbing fixtures must be replaced with new, water-conserving products. There are a number of municipalities in California with "retrofit on resale" programs to conserve water, but such programs are rare outside of California. Dekalb County's Inefficient Plumbing Fixture Replacement Plan went into effect in 2008 and requires that pre-1993 toilets, showerheads, and other plumbing fixtures be replaced when a property is sold.
http://dekalbwatershed.com/PDF/plumbingFixturesReplacement.pdf

Incentives for voluntary actions

Using a carrot rather than a stick to change practices often proves more effective than mandatory actions. Many municipalities are implementing resilience strategies very successfully by incentivizing the more resilient practices. In this section examples of such programs are highlighted.

Portland, OR – Stormwater Reduction.

Portland has long promoted vegetated roofs (Ecoroofs in the local parlance) as a strategy reducing stormwater flows. The City offers a Floor Area Ratio (FAR) bonus of an extra three square feet of building for every 1 square foot of ecoroof installed.
http://www.portlandoregon.gov/bes/48724

The International green Construction Code and Resilience

-A. Vernon Woodworth FAIA, LEED AP
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The publication of the 2012 International green Construction Code (IgCC) marks a new direction in the regulatory scope of building codes, focusing on sustainability rather than life-safety. The IgCC also offers a different format, with several compliance options, including the "ANSI/ASHRAE/USGBC/IES Standard 189.1, Standard for the Design of High Performance, Green Buildings Except Low-Rise Residential Buildings". The structure and much of the prescriptive content of the IgCC resembles LEED language translated into code format. A list of jurisdictional requirements allows the code to be customized to local needs, and an appendix of "project electives" provides an additional level of flexibility at the discretion of the adopting jurisdiction.

The IgCC was conceived and written as an overlay code, intended to be enforced in conjunction with the other I-codes from the International Code Council: the IBC (International Building Code), the IRC (International Residential Code), the IPC (International Plumbing Code), and the IECC (International Energy Conservation Code). Its mandate is to establish a sustainable overlay on top of base code requirements. Therefore provisions for resiliency that do not address environmental sustainability, such as back-up power generation and sewage back-flow prevention, belong in the base codes rather than the IgCC.

Although the term "resiliency" does not appear in the IgCC, many of the goals of this code will benefit the sustainability of the built environment in extreme weather events. Unlike any previous building code the IgCC contains provisions for site and land use that provide development buffers at wetlands and water bodies as well as mandatory storm water management requirements. These provisions can enhance absorption of storm surge and mitigate flooding. Permeable paving can also reduce run-off, which pollutes waterways and contributes to flooding. Provisions to reduce heat island effect will reduce cooling loads and facilitate survivability in heat waves. A project elective for vegetative roofs would contribute to the reduction of heat island effect and reduce storm water runoff.

The heightened attention to issues of resiliency resulting from the devastation of Hurricane Sandy and several destructive tornados in the mid-west has stimulated discussion on the potential role of building codes in disaster preparedness. Because the IgCC is scheduled to be updated every three years it is likely that a future edition will specifically address resiliency. However the overarching intent of the IgCC encompasses a larger scope: the overall impact of the built environment on ecosystems.

Photo: John Gravelin

Austin, TX – Density Bonus for Vegetated Roofs.

Austin offers developers a density bonus for providing vegetated roofs on structures. The density bonus ranges from 2:1 to 8:1, depending on the percent coverage (30-49% vs. over 50%) and the public access to those roof areas.
http://www.austintexas.gov/sites/default/files/files/Sustainability/Green_Roof/Existing_Credit.pdf

Austin, TX – Tiered Pricing for Water.

While Austin receives nearly 80% as much rainfall as Boston annually (33 inches per year in Austin vs. 42 inches in Boston), that rainfall is more seasonal and more prone to fluctuation. As a result, the City has adopted a tiered pricing structure for water to encourage conservation. Single-family residential customers pay $1.25 per thousand gallons for the first 2,000 gallons per month consumed, with the cost per thousand gallons rising incrementally for greater consumption: $2.80 for 2,001 to 6,000 gallons; $5.60 for 6,001 to 11,000 gallons, $9.40 for 11,001 to 20,000 gallons; and $12.25 for over 20,000 gallons.
http://austintexas.gov/department/austin-water-utility-service-rates

Weymouth, MA – Water Demand Offsets.

To manage town water consumption, Weymouth, Massachusetts (population 55,000) has a water demand offset program, or "water bank" program. Any new development in the town is required to offset its projected water consumption in a 2:1 ratio through water conservation measures elsewhere in the town. In other words, if a developer wants to build a new subdivision, that developer has to determine the water consumption of that project and then pay for water conservation retrofits that will save twice as much water as the new development will use.
http://www.weymouth.ma.us/index.php/departments/dpw/water-sewer/

Raynham, MA – Transfer of Development Rights.

In this regulatory provision, a municipality can both protect areas that should not be developed (such as prime farmland or areas that may be vulnerable to future sea level rise and flooding) and achieve beneficial density in other areas—which can make communities more resilient (through greater walkability and bikability) were there to be an interruption of gasoline. The Town of Rayanham in 2001. "Sending" areas" benefit by being protected, while greater density is achieved over time in "receiving" areas.
http://www.town.raynham.ma.us/Public_Documents/RaynhamMA_ZoningRegs/article17

Financing mechanisms and grants to facilitate voluntary actions

While regulations and incentives help when implementing resilience actions, access to financing to carry out such actions often remains a significant challenge. Here we provide a survey of various programs to providing financing or grants for such projects.

Minneapolis, MN – Stormwater Management.

Minneapolis offers a 50% credit against mandated stormwater usage fees for building features, such as vegetated roofs, that reduce stormwater flows.
http://www.minneapolismn.gov/publicworks/stormwater/fee/stormwater_fee_stormwater_mngmnt_feecredits

Portland, OR – Sewage Backflow Valves.

Financing is available in Portland, Oregon to pay for the installation of sewage back-flow-prevention valves on buildings connected to the City's sewer system. Under this provision, the building owner pays the first $100 of the cost of installation, the Portland Bureau of Environmental Services pays the next $1,500, and the building owner assumes costs above $1,600.
http://www.portlandonline.com/auditor/index.cfm?a=73518

State of Florida – Wind Resistance Retrofits.

A $3.4 million fund has been created in Florida to improve the wind resistance of residences through loans, subsidies, grants, demonstration projects, direct assistance, and cooperative programs with local and federal governments. This fund is administered through the Florida Division of Emergency Management. This is a program of the Residential Construction Mitigation Program (RCMP), which receives $7 million annually from the Florida Hurricane Catastrophe Trust Fund.
http://www.floridadisaster.org/mitigation/rcmp/

Burlington, VT – PACE Financing.

Property Assessed Clean Energy (PACE) financing is one of the most attractive options for financing significant energy improvements, including insulation and air sealing, in residential and commercial buildings. Such energy improvements go a long way toward creating buildings that will maintain habitable conditions in the event of extended power outages. Burlington, Vermont is perhaps furthest along of any city in the country with implementation of a full PACE program through the Burlington Electric Company that includes energy performance upgrades.
https://www.burlingtonelectric.com/page.php?pid=141&name=Burlington%20PACE%20Program

Berkeley, CA – Seismic Retrofit Rebates.

A Seismic Retrofit Fund has been created in Berkeley to refund costs of voluntary seismic upgrades. The fund is supported by a 1.5% real estate transfer tax. Up to one-third of that tax may be used within a one-year period (with potential for a one-year extension) to pay for seismic retrofits of purchased buildings.
http://www.ci.berkeley.ca.us/ContentDisplay.aspx?id=6282

Las Vegas, NV – Direct Payment for Lawn Conversion.

The Southern Nevada Water Authority, which is heavily dependent on water from the Colorado River impounded in Lake Mead, offers numerous incentives to reduce water consumption. One such incentive is paying residents (commercial or residential) to remove lawn. The Authority pays $1.50 per square foot for the first 5,000 square feet of turf converted to desert landscaping and $1.00/square foot for area converted over 5,000 square feet, with a limit per customer of $300,000 in a fiscal year.
http://www.snwa.com/rebates/wsl.html

Salt Lake City, UT – Historic Preservation Grants and Incentives.

In many cities, including, a wide variety of historic preservation grants and incentives can be obtained for historic preservation work. This model could be adapted or emulated to address various aspects of resilience. For example, conditions could be imposed for when grants are provided to boost resilience.
http://www.slcgov.com/historic-preservation/historic-preservation-incentives

Education and outreach efforts

Education is a key component of municipal programs in North America that are addressing resilience and adaptation to climate change. Public education is affordable and extremely cost-effective.

Toronto, Ontario – Extreme Heat Alert Program.

Like many cities, Toronto has a Heat Alert System during extremely hot weather to provide information to residents on keeping safe. Information is available online and in downloadable PDFs in 20 different languages. The program advises people in non-air-conditioned spaces to go to public buildings that are air conditioned (with online map), offers an e-mail alert system during extreme heat alerts, and provides a specific plan for landlords.
http://www.toronto.ca/health/heatalerts/index.htm
Map: http://www.toronto.ca/health/heatalerts/beatheat_ac_places.htm

Other Actions

State of Oklahoma – Good Samaritan Law.

In May, 2012, the Oklahoma governor signed into law a measure protecting citizens from liability if they provide assistance to strangers during severe weather. While so-called "Good Samaritan" laws are relatively common (addressing providing first aid, for example), the Oklahoma law specifically addresses emergency situations caused by tornados, high winds, and floods.
https://www.sos.ok.gov/documents/legislation/53rd/2012/2R/HB/2419.pdf

State of Massachusetts – Compact Neighborhoods Policy.

The Massachusetts Executive Office of Housing and Economic Development adopted policies in November, 2012 to encourage municipalities to adopt compact, walkable communities. Under the designation of "Compact Neighborhood," a community would need to allow a minimum of four housing units per acre for single-family homes and a minimum of eight units per acre for multifamily. Such zoning would enhance resilience by creating communities that offer greater mobility in the event of a gasoline shortage or an inability to pump gasoline.
http://www.mass.gov/hed/docs/dhcd/cd/ch40r/compact-neighborhoodspolicy.pdf

Section 5:
Potential Next Steps

Photo: © Astro Ltd. 2013

Section 5: **Potential Next Steps**

Summary of Study Findings

Resilience can be defined as the ability to recover from or adjust easily to misfortune or change. For cities like Boston, which was settled over 350 years ago, a critical aspect of resilience is adapting existing buildings to improve resilience to natural hazards, particularly in light of pending climate change impacts.

The most common natural hazards in the Boston area are floods (including both rain events and coastal flooding with storm surge), severe storms (which include both rain and high wind conditions), and extreme temperatures (both hot and cold). A common secondary impact from extreme weather events is the loss of critical infrastructure services, including energy, water, wastewater, transportation, and communications.

Climate change impacts are projected to exacerbate these extreme weather events, increasing both the frequency of the events as well as the magnitude of the impacts. As an example, sea level rise is expected to increase the incidence of coastal flooding, especially with storm surge, and the magnitude of the flooding will increase with the rising tides. More severe storms will, likewise, increase rain floods and extreme wind conditions, and increased ambient temperatures will likely increase the number of high heat degree days.

Boston has the largest percentage of residential buildings built before WWII across all major U.S. cities, and the majority of these buildings are wood-framed low-rise buildings ("triple-deckers"). This building category sustained the greatest extent of damage of buildings in the flood zone in New York City during Hurricane Sandy from flood and wind damage. Multi-story steel or concrete residential buildings are less vulnerable to wind damage, but are susceptible to flooding and loss of critical services. Extreme temperatures become a factor in public health and safety, particularly when critical services (especially energy) are lost in residential buildings.

A large percentage of Boston's commercial buildings (by floor area) were constructed after WWII and tend to be less susceptible to wind damage (as seen in Hurricane Sandy in NYC), but, according to Preparing for the Rising Tides (BHA, 2013) over 40% of commercial buildings in Boston are vulnerable to flooding (both from rain events as well as coastal flooding and storm surge) and all commercial buildings are vulnerable to the loss of critical services.

Healthcare facilities in Boston are located in different regions and elevations across the city, and the vast majority were constructed post-WWII. Selected facilities may be vulnerable to flooding (both in rain events as well as coastal flooding and storm surge) and all are extremely vulnerable to the loss of critical services. In addition, the healthcare facilities bear the brunt of illnesses, injuries, and deaths during extreme events, and must be operational even when other buildings (such as commercial or retail) can be closed and evacuated.

Emergency Response in Back Bay Neighborhood

Photo: John Gravelin

The vulnerable populations in Boston (including the very old and very young, physically or mentally impaired, lower income, and without English language proficiency) appear in certain clusters throughout the neighborhoods. For instance, East Boston has a higher proportion of vulnerable populations than downtown Boston.

While local emergency response (police, fire, EMTs) may be cognizant of the locations of assisted living facilities, daycare and elder care centers, and other officially designated places of refuge for vulnerable populations, experience in other cities has indicated that unofficial centers may need to be monitored during extreme events to protect people in need; in New York City, certain apartment buildings have become de facto retirement communities with high concentrations of elder populations (interview with Robin Guenther), and many of these buildings are located within close proximity to coastal regions. Additional attention may needed to identify these informal centers and to explicitly incorporate the upgrade of these facilities with respect to their higher density of vulnerable persons.

Improving the resilience of existing buildings for climate change impacts requires direct consideration of a multi-hazard approach with proactive development and implementation of upgrades. As noted above, expected climate change impacts will increase the frequency and magnitude of extreme events in Boston throughout the seasons, and prudent planning will consider all relevant hazards for each location and building type.

Many of the adaptation strategies for buildings identified in this study improve resilience for several hazards at once and also provide additional benefits during normal conditions. A recent study found that, for each dollar invested in mitigation, over $4 of benefits are provided (MMC, 2006). For example, a strategy to add trees to a site to increase shading reduces stormwater flow, lowers ambient temperatures, and lessens wind impacts as well as improving air quality and quality of life.

The adaptation strategies identified in this research work at different scales, from the site to specific building systems. The collection of strategies includes both smaller or incremental improvements that can be implemented over time and larger or major improvements that may require significant investments and coordination with building occupants.

Communities often develop and rapidly implement strategies to improve the resilience of existing buildings after extreme events. California instituted major code and standard changes, and required the retrofit of existing buildings for seismic loads (earthquakes) after the Loma Prieta earthquake in 1989. Florida instituted major changes in building performance requirements for hurricane loads after Hurricane Andrew in 1992 and Hurricane Katrina in 2005.

Most cities have taken a multi-pronged approach, using a combination of mandatory upgrades, incentive programs, funding mechanisms, and education/outreach programs to develop more resilient building stock. Depending on vulnerabilities to specific hazards, cities may employ smaller or more incremental programs to gradually improve resilience or institute a larger-scale coordinated programs to respond to critical deficiencies.

As an example of a larger effort, New York City has proposed a significant investment program to upgrade its critical infrastructure systems and buildings to withstand a storm similar to Hurricane Sandy. Faced with limited resources, most cities have developed upgrade programs that can be changed over time to respond most effectively to climate trends,such as the acceleration of sea level rise which may induce major East Coast U.S. cities to move more quickly on their coastal adaptation plans than was originally budgeted.

View from Boston's Prudential Center

Photo: John Gravelin

Potential Next Steps

Boston has completed several studies on the vulnerabilities of and risks to its built environment from climate change impacts, and is one of the leading cities in the U.S. to start to address disaster resilience to natural hazards. Boston is in an excellent position to focus specifically on improving the disaster resilience of its existing buildings to ensure health, safety and well-being of its citizens and to enable commerce.

As noted previously, Mayor Bloomberg and the New York City Council convened a panel of experts from private and public organizations across a range of disciplines to assess NYC's building stock and suggest specific actions that could improve the disaster-resilience by building type, hazard vulnerability and risk, and community characteristics. The resulting report is a key reference document for this study, and could be a model for future Boston activities.

The Federal Emergency Management Administration (FEMA) has several guidance documents and training programs to help communities move forward on their multi-hazard planning, development, and implementation. Additional resources provide guides for regional disaster resilience planning (TISP, 2011), which include recommendations for specific next steps.

One step is to convene members of the community, particularly in the neighborhoods, to define the specific vulnerabilities and levels of risks for each community as a basis to identify and prioritize adaptation strategies. The New York City Environmental Justice Alliance helped convene over 200 community representatives for disaster resilience planning after Hurricane Sandy (Farinacci, 2013), and these groups presented their recovery agenda in April 2013 (NYC EJA, 2013).

San Francisco convened a Lifelines Council under its ResilientSF Initiative to enhance collaboration across the city for post-disaster reconstruction and recovery, and the Council members are executive officers and senior-level representatives of state and city agencies responsible for critical infrastructure systems, and telecommunications companies (San Francisco, 2013). Several cities, including Cedar Rapids and New York City, have convened Healthcare Councils that consist of representatives of all of the local healthcare organizations to coordinate disaster resilience planning and implementation (NRC, 2012, p. 133).

Another step is to develop the capacity of local organizations to develop and implement effective resilience plans. A recent study by the National Research Council emphasizes the critical importance of private-public collaboration for effective disaster-resilience planning and implementation, and recommends continuous capacity development for all involved (NRC, 2011). For example, several philanthropies in the San Francisco area were interested in developing the disaster resilience capabilities of community and faith-based organizations that are direct service providers that often provide safety-net services to vulnerable and special needs populations (Fritz Institute, 2009). The Oregon Partnership for Disaster Resilience, with the University of Oregon, has been working with state, regional, and local organizations since 2000 to develop local capacity for resilience plan development and implementation (Oregon, 2013).

A related step is to coordinate among local, state and federal public and private organizations to intervene strategically to mitigate vulnerabilities and improve community resilience. The Public Health-Seattle and King County in Washington worked with the Vulnerable Population Action Team to develop a system to communicate among the diverse populations in the area to reduce injuries and deaths during extreme events, and eliminated fatalities from certain causes within 5 years (NRC, 2012, p. 122). St. Louis, MO initiated a new program to promote resilience under extreme temperatures after the 2012 record heat wave that killed 23 people. This program includes significantly expanding a program to distribute and install air conditioners (donated by the utilities and private donors) in the homes of vulnerable persons (Cusick, 2013).

While it is developing its disaster resilience plan, Boston can leverage current and emerging state and federal regulations to accelerate the upgrade of existing buildings to improve resilience. One such program is from the Environmental Protection Agency (EPA), which is developing regulatory approaches for implementing the proposed National Stormwater Rule (WEF, 2013). Boston can potentially leverage the regulations to reduce stormwater flooding that threatens buildings. The U.S. Department of Homeland Security, under Presidential Directive-8 2011, recently completed its second annual National Preparedness Report, and plans greater coordination among its activities with other federal state, and local agencies to improve resilience (US DHS, 2013).

Boston can also leverage related ongoing local activities. For example, the Massachusetts Port Authority (MassPort) has implemented a "sound insulation" program in over 9,000 dwelling unit and 36 schools, all existing buildings, to provide noise abatement for facilities in close proximity to Logan Airport has completed renovation to 90% of eligible structures (Massaro, 2009) (Massport, 2013). Many of these upgrades to existing buildings can be accomplished without requiring the occupant to vacate the premises, and the soundproofing upgrades can not only lower noise within the building but can also improve comfort and energy efficiency, since they block air penetrations in the exterior enclosure (Cox, 2011; Monterey, 2010). Boston is fortunate to have a number of strong community-centered nonprofit organizations that address resilience and community capacity development, including the Boston Local Initiative Support Corporation (Boston LISC, 2013) and the Pueblo Community Land Trust (Pueblo, 2013).

Developing and implementing the full resilience plan for existing buildings in Boston may require additional resources. Federal, state, and local government agencies can provide funding and resources for studies and selected upgrades. For example, the US Department of Health and Human Resources provides grants to state and local health departments to enhance disaster resilience (CDC, 2013). In New York State, Governor Cuomo recently announced over $500 million in hazard mitigation grants to local governments and nonprofit institutions (NY State, 2013). Additional funding may be available through national or local foundations, such as the Rockefeller Foundation's new grant program "100 Resilient Cities Centennial Challenge" (Rockefeller Foundation, 2013).

This study provides the results of a review of the literature and practice for improving the disaster resilience of existing buildings, particularly focusing on those hazards and buildings types that are most common in the Boston area. The research includes explicit consideration of the impacts of climate change on the potential frequency and magnitude of extreme events in the Boston area, and provides a compilation of over 100 potential strategies to adapt existing buildings to improve disaster resilience.

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Rockefeller Foundation (2013). "100 Resilient Cities Centennial Challenge." (http://www.rockefellerfoundation.org/our-work/current-work/100-resilient-cities, accessed 7/1//13)

San Francisco General Services Agency (2013). "Lifelines Council." (http://www.sfgsa.org/index.aspx?page=4964, accessed 7/10/13)

The Infrastructure Security Partnership (TISP) (2011). *Regional Disaster Resilience: A guide for Developing an Action Plan, 2011 edition.* The Infrastructure Security Partnership, Alexandria, VA.

Tomkins, E.L. and W.N. Adger (2004). "Does Adaptive Management of Natural Resource Enhance Resilience to Climate Change?" *Ecology and Society* 9(2) article 10. (http://www.ecologyandsociety.org/vol19/iss2/art10)

Toronto, City of (2008). *Ahead of the Storm: Preparing Toronto for Climate Change.* Toronto, Canada. (http://www.toronto.ca/teo/pdf/ahead_of_the_storm.pdf)

Toronto, City of (2009). *Appendix B: Detailed Listing of Green initiative and Their Environment Benefits for GHG Reduction Claims during the period of 2001-2011*. Toronto Environment Office, Toronto, Canada. (http://www.toronto.ca/legdocs/mmis/2009/pe/bgrd/backgroundfile-23953.pdf)

Toronto, City of (2011). "Toronto's Adaptation Actions: Updated April 2011." Toronto Environment Office, Toronto, Canada.

U.S. Army Corps of Engineers (2013a). *Charles River Dam.* (http://www.nae.usace.army.mil/Missions/CivilWorks/FloodRisk-Management/Massachusetts/CharlesRiverDam.aspx, accessed 6/20/13)

U.S. Army Corps of Engineers (2013b). *Mystic River Dam.* (http://www.nae.usace.army.mil/Missions/CivilWorks/Navigation/Massachusetts/Mystic.aspx, accessed 6/20/13)

U.S. Census Bureau (2011). "Boston Quick Facts." U.S. Census Bureau, Washington, DC. (http://quickfacts.census.gov/qfd/states/25/2507000.html)

U.S. Department of Homeland Security (DHS) (2013). *National Preparedness Report 2013.* US Department of Homeland Security, Washington, DC.

U.S. Geological Survey (1974). *Geographic Names Information System: Boston Feature Detail Report.* (http://geonames.usgs.gov/pls/gnispublic/f?p=gnispq:3:916437323487290::NO::P3_FID:617565 , accessed 6/13/13)

U.S. Global Change Research Program (USGCRP) (2013). *National Climate Assessment – Draft.* Washington, DC. (http://ncadac.globalchange.gov)

Water Environment Federation (WEF) (2013). "U.S. EPA Considers Options for New Stormwater Rule." *Stormwater Report,* March 7, 2013. (http://stormwater.wef.org/2013/03/u-s-epa-still-considering-options-for-new-stormwater-rule/, accessed 7/11/13).

Wilson, A. (2013). "RDI's Resilient Design Principles." Resilient Design Institute, Brattleboro, VT. (http://www.resilientdesign.org/rdis-resilient-design-principles-need-your-feedback/)

Appendix A: Annotated Bibliography

A Better City and Greenovate Boston (2013). *Energy Efficiency & Commercial Real Estate: Barriers and Opportunities in the Boston Market*. A Better City, Boston, MA. (http://www.greenribboncommission.org/downloads/ABC_Boston_Commercial_Real_Estate_-_Barriers_and_Opportunities.pdf)

This report characterizes the Boston commercial real estate market and identifies the key barriers that prevent wide-scale adoption of energy-efficiency strategies. The final section provides recommendations for the City of Boston to pursue to improve energy-efficiency progress in commercial buildings.

Aldrich and Lambrechts (1986). "Back Bay Boston, Part II: Groundwater Levels." *Civil Engineering Practice: Journal of the Boston Society of Civil Engineers.* Volume 1, Number 2. (Online Resource, accessed 7/14/2013. http://www.boston-groundwater.org/ceprep.html)

This report analyzes the patterns of subsidence in the city of Boston for different neighborhoods.

Baise and Brankman (2004). "Liquefaction Hazard Mapping in Boston, Massachusetts – Technical Report." Dept. of Civil and Environmental Engineering, Tufts University and William Lettis & Associates, Inc., Medford, MA.

This report culminates in a liquefaction susceptibility index for the Boston metropolitan area (see appendix 4 for the map).

Beaulieu, Colon, and Toussi (2011). "Sea Level Rise Adaptation in the Boston Harbor Area: Interactive Qualifying Project." Worcester Polytechnic Institute, Worcester, MA.

This report identifies options for coastal adaptive responses: Accommodation, Protection, Beach Nourishment, and Retreat (see appendix 2). It also provides building level strategies and examples of Boston-based vulnerabilities and disasters. It also includes an extensive Boston-based account of state-local building codes and building code possibilities and action-oriented political memos.

Boston Harbor Association (Douglas, Kirshen, Li, Watson, Wormser) (2013). *Preparing for the Rising Tide.* The Boston Harbor Association, Boston, MA.

This report contains case studies of SLR vulnerabilities and solutions sets for key Boston cultural assets: long and central Wharves, Downtown Boston, UMass Boston**;** and detailed vulnerability assessment at the district scale and the building scale (see appendix A for vulnerability maps and site specific solutions)**.** The report identifies the vulnerability of each neighborhood by flood scenario and shows flood depth maps for Boston**.** The report references SPUR's Recommendations for Sea Level Rise Planning.

Canterbury Earthquake Recovery Authority. *Land Use Recovery Plan.* Canterbury Earthquake Recovery Authority, Christchurch, New Zealand. (http://cera.govt.nz/recovery-strategy/overview)

The report summarizes the built environment recovery goals after the series of earthquakes that damaged Christchurch and surrounding communities, specifically to "develop resilient, cost effective, accessible and integrated infrastructure, buildings, housing and transport networks", and explicitly considering seismic activities and other natural hazards in light of climate change.

City of Boston (2011). *Climate Adaptation Plan: A Climate of Progress Update 2011*. City of Boston, Boston, MA.

This report provides a general climate mitigation strategy and baselines for buildings, transport, solid waste and recycling, municipal operations. The Building section covers: GHG from buildings, incentives for energy efficiency, building level strategies (see appendix 1), existing retrofit programs, Renew Boston strategies, Campaigns, Energy Building Codes, Energy Conservation ordinances, and renewable energy.

City of Boston (2010). "Sparking Boston's Climate Revolution- Recommendations of the Climate Action Leadership Committee and Community Advisory Committee." Green Boston, Boston, MA.

This report contains climate definitions and broad strategies for climate mitigation, adaptation, and community engagement. The report recommends that neighborhood planning should consider climate change adaptation.

City of Chula Vista (2011). *Climate Adaptation Strategies: Implementation Plans.* Chula Vista, CA.

The City of Chula Vista's Climate Change Working Group recommends eleven strategies to adapt to climate change, including cool roofs, cool paving, and shade trees, as well as local water supply and re-use, stormwater re-use, extreme heat plans, open space management, wetlands preservation, codes for sea level rise and land development, "green economy", and education for wildfires, and has developed detailed implementation plans.

Clean Air Cool Planet (2011). *Preparing for the Changing Climate: A Northeast-Focused Needs Assessment*. Clean Air Cool Planet, Washington, DC.

The study summarizes the results of survey of organizations across the Northeast U.S. on current and emerging climate change adaptation activities. It describes the activities by state, regional planning commissions and local governments. It concludes that these organizations need more technical assistance to vulnerability assessments, particularly for infrastructure systems, as well as access to applicable climate change data and flood maps.

Consortium for Climate Risk in Urban Northeast (CCRUN). (2011). "How will these change affect the region?" CCRUN, Columbia University, New York City, NY. (http://ccrun.org/ccrun_files/attached_files/FactSheet6.pdf)

CCRUN conducts research focused on the urban corridor between Boston and New York City for climate change vulnerability and risk analysis. Current research topics include: water, coasts, and health, with several cross-cutting themes.

Frumhoff, P. et al. (2007). *Confronting Climate Change in the U.S. Northeast.* Union of Concerned Scientists, Cambridge, MA. (http://www.climatechoices.org/assets/documents/climatechoices/confronting-climate-change-in-the-u-s-northeast.pdf)

This report describes the impact of climate change on the U.S. Northeast, specifically, the coast, marine systems, forests, water, agriculture, winter recreation and human health. It provides examples of successful action by individuals, communities, and regions.

Giguere, M. (2009). *Literature Review of Urban Heat Island Mitigation Strategies.* Institut National de Sante Publique, Quebec, Canada.

The Quebec Department of Health and Human Services addresses six areas for action to target urban heat island effects, including monitoring systems for real-time urban heat and related health impacts, spread of infectious diseases, and physical and psychosocial effects of extreme heat, and to support local healthcare organizations, preventive management, and training activities.

Gilbert, S.W. (2010). *Disaster Resilience: A Guide to the Literature.* NIST SP-117. National Institute of Standards and Technology, Gaithersburg, MD. (http://www.nist.gov/manuscript-publication-search.cfm?pub_id=906887)

This report provides a description of the state of knowledge on disaster resilience and provides an extensive annotated bibliography. The approach includes individual constructed facilities as well as larger social and community systems.

Grannis, J. (2011). *Adaptation Tool Hit: Sea-Level Rise and Coastal Land Use.* Georgetown Climate Center, Georgetown University, Washington, DC. (http://www.georgetownclimate.org/sites/default/files/Adaptation_Tool_Kit_SLR.pdf)

The tool kit provides tools and examples of each tool applied for sea level rise planning. The report lists advantages and disadvantages of each tool: land use, setbacks/buffers, conditional development and exactions, rebuilding restrictions, subdivisions and cluster development, permitting for property armoring, rolling coastal management/easement statues, capital improvements, acquisitions and buyout programs, conservation easements, tax and other development incentives, transferable development credits, and real estate disclosures. The report describes evaluation and governance criteria for each tool. The report also separates the strategies into four categories: protect, retreat, accommodate, and preserve.

Hallegatte, S. et al. (2011). "Assessing Climate Change Impacts, Sea Level Rise and Storm Surge Risk in Port Cities: A Case Study on Copenhagen," *Climatic Change* **104:113-137.**

The study calculates the economic cost of storm surges under different scenarios relative to insured assets, population density, and industrial assets. It provides estimates for direct losses as well as losses associated with reduced economic activity, replacement costs, and resources required for reconstruction instead of normal activities. It then provides cost-benefit curves for adaptation efforts.

Hansen, L. et al. (2013). *The State of Adaptation in the United States: An Overview.* Report for the John D. and Catherine T. MacArthus Foundation, New York City, NY. (http://www.georgetownclimate.org/sites/default/files/The%20State%20of%20Adaptation%20in%20the%20United%20States.pdf)

This report analyzes the state of adaptation activities in the U.S., specifically focusing on agriculture, the built environment, human health, and natural resources management. The report generally concludes that there is a plethora of activities related to climate change impacts assessment, and, to a somewhat lesser degree on vulnerability assessment, resources/tools, and planning, but there is a shortage of work in capacity building and implementation and essentially no activity in monitoring and evaluation of implemented projects.

Hoverter, S. (2012). *Adapting to Urban Heat: A Tool Kit for Local Governments.* Georgetown Climate Center, Georgtown University, Washington, DC. (http://www.law.georgetown.edu/academics/academic-programs/clinical-programs/our-clinics/HIP/upload/Urban-Heat-Toolkit_RD2.pdf)

The report provides a tool for policymakers to consider several specific approaches to reduce urban heat island effects; specifically, cool roofs, green roofs, cool pavements, and urban forestry options are considered for direct municipal actions and to provide incentives and education for citizens and businesses.

ICLEI (2010). "Case Study: Keene, New Hampshire Leading on Climate Preparedness." (http://www.icleiusa.org/action-center/learn-from-others/ICLEI_case%20study_Keene_adaptation.pdf)

The case study describes Keene, NH's adaptation planning, and concludes that the city's inclusion of mitigation and adaptation planning into the comprehensive plan demonstrates institutionalization of climate protection into governance systems. It also describes some of the recent ordinances (such as hillside protection and surface water protection).

Kirshen, Knee, and Ruth (2008). "Climate Change and Coastal Flooding in Metro Boston: Impact and Adaptation Strategies." *Climatic Change*, Springer Science + Business Media B.V.

This paper projects multiple build out scenarios and disaster scenarios for Boston's future growth. They use various comprehensive plans and population growth projections to examine the build-out and vulnerability of Boston Metro's Future. (See appendix 3 for land use map). The report projects the damage and adaptation costs of future preparedness scenarios (See appendix 3 for graph of economic impacts)

Larson, L. et al. (2011). *Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions*. University of Michigan and U.S. Green Building Council, Ann Arbor, MI.

The report describes the probable impacts from climate change at the global, regional and local scales, and discusses specifically the impacts on buildings. Appendix C provides general strategies for climate change adaptation for multiple sectors, including buildings.

Meijer, F., L. Itard, M. Sunikka-Blank. (2010). "Comparing European Residential Building Stocks: Performance, Renovation, and Policy Opportunities." *Building Research & Information* 37:5-6, 533-551.

The study noted that across 8 countries, the barriers to sustainability upgrades were lack of knowledge and the unconvincing cost-benefit relation where there is not a guaranteed return on investment for the upgrade. The policy overview shows that all countries studied have adapted their building regulations in recent years in order to promote energy efficiency. In principle, energy requirements for new buildings need to be met when dwellings are drastically renovated, e.g. in Germany and the Netherlands. The implementation of this principle varies from a requirement at the component level (e.g. insulation values) to performance agreements for buildings. In Germany, when more than 20% of a component (wall, roof or window) is changed, the dwelling needs to meet building regulations comparable with those for new construction. In Sweden, a component must meet the equivalent requirements for the newly built. In the UK, any work on existing buildings is expected to meet minimum energy-efficiency standards. For specified major improvements in buildings with floor areas exceeding 1000 m2, where there is a potential to increase energy intensity, for example, by extending a building or installing air-conditioning, there are further energy-efficiency requirements, taking into account the consideration that these requirements are technically, functionally and economically feasible.

Miller, J. (2008). "Could Harvard's Expansion Restore Allston's Watery Ways?" *The Boston Globe, January 7, 2008, Science Section,* Boston, MA.

This article describes the previous streams that once ran through Allston into the Charles River, including Allston Creek, and proposals to "daylight" the creek and reduce local flooding.

Muddy River Restoration Project. "Muddy River Project Restoration Overview." Maintenance and Management Oversight Committee, Muddy River Restoration Project, Boston, MA. (http://www.muddyrivermmoc.org/restoraton-overview/)

This article describes the objectives of the Muddy River Restoration project, specifically flood control improvement, water quality improvement, aquatic and riparian habitat improvement, and rehabilitation of landscape and historic resources.

New York City, Department of City Planning (2011). *Vision 2020: New York City Comprehensive Waterfront Plan*. City of New York, New York City, NY. (http://home.nyc.gov/html/dcp/pdf/cwp/vision2020_nyc_cwp.pdf)

Chapter 8 focuses specifically on climate change adaptation

Silton, A.C. and J. Grannis (2013). *Virginia Case Study: Stemming the Tide: How Local Governments Can Manage Rising Flood Risks."* Georgetown Climate Center, Georgetown University, Washington, DC.

The study analyzes the legal authority of the Virginia local governments to use existing land-use regulations and ordinances to adapt effectively to increased flooding and expected sea-level rise impacts.

Southeast Florida Regional Climate Change Compact Communities (2012). *A Region Responds to a Changing Climate Regional Climate Action Plan."* Southeast Florida Regional Compact, Palm Beach, FL. (http://southeastfloridaclimate-compact.org/pdf/Regional%20Climate%20Action%20Plan%20FINAL%20ADA%20Compliant.pdf)

This report describes the collaborative effort among the counties in southeast Florida, and provides 110 action items to mitigate climate change impacts and adapt to climate change impacts.

SPUR Report (2009). *The Dilemma of Existing Buildings: Private Property, Public Risk*. San Francisco Planning and Urban Research Association, San Francisco, CA. (http://www.spur.org/files/SPUR_The_Dilemma_of_Existing_Buildings.pdf)

The report analyzes the resilience of San Francisco's existing building stock to earthquake risks, and recommends several policy alternatives for upgrading existing buildings to protect public safety, including mandated upgrades.

Strategic Environmental Research and Development Program, U.S. Department of Defense (2013). *Assessing Impacts of Climate Change on Coastal Military Installations: Policy Implications.* US Department of Defense, Washington, DC.

The study analyzes the vulnerability of military coastal installations in the context of federal, state and local adaptation activities. It discusses the nature and extent of investments needed for improved resilience, and potential opportunities to work with local communities to improve resilience.

Tetra Tech (2009). *Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities."* Tetra Tech, Fairfax, VA. (http://www.mass.gov/eea/docs/dep/water/resources/n-thru-y/upchasps.pdf)

The report summarizes a demonstration project to use optimization techniques to idneitfy cost-effective solutions to meet phosphorous reduction targets, included in the Total Maximum Daily Load requirements for the lower Charles River, by targeting activities in Bellingham, Franklin, and Milford in the Upper Charles River.

Appendix B: Interviewees for This Study

Murat Armbruster – CoEfficient and Carbon War Room

President and Senior Fellow

Guy Battle and Maeve Hall – Deloitte dcarbon8

Lead Partner for Sustainability Services

Dennis Carlberg – Boston University

Sustainability Director

Edward Connolly – New Ecology

President

Jack Dempsey – Jacobs

Principal, National Leader, Asset Management Advisory Services

Olga Dominguez – NASA

Assistant Administrator, Office of Strategic Infrastructure

Brenda Enos – Massachusetts Port Authority

Assistant Director of Capital Program and Environmental Management

David Greenall – Deloitte & Touche LLP

Eastern Canada Leader, Enterprise Risk / Sustainability

Louis Gritzo – FM Global

Vice President, Research

Robin Guenther – Perkins +Will

Heather Henriksen – Harvard University

Director, Office for Sustainability

Brian Koop – Boston Properties

Senior Vice President and Regional Manager of the Boston Office

Ben Meyers, Peter See, Dean Larson – Boston Properties

Kevin Leahy – Duke Energy

Managing Director, Energy & Environmental Policy

Vivien Li – Boston Harbor Association

President

Jordan Macknick – National Renewable Energy Laboratory (NREL)

Energy and Environmental Analyst

David MacLeod – City of Toronto

Senior Environmental Specialist, Environment & Energy Office

John Messervey – Partners Healthcare

Director of Capital and Facilities Planning for Partners Healthcare

Hubert Murray and David Burson – Partners Healthcare

Shola Olatoye – Enterprise Community Partners, New York City Office

Jason Wheeler- Enterprise Community Parters

Michal Pelzig – Hess

Senior Manager, Corporate EHS & SR

Paul Shoemaker – Boston Public Health Commission

Associate Director, Environmental Health Division

Katie Swenson – Enterprise Community Partners

Vice President, National Design Initiatives

Cherilyn Widell – Seraph LLC

President

Fiona Cousins - ARUP

Principal

Appendix C: Building Types and Occupancy Codes

BSA Resilience Scan Building Categories	Assessor's Property Type Summary (exempt categories paired with taxable categories)	IBC Occupancy Code	
Small Scale Residential	Residential (1-2 Family Dwelling)	Residential	R-1
	Residential Condo (1-2 Units)		R-2
	Residential Apartment Units (1-4 bed)		R-3
	Rooming / Housing		R-4
	Lodging Suites (Short Term)		
	Residential (3 Family Dwelling)		
	Residential Condo (3 Units)		
Mid Scale Residential	Residential Apartment Units (7-30)	Residential	R-1
	Elderly Home / Assisted Living		R-2
	Dormitory, Residence Hall , Fraternity		R-3
	Subsidized Housing (S-8, S-231D, S-202)		R-4
	Apartment Units (31-100 Plus)		
High Rise Residential	Condo (Commercial, Retail, Office, Multi Use)	Residential	R-1, R-3
	Residential / Commercial Space		R-2, R-4
Residential / Commercial Mixed Use	Offices (1-2 Story, Attached)	Business	B
	Hotel, Motel, Inn, Resort, B+B	Residential	R-1, R-3
	Retail, Wholesale, Department Store, Mall		R-2, R-4
Mid Scale Commercial	Restaurant, Bar, Cafeteria, Dining	Business	B
	Office, Administration, Computer Equipment Building	Institutional	I-1
	Loft Building, Convention Center, Social Club		I-2, I -3, I-4
		Mercantile	M
High Rise Commercial	Office (3-9 Stories, Class A-, B, B+)	Business	B
	Office Tower Class A		
Industrial	Warehouse, Distribution, Storage, Maintenance	Business	B
	Bus, Rail, Airport Terminals	Factory and Industrial	F-1
	New, Old, Light Manufacturing		F-2
	Newspaper Plant, Machine Shop,	High Hazard	H-1
	Utility,		H-2, H-3, H-4, H-5
		Storage	S-1, S-2
		Utility and Miscellaneous	U
School / Daycare / Church	Daycare, Education, Private School, Child Care Facility	Assembly	A-1
	College, High School, Elementary,		A-2
	Library, Church, Synagogue, Mausoleum, Rectory, Convent		A-3, A-4, A-5
		Education	E
Medical / Laboratory	Medical Office, Medical Clinic Outpatient	Education	E
	Science Lab, Laboratory (Medical, Biological)		
	Hospital		
Government	US Government, Commonwealth of Massachusetts, City of Boston,	Institutional	I-1
	Massachusetts Departments		I-2
	Religious Organization, Charitable Organizations		I-3
	Fire, Police Stations		I-4
	Armory		
Other / Land	Residential, Commercial, Industrial Land	Assembly	A-1
	Garage, Parking Lot		A-2
	Auditorium, Movie Theater, Gymnasium, Museum		A-3
	Parkingm Garage		A-4
	Bowling Alley, Race Track,		A-5
		Education	E
		Institutional	I-1, I-2, I-3, I-4
		Storage	S-1, S-2

BSA Occupancy #	Building Classification	2009 IBC Occupancy	Building Area in Greater Boston
1	Small Scale Residential	R 1-4	33%
2	Mid Scale Residential	I1; R 2-4	15%
3	High Rise Residential	B; M; R2	1%
4	Residential / Commercial Mixed Use	B; M; R1	5%
5	Mid Scale Commercial	A 2-3; B	5%
6	High Rise Commercial	B	10%
7	Industrial	A3; F 1-2,4; H4; U	4%
8	School / Daycare / Church	A3; B; E; I 2-4	7%
9	Medical / Laboratory	B; I2	4%
10	Government	A3; B; I3	7%
11	Other / Land	A 1,3,5; B; R 1-4; S2	8%

**See "Property Type Description"*　　**See IBC Legend*

Appendix D: MAP CITATIONS AND REFERENCES

Figure 1.2: Overlay of Historic Boston and Current City Land

Sources:

2010 Census Boundaries

Linnean Solutions, Gravelin, John. "Census Land of Greater Boston" [map]. 1:200,000. MassGIS Data – Datalayers from the 2010 U.S. Census [database and shapefiles]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS). U.S. Census Bureau. Apr. 2012. <http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/census2010.html>

Original Waters Overlay Map from the 1800's:

"Map of Boston and Environs, Circa 1800." Archiving Early America. Accessed July 9, 2013. <http://www.earlyamerica.com/earlyamerica/maps/bostonmap/enlargement.html>

Description:

This map depicts an estimation of the original land mass of Boston. The historic map helped depict natural land from the 1800's and shows the extent of how much the landscape has changed over the past 200 years. Most of the Back Bay, East Boston and South Boston were once marshes and wetlands.

Figure 1.3: Boston Neighborhoods

Source:

"Neighborhoods." City of Boston. Dec. 2009. http://www.cityofboston.gov/images_documents/Neighborhoods_tcm3-8205.pdf

Figure 1.4: Environmental Justice Populations

Source:

Linnean Solutions, Gravelin, John. "Environmental Justice Populations of Greater Boston" [map]. 1:200,000. MassGIS Data – 2010 U.S. Census – Environmental Justice Populations [layer]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS).Office of Energy and Environmental Affairs. Dec. 2012. < http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/cen2010ej.html>

Description:

Quotations found in source link above:

"What is Environmental Justice?"

Historically, the environmental justice movement has been one of grassroots activism focusing on the rights and liberties of people of color and low-income communities relative to the environment and particularly, in response to the disproportionate burden of industrial pollution and lack of regulatory enforcement in these communities.

In 1994, President William Clinton issued Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," directing federal agencies to address environmental injustices in their operations and in communities across the country. Since, and in accordance with Title VI of the Civil Rights Act of 1964, states and municipalities have developed policies and programs to pro-actively address environmental equity concerns to help ensure that minority and low-income communities are not disproportionately impacted by environmental hazards."

Detailed Description Quotations:

"MassGIS Data - 2000 U.S. Census - Environmental Justice Populations." Executive Office for Administration and Finance. Commonwealth of Massachusetts. July, 2003. <http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/cen2000ej.html>

Environmental Justice (EJ) populations are determined by three categories:

1. % Minority

Non-minority categories consist of populations other than white alone. Any blockgroup with a minority population greater than 25% was selected as an EJ population.

2. Income

The statewide median household income in 2000 (determined by the Dept. of Economic Development) was $46,947. 65% of this value is $30,515. Any blockgroup that had a median household income less than $30,515 is considered as an EJ population.

3. English Proficiency

Linguistic isolation refers to a household in which no person 14 years old and over speaks only English and no person 14 years old and over who speaks a language other than English speaks English "Very well" is classified as "linguistically isolated." In other words, a household in which all members 14 years old and over speak a non-English language and also speak English less than "Very well" (have difficulty with English) is "linguistically isolated."

Figure 1.5: Boston Population Density

Source:

Linnean Solutions, Gravelin, John. "Population Density of Greater Boston" [map]. 1:200,000. MassGIS Data – Datalayers from the 2010 U.S. Census [database and shapefiles]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS). U.S. Census Bureau. Apr. 2012. <http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/census2010.html>

Description:

Data obtained from the Census Bureau is shown displaying population density as a color gradient by 1,000 square foot grids. Each grid contains a value between 0-3,200 people determined by the 2010 Census Blocks.

Figure 1.6: Topography of Boston

Source:

Linnean Solutions, Gravelin, John. "Elevation of Greater Boston" [map]. 1:200,000. MassGIS Data – Elevation Contours (1:5,000) [layer]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS). U.S. Geological Survey (USGS). Jun. 2003.

< http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/hp.html>

Description:

The elevation of Boston ranges from -56 feet (including underground highways and tunnels) to 340 feet at its highest peak to the south known as Bellevue Hill.

Figure 1.7: Natural Landscapes and Wetlands

Source:

National Wetlands Inventory:

Linnean Solutions, Gravelin, John. "National Wetlands Inventory of Greater Boston" [map]. 1:200,000. MassGIS Data – DEP Wetlands (1:12,000) [layer]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS). Department of Environmental Protection, Wetlands Conservancy Program, UMass Amherst. Jan. 2009.

< http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/depwetlands112000.html>

Land Use:

Linnean Solutions, Gravelin, John. "Natural Landscapes of Greater Boston" [map]. 1:200,000. MassGIS Data – Land Use (2005) [layer]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS). Sanborn. Jun. 2009.

< http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/lus2005.html>

Wetlands Description:

Defining Wetlands:

Kusler, Jon. "Common Questions: Wetland Definition, Delineation, and Mapping." Association of State Wetland Managers, Inc, The International Institute for Wetland Science and Public Policy. Berne, New York. 2006. <http://aswm.org/pdf_lib/14_mapping_6_26_06.pdf>

"What "parameters" are considered by wetland scientists in defining, mapping, and delineating wetlands?

Wetland scientists and regulators use three principal types of wetland characteristics or "parameters" in defining, mapping, and delineating wetlands:

• Vegetation. The types of plants that can live in wetlands are determined by the depth and duration of flooding and saturation. Vegetation is the most common paremeter used in defining, mapping, and delineating wetlands. There are over 7,000 plants which grow in wetlands in the U.S. A much smaller number, about 26%, are "obligate". Obligate species grow only in wetlands and are strong indicators of wetland boundaries. "Facultative" plants grow in both wetlands and uplands and are a less good indicator but are useful when combined with soils and hydrologic information.

• Evidence of hydrology. Hydrology (water depth, extent of inundation, period of inundation) determines all other wetland characteristics. However, hydrology is often not easily assessed. Often water can be observed at the surface only part of the year for many wetlands. Other evidence of hydrology (other than surface observation) may include flood records and flood maps, debris lines and evidence of flooding in trees and other vegetation, evidence of scour, and soils. Where there are uncertainties and disputes, field measurements of vegetation and soils may be taken over a growing season. Piezometers measuring water levels and hydrologic models may be used (although rare) to calculate the depth and frequency of inundation and saturation and ground water levels.

• Soils. Wetland soils often contain large amounts of organic matter because saturation prevents oxidation of plant materials. Soils reflect long term hydrology and are, therefore, useful in identifying wetlands even where hydrology and plants have been disturbed or during periods of drought."

Land Use Descriptions: (same land use source above)

Brushland / Successional: Predominantly shrub cover, and some immature trees not large or dense enough to be classified as forest. It also includes areas that are more permanently shrubby, such as heath areas, wild blueberries or mountain laurel.

Forested Wetland: Department of Environmental Protection (DEP) Wetlands. Wooded Swamp Deciduous, Wooded Swamp Coniferous, Wooded Swamp Mixed Trees, Barrier Beach – Wooded Swamp Deciduous, Barrier Beach – Wooded Swamp Coniferous, Barrier Beach – Wooded Swamp Mixed Trees.

Non-Forested Wetland: Bog, Deep Marsh, Shallow Marsh, Meadow or Fen, Shrub Swamp, Barrier Beach – Shrub Swamp, Barrier Beach – Bog, Barrier Beach – Deep Marsh, Barrier Beach – Marsh.

Saltwater Wetland: Salt Marsh, Barrier Beach – Salt Marsh.

Saltwater Sandy Beach: Coastal Bank Bluff or Sea Cliff, Barrier Beach System, Coastal Beach, Rocky Intertidal Shore, Tidal Flat, Barrier Beach – Coastal Beach, Barrier Beach – Coastal Dune.

Figure 1.10: Density of Living Spaces in Boston

Source:

Assessor's Database Citation:

Parcel Boundaries: Linnean Solutions, Gravelin, John. "Parcel Boundaries of Greater Boston" [map]. 1:200,000. MassGIS Data – Level 3 Assessors' Parcel Mapping [layer]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS). Department of Revenue's Bureau of Local Assessment. Jun. 2013. <http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/l3parcels.html>

Parcel Data:

City of Boston. "Property Parcel Data FY 2013 FULL Version." City of Boston Assessing Department. 2013.

Description:

All residential parcels are seen in this map including low, medium and high density residential.

Figure 1.15: Flood Levels in Boston, based on a water level 9 feet above current levels

Source:

Reference source of Figure 1.6 "Topography of Boston."

Description:

This map highlights the elevations below 9 feet in red. These areas are particularly vulnerable to large storm surge and sea level rise.

Figure 1.16: Boston Storm Surge Vulnerability, based on NOAA Models

Also used in Figures 1.17.1-4, 1.18

Source:

Linnean Solutions, Gravelin, John. "Boston Harbor SLOSH Display Package" [zip file]. July, 2013. National Oceanic and Atmospheric Administration (NOAA), National Weather Service. http://slosh.nws.noaa.gov/sloshPub/disclaim.php

Description:

Hurricane categories 1 and 2 cause little damage to Boston's coastal development. However categories 3 and 4 cause significant damage to parts of the city primarily because the elevation of the ocean would exceed that of the Charles River dam.

Summary:

The hurricane flooding layer was obtained from the National Oceanic and Atmospheric Administration (NOAA) Hurricane Research Division Atlantic Oceanographic & Meteorological Laboratory. The map chosen for the report represents the potential flood damage as provided by computer generated models that calculate the potential extent from different hurricane categories (Category 1,2,3 and 4). The highest category hurricane that has directly hit Boston in the past was a Category 3 Hurricane of 1869 (not named). The eye of this storm passed Boston ten miles inland and slowed to a Category 2 hurricane over New Hampshire and Maine. 29 different Hurricane and Tropical Storms and Depressions intersect a 50 miles radius of Boston.[1]

1. "Historical Hurricane Tracks." National Oceanic and Atmospheric Administration. Accessed July 2013. http://csc.noaa.gov/hurricanes/

METHODOLOGY and TERMINOLOGY of GIS Layers Reference and Production:

Quotations below directly from:

"How is storm surge forecast at NHC." National Oceanic and Atmospheric Administration (NOAA) Hurricane Research Division Atlantic Oceanographic & Meteorological Laboratory. Accessed July 2013.

http://www.aoml.noaa.gov/hrd/tcfaq/F7.html

Hurricane Categories defined directly as:

"Maximum of MEOW (MOM) runs
This is an ensemble product of maximum storm surge heights for all hurricanes of a given category regardless of forward speed, storm trajectory, landfall location, etc.. MOMs are created internally by pooling all the [Maximum Envelope of Water] MEOWs for a given basin, separated by category and tide level (zero/high), and selecting the MEOW with the greatest storm surge value for each basin grid cell regardless of the forward speed, storm trajectory, landfall location, etc. This procedure is done for each category of storm. Essentially, there is 1 MOM per storm category and tide level (zero/high).

MOMs represent the worst case scenario for a given category of storm under "perfect" storm conditions. The MOMs provide useful information aiding in hurricane evacuation planning and are also used to develop the nation's evaluation zones. The GIS models and values reflect the mean of the MOM results. "

Maximum Envelope of Water (MEOW) runs
This is an ensemble product representing the maximum height of storm surge water in a given basin grid cell using hypothetical storms run with the same:

Category (intensity)

Foreward speed

Storm trajectory

Initial tide level

Internally a number of parallel SLOSH runs with same intensity, forward speed, storm trajectory, and initial tide level are performed for the basin. The only difference in runs is that each is conducted at some distance to the left or right of the main track (typically at the center of the grid). Each component run computes a storm surge value for each grid cell. For example, five parallel runs may yield storm surge values of 4.1, 7.1, 5.3, 6.3, and 3.8 feet. In this case, the MEOW for the cell is 7.1 ft. It is unknown (to the user) which track generated the MEOW for a particular cell, so it is entirely possible that the MEOW values for adjacent cells may have come from different runs. MEOWs are used to incorporate the uncertainties associated with a given forecast and help eliminate the possibility that a critical storm track will be missed in which extreme storm surge values are generated.

MEOWs provide a worst case scenario for a particular category, forward speed, storm trajectory, and initial tide level incorporating uncertainty in forecast landfall location. The results are typically generated from several thousand SLOSH runs for each basin. Over 80 MEOWs have been generated for some basins. This product provides useful information aiding in hurricane evacuation planning.

Also Reference: Glahn et al. "The Role of the SLOSH Model in National Weather Service Storm Surge Forecasting." Meterological Development Laboratory. National Weather Service, NOAA, National Weather Digest. Silver Spring, Maryland. http://slosh.nws.noaa.gov/sloshPub/pubs/Vol-33-Nu1-Glahn.pdf

Abstract:

"The storm surge model, Sea, Lake, and Overland Surges from Hurricanes (SLOSH), is used by the National Weather Service (NWS) in producing storm surge guidance in several ways. SLOSH is run by the National Hurricane Center (NHC) to forecast storm surge in real-time when a hurricane is threatening. The model is applied to 38 specific coastal areas, called basins, along the Atlantic and Gulf of Mexico coasts of the U.S.; Oahu, Hawaii; Puerto Rico; and the Virgin Islands. SLOSH is also used to create simulation studies to assist in the "hazards analysis" portion of hurricane evacuation planning by the Federal Emergency Management Administration (FEMA), the U.S. Army Corps of Engineers, and state and local emergency managers. Two composite products, Maximum Envelopes of Water (MEOW) and Maximum of the MEOWs (MOM), are created to provide manageable datasets for planning. The Probabilistic Storm Surge model (P-surge) overcomes the limitations of a single deterministic SLOSH storm surge forecast by being comprised of an ensemble of SLOSH forecasts. The members of the ensemble vary in speed, direction, intensity, and size, based on NHC's forecast and past errors associated with NHC's forecasts. P-surge is prompted to run when NHC issues a hurricane watch for the Atlantic or Gulf coasts. The Extratropical storm surge (ET surge) model uses SLOSH to forecast storm surge from extratropcial cyclones. The ET surge model uses surface wind and pressures that are generated by NWS's Global Forecast System (GFS) model as driving forces."

Figure 1.18: Wind and Hurricane Hazards for Boston

Source:

Wind Map: Linnean Solutions, Gravelin, John. "Estimated Wind Speeds of Greater Boston" [map]. 1:200,000. MassGIS Data – Wind Power Density at 50m [shapefile]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS). AWS Truewind, LLC, Massachusetts Technology Collaborative, Conneticut Clean Energy Fund, Northeast Utilities System, Massachusetts Water Resources Authority. Aug. 2007.

<http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/wind-power-density-at-50m.html>

Description:

Quotations sourced directly from:

Elliot, D.L. et al. "Wind Energy Resource Atlas of the United States." National Renewable Energy Laboratory (NREL), Pacific Northwest Laboratory, U.S. Department of Energy, Wind / Ocean Technologies Division, Solar Energy Research Institute. < http://rredc.nrel.gov/wind/pubs/atlas/>

"Wind power density and speed determined by watt per feet or meter."

Wind Power Class (WPC) Categories Table: http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html

"Annual Average Wind Resource: Along many coastal areas, the abrupt increase of surface roughness inland from the coastline because of vegetation and topography can rapidly attenuate the wind resource inland. Notable exceptions occur along the Texas coast and Cape Cod in Massachusetts where the coastal wind resource extends inland a considerable distance." http://rredc.nrel.gov/wind/pubs/atlas/chp2.html

"The wind resource assessment was based on surface wind data, coastal marine area data and upper-air data, where applicable. In data-sparse areas, three qualitative indicators of wind speed or power were used when applicable: topographic/meteorological indicators (e.g. gorges, mountain summits, sheltered valleys); wind deformed vegetation; and eolian landforms (e.g. playas, sand dunes). The data was evaluated at a regional level to produce 12 regional wind resource assessments, the regional assessments were then incorporated into the national wind resource assessment.

The conterminous United States was divided into grid cells 1/4 degree of latitude by 1/3 degree of longitude. Each grid cell was assigned a wind power class ranging from 1 to 6, with 6 being the windiest. The wind power density limits for each wind power class is shown in Table 1-1. Each grid cell contains sites of varying power class. The assigned wind power class is representative of the range of wind power densities likely to occur at exposed sites within the grid cell. Hilltops, ridge crests, mountain summits, large clearings, and other locations free of local obstruction to the wind are expected to be well exposed to the wind. In contrast, locations in narrow valleys and canyons, downwind of hills or obstructions, or in forested or urban areas are likely to have poor wind exposure..."

Figure 1.19: Impervious Surfaces in Boston

Also used in Figures 1.20

Source:

Linnean Solutions, Gravelin, John. "Impervious Surfaces of Greater Boston" [map]. 1:200,000. MassGIS Data – Impervious Surface [self-extracting files]. Commonwealth of Massachusetts; Office of Geographic Information (MassGIS). Sanborn. Feb. 2007. < http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/impervioussurface.html>

Description:

"**Impervious surfaces** are defined as:

All constructed surfaces such as buildings, roads, parking lots,brick, asphalt, concrete.

Also included are areas of man-made compacted soil or material such as mining or unpaved parking lots (no vegetation present).

Non-impervious surfaces can be defined as:

All vegetated areas, natural and man-made water bodies and wetland area. Natural occurring barren areas (i.e. rocky shores, sand, bare soil)."

See "Impervious / Non-Impervious Classification" Table in source link above for details and permeability rates.

Figure 1.21: Allston Category 4 Hurricane Flood Risk

See source reference for Figure 1.16