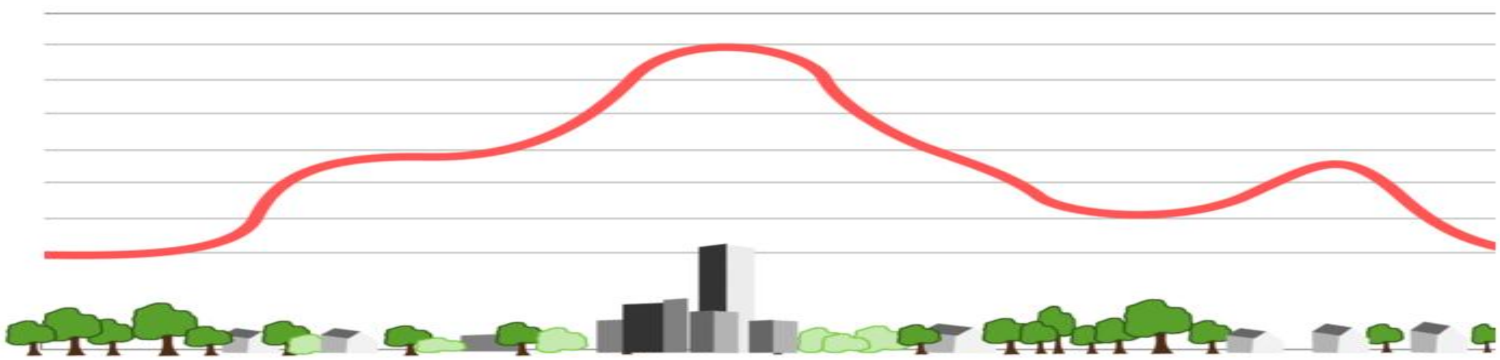
PLANNING URBAN HEAT ISLAND MITIGATION IN BOSTON



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The Trust for Public Land
LAND FOR PEOPLE

Abstract

Extreme heat is the leading weather-related cause of death in the U.S (Luber & McGeehin, 2008a). This is particularly of concern in urban areas due to the Urban Heat Island (UHI) effect. The UHI is the phenomenon in which urban areas are warmer than their surrounding suburban and rural regions (U.S. EPA, 2008c). The City of Boston is home to nearly 646,000 residents in 23 neighborhoods (City of Boston, 2014). Currently, heat-related mortality in Boston is approximately 2.9 per 100,000 residents and is expected to triple in the next thirty years (Petkova, Horton, Bader, & Kinney, 2013). This report researched UHI green infrastructure mitigation strategies, conducted a Geographic Information Systems (GIS) vulnerability analysis, and developed Boston-specific mitigation recommendations. A national Heat Vulnerability Index (HVI) was adapted to identify eleven heat vulnerable census tracts within Boston. These eleven areas should be prioritized when considering UHI mitigation strategies, such as increasing the amount of vegetation, phasing out dark roofs for cool and green roofs, and replacing pavement with cool pavement materials. As heat vulnerability depends on both environmental and social factors, in addition to green infrastructure projects, citywide policies should be leveraged to systematically mitigate the UHI effect in Boston.

Acknowledgements

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Part I: Urban Heat Island & Green Infrastructure

1 Introduction

The Trust for Public Land launched a pilot project in partnership with the City of Boston to inform and catalyze green infrastructure work in the metropolitan Boston region that will advance the resilience objectives of the Trust for Public Land Climate-Smart Cities effort. Climate-Smart Cities is built around four goals (The Trust for Public Land, 2015):

- *Connect* – Linking walk-bike corridors at the city scale to create carbon-free transportation options for all residents.
- *Cool* – Planting shade trees and creating new parks to lessen the urban "heat island effect" that drives increased summer energy use and worsens heat waves.
- *Absorb* – Creating "water smart" parks and green alleys that manage stormwater naturally to reduce flooding, save energy used for water treatment, and recharge drinking water supplies.
- *Protect* – Establishing waterfront parks, wetlands, and other green shorelines to buffer low-lying cities from sea level rise, coastal storm surges, and other flood risks.

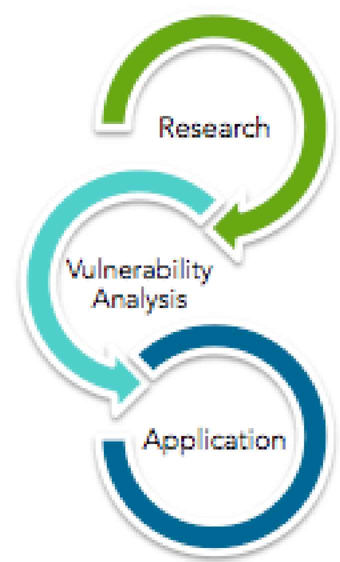

Figure 1: Field Project Approach

The City of Boston, home to nearly 646,000 residents in 23 neighborhoods, is approximately 48 square miles of land abutting the Atlantic Ocean (City of Boston, 2014). The Boston pilot was initiated in 2015. Over two years, TPL, the City of Boston, and a variety of partners will research the urban heat island (UHI) effect and use Geographic Information Systems (GIS) with the goal of identifying a green infrastructure demonstration project (s).

As the Boston pilot project was getting off the ground, TPL engaged a Tufts' graduate student team in the Urban and Environmental Planning and Policy (UEP) program from February – April 2015. We examined UHI green infrastructure mitigation strategies, conducted a census tract level vulnerability analysis, and developed Boston-specific recommendations for green infrastructure mitigation of the UHI effect using a similar approach as the larger Climate Smart Cities program (Figure 1). The role of this project was to help frame general areas where TPL may want to focus their Boston Climate Smart Cities' demonstration project (s), particularly around their "cool" or UHI mitigation efforts. This project only attempts to help guide and provide TPL with background research and priority areas to consider helping start the longer Climate Smart Cities project in Boston.

This document is divided into three parts: Background, Vulnerability Analysis, and Recommendations. The Background section provides the context on the UHI effect, green infrastructure mitigation strategies, and community engagement; the Vulnerability Analysis section explains our methodology, provides a social and environmental vulnerability map of the City of Boston, and priorities case study areas/neighborhoods; and the Recommendations section provides guidance on how to implement green infrastructure solutions in the Boston context.

2 What Is the Urban Heat Island Effect?

Urbanization has brought about higher temperatures in cities and towns than in their surrounding rural areas. This phenomenon is called the urban heat island (UHI) (IPCC, 2007; Mirzaei & Haghighat, 2010; Oke, 1982; Rizwan, Dennis, & Chunho, 2008; U.S. EPA, 2008c). It is the result of the urban form trapping, storing, and slowly releasing solar radiation (Arnfield, 2003; Mirzaei & Haghighat, 2010; Oke, 1982; Rizwan et al., 2008; U.S. EPA, 2008c).

The UHI is often regarded as the best-documented example of anthropogenic climate modification (Arnfield, 2003). Since 1833, there have been studies of the UHI effect in hundreds of cities worldwide (Oke, 1982; Stewart, 2011). UHI intensity varies from city to city. This is because UHI intensity depends on climate features –wind, cloudiness, latitude, proximity to the ocean, and urban features –surface roughness, shape and height of buildings, orientation of street canyons, topographical features, view factor, city size, population density, and anthropogenic heat release (Arnfield, 2003; Bonacquisti, Casale, Palmieri, & Siani, 2006; Oke, 1982; Rizwan et al., 2008). For example, in equatorial climates, radiation absorption can be a dominant factor for daytime UHI, especially when the sky is calm and cloudless. However, anthropogenic heat release can be the main cause of nocturnal UHI in high-rise and dense metropolitan areas when the sky is cloudy (Mirzaei & Haghighat, 2010).

In a review of two decades of heat island literature, Arnfield (2003) found that in general UHI intensity:

- Decreases with increasing wind speed;
- Decreases with increasing cloud cover;
- Is more severe during summer;
- Increases with increasing city size and population; and
- Is greatest at night.

However, some studies have found conflicting evidence about the above generalizations depending on the city (Mirzaei & Haghighat, 2010). This reinforces the notion that the UHI effect is highly dependent upon the local environment. While there is abundant research on the UHI effect, there are not many studies on the UHI effect in Boston specifically.

Surface and Atmospheric UHIs

There are two types of UHIs: surface and atmospheric. The Table 1 below summarizes the differences between the two types (U.S. EPA, 2008c). Surface heat islands refer to hotter temperatures of urban surfaces, such as roofs and pavement, relative to the air temperature. Typically, surface heat islands are present day and night, but are strongest during the day when the sun is shining (U.S. EPA, 2008c).

Table 1: Comparison of Surface and Atmospheric UHIs (EPA)

Feature	Surface UHI	Atmospheric UHI
Temporal Development	Present during the day and night Most intense during the day and in the summer	May be small during the day Most intense at night or predawn and in the winter
Peak Intensity	More spatial and temporal variation: - Day: 18-27°F - Night: 9-18°F	Less variation: - Day: -1.8-5.4°F - Night: 12.6-21.6°F
Typical Identification Method	Indirect measurement: - Remote sensing	Direct measurement: - Fixed weather stations - Mobile traverses
Typical Depiction	Thermal image	Isotherm map Temperature graph

Source: (U.S. EPA, 2014)

Atmospheric heat islands, on the other hand, are defined as warmer air in urban areas compared to cooler air in nearby rural surroundings. There are two types of atmospheric UHIs:

- Canopy layer UHIs: defined as the layer of air from the ground to below the tops of trees and roofs. These UHIs are largely a nocturnal phenomenon due to the slow release of heat from the urban form (Oke, 1982). This type of UHI is the most commonly referred to UHI.
- Boundary layer UHIs: start from the rooftop and treetop level and typically extend up to approximately one mile from the surface (U.S. EPA, 2008c).

There is evidence that there is a positive relationship between the surface and ambient air temperature (D. P. Johnson, Stanforth, Lulla, & Luber, 2012; Voogt & Oke, 2003). However, more research is needed to understand this relationship and how it affects the heat island effect within cities.

Limitations

Most studies focus on detection and description of the UHI intensity and effect based on empirical evidence in a single city (Mirzaei & Haghighat, 2010; Oke, 1982; Rizwan et al., 2008; Stewart, 2011; Voogt & Oke, 2003). Therefore, findings from these studies are not typically generalizable. Additionally, the methods, technologies, and science around UHIs have evolved over the years. This has raised issues about measurement, definition, and reporting of heat island magnitudes (Stewart, 2011). It has also complicated definitions of urban heat islands and interpretations of the resulting observations (Oke, 1982; Voogt & Oke, 2003).

Traditionally, UHIs were studied from fixed thermometer networks. Therefore, researchers observed the atmospheric UHI. However, with the advent of thermal remote sensing technology, remote or indirect observation of UHIs became possible using satellite and aircraft platforms. However, it is important to note that these indirect techniques are measures of land surface temperature or the surface UHI. This has allowed researchers in recent years to see the more nuanced relationship between the two UHI types. Many studies tend to use remote sensing to measure the UHI intensity because data are available at smaller resolutions and show considerably more variation in temperature within cities (D. P. Johnson et al., 2012).

2.1 Impacts

There are three major ways that the UHI effect and the warmer temperatures it brings impact cities: 1) human health and comfort, 2) increased energy consumption, and 3) impaired air and water quality (U.S. EPA, 2008c). These impacts are detailed in the following sections.

2.1.1 Human Health and Comfort

More frequent occurrences of extreme heat due to the UHI have global public health consequences (Golden, 2004). The synergistic effects of global climate change, urbanization, and an aging population will exacerbate the UHI and the warmer temperatures. Extreme heat is already the leading weather-related cause of death in the United States (Luber & McGeehin, 2008b). Prolonged exposure to high temperatures can cause heat-related illnesses, such as heat cramps, heat syncope, heat exhaustion, heat stroke, and death. Heat exhaustion is the most common heat-related illness. If untreated, it may progress to heat stroke (Luber & McGeehin, 2008b). Additionally, heat is expected to contribute to the exacerbation of chronic health conditions (Kravchenko, Abernethy, Fawzy, & Lyerly, 2013). In particular, hyperthermia—elevated body temperature due to failed thermoregulation, which is commonly caused by heat stroke — is a contributing factor to cardiovascular, metabolic, and other causes of death (O'Neill & Ebi, 2009).

2.1.2 Energy Consumption

Much of human resilience to heat and the UHI are dependent on mechanical cooling systems, such as air conditioning. During heat waves, demands on power can severely tax the power grid, which can lead to power outages (Golden, 2004; Luber & McGeehin, 2008b; Mirzaei & Haghighat, 2010). Air conditioning lessens the threat of heat stress and protects large portions of the population during heat waves. However, at the same time, it can increase the street temperature and contribute to the overall issue of the UHI (Tremeac et al., 2012). The reliance on air conditioning raises the demand for electricity as well as contributes to the formation of ground-level ozone. Power plants, typically powered by fossil fuels, must produce more electricity to meet the demand. Primary pollutants from power plants include sulfur dioxide, nitrous oxides, particulate matter, carbon monoxide, and mercury. These pollutants are harmful to human health (U.S. EPA, 2008d).

2.1.3 Air Quality and Water Quality

The UHI impacts environmental quality, in particular air and water quality. Air quality is affected by the UHI in a variety of ways. First, daytime UHI often accelerates the formation of harmful ground-level ozone, which is produced by the combination of nitrous oxide (NOx) and volatile organic compounds (VOCs) (Golden, 2004; Mirzaei & Haghighat, 2010). This may be exacerbated by stagnant air masses (O'Neill & Ebi, 2009). Second, aerosols, a type of air pollutant, may produce a pseudo-greenhouse effect. These pollutants may absorb and re-radiate heat and, concurrently, inhibit the corresponding cooling process (Rizwan et al., 2008).

The warmer temperatures caused by urban form also impact water quality. A recent study investigated streams draining from urban areas. Somers and colleagues (Somers et al., 2013) found that streams draining urban areas tend to be hotter than rural and forested streams at baseflow because of warmer urban air and ground temperatures, paved surfaces, and decreased riparian canopy. Stormwater runs over hot impervious surfaces and through storm drains into streams. This can lead to rapid, dramatic increases in temperature. These changes can be lethal to aquatic fauna if temperatures exceed upper tolerance limits (Somers et al., 2013; U.S. EPA, 2008c).

2.2 Vulnerable Populations

There is a strong consensus in the literature regarding the groups of people most vulnerable to heat. In Part II of this report, we conduct a vulnerability analysis to identify where these populations live in Boston. Those at particularly high risk of adverse health effects from extreme heat exposure are older adults, children, those living alone (i.e. in social or geographic isolation), those with chronic illnesses (particularly cardiovascular or mental diseases), urban residents, minorities, people of low income, people with less education, and people without access to air conditioning (Basu, 2009; Belmin et al., 2007; Holstein, Canouï-Poitrine, Neumann, Lepage, & Spira, 2005; Kravchenko et al., 2013; Luber & McGeehin, 2008b; O'Neill & Ebi, 2009). In addition, people with chronic mental disorders or pre-existing medical conditions (e.g., cardiovascular disease, obesity, neurologic or psychiatric disease), and those participating in outdoor manual labor or sports in hot weather also are at increased risk for heat-related illness (Holstein et al., 2005; Luber & McGeehin, 2008b). People living in normally cool climates where residents are less acclimatized to hot temperatures and are less likely to have air conditioning are also vulnerable to heat (Basu, 2009; Kravchenko et al., 2013). Lastly, although there has been less attention to this subject, the homeless are an already at-risk population that is also vulnerable to extreme heat (Ramin & Svoboda, 2009).

Older adults may be most at risk for heat-related mortality in the United States. This is because they are more likely to have diminished heat adaption ability, may be more likely to live alone, have reduced social contacts, and experience poor health (Belmin et al., 2007; Luber & McGeehin, 2008b). Furthermore, most older adults spend the majority of their time indoors. White-Newsome and colleagues (White-Newsome et al., 2012) investigated the relationship between outdoor and indoor temperatures in elderly housing and found that indoor temperatures were higher than average maximum outdoor temperatures.

3 Green Infrastructure Mitigation

Climate change over the next decades is projected to increase the frequency and intensity of heat waves (Jenkins et al., 2014; Kovats & Hajat, 2008; Oleson, 2012; Patz, Campbell-Lendrum, Holloway, & Foley, 2005; Sheridan, Lee, Allen, & Kalkstein, 2012). In turn, heat-related mortality and morbidity are expected to increase (Jenkins et al., 2014; Luber & McGeehin, 2008b; O'Neill & Ebi, 2009; Patz et al., 2005). Currently, heat-related mortality in Boston is approximately 2.9 per 100,000 residents (Petkova et al., 2013). However, a recent study used the IPCC's Fifth Assessment Report to project that Boston will see an increase of 5.9 - 6.5 heat-related deaths per 100,000 by 2020 and further an increase of 8.8 - 11.7 heat-related deaths per 100,000 by 2050 (Petkova et al., 2013).

The UHI effect is commonly addressed through green infrastructure improvements. We focus on three strategies for reducing urban temperatures: vegetation, roofs, and pavement. This section provides definitions, benefits, and considerations for each approach. We consider the effectiveness and sustainability of each UHI mitigation strategy. Finally, we examine the importance of community engagement in successfully applying appropriate and effective green infrastructure mitigation strategies.

3.1 Vegetation

Trees and vegetation provide numerous benefits to cities and their inhabitants. Researchers studying how trees affect the urban atmosphere offer an acronym for those impacts: TREE, which stands for: (1) **T**emperature and microclimatic effects, (2) **R**emoval of air pollutants, (3) **E**mission of volatile organic compounds by trees and emissions due to tree maintenance, and (4) **E**nergy conservation in buildings and consequent effects on emissions from power plants (Nowak & Dwyer, 2007).The primary focus of this section is the first and last of these impacts.

Vegetation mitigates heat in two ways. First, trees shade buildings, pavements, and other surfaces, preventing solar radiation from reaching surfaces that absorb heat and then transmit it to buildings and the surrounding air. Second, vegetation reduces air temperatures indirectly through evapotranspiration, the process by which plants absorb water and transfer it back into the air, which cools the air (U.S. EPA, 2008c). Vegetation is an appealing mitigation strategy because it also has a variety of benefits, such as cooling, economic, and social/health benefits.

3.1.1 Benefits

Cooling Benefits

Numerous studies have attempted to quantify the cooling effect of vegetation. A review of six studies conducted in hot humid and hot dry climates (e.g. Miami, Tokyo, and Tucson) found that shaded walls had peak surface temperatures 9-36°F cooler than unshaded walls (Meier, 1990). In a Sacramento study, tree shade reduced the surface temperatures of walls and buildings by 20-45°F (Akbari, Kurn, Bretz, & Hanford, 1997). Cooler surfaces are important because they transmit less heat to the surrounding air, reducing the heat island effect.

Figure 2: New York City High Line Park

Source: (Ken, 2010)

The research investigating the relationship between vegetation and air temperature is extensive, but also problematic. Many researchers cite statistics without returning to original papers to confirm findings. The research that could be verified indicated that vegetation provides modest ambient cooling effects of 2 to 4ºF (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Kurn, Bretz, Huang, & Akbari, 1994; Scott, Simpson, & McPherson, 1999). More extreme temperature reductions can be found in reports on the UHI effect, but these should be used with extreme caution as our research found that the foundational studies were not relevant to the urban context or failed to corroborate the claims.

Economic Benefits

Trees provide numerous economic benefits. First, trees can decrease residential energy use and cost. These benefits can be observed in the summer by decreasing demand for air conditioning, and in winter as the wind-shielding effects of trees can reduce the amount of heat lost through windows, doors, and other joints. For example, a Chicago study found that increasing tree cover by only 10 percent can lower total heating and cooling energy use by 5 to 10 percent annually ($50 to $90 per dwelling unit) (McPherson et al., 1997).

The economic benefits of vegetation are not limited to residential buildings and energy costs. Numerous studies have evaluated the impact of streetscaping and trees on consumer behavior. These studies find that patrons spend more time and money in shopping centers with landscaping (Wolf, 2003, 2004, 2005a, 2005b).

Finally, municipalities can find cost savings in trees through reduced pavement maintenance and stormwater retention. While large trees may require additional cleanup and repairs to sidewalks, their shade can extend the life of street surfaces and postpone costs for re-paving; well-shaded asphalt pavements need to be resealed every 20-25 years, compared to every 10 years for unshaded streets (McPherson, Simpson, Peper, & Xiao, 1999).

Health and Social Benefits

As described above, the UHI effect impacts human health and comfort. Researchers compared two heat waves in Shanghai, one in 1998 an one in 2003, and found that the decrease in deaths in 2003 could be attributed, in part, to an increase in urban green space (Tan et al., 2006). In addition to improving health by cooling and filtering the air, shade trees provide protection from ultraviolet light. Everyday exposure to the sun's rays can increase the risk of skin cancer; thus, shading areas where children play can reduce exposure to these harmful rays by about half (Grant, Heisler, & Gao, 2002).

Planting trees along streets can make these spaces safer for pedestrians and cyclists. The vegetation serves as both a visual and physical barrier between vehicles and pedestrians; a tree-lined street gives drivers a defining edge, which helps guide their movements and reduces driving speeds (Ewing & Dumbaugh, 2009).Properly designed plantings of dense vegetation (e.g. a row of shrubs along a road and a row of trees behind it) can reduce noise by 3 to 5 decibels (Nowak & Dwyer, 2007).Finally, trees improve community comfort in winter months by reducing wind speeds, making public spaces more comfortable and buildings less susceptible to heat loss.

3.1.2 Strategies

This section provides an overview of the most effective places to add vegetation, and examples of specific interventions. It focuses on increasing vegetation around buildings, streets, parking lots, and areas were people congregate.

Landscaping Buildings

Plant trees to the south and west of buildings for optimal shading in the summer months. Such plantings will also reduce building heat loss though walls, roofs, and cracks around windows, doors, and joints in winter months by slowing wind speeds by 20-80 percent (Huang, Akbari, & Taha, 1990).

Landscaping Streets and Parking Lots

Gartland (2008) provides two specific recommendations:

1. Plant trees at regular intervals (20-40 feet, depending on tree size at maturity) along both sides of a street and along any medians to shade the street, sidewalk, and parked cars.
2. Implement ordinances requiring that trees must shade 50 percent of parking lots within 15 years of construction (e.g. Davis and Sacramento, CA have such requirements). This requires planting .5 – 2 trees per thousand square feet of parking lot, depending on the canopy of the species of tree chosen.

Landscaping Playgrounds/School Yards/Sports Fields

Trees and other shade structures are needed to protect children from the sun's heat and ultraviolet rays. Plant shade trees where people are likely to congregate, such as over benches for sports teams, spectator stands, picnic tables, and play equipment. Vines on trellises are useful for producing shade more quickly than trees, and require less soil. To increase year-round use of public benches, surround them with u-shaped rows of both high evergreen shrubs that open to the south, and deciduous trees with high trunks, which will allow people to be exposed to the sun and protected from the wind in winter, while enjoying the shade of the trees in summer (Givoni, 1991).

3.1.3 Considerations in Increasing Vegetation

Plants in urban environments face numerous challenges and their management requires attention to a variety of concerns, including the following:

Maintenance

Trees must be heavily pruned to avoid conflicts with utility lines and reduce the risk of trees causing damage or injury during a storm. When plants are not well watered, their roots will seek out water, which can damage pavements and sidewalks, resulting in costly repairs. The costs of and construction protocols to limit tree root and urban infrastructure conflicts are reviewed in Randrup, McPherson, & Costello (2001).

Inhospitable environments

There is limited space for root and canopy growth in an urban environment. The soils are often compacted and low in nutrients. Irrigation can be difficult, and plants that do not receive enough rainfall may fail. Pedestrians and passing vehicles can damage vegetation. Pruning strategies must balance plant viability with keeping utility wires and sightlines to businesses clear.

Humidity

As evapotranspiration cools the air, it adds moisture and increases humidity, a possible concern in Boston's humid summer months. Gartland (2008) argues that the benefits of lowering temperatures by shading buildings and pavement outweigh the negative effects of higher humidity.

Community Opposition

Some trees produce disagreeable smells or pollens that affect people with allergies. Trees that produce fruits may attract insects or require additional cleanup. For these reasons, and others, communities may resist tree plantings.

We note a dichotomy between perceptions of public opinion and surveyed opinions. A review of the literature shows that while residents identify potential problems such as falling branches, leaf litter, tree debris and infrastructure damage, residents believe that the benefits provided by street trees outweigh any detriments (Mullaney, Lucke, & Trueman, 2015). A study of public reactions to a major tree-planting initiative in NYC suggests that "public education on tree benefits and notification of planting processes could change perceptions of new street tree plantings" (Rae, Simon, & Braden, 2011, p. 1).

Density and Shape of Vegetation

The cooling effect of vegetation is dependent upon a variety of factors, including tree size, type, location, and planting density. On this final point, a metadata analysis of the literature on vegetative cooling found that a tree stand must reach three hectares (7.4 acres) to reduce the air temperature beyond the patch of trees, and impact is reduced as the distance increases from tree cover location (Bowler et al., 2010).[1]

A study (Cao, Onishi, Chen, & Imura, 2010) of the "Park Cool Island" (PCI) effect of 92 parks in Japan produced several interesting findings:

1. The cooling effect depends on park size, and larger parks have stronger cooling effects.
2. Trees, shrubs and compactness of parks benefit the PCI development in spring and summer, while grass and soil may decrease PCI in spring.
3. Park shape is strongly correlated with PCI intensity. They developed a tool they called the "Park Vegetation and Shape Index" (PVSI) to predicted PCI intensity of selected parks. The PVSI could help identify land that a city already owns that has sub-optimal tree and shrub plantings.

3.2 Roofs

Green infrastructure interventions on buildings are effective and long-term solutions for the UHI effect. Commonly implemented strategies include installing green roofs (vegetated roofs), cool roofs (which have high solar reflectivity), photovoltaic panels, green walls, ventilation systems, and operable windows. Another less-well-known form of green infrastructure is blue roofs, non-vegetated systems that aim to manage stormwater. They are most applicable and provide the most benefit in avoiding overflows of combined sewer systems (Roy et al., 2014). Blue roofs are less expensive than green

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[1] For comparison, Boston City Hall Plaza is approximately 2 hectares.

roofs and can be cooler than conventional roofs due to light colored roofing material (NYC Environmental Protection, 2015). However, blue roofs do not provide benefits such as energy use reduction; thus, we focus on green roofs and cool roofs.

In the scholarly research, and the guidelines of public and private organizations, green roofs and cool roofs stand out as the most highly recommended ways to mitigate the UHI effect. Both green and cool roofs dramatically cool working and living spaces, engendering a slew of benefits related to improving human comfort and reducing energy consumption. Additionally, green roofs can reduce storm water runoff, provide space for local food cultivation, create leisure space, and enhance urban esthetics. This section examines these two solutions independently, and then offers a summary of the literature comparing the methods.

3.2.1 Green Roofs

A green roof, or living roof, is a vegetated rooftop consisting of the following materials: plants, a lightweight, engineered planting medium, a filtration layer, a root barrier, a waterproofing membrane, insulation, the roof structure, and the building. They can be sited on multi-story constructions, single-family dwellings, commercial buildings, and other structures ("DC Greenworks," n.d.).Generally, there are two types of green roofs: extensive and intensive, with the former being much lighter in weight due to a shallower growing medium (generally up to 4 inches) and the latter being much deeper and heavier. While being much more expensive, an extensive system can support a great variety of plants and are often designed for public access.

Benefits

Green roofs improve building energy performance as well as the environmental conditions of the surroundings. Through shading and evapotranspiration, they help to moderate air temperature, decrease electricity consumption, reduce air pollution by filtering dust from the air, reduce rainwater input into the sewage system, and mitigate the risk of flooding (Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013; U.S. EPA, 2008a).

Figure 3: Chicago City Hall Green Roof

On a typical day, the Chicago City Hall green roof is approximately 80°F (40°C) cooler than the neighboring conventional roof. There is a combination of both extensive and intensive green roofs on this building. Chicago estimates that its City Hall green roof project could provide cooling savings of approximately 9,270 kWh per year and heating savings of 740 million BTUs[2] (U.S. EPA, 2008a).

Source: (raeky, 2010)

Considerations in Building Green Roofs

Green roofs (horizontal) are more efficient than green walls (vertical). Alexandri and Jones demonstrate that the quantity and geometry of the vegetation are the most important elements in cooling temperatures, whereas urban canyon orientation—i.e. where buildings line a street creating a man-made canyon—and wind direction have little to no significant effect. While green walls are more effective inside the urban canyon, greening roofs is more effective in cooling temperatures at the roof level and, therefore, at the urban scale (Alexandri & Jones, 2008).

Additionally, the mitigation potential of green roofs varies significantly based on the design and performance of the vegetation. Thus, green roofs must be designed with considerations for the local context and specific objectives in mind, instead of relying upon some assumed attributes (Simmons, Gardiner, Windhager, & Tinsley, 2008).

[2] 1 British thermal unit = 1,055.05 Joules; it is the amount of energy needed to cool or heat one pound of water by one degree Fahrenheit

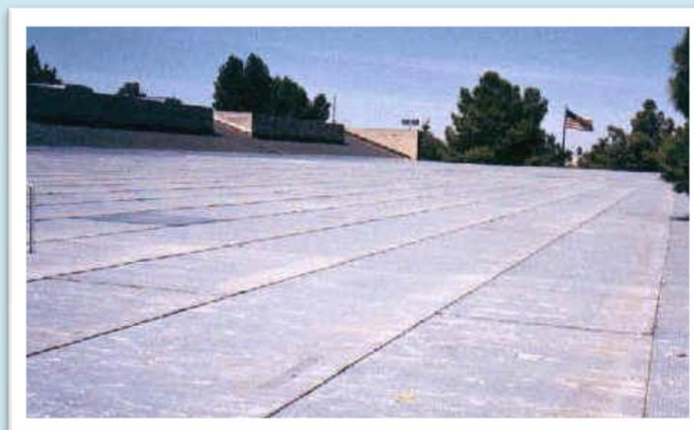
Though green roofs are an effective UHI mitigation strategy, they have high installation costs and structural requirements. They can be challenging to implement as they require additional structural support for the weight of vegetation and wet soil, and are not suitable for steep-sloped roofs (Hoverter, 2012).

3.2.2 Cool Roofs

Cool roofs reflect more light and absorb less heat than traditional roofs. They reduce surface and air temperatures by minimizing the impact of solar energy due to properties of alternative materials and/or using white or light colors. That means cool roofs can be either light or dark colors as long as they have both high solar reflectance (albedo) and high thermal emittance (Hoverter, 2012). There are two types of cool roofs: low-sloped and steep-sloped cool roofs. Low-sloped cool roofs have higher solar reflectance, achieved by covering the existing material with a light-colored coating or single-ply membrane. Steep-sloped cool roofs are an emerging market, with asphalt shingles remaining the most popular material; other products include metal roofing, tiles, and shakes (U.S. EPA, 2008b).

Figure 4: Cool Roof, Tucson, Arizona

In June 2001, the City of Tucson applied a white elastomeric top coating to the roof of a large administrative office building, as part of its Creating Cool Communities program. Comparing data before and after installation, the cool roof reduced surface temperatures 40°F to 70°F, cutting energy usage in half and saving $40,000 annually. Total cost was $187,500; thus, the payback period of the projects is 4.7 years.



Source: (*Thomas O. Price Service Center*, n.d.)

Benefits

According to the EPA, "cool roofing products are made of highly reflective and emissive materials that can remain approximately 50 to 60°F (28-33°C) cooler than traditional materials during peak summer weather." (U.S. EPA, 2008b, p1) Three main benefits of cool roofs are: reduced energy use, reduced air pollution and greenhouse gas emissions, and improved human health and comfort.

Considerations in Building Cool Roofs

Cool roofs can pose a number of challenges. Although cool roofs need less maintenance efforts than green roofs in general, they require regular washing to remove the accumulated dirt that lowers the solar reflectance over time (Bretz & Akbari, 1997). In addition, weathering, location within a city (relative to a heat island), and climate (northern latitude) possibly reduce the heat mitigation potential of cool roofs. In spite of outperforming traditional roofs, cool roofs trap more heat than green roofs. Cool roofs can also reflect sunlight to taller surrounding buildings, and produce unwanted glare (Hoverter, 2012). Furthermore, cool roofs may have negative impacts in winter for northern latitudes and cooler climates. Cool roofs continue to reflect heat from the sun during the cold months, which can potentially increase heating costs (U.S. EPA, 2008a).

3.2.3 Green vs. Cool Roofs

When it comes to price comparison, coatings for cool roofs may cost $\$0.75/ft^2$-$\$1.50/ft^2$and single-ply membrane options may cost $\$1.50/ft^2$-$\$3.00/ft^2$ (U.S. EPA, 2008b). Meanwhile, the costs for extensive green roofs might start at $\$10/ft^2$ and intensive ones at$\$25/ft^2$ (Peck & Kuhn, 2003).

Regarding cooling benefits, both green and cool roofs have been proven to reduce air temperatures at the upper limits of the urban canopy and reduce energy consumption. Some comparative analyses have led to the general conclusions that both solutions are effective to improve the urban environment (Kolokotsa, Santamouris, & Zerefos, 2013; Takebayashi & Moriyama, 2007). However, a recent study clearly demonstrated that "white roofs cool the globe three times more effectively than green roofs" (Sproul, Wan, Mandel, & Rosenfeld, 2014, p20). This study of white, green, and black flat roofs in the United States found that white roofs are the most cost-effective solution. Similarly, white roofs are proven to have higher efficacy than a typical green roof whose configuration was modeled in summertime conditions in Portland, Oregon (Scherba, Sailor, Rosenstiel, & Wamser, 2011).

Nonetheless, in a field experiment, Scherba et al. (2011)solely concentrated on calculating sensible flux among types of roofs: a dark roof, a cool roof, a green roof, and photovoltaic panels elevated above various base roofs. The authors did not attempt to predict urban air temperatures impact. Thus it is not clear whether cool roofs are definitively the better solution to mitigate urban heat. Sproul et al. (2014) also stated that green roofs would be preferred if the building owner is concerned about the local environment, built-in stormwater management, and esthetics and usability of the vegetation. In the same view, Coutts et al. (2013) underscore that roof design must be in accordance with specific goals: cool roofs are more useful in lessening atmospheric heat while green roofs help to insulate the buildings (Coutts, Daly, Beringer, & Tapper, 2013).

Most recently, Santamouris (2014)holistically reviewed the difference between various types of roofs and UHI mitigation. Cool roofs are more effective when the albedo is equal or higher than 0.7 and in sunny climates. Whereas, green roofs might be more predominant when latent heat losses exceed roughly 400W/m2[3], in moderate and cold climates, and in the cases of weatherization (Santamouris, 2014).

In sum, either option can be utilized to mitigate the UHI effect while dark roofs should be phased out in policies and practices (Sproul et al., 2014). A combination of both solutions should be considered, in which cool roofs might be aimed at for the short term and green roofs for the longer term.

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[3] Heat (thermal) flux density is measured by the rate of heat energy (Watt) transfer through a given surface, per unit area (m^2 or f^2).

3.3 Pavement

Currently, one of the most significant factors contributing to the UHI is the amount of dark, impervious surfaces that make up most cities' roads and sidewalks. Paved surfaces often cover between 25-50%of land in urban areas. Therefore, pavement contributes significantly to the UHI effect (Asaeda, Ca, & Wake, 1996; Gartland, 2008; Santamouris, 2013).The majority of the impervious pavement surface found in urban areas is made up of concrete and asphalt, which are not optimal materials for combating the UHI effect (Asaeda et al., 1996).

Figure 5: "Boston Complete Street" Pavement

Source: (Boston Transportation Department, 2013a)

The most common paving materials in cities are concrete and asphalt (Gartland, 2008; Santamouris, 2013). Asphalt is characterized by its black or dark grey color and concrete is a lighter grey color (Gartland, 2008). Traditional paved surfaces store heat during the day and then release it in the evening and into night (Asaeda et al., 1996; Nakayama & Fujita, 2010). Anthropogenic factors such as vehicular traffic may also affect the temperature of paved surfaces (Santamouris, 2013). A study conducted by Doulous et al. (2004) found that in addition to the color of the pavement (light or dark) the texture of the pavement (smooth or rough) was also a factor. Doulous et al. (2004) characterize "warm" materials as dark and rough, while "cool" materials are lighter in color and smooth. However, the two factors that have the greatest impact on the temperature of pavement are its solar reflectivity and permeability (Gartland 2008, Santamouris 2013). Therefore the major UHI pavement mitigation strategies are decreasing the amount of paved or impervious surface and using alternative pavement materials, such as "cool pavement"—pavement with increased solar reflectivity and porosity (Gartland, 2008).

The use of reflective and permeable pavement will help mitigate the UHI effect, while providing numerous co-benefits. These benefits include but are not limited to: improved stormwater management, the prolonged life of pavement, improved night-time visibility and decreased energy use for lighting, reduced noise pollution, and increased opportunities for creative urban design (Gartland 2008). The subsequent sections discuss pavement albedo, or solar reflectivity and permeability to water based on the porosity of paving materials.

3.3.1 Pavement Albedo (Solar Reflectivity)

The albedo of pavement materials, or how much solar radiation is reflected rather than absorbed, is determined by its color and texture (Santamouris, 2013). Lighter colors absorb less solar heat and flat surfaces tend to be cooler than rough surfaces (Santamouris, 2013). The solar reflectivity of asphalt is low, only 5-10% when new. Its reflectivity increases to about 10-20% as the color of the material lightens with time. During the summer months, asphalt can reach temperatures of up to 65°C or 150°F (Gartland, 2008). In general, asphalt is the material that heats up the most and releases a significant amount of heat back into the atmosphere (Asaeda et al 1996). Gartland suggests that there are strategies to increase asphalt albedo primarily through lightening its color. For example, lighter colors can be incorporated in the mixing or finishing of asphalt (Gartland 2008). Another strategy is white topping. It is a method to cool asphalt whereby concrete is installed on top of asphalt and could be considered an important strategy as some scholars argue that color has the greatest impact on pavement solar reflectivity (Gartland 2008).

Concrete, on the other hand, initially has solar reflectivity of 30-40% and drops to 25-35% as it grows darker overtime. Concrete can heat up to 50°C or 120°F, consistently cooler than asphalt (Gartland, 2008). While concrete has higher albedo than asphalt, light aggregates can still be added to improve its solar reflectivity (Gartland 2008).Taha (1997) argues that increasing albedo in general (including that of roofs and pavement) combined with the reforestation of urban areas can effectively reverse the urban heat island effect.

3.3.2 Pavement Permeability (Porosity)

According to Asaeda et al. (1996), above all else, evaporation of the underlying soil has the greatest ability to cool pavement at the surface level. The basic concept behind pavement permeability is to allow stormwater to drain through the pavement material into the soil below. On warm, dry days, the water will evaporate and in the process, cool the pavement. In order for evaporation to happen regularly, the soil underneath must consistently be moist either from accumulated stormwater or manual watering (Gartland 2008). Another important factor that impacts evaporation and drainage according to some studies (Kertesz & Sansalone, 2014) is the size of the soil particles beneath the surface material (Nakayama and Fujita 2010). Furthermore, some studies have shown that porous pavement which is not kept moist has a higher surface temperature than non-porous materials. Other studies dispute the connection between pavement surface temperature and its permeability (Santamouris, 2013). Santamouris (2013) concludes that pervious pavement is best suited for more humid areas that receive regular rainfall. It is important to note that a challenge with pervious pavement is ensuring that it does not get clogged with sand and other particles, which affect its permeability (Gartland 2008).

3.4 Community Engagement

This section provides a brief background and description of techniques used in a civic engagement or participatory planning process. It also shows why community engagement is integral to the planning process and how it is necessary to implement green infrastructure strategies in a sustainable and equitable manner.

Community engagement strategies in urban planning have been developed since the 1960s, after the modernist approach to planning led to an over-emphasis on technocratic policy that neglected the practical and social needs of local communities. The movement towards participatory planning was a response to the failure of Urban Renewal, rational master planning, and centralized top-down processes, and paralleled the rise of the Civil Rights Movement. By definition, participatory planning implies that all stakeholders participate in the process. For example, stakeholders may include affected communities, local government, community-based organizations, private developers, NGOs, and anchor institutions[4] (e.g. medical and educational institutions, churches, and libraries). The most efficient and equitable approach to community engagement is to include local communities in the early phases of the planning process, when key decisions are discussed, and throughout the planning and implementation process.

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[4] "Big non-profits and businesses that are structurally tied to the area and unlikely to move out of the region" (Loh & Shear, 2015, p7).

Scholars and practitioners have inventoried a long list of successful techniques for civic engagement through international and domestic case studies. Some examples include: action plans, participatory design, Participatory Rapid Appraisal (PRA), stakeholder analysis (Hamdi & Goethert, 1997), visioning, the charrette process, participation games, workshops (Sanoff, 1999), transect walk, diagramming, modeling, mapping, role play and negotiation (Hamdi, 2010). Problem-solving techniques such as Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis and Problem and Objective Trees Analysis (POTA) are also widely used in Community Action Planning (CAP) (Hamdi & Goethert, 1997).

As an inter-disciplinary approach, there is a strong connection between community engagement in urban planning and other fields such as public health, education, political science, sociology, art, architecture, and others; as well as with institutions such as hospitals, museums, universities and libraries.

- Public health: Examples in Sacramento, California (the Building Healthy Communities program) and San Francisco (Sunnydale-Velasco major housing revitalization initiative) have shown the contribution of interdisciplinary approaches for "economic mobility, full democratic participation, and community health" (Pastor & Morello-Frosch, 2014, p1890,1895).
- Education: Educational institutions have a vital role to play as network hubs in civic engagement and social capital. School-based programs, for instance, Farm-to-school, Safe Routes to School, and joint usage of school infrastructure are successful in engaging with communities (Cohen & Schuchter, 2012). Some programs can target children to raise their awareness of the environment and help them "feel more confident and strong to act" (Tsevreni, 2011).
- Librarianship: Community engagement has a significant correlation with the role of librarians and e-government for a more transparent participation process (Quinn & Ramasubramanian, 2007).
- Information and communication technology: Internet-based tools, online platforms and applications, and new technologies such as GIS, computer aided design, planning support systems, virtual environments, and digital games have engendered the new generation of public participation (Evans-Cowley & Hollander, 2010; Gordon, Schirra, & Hollander, 2011). Crowdsourcing has been an innovation for planning projects and local engagement (Brabham, 2009; Seltzer & Mahmoudi, 2013). As an example, the Beacon of Hope - University of New Orleans Community Recovery Project (BUCRP) intensified the engagement of stakeholders through utilizing community-led public

participation GIS (PPGIS) after Hurricane Katrina in New Orleans (Thompson, 2012). Other examples include using interactive online games (Gordon & Baldwin-Philippi, 2014) and applying augmented deliberation through using Second Life software (Gordon & Manosevitch, 2011).

Throughout the literature, the issue of engagement is discussed using varied terms such as participatory development, participatory budgeting, and inclusive cities. This sizable body of work demonstrates that public participation has become a prerequisite for equitable and sustainable planning efforts.

3.4.1 Community Engagement for UHI

Community engagement has a significant role to play in collaborating with local stakeholders to address the problems of climate change, carbon management planning, and disaster risk reduction (C. Johnson & Blackburn, 2014; Peters, Fudge, Hoffman, & High-Pippert, 2012; Sheppard et al., 2011). While there are numerous examples in the literature around community engagement and climate change issues, there is little literature specific to the UHI effect.

Recently, guidelines to address urban heat have been embedded with more detailed instructions for public participation. For instance, when Chicago launched its Climate Action Plan in 2005, several public health considerations were folded into the strategies (Cooney, 2011). This echoes the EPA's recommendation that "communities can integrate measures to reduce urban heat islands into climate mitigation, climate adaptation, energy efficiency, sustainability, air quality, stormwater, land use planning or green building programs" (U.S. EPA, 2012, p34). In an August 2012 presentation, the EPA offered four solutions to reducing urban heat: trees and vegetation, green roof, cool roofs, and cool pavements, together with examples of voluntary efforts throughout the country (e.g. Climate Showcase Communities in fifty pilot local government and tribal governments). Besides policy efforts, there are six voluntary efforts that should be taken into consideration: demonstration projects, incentives, urban forestry programs, weatherization, outreach and education programs and awards (U.S. EPA, 2008d). Another toolkit designed for local governments offers tools to implement four solutions (cool roofs, green roofs, cool pavements and urban forestry) through mandates, incentives, and public education programs (Hoverter, 2012). Without community participation, green infrastructure strategies to mitigate the UHI effect will not be as long lasting or as efficient.

Figure 6: Civic Engagement, Portland, Oregon

Environmental-based civic engagement efforts in Portland include volunteer activities to plant and care for city trees and green spaces. Nonprofit organizations, such as Friends of Trees, SOLVE & Trees For All, the Nature Conservancy, the Friends of Tualatin River National Wildlife Refuge, and the U.S. Fish and Wildlife Service, have engaged residents to join hands and shovels to plant millions of trees.

Source: (Vuong, 2015)

3.4.2 Community Engagement in Boston

In the City of Boston, participation in general and in local organizations in particular, is strongly related to ethnic and racial diversity (Tran, Graif, Jones, Small, & Winship, 2013). The ethnic and racial heterogeneity of Boston is derived from a long history of foreign and internal migration. A number of grassroots community organizations have worked for the justice of these minority groups such as the Chinese Progressive Association (CPA), Dudley Street Neighborhood Initiative (DSNI), and Alternatives for Community and Environment (ACE), among many others.

Different cities will seek to engage different groups as part of the planning process. In Boston, one important group is recent immigrants. Conducting a project on community engagement in fourteen communities throughout the country, the National League of Cities claimed that Boston is the leading example of "welcoming new Americans" (Hoene, Kingsley, & Leighninger, 2013, p13).

Understanding the importance of public participation, the City updated its 2011 Climate Action Plan with more extensive and inclusive community engagement (Greenovate Boston Community Summit, 2014). Launching January 15, 2014, the updated Climate Action Plan considered community engagement one of the four crosscutting themes, alongside social equity, economic development, and public health and safety. Seven actions have been listed in order to realize strategies for climate preparedness at the neighborhood level. Two focus groups are (i) residents and businesses and (ii) youth and youth-serving adults. Although most of the actions are incomplete, these strategies illustrate that community engagement is a priority in implementing climate action initiatives in Boston.

Table 2. Two Strategies and Seven Actions in Neighborhood Category (Greenovate Boston Community Summit, 2014)

Neighborhood Strategies and Actions	Implementers	Updates
Strategy 1: Empower residents and businesses to take climate action in their neighborhoods	—	—
1 Create a neighborhood network	Community, Greenovate	Coming soon
2 Pilot neighborhood-level sustainability planning	Greenovate	Neighborhood Green Map under development
3 Create a one-stop-shop for sustainability resources	Greenovate	Coming soon
4 Expand messaging and communications	Community, Greenovate	Coming soon
5 Create a performance measurement system	Greenovate	Complete
Strategy 2: Empower and educate youth and youth-serving adults to create tangible projects in their communities	—	—
1 Establish Green Teams and Sustainability Champions at every school	Boston Public Schools	Coming soon
2 Integrate sustainability into BPS curriculum and youth programming	Boston Public Schools	Coming soon

Part II: Vulnerability Analysis

We used Geographic Information Systems (GIS) to map heat vulnerability by census tract in Boston. These maps provided a framework for recommending potential locations for siting green infrastructure interventions where they are most needed.

4 Vulnerability Mapping Literature

After conducting a literature review of the UHI effect and UHI green infrastructure mitigation strategies, we used GIS to map areas of Boston where residents are most vulnerable to heat. We adapted a national Heat Vulnerability Index (HVI) created by Reid and colleagues (2009) to identify areas within Boston that would most benefit from green infrastructure interventions.

Prior to Reid and colleagues' (2009) work, the literature on mapping heat vulnerability in the US was scant. However, since 2009, there have been several studies that map heat vulnerability. Ueijo and colleagues (2011) investigated the relative importance of heat exposure and the built environment, socioeconomic vulnerability, and neighborhood stability for heat mortality in Philadelphia, PA and Phoenix, AZ. In 2012, Johnson et al. (D. P. Johnson et al., 2012) developed an Extreme Heat Vulnerability Index that combined 25 heat-related indicators to analyze the 1995 extreme heat wave in Chicago. Finally, Harlan and colleagues (2013) adapted Reid et al. 2009's HVI to create a block group analysis of heat vulnerability in Maricopa County, Arizona. While these heat vulnerability mapping studies use different variables and different spatial scales, all have generally found positive associations between city areas vulnerable to heat and heat-related morbidity and mortality (Harlan et al., 2013; D. P. Johnson et al., 2012; Reid et al., 2012).

After reviewing these studies, we chose to adapt the HVI from Reid et al.'s 2009 methodology because of its parsimony, ability to be replicated nationally, and its alignment with the goals for this project. We considered adapting the Harlan et al. 2013 methods in order to conduct a block group level analysis. However, Harlan's adaption of the HVI was tailored for a desert city. Therefore, we did not feel the model was applicable to Boston. Additionally, Reid et al 2009 is widely cited and used. In 2012, they validated their HVI. In their follow-up study, they investigated whether areas with higher heat vulnerability, as defined by the HVI, experienced higher rates of morbidity and mortality on hot days. They found that the HVI was consistently associated with most health outcomes on both normal and hot days, which suggests that the HVI may be a good indicator of overall health vulnerability, independent of heat exposure (Reid et al., 2012).

Reid et al. 2009 methodology

Reid et al. (2009) mapped 10 vulnerability indicators for heat-related morbidity and mortality at the census tract level in their HVI (Table 3).

Table 3: Heat Vulnerability Variables (Reid et al. 2009)

Variable	Measure	Data Source
Percent population below the poverty line	- Higher mortality during heat waves	US Census 2000
Percent population with less than a high school diploma	- Higher mortality during heat waves	US Census 2000
Percent population of a race other than white	- Higher mortality during heat waves	US Census 2000
Percent population living alone	- Higher mortality during heat waves - At higher risk of death compared to people with social contacts and access to transportation	US Census 2000
Percent population ≥ 65 years of age	- Higher mortality and hospitalization rates during heat waves	US Census 2000
Percent population ≥ 65 years of age living alone	- Higher mortality and hospitalization rates during heat waves - At higher risk of death compared to people with social contacts and access to transportation	US Census 2000
Percent census tract area not covered in vegetation	- Green space has been associated with decreased risk of heat-related illness and death	National Land Cover Database 2001
Percent population ever diagnosed with diabetes	- Preexisting health conditions lead to further vulnerability to heat-related morbidity/ mortality - Diabetes is one of the only national data sets available	Behavioral Risk Factor Surveillance System 2002
Percent households without central AC	- AC is a strong protective factor against heat-related deaths - Central AC may have a stronger protective effect than room AC	American Housing Survey 2002
Percent households without AC of any kind	- AC is a strong protective factor against heat-related deaths	American Housing Survey 2002

Source: Reid et al. 2009

Using primary component analysis on the 10 variables at the national level, Reid et al. found four major factors that explained 75% of the total variance in the 10 vulnerability variables. They labeled their four factors: 1) social/environmental vulnerability, 2) social isolation, 3) prevalence of no air conditioning, and 4) proportion of elderly/diabetes. The differential weightings of the ten variables that make up the four factors are provided in Table 4 below. The ability to view the data by each factor and by total score is an added benefit of this approach.

Table 4: Factor Weightings (Reid et al. 2009)

Variables	Factor 1: Social/ Environmental Vulnerability	Factor 2: Social Isolation	Factor 3: Prevalence of No AC	Factor 4: Proportion of Elderly/ Diabetes
Diabetes	0.37	-0.10	0.07	0.78
Below Poverty Line	0.87	0.18	-0.05	-0.03
Race Other Than White	0.85	-0.05	0.03	0.02
Live Alone	-0.06	0.91	-0.002	0.16
Age ≥ 65 Living Alone	0.19	0.87	0.001	-0.06
Age ≥ 65	-0.32	0.38	-0.04	0.67
Less than High School	0.85	-0.06	-0.05	0.07
Not Green Space	0.54	0.33	0.31	0.13
No Central AC	0.02	0.02	0.92	0.06
No AC of Any Kind	-0.01	-0.03	0.92	-0.03
*Absolute values greater than 0.4 are the most significant loadings				

We used these factor weightings to construct the four factors and the HVI composite score for the City of Boston. Our methods are detailed in the next section.

5 Methodology

We adapted the Reid et al. 2009 HVI methodology for the City of Boston. We used American Community Survey (ACS) data from 2013, the most recent data available, for our analysis. There are 175 census tracts in the City of Boston; however we removed the census tracts which contain less than 25 people. Table 5 includes the list of HVI indicators that we used.

Table 5: Boston Heat Vulnerability Variables Based on Reid et al. 2009

Variable	Data Source
Percent population below the poverty line	ACS 2013 5-Year Estimates
Percent population with less than a high school diploma	ACS 2013 5-Year Estimates
Percent population of a race other than white	ACS 2013 5-Year Estimates
Percent population living alone	ACS 2013 5-Year Estimates
Percent population ≥ 65 years of age	ACS 2013 5-Year Estimates
Percent population ≥ 65 years of age living alone	ACS 2013 5-Year Estimates
Percent census tract area not covered in vegetation	National Land Cover Database 2011
Percent population ever diagnosed with diabetes	Boston Behavioral Risk Factor Surveillance System 2010 – by neighborhood
Percent parcels without central AC	American Housing Survey 2007
Percent parcels without AC of any kind	American Housing Survey 2007

After compiling the variables, we multiplied the variable percentages for each census tract by the weightings in Table 4 in order to calculate each of the four factors. The values from all four factors are then summed to create the HVI composite score. The data are displayed by standard deviation (SD) in order to easily interpret the score and to decrease the influence of outliers (Table 5).

Table 6: Standard Deviation Values Based on Reid et al. 2009

Category	Assigned Value
≥ 2 SD below mean	1
1-2 SD below mean	2
< 1 SD below mean	3
< 1 SD above mean	4
1-2 SD above mean	5
≥ 2 SD above mean	6

The analysis of the ACS data was straightforward; however we provide below more detail on the variables for non-green space, diabetes prevalence, and air conditioning.

Non-Green Space

The percent of census tract not covered in vegetation was obtained for the most recent year available, the 2011 National Land Cover Database (NLCD). Using the reclassify tool, we created a non-green space layer with the same definition Reid et al. 2009 used. Our non-green space layer was composed of open water, all development intensities, and barren land. We then used zonal statistics as table to calculate the area of each census tract that was covered by non-green space.

Diabetes

Diabetes prevalence was only available at the neighborhood level. Therefore, using the methodology that Reid et al. 2009 used to assign AC prevalence by county to census tract as a model, we assigned each census tract the diabetes prevalence of its respective neighborhood.

Air Conditioning

According to the Boston Metropolitan Statistical Area (MSA) analysis from the American Housing Survey (AHS) 2007, 71.3% of total housing units do not have central AC and 16.3% of total housing units do not have AC of any kind. These values were assigned to each census tract per Reid et al. 2009 methods.

Overlay

We next sought to identify areas of Boston with high vulnerability to heat without access to public cooling resources. The literature on reaching vulnerable populations during heat waves indicates that residents go to "public pools, libraries, malls, movie theaters, homeless shelters, parks, senior centers, and churches" (Sampson et al., 2013). Thus, we compiled data on Boston pools, parks with spray features, and community centers that are advertised as cooling centers during heat waves. This data was sourced from the City of Boston and MassGIS (see Table 6 for details). There were 91 locations in the city that were checked for positional accuracy against an orthographic image of the city. The data points for the spray features were repositioned from the street address to the actual location of the feature. We then conducted a network analysis around these points in order to identify the half-mile walkshed for these locations.

Table 7: Boston Cooling Variables

Data Source	Data Source	Data Source
Cooling Centers	Boston Centers for Youth & Families (BCYF)	(City of Boston, n.d.-a)
Pools & Spray Features	BCYF, City of Boston, MassGIS	(City of Boston, n.d.-a, n.d.-b; MassGIS, 2014)

6 Results

Figures 2-7 below show the four major factors and the composite HVI. The composite HVI score ranged from 9-18. The minimum possible score—or the least heat vulnerable—on the HVI is 4 and the maximum score—or the most heat vulnerable—is 24. Our analysis shows that there are eleven census tracts in the city that score the highest in the HVI with a 17 or an 18. Only three of the 14 received the score of 18.

6.1 Heat Vulnerability Maps

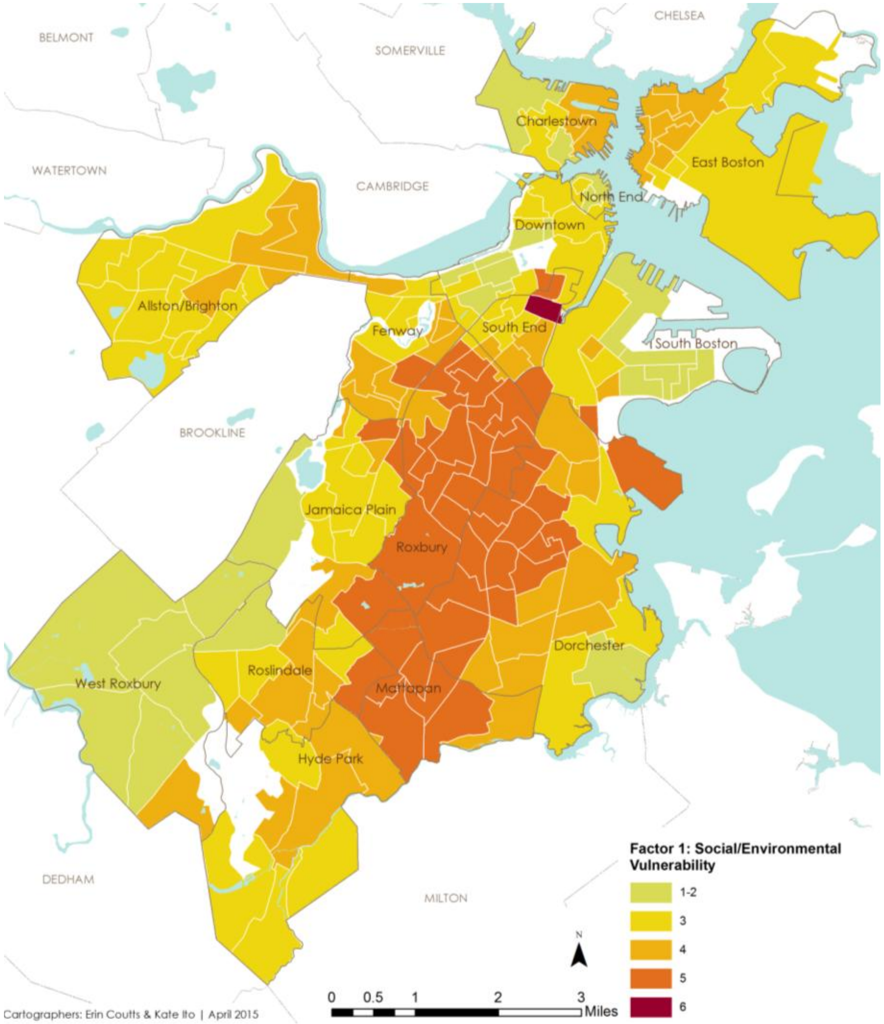

Figure 7: Factor 1 - Social/Environmental Vulnerability

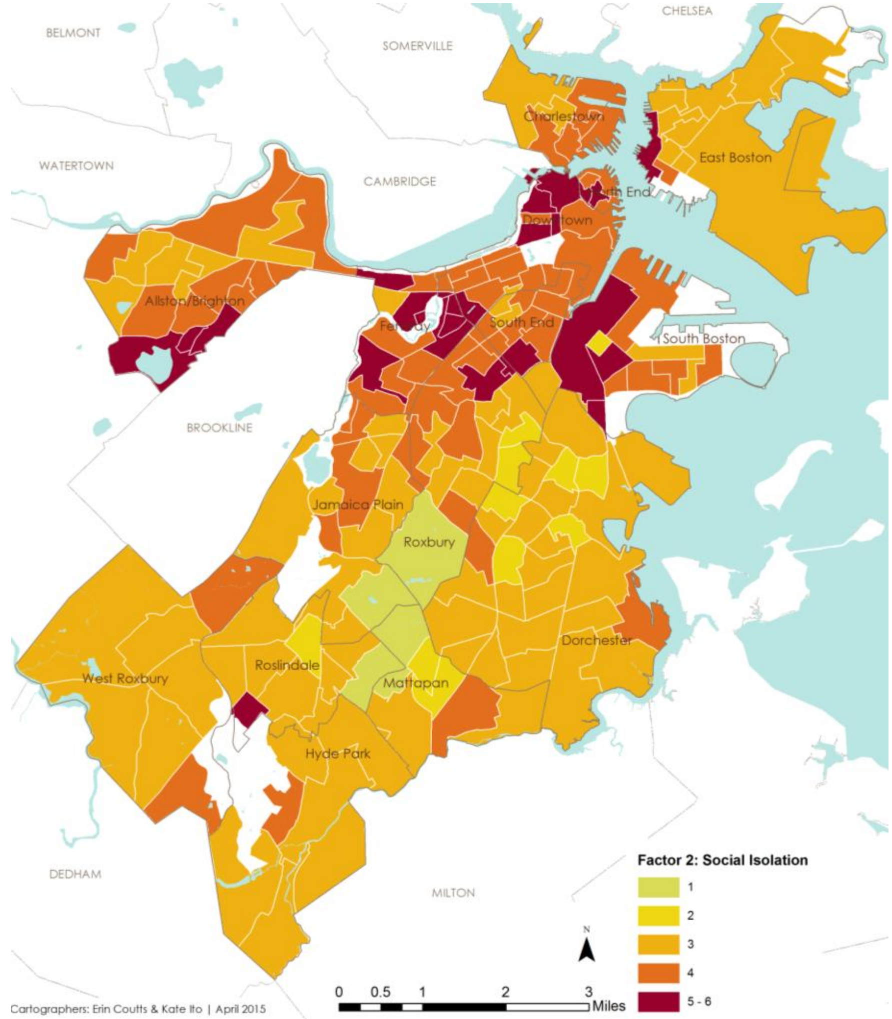

Figure 8: Factor 2 - Social Isolation

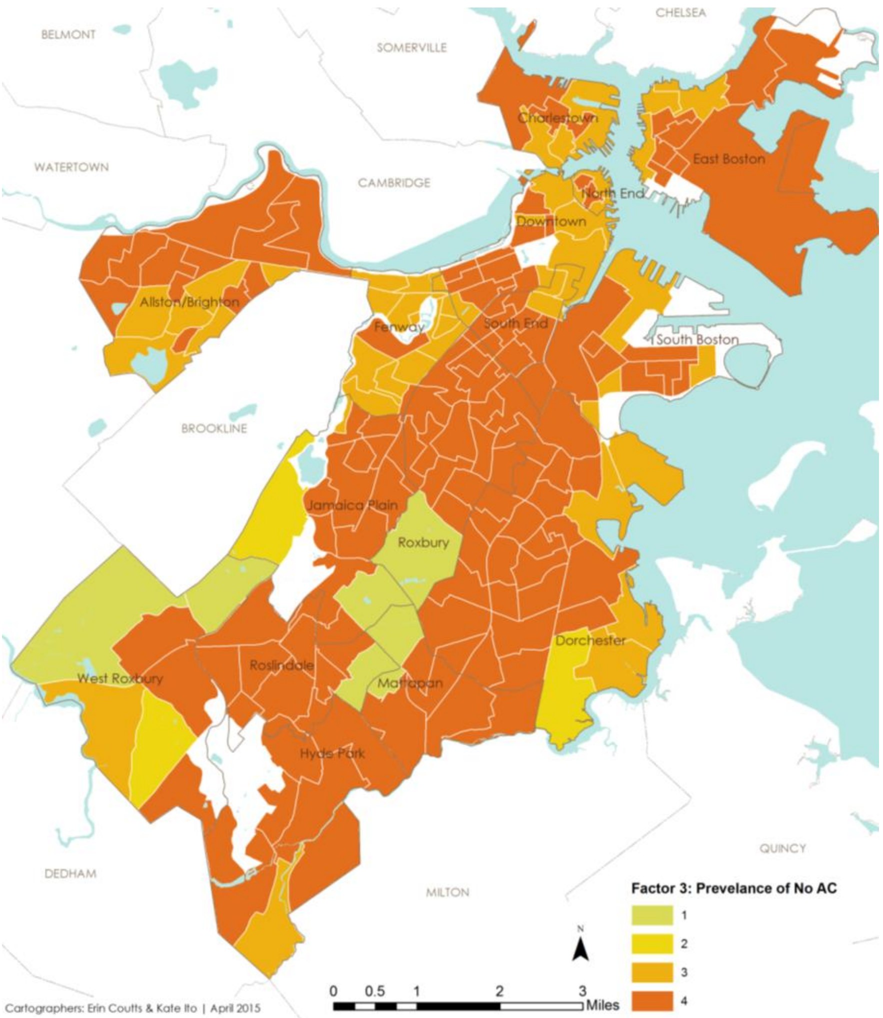

Figure 9: Factor 3 – Prevalence of No Air Conditioning

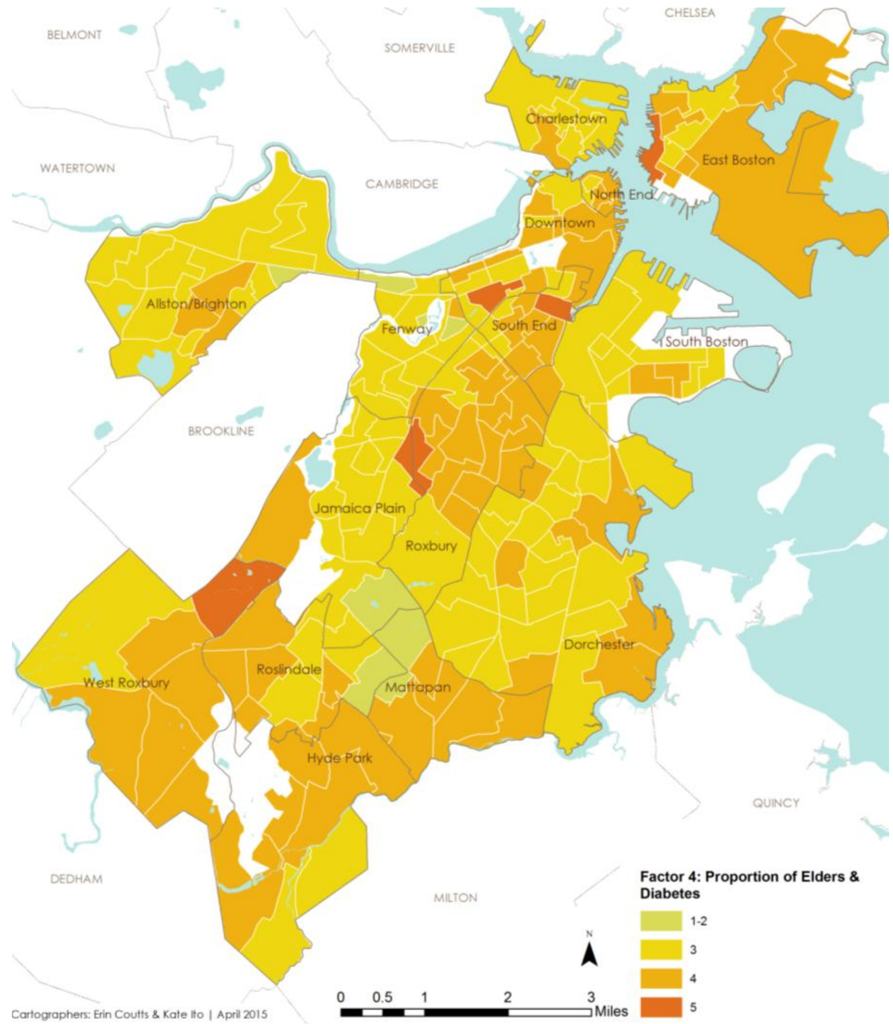

Figure 10: Factor 4 – Proportion of Elders/Diabetes

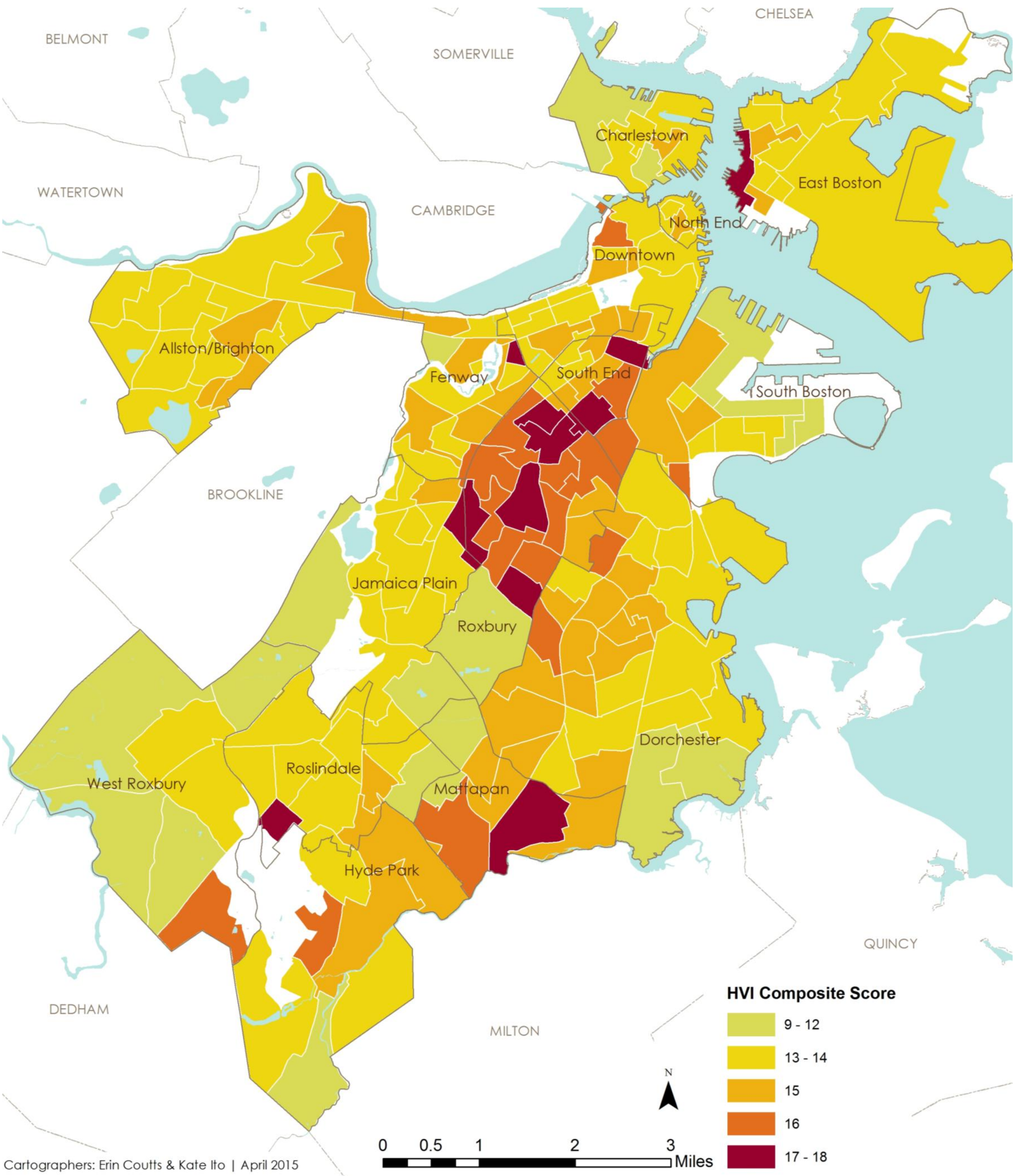

Figure 11: HVI Composite Score

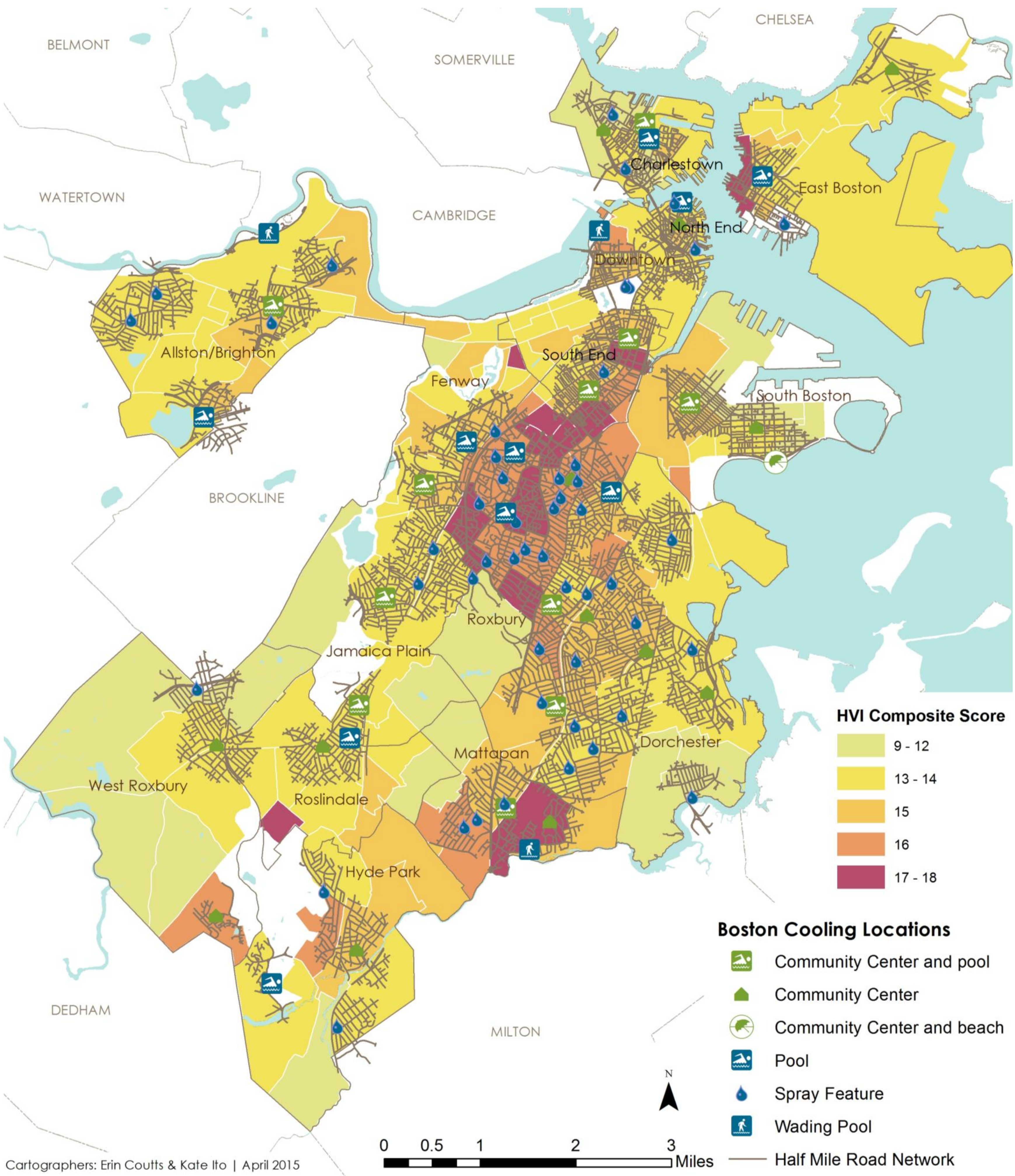

Figure 12: Cooling Features Overlay

The canopy cover in Boston is under 20% for most of the city. The map and table below highlight the eleven most vulnerable census tracts and their percent canopy cover.

Table 8. Most Vulnerable Census Tracts and Tree Canopy

ID*	Neighborhood	HVI	% Canopy Cover
1	East Boston	17	0.6
2	Chinatown (South End)	18	3.9
3	Fenway	17	1.5
4	South End	17	4.4
5	Roxbury	17	6.8
6	Roxbury	18	5.9
7	Roxbury	17	13.6
8	Roxbury	18	10.4
9	Roxbury	17	13.5
10	Mattapan	17	25.9
11	Roslindale	17	26.08

* The ID's were placed from north to south on the map. It is not a ranking.

Coverage category	Percentage range
Very light	0–5%
Light	6–20%
Medium	21–40%
Heavy	41–60%
Covered	> 60%

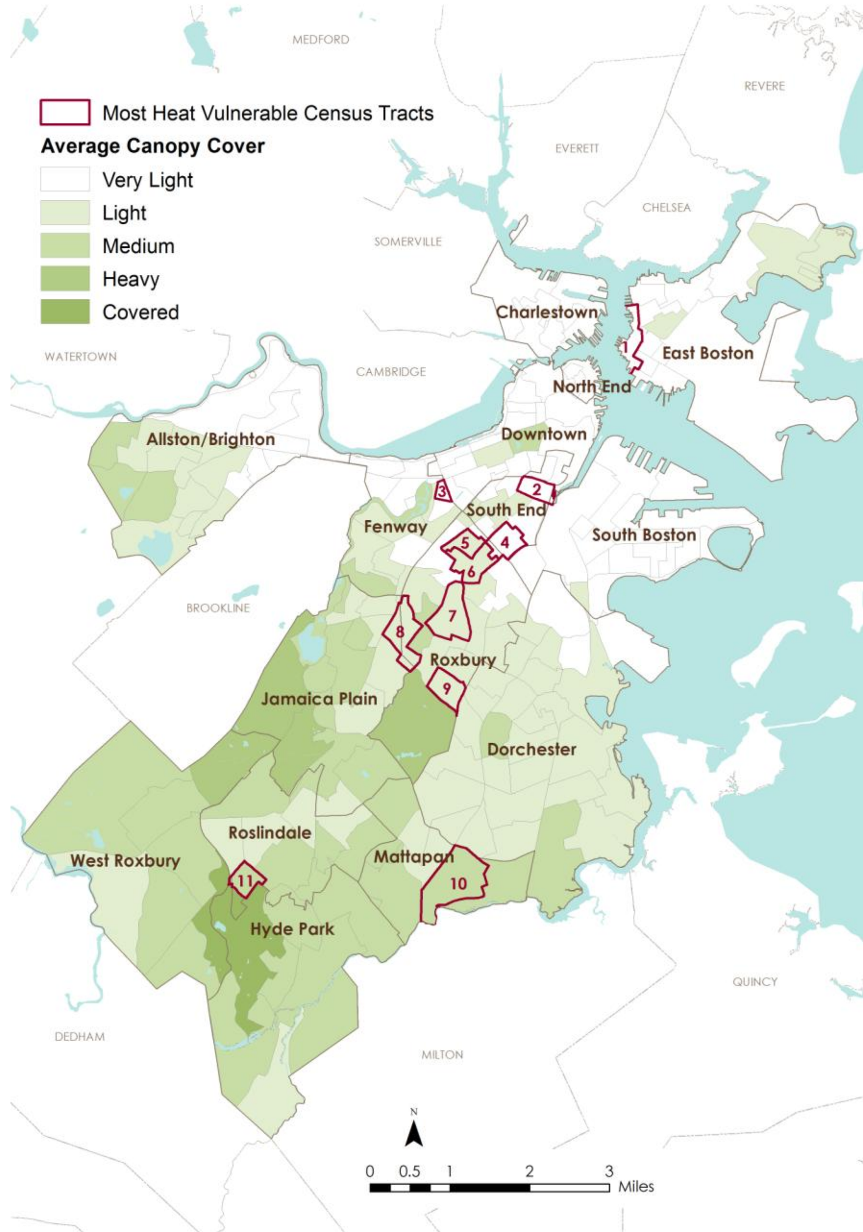

Figure 13. Most Vulnerable Census Tracts and Tree Canopy

6.2 Analysis

The census-level vulnerability analysis identified general areas of Boston that could be prioritized for siting a green infrastructure demonstration project and for further study. Eleven census tracts emerged from this analysis with HVI composite scores of 17 or 18, based on the sum of the four factors. Table 9 summarizes the results below.

Table 9: Census Tracts with a High HVI Score

GEOID	Neighborhood	Population	HVI	Factor 1	Factor 2	Factor 3	Factor 4	High Factor Scores
25025070402	Chinatown (South End)	1718	18	6	4	3	5	-Social/Environ. Vulnerability -Proportion of Elders/Diabetes
25025080401	Roxbury	2543	18	5	5	4	4	- Social/Environ. Vulnerability - Social Isolation
25025081300	Roxbury	5382	18	5	4	4	5	-Social/ Environ. Vulnerability -Proportion of Elders/Diabetes
25025010403	Fenway	2894	17	4	6	3	4	-Social Isolation
25025050300	East Boston	2197	17	4	5	3	5	-Social Isolation -Proportion of Elders/Diabetes
25025071101	South End	4069	17	4	5	4	4	-Social Isolation
25025080500	Roxbury	3168	17	5	4	4	4	-Social/ Environ. Vulnerability
25025081700	Roxbury	3277	17	5	4	4	4	-Social/ Environ. Vulnerability
25025082100	Roxbury	4924	17	5	4	4	4	-Social/ Environ. Vulnerability
25025101002	Mattapan	4933	17	5	4	4	4	-Social/ Environ. Vulnerability
25025140106	Roslindale	1961	17	4	5	4	4	-Social Isolation

Seven of the eleven census tracts had high scores (a 5 or 6) for the Social/Environmental Vulnerability Factor. Five census tracts scored highly on the Social Isolation Factor, and three census tracts scored a 5 for the Proportion of Elders/ Diabetes Factor. Notably, five of the census tracts were located in the neighborhood of Roxbury.

We aimed to further prioritize these results through the overlay map. However, the overlay map showed very few areas in Boston with high HVI scores that are without access to a public cooling feature. Notable exclusions to this include census tracts in Fenway and Roslindale, and small areas of Roxbury and Mattapan.

6.3 Discussion

The HVI map for the City of Boston is a data-driven method for identifying heat vulnerable census tracts by visualizing both social and environmental factors that affect heat vulnerability. We feel that the HVI can function as a screening tool to inform the longer, in-depth process of the Climate-Smart Cities program in Boston, and to incorporate an equity lens from the beginning of the project.

While serving as a valuable first review of heat vulnerability risk in Boston, this project had some limitations, including a short timeframe, and data and methods limitations and assumptions. Therefore, a technical and more in-depth review is required.

Limitations

We chose the Reid et al. 2009 methodology because it provided a way to identify areas within Boston that may be most vulnerable to heat-related morbidity and mortality. While it is a widely-cited methodology and has been validated to show that it is a good indicator of health, it does have limitations. Their analysis was limited by data that were available at the national level and the scale of the data. For example, the American Housing Survey (AHS), the data source for the AC variables, is only available at the metropolitan statistical area. To use their methodology and weightings between the variables, we used their same variables. Therefore, while there are other indicators of vulnerability, we were not able to consider them in our analysis. Our two attempts to customize these methods further were using the Boston Assessors' data as a data source for access to AC (see below and Appendix A for details) and the overlay of cooling features over the composite HVI score.

The original Reid et al. 2009 paper states that city-level analyses of heat vulnerability may give more information about local vulnerability and that their methodology can be used for these local vulnerability maps, however they note that the relationships between the variables may be different at smaller spatial scales. We encountered this when we investigated using the Harlan and colleagues 2013 methodology, which adapted the Reid et al. 2009 methodology for a desert city in Arizona. Therefore, the mapping included in this report is primarily for informational purposes. More research is needed on city-specific heat vulnerability mapping.

Air Conditioning

Our HVI replicated the same methods and data sources used by Reid et al. 2009. However, this methodology uses American Housing Survey (AHS) data for air conditioning indicators. These indicators are only available at the Metropolitan Statistical Area (MSA), which is larger than the City of Boston. Therefore, this method does not offer any variability in access to AC between census tracts.

In order to see variability in access to AC, we replicated the Reid et al. 2009 methods, but substituted the AHS data with Boston Assessors' data from 2014 (methods and maps are provided in detail in Appendix A). Using the Assessors' data, we found that there were twelve census tracts that had an HVI score of 17 or 18. Seven of the twelve census tracts also scored a 17 or 18 in our HVI using AHS data. The remaining five census tracts in the Assessors' version were located in the neighborhoods of Dorchester and Hyde Park. These five census tracts all have high factor scores for Factor 3, Prevalence of no AC. Therefore it is likely that there is less access to AC in these census tracts.

Future Directions

Due to the time constraints and limited resources of this project, we only created the HVI for the City of Boston. We suggest vetting this methodology with experts in the field and validating the Boston-specific HVI against:

- Land Surface Temperature or Ambient Air Temperature
- Heat-related Hospitalizations.

We find this to be a useful, nationally replicable method that broadly outlines locations of heat vulnerable populations. As the Reid et al. 2012 follow-up study showed, the HVI may be a good indicator of overall health vulnerability, independent of exposure to heat (Reid et al., 2012). Therefore, the HVI may be useful as a screening tool in future cities in the Climate-Smart Cities program.

Finally, while green infrastructure mitigation was a focus of this report, the HVI highlights that other social aspects, policies, partnerships, education, and engagement may be just as important in mitigating the UHI effect in Boston as physical interventions. For example, our analysis found that, while having physical cooling facilities available is important, the overlay map does not tell us about use and behavior. Thus, Part III supplements the physical green infrastructure recommendations with several social and policy recommendations.

Part III: Recommendations

7 Summary of Findings

This section provides an overview of the key findings from the different topic areas of the literature review. Figure 8 shows the key recommendations from the UHI mitigation literature. These recommendations should be considered first in the eleven most vulnerable census tracts found in this report.

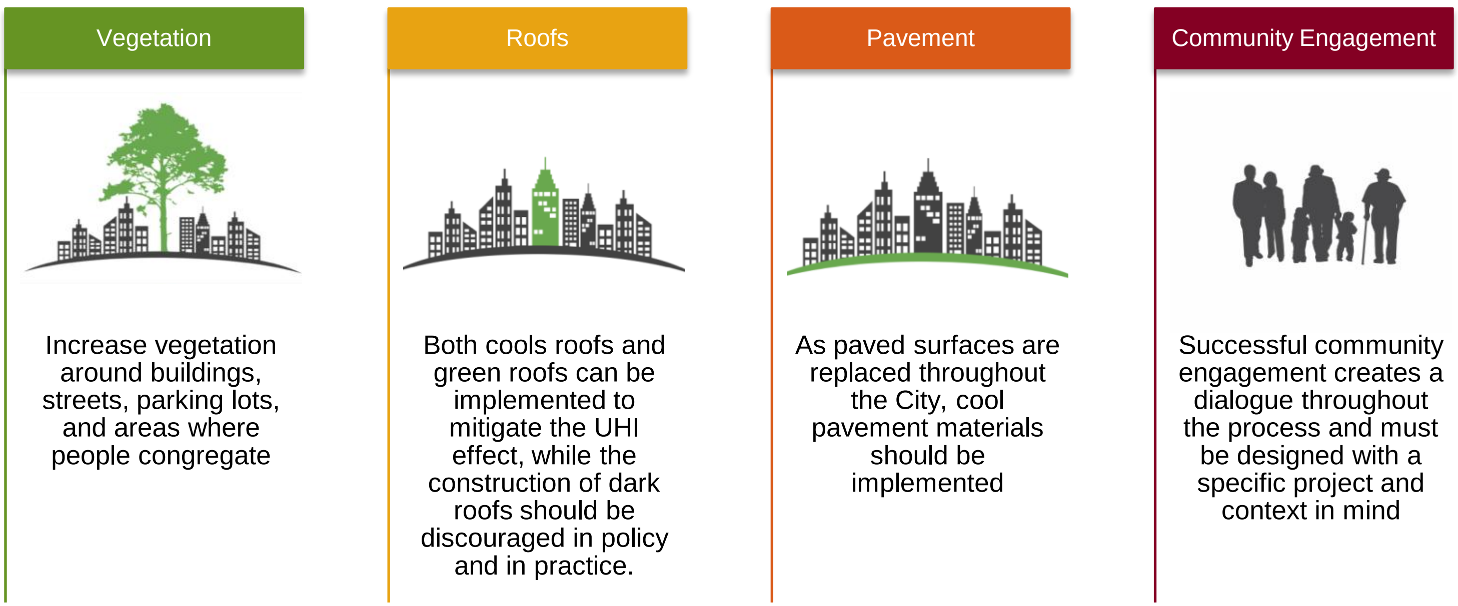

Figure 14: Key Recommendations (Source: E. Coutts, 2015)

UHI Effect

The UHI effect is where urban areas are warmer than their surrounding suburban and rural regions. Therefore, with 81% of Americans living in urban areas (World Bank, 2015), an aging population, and climate change, it is likely that the population vulnerable to heat and the UHI effect will increase (Hondula, Georgescu, & Balling, 2014). Consequently, the UHI effect is important for planners and public health professionals to be aware of. In general, UHI intensity decreases with increasing wind speed, decreases with increasing cloud cover, is more severe during the summer, increases with growing city size and population and is greatest at night (Arnfield, 2003). However, due to evolving technologies and methods, the definition of what a UHI is may be changing.

There are three major ways that the UHI effect and the warmer temperatures it brings impact cities: 1) human health and comfort, 2) increased energy consumption, 3) impaired air and water quality (U.S. EPA, 2008c). These impacts have a disproportionate effect on some populations. There is a strong consensus in the literature around those at particularly high risk of adverse health effects from extreme heat exposure. This includes older adults, young children, those living alone (i.e. in social or geographic isolation), those with chronic illnesses (particularly cardiovascular or mental diseases), urban residents, minorities, people of low income, people with less education, and people without access to air conditioning (Basu, 2009; Belmin et al. 2007; Holstein, Canouï-Poitrine, Neumann, Lepage, & Spira, 2005; Kravchenko et al., 2013; Luber & McGeehin, 2008; O'Neill & Ebi, 2009).

Vegetation

Vegetation mitigates heat in two ways: shading and evapotranspiration. Numerous studies have attempted to quantify the cooling effect of vegetation. Shade from trees can reduce the surface temperatures of walls and buildings by up to 45°F (Akbari, Kurn, Bretz, & Hanford, 1997). The research investigating the relationship between vegetation and air temperature is extensive, but also problematic. Future reports citing the ambient cooling effects of vegetation should not claim air temperature reductions of more than 2 to 4ºF.The cooling effect of vegetation is dependent upon a variety of factors, including tree size, type, location, and planting density. Vegetation is a unique mitigation strategy in that it has a variety of social, health, and economic benefits along with its cooling effects. For example, the economic benefits of vegetation include energy savings in residential and commercial buildings, increased spending in shopping centers with landscaping, reduced pavement maintenance, and storm water retention. Finally, it should be recognized that plants in urban environments face numerous challenges. Yet, while residents identify potential problems from street trees such as falling branches, leaf litter, tree debris and infrastructure damage, surveys show that they believe the benefits outweigh any costs (Mullaney et al., 2015).

Increasing vegetative cover and shading over grass fields and impermeable surfaces will provide measurable benefits. **The City of Boston should focus on increasing vegetation around buildings, streets, parking lots, and areas where people congregate.** For example, planting trees and shrubs along streets can make these spaces safer for pedestrians and cyclists and quieter for all residents. However, before beginning a new tree-planting or vegetation initiative, the City should engage the public in education on tree benefits and ensure thorough notification of planting processes.

Roofs

Overall, cool roofs are more economically efficient in cooling the atmospheric temperature of a large-scale area. Green roofs have benefits that go beyond cooling the area, including: insulating buildings, improving the small-scale local environment, managing storm water, esthetic improvements and sometimes food from vegetation. **Both cool roofs and green roofs can be implemented to mitigate the UHI effect in Boston, while the construction of dark roofs should be discouraged in policy and in practice.** Cool roofs should be considered as a short-term solution while green roofs should be considered as a long-term solution.

Pavement

Paved surfaces cover a significant amount of land in urban areas, usually between 25-50%. Traditional paving materials, most commonly asphalt and concrete, store heat during the day and release it in the evening and into the night (Asaeda et al., 1996; Nakayama & Fujita, 2010). During summer months, asphalt can heat up to 65°C or 150°F and concrete can heat up to 50°C or 120°F (Gartland 2008). The main strategies to mitigate the impact of pavement on the UHI is by decreasing the amount of paved or impervious surface and using alternative pavement materials, such as "cool pavement" — pavement with increased solar reflectivity and porosity (Gartland, 2008).The basic concept behind pavement permeability is to allow stormwater to drain through the pavement material into the soil below. On warm, dry days, the water will evaporate and in the process, cool the pavement. In order for evaporation to happen regularly, the soil underneath must consistently be moist either from accumulated stormwater or manual watering (Gartland 2008).

As paved surfaces are replaced throughout the City, cool pavement materials should be implemented. While there are necessary cost and safety considerations associated with the installation of new pavement materials, cool pavement is an important long-term strategy for mitigating the UHI effect in Boston.

Community Engagement

Community engagement is considered to be a prerequisite for equitable and sustainable planning efforts. Community engagement is interdisciplinary and should be integrated with other fields, for example: public health, education, and communications and media. In order to implement green infrastructure strategies to mitigate the UHI effect in Boston, and to ensure their long-term success, it will be necessary to develop a strong public participation process. **An important consideration in Boston is the city's ethnic and racial diversity and immigrant population. Outreach to and participation by these groups in Boston should be prioritized.**

8 Citywide Recommendations

This section provides general citywide recommendations in order to help maximize the impact of UHI mitigation efforts. Our vulnerability analysis highlighted the importance of both social and environmental factors in heat vulnerability. Therefore, in addition to broad evidence-based environmental strategies to mitigate the UHI effect recommended above, this section outlines recommendations in five broad areas that the Trust for Public Land does work in. The five areas are: 1) UHI education and awareness, 2) demonstration projects, 3) policy recommendations based on existing City policies and programs, 4) partnership opportunities across different sectors, and 5) community engagement around the specific intervention.

The Trust for Public Land has a sound methodology and process for implementing their Climate-Smart Cities program, as well as a proven track record of implementation in other cities. Therefore, these recommendations are offered as additional considerations to the Trust for Public Land's Boston Climate-Smart Cities pilot project framework. For these reasons, our recommendations are intentionally broad.

8.1 Extreme Heat Education and Awareness

Extreme heat poses a significant threat to human health and comfort as discussed in the impacts section of this report. Despite the prevalence of heat-related death and illness in the United States, there is inadequate education and awareness about the risks and how to best cope with the heat. An awareness campaign with multiple partners and outreach efforts is needed in Boston. The Trust for Public Land could consider partnering with the Boston Public Health Commission (BPHC), City of Boston Office of Emergency Management (OEM), and other City departments to educate residents on the risks related to extreme heat and the resources available. This could include informing the public on the cooling resources (cooling centers, pools, spray features, etc.) located throughout Boston's neighborhoods; encouraging people to participate in "cool" activities, such as visiting pools and movie theaters, to escape the heat; and asking people to check in on their friends and neighbors during heat waves much like they do during snowstorms.

Although it may be outside the mission of the Trust for Public Land, a corporate sponsorship program whereby certain companies help to subsidize the costs for cooling activities may be an effective way to encourage people to stay cool. During summer heat waves, discounted tickets to the movies, museums, duck boat tours, Harbor Island tours, and so forth may offer a way for many people to stay cool during the hottest part of the day.

This is a strategy that addresses staying cool in the short term. It is important that people become aware of the risks and what they can do to be safe. This is especially true for the most vulnerable populations within the city.

8.2 Demonstration Projects

The GIS maps developed for this report are intended to be used as a screening tool rather than a prescriptive measure for where projects should be sited. The possible case studies listed earlier in this report identify the areas at greater risk of heat impacts which would benefit from further study and analysis. The maps can be evaluated based on the composite vulnerability score or they can be evaluated based on one of the four factors (social/environmental vulnerability; social isolation; air conditioning prevalence; and proportion elders/diabetes).

In general, we recommend that the Trust for Public Land identify demonstration projects, which can be implemented in the short, mid, and long term.

8.3 Policy Recommendations

Currently, there are many programs, plans and regulatory mechanisms spanning multiple City departments, which address climate change (see Appendix B for a more detailed list). Some of these directly address extreme heat while others address a broader issue that is related to extreme heat or the UHI effect. Many of these programs could benefit from further advocacy and implementation. We recommend that the Trust for Public Land consider leveraging these existing programs, as they will likely have a broader application than a one-off project. A demonstration project based on an existing program, which is able to demonstrate feasibility, may have significant impact.

The following policies, programs and regulatory tools provide unique opportunities to implement strategies that will help mitigate the UHI effect. However, there are many others and it is advisable for the Trust for Public Land to consult with the City to gain more insight into specific programs and their current planning or implementation status.

Complete Streets

The Boston Complete Streets guidelines were published in 2013. The vision of the guidelines is "to improve the quality of life in Boston by creating streets that are both great places to live and sustainable transportation networks. The Complete Streets approach places pedestrians, bicyclists, and transit users on equal footing with motor vehicle users, and embraces innovative designs and technologies to address climate change and promote active healthy communities" (Boston Transportation Department, 2013b, p. xiii).

Complete Streets policies are becoming more widespread throughout American cities. While this marks an important paradigm shift from when cars ruled the road, there are barriers to the implementation of many aspects of Complete Streets. Perhaps the most widespread concern is the cost associated with full implementation of Complete Streets. It would be extremely beneficial if the Trust for Public Land were able to help leverage funds and recommend a sustainable funding structure for future implementation.

While there are seemingly endless benefits of complete streets implementation there are a few elements, which are particularly important opportunities for addressing the UHI effect:

Green Walls

The policy handbook specifically acknowledges the potential for green walls to reduce the heat island effect. They are encouraged on street edges where building transparency is not possible. The policy makes it clear that green walls are the responsibility of building owners and if they enter the public right of way they will require approval from the City Public Improvements Commission (PIC). Green walls could be an opportunity for a short- to mid-term strategy which the Trust for Public Land could help implement by partnering with private property owners.

Permeable Paving Materials

As discussed earlier in the report, permeable pavement is an important strategy to reduce the UHI effect. The Boston Complete Streets handbook primarily acknowledges the stormwater management benefits of permeable pavement, but we know from the literature that there are additional heat-mitigation benefits. It should be noted that "all permeable materials are considered enhanced or pilot treatments, and require maintenance agreements with the City of Boston" (Boston Transportation Department, 2013b, p. 44). We recommend that The Trust for Public Land encourage the installation of permeable pavement and consider ways to facilitate the maintenance agreement process. This often means helping to identify funding sources for ongoing maintenance needs.

Street Trees

The myriad of benefits that street trees provide is acknowledged in the Complete Streets guidelines. One of which is the ability of trees to cool streets through shade, evaporation and plant transpiration. The City of Boston is roughly thirty-one thousand acres, of which about half is streets, buildings and parking lots. As has previously been mentioned in this report, Boston would benefit from the strategic siting of street trees and other vegetation. The handbook notes that trees in the public right-of-way are maintained by the Boston Parks Department. The Trust for Public Land may want to consider engaging the Parks Department to understand the unique challenges to planting and maintaining street trees in order to identify opportunities to expand the City's street treat network.

Public Involvement

This policy document acknowledges Boston's history of "community leadership in creating people-oriented streets and public spaces" as well as the effort of many city agencies along with the MONS collaborate with local stakeholders during planning processes (Boston Transportation Department, 2013b, p. 256). It also notes the involvement of universities and advocacy groups. The handbook recommends that new engagement strategies be developed to go along with the new infrastructure that is part of complete streets. It is suggested that in addition to public meetings, site visits, guided activities and temporary interventions be employed. In sum, "the excitement around a community-initiated event can be the best way to bring a more diverse crowd into the conversation" (Boston Transportation Department, 2013b, p. 256).

Climate Preparedness and Resiliency Checklist

Since November of 2013, all new development projects requiring Article 80 review from the Boston Redevelopment Authority (BRA) must complete this checklist. The goal of the checklist is to "analyze project impacts on the surrounding environment that are attributable to forecasted climate conditions over the full duration of the expected life of the project. Utilizing the best available science, identify changes in the climate and environment and how such changes will affect the project's environmental impacts including the survivability, integrity and safety of the project and its inhabitants" (Boston Redevelopment Authority, 2013, p. 1).

The checklist seeks to gather information on the various elements and related impacts of the building. This includes the building's green building LEED specifications, energy consumption, considerations for extreme weather and heat events, mitigation strategies, sea-level rise and storm considerations, flood proofing, and general resilience and adaptability. It is important to note that there is a section that solicits information on building response to extreme heat and anticipated mitigation strategies.

The Trust for Public Land may find the responses to the checklist valuable, particularly regarding which systems new buildings are already planning to implement in order to address extreme heat. If the responses are not ambitious enough, the Trust for Public Land may want to consider working with the development community to encourage more ambitious strategies.

Boston Zoning Code: Article 37 Green Buildings

Article 37 was inserted in the Boston Zoning Code in 2007. It requires any development project subject to large project review (projects 50,000 square feet and larger) under Article 80 of the Zoning Code to meet LEED Certifiable requirements. The statement of purpose of this article is to "ensure that major building projects are planned, designed, constructed, and managed to minimize adverse environmental impacts; to conserve natural resources; to promote sustainable development; and to enhance the quality of life in Boston" (Boston Redevelopment Authority, 2007, sec. 37–1).

Boston was the first American city to formally require LEED building certification through zoning. The private development community was initially concerned with the additional costs associated with LEED design and construction but the requirement proved to be a market boon rather than an impediment. The Trust for Public Land might consider looking at Article 37 and suggesting opportunities for the regulation to go further in its requirements. It has been eight years since the original regulation was codified, and in that time there have been advancements in technology, which likely make more ambitious regulations feasible.

8.4 Partnership Opportunities

The Boston area offers many opportunities for partnerships, whether it is with the public, private or non-profit sector. Partnerships can provide opportunities for enhanced outreach, advocacy, planning and funding.

Public Sector

As has already been mentioned in this report, it will be important for the Trust for Public Land to coordinate with the City of Boston and to leverage the knowledge and expertise of its various departments and agencies. In addition to the City, other public sector partners can be found on a regional and state level. This includes but is not limited to: the Metropolitan Area Planning Council (MAPC); Massachusetts Department of Health (MDPH); Massachusetts Department of Environmental Protection (DEP); Massachusetts Department of Conservation and Recreation (DCR). These agencies have other regulatory and planning mechanisms, which may be leveraged.

An example of this would be Chapter 91, The Massachusetts Public Waterfront Act, administered by the DEP. Chapter 91 is the regulatory mechanism that protects the public use of tidelands throughout the Commonwealth of Massachusetts (Mass DEP). When there are non-water dependent projects proposed, Chapter 91 is employed to ensure that the development "provide greater benefits than detriments to the public's rights in waterways" (MassDEP, 2012, sec. Determinations and How They Work). The Trust for Public Land might consider tracking the coastal projects that will fall under Chapter 91 jurisdiction in order to leverage the public benefits that will likely be necessary to mitigate the impact of the development. This may be an opportunity to partner with the DEP and private developers as well as potentially unlock additional funding.

Private Sector

Like many municipalities throughout the United States, the City of Boston relies on the private sector to help build and fund projects and amenities when the City is not able to do on its own. In many cases, and especially related to real estate development, this comes in the form of public benefits. It is common that as a condition for development approval, private developers will be required to deliver a specific public benefit that helps mitigate the impact of their project or to pay into a fund that supports public benefits in the neighborhood. Public benefits encompass a wide range of improvements and some examples include but are not limited to: open space, transportation, affordable housing, and public art. In order to attempt to leverage this kind of opportunity, the Trust for Public land should consider tracking new development projects that potentially require public benefits. It is also advisable for the Trust for Public Land to become acquainted with local developers so that when they are looking for partners on future public benefits they may consider the Trust for Public Land.

Q Park in the Seaport Square development area on the South Boston Waterfront is a recent example of a public benefit associated with a large real estate venture. In order to secure the necessary approvals for the large development area, the private developers were required to design, construct and maintain Q Park as one of the public benefits. The current real estate market in Boston is very strong, and there will undoubtedly be frequent opportunities for input on public benefits. The Trust for Public Land should consider what kinds of public benefits it believes to have the greatest impact both in regards to climate change as well as within the neighborhood context.

In addition to the specific public benefits that are negotiated in connection with a development, there are also funds that developers can contribute to in order to satisfy the mitigation requirement. The Trust for Public Land should research these existing funds and their associated priorities to evaluate whether there is potential overlap with their mission to promote Climate Smart Cities. We recommend that the Trust for Public Land ask local organizations and municipal partners to help identify these kinds of opportunities.

Professional, Advocacy, and Academic Organizations

Boston is rich with non-profits ranging from smaller advocacy-based organizations to large medical and educational institutions. It would be wise to consider these organizations in both the planning and implementation phases of a project or awareness campaign. They also may present opportunities for funding.

Professional groups like the Boston Society of Architects (BSA) and the Urban Land Institute (ULI) offer access to a broad network of professionals in the planning, architecture and urban design fields. Other groups like Walk Boston and Livable Streets have specific missions which may be well aligned with the goals of a specific project or in general with the work that the Trust for Public Land seeks to accomplish. Local Community Development Corporations (CDCs) may also have projects or programs that would benefit from a partnership. There are many CDCs throughout the city, and many operate within the neighborhoods that were mentioned earlier in this report as particularly vulnerable to the UHI effect. CDCs also often work to address the needs of some of the more vulnerable populations, which could offer important insight to the Trust for Public Land.

Finally, Boston is renowned for its numerous medical and educational institutions, which should be considered. There are seemingly endless angles for a partnership with these institutions, whether it be connected to the research they conduct, through their specific schools (schools of public health, sustainability, community development, etc.), or the connection or impact they have in certain Boston neighborhoods. In general these institutions have great expertise and networks at their disposal.

8.5 Community Engagement

Boston was not immune to the missteps of the centralized, top-down planning which emerged in the 1960s. As a result, participatory planning and inclusive community engagement processes have emerged over recent decades. Participatory community planning, although not perfect, has resulted in more equitable and sustainable planning across Boston. Today, many communities are evaluating their current public engagement strategies and are beginning to reimagine them. The traditional public meeting style of community engagement is not reaching many important constituent groups, such as young families, young professionals, students, recent immigrants and others. These groups all have specific concerns and distinct needs, which ought to be addressed. Communities are beginning to employ new tactics including holding meetings at more convenient and flexible times, engaging constituents through online platforms, and providing translation services as well as child care. There is an appetite for change and we recommend that the Trust for Public solicit feedback from constituents and the City on how they would like to engage in a public process. In addition to developing a physical pilot project to address climate change, the Trust for Public land could simultaneously pilot the engagement strategy to accompany it.

The Boston Living with Water (BLwW) international design competition is a recent example of a non-traditional approach to community engagement. The competition sought design solutions to address resiliency and preparedness in the City of Boston in the face of climate change and sea-level rise. Design and planning teams were asked to respond to one of three coastal sites throughout the City of Boston at the building, neighborhood and district scale. A jury representing many different important interests and sectors voted on the finalists and will pick the final winners in late spring of 2015. Public events were held throughout the process so that interested persons could learn about the competition and hear about the submissions.

Every planning effort is unique in its size, scope, and objectives and requires a complementary public engagement process. Both the process itself, as well as the participants in the process, is project- and location-specific. Once a specific project and location are identified, an appropriate planning process can be devised.

Through the current partnership with the City of Boston, the Trust for Public Land is well positioned to collaborate with the City and Boston Redevelopment Authority (BRA) on community engagement strategies. In every neighborhood of Boston there are numerous civic and community groups as well as other important stakeholders which are important to consider when crafting a public engagement strategy. Whether the Trust for Public Land embarks on an independent community engagement process or not, the City and BRA can offer important insight. The Mayor's Office of Neighborhood Services (MONS) as well as the BRA can assist the Trust for Public Land in identifying the community partners and stakeholders to include.

While this report has begun to identify neighborhoods and census tracts with vulnerable populations, it does not go as far as to recommend a specific project or parcel-level location. Until that has been decided, we feel it may be premature to recommend a specific community engagement process or identify community partners.

9 Further Study

Since the Climate Smart Cities program has just begun in the City of Boston, the scope and recommendations of our report are limited. As planning continues around mitigating the UHI effect in Boston, the following are considerations for further study.

The HVI as a Screening Tool

For future Climate-Smart Cities projects in different cities in the United States, the HVI as conducted for the City of Boston in this project may be a useful screening tool. The HVI identifies heat vulnerable populations at the census tract level, which may provide target areas for interventions. The HVI should be compared with temperature and health data, which was not something we were able to verify in the time and scope of our project. The specific location and project could then be narrowed through a context-specific engagement process.

Cost Benefit Analysis for Green Infrastructure

One of the greatest challenges for municipalities considering new approaches in design and materials for infrastructure is cost. New materials may initially be more expensive than the current materials, but it is worth understanding the long-term lifecycle costs of new material and technology versus the status quo. For example, some research suggests that while upfront costs for permeable pavement are greater than traditional pavement, the long-term costs are less (Gartland, 2008).

Another important consideration is the cost of the maintenance of new green infrastructure. Cities are already burdened with the costs they incur to maintain current infrastructure. New materials and infrastructure that require specialized maintenance might be considered prohibitive. Understanding both the hard and soft costs associated with new infrastructure and how the benefits potentially outweigh the costs will have great impact on whether a city believes it can implement such infrastructure.

Parcel-Level Analysis

As has been previously mentioned, the GIS work that was completed as a part of this report did not include a parcel-level analysis of potential sites for a demonstration project. We recommend that the Trust for Public Land embark on such an analysis in order to evaluate the opportunity sites available. This would include mapping private versus public ownership in order to understand if there is land available for purchase or if there is a chance to partner with a public entity. It will be important to understand the current land uses of the area and the applicable zoning.

Furthermore, it will be helpful to understand the development projects that are planned for a given area. This will help to identify the potential users of the green infrastructure and may also reveal opportunities to coordinate the construction of the demonstration project with mitigation that new development many need to incorporate as part of their project.

10 Conclusions

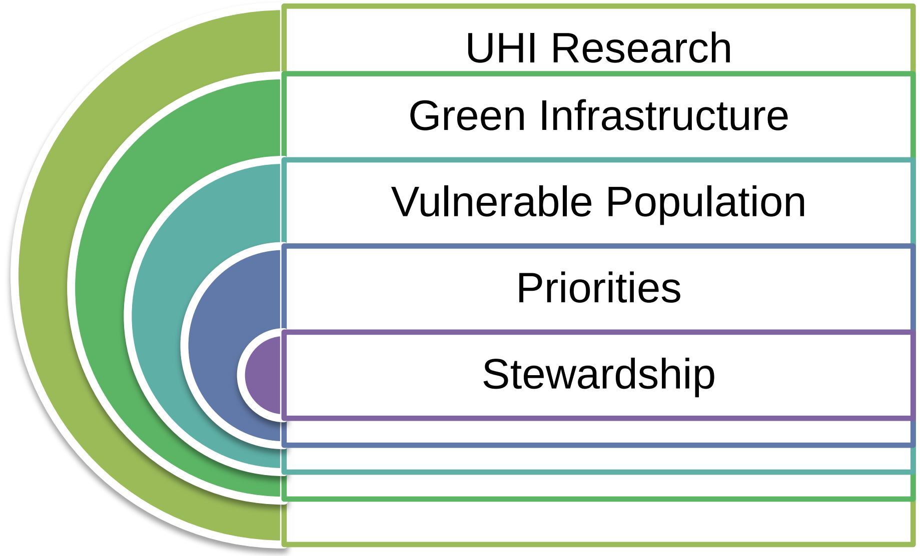

Figure 15: Conclusions

The effect of heat in cities has been studied for many decades. There is a significant amount of scholarly research on UHIs and their adverse impact both on the natural environment and the vulnerable populations living within cities. Additionally, there is a large body of evidence that supports the implementation of green infrastructure as a strategy to mitigate the UHI effect and lessen the adverse impacts of extreme heat. Several green infrastructure interventions can be implemented and location-based context is an important consideration.

Through the heat vulnerability analysis conducted as part of this report, several areas throughout the City of Boston have been identified, including eleven census tracts as being most vulnerable to heat. Most of these areas have access to cooling features with the exception of the census tracts in Fenway, Roslindale, and parts of Mattapan and Roxbury. The Reid and colleagues' (2009) Heat Vulnerability Index (HVI) is a useful screening tool to help bring an equity lens into a project from the beginning. The HVI is not intended to be a prescriptive measure, but a way to help prioritize areas that may have more need. Further research and validation of the HVI is needed. However, what this analysis does add is that it may prioritize interventions that are not just physical interventions.

This report has two overarching recommendations: 1) consider UHI mitigation strategies in the eleven most vulnerable census tracts found in this report, and 2) consider leveraging existing citywide processes in order to help maximize the impact of UHI and heat mitigation strategies in addition to a demonstration project. Strategies implemented on a citywide scale could potentially have a larger population impact. The Trust for Public Land is in a unique position to promote Climate Smart Cities and help mitigate the adverse impacts of climate change in Boston. While the City of Boston is working across departments to address different aspects of climate change, the Trust for Public Land can help the City prioritize the approaches that will have the greatest impact. Knowing that the City has limited resources, it would be beneficial to offer the city recommendations on how their resources are best used. We have provided some recommendations on existing programs and infrastructure in this report, but the Trust for Public Land should evaluate them further.

Furthermore, one of the most challenging aspects of creating new infrastructure and implementing projects is ensuring its future stewardship after construction. To help ensure project feasibility, it would be extremely beneficial if the Trust for Public Land were able to develop a strategy for stewardship. While it depends on the type of project that is chosen, at a minimum, the strategy should identify who the stewards would be and how future maintenance would be funded. It is often more difficult to find partners that are willing to assist with the ongoing and future needs associated with a project rather than the capital funding. With this in mind, The Trust for Public Land should strive to strike agreements with future stewards as early on in the process as possible.

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Figure 2: Ken, B. M. (2010). *The High Line in Manhattan, New York City at West 20th Street, looking downtown (south)*. Retrieved from http://commons.wikimedia.org/wiki/File:High_Line_20th_Street_looking_downtown.jpg

Figure 3: raeky. (2010). *Chicago City Hall Green Roof*. Retrieved from http://commons.wikimedia.org/wiki/File:20080708_Chicago_City_Hall_Green_Roof_Edit1.jpg

Figure 4: *Thomas O. Price Service Center*. (n.d.). Tucson, Arizona. Retrieved from http://swenergy.org/publications/casestudies/arizona/tucson_topsc.htm

Figure 5: Boston Transportation Department. (2013a). Boston Complete Streets | Sidewalks. Retrieved April 26, 2015, from http://issuu.com/bostontransportationdepartment/docs/chap2_all

Figure 6: Vuong, T. (2015). *Community Engagement in Portland*.

Figure 13: Coutts, E. (2015). *Green Infrastructure and Community Engagement Strategies*.

11 Appendix

11.1 Appendix A

Heat Vulnerability Maps including Assessors' Data

The Reid et al. 2009 methodology uses American Housing Survey (2007) for two variables: 1) percent of households without central AC and 2) percent of households without AC of any kind. However, the smallest geography that these data are available is the Boston Metropolitan Statistical Area. In order to see variation in access to AC between census tracts, we provide an alternative way to replicate the Reid et al. 2009 methodology using Boston Assessors' data. This methodology was inspired by the Harlan and colleagues' (2013) adaptation of the HVI. AC is an important protective measure again heat-related morbidity and mortality, particularly in the short-term. While assessors' data may be best data source for AC prevalence in a small geographic analysis, it is an incomplete data source. There were no data available for 38% of the parcels.

We spatially joined the parcel-level Assessors' data and the census tract boundaries. This decreased the number of parcels from 166,224 to 101,935. This is because condominiums are assigned the same parcel identification number, and therefore only the first parcel identification number is retained. Nevertheless, we do not believe this affects our analysis significantly as we reviewed the AC condominium data and there was almost no data for AC for those units. We then exported the data to excel and used a pivot table to calculate the percent of parcels without AC by census tract.

However, in using this methodology, we had to eliminate one of the 10 variables in Reid et al.'s methodology. We omitted the "percent households without AC of any kind." This variable is not significantly weighted in three of the four factors so we believe this has minimal impact on the final results. Additionally, while AC is a very important protective factor against heat-related morbidity and mortality, our project is most concerned with identifying locations with high concentrations of people likely to be impacted by the UHI effect in order to site green infrastructure interventions. Also because the housing stock in Boston is relatively old, many households of various incomes do not have access to AC, therefore it may not even be an accurate indicator of socioeconomic status in Boston either. However, it does provide another way of looking at the data.

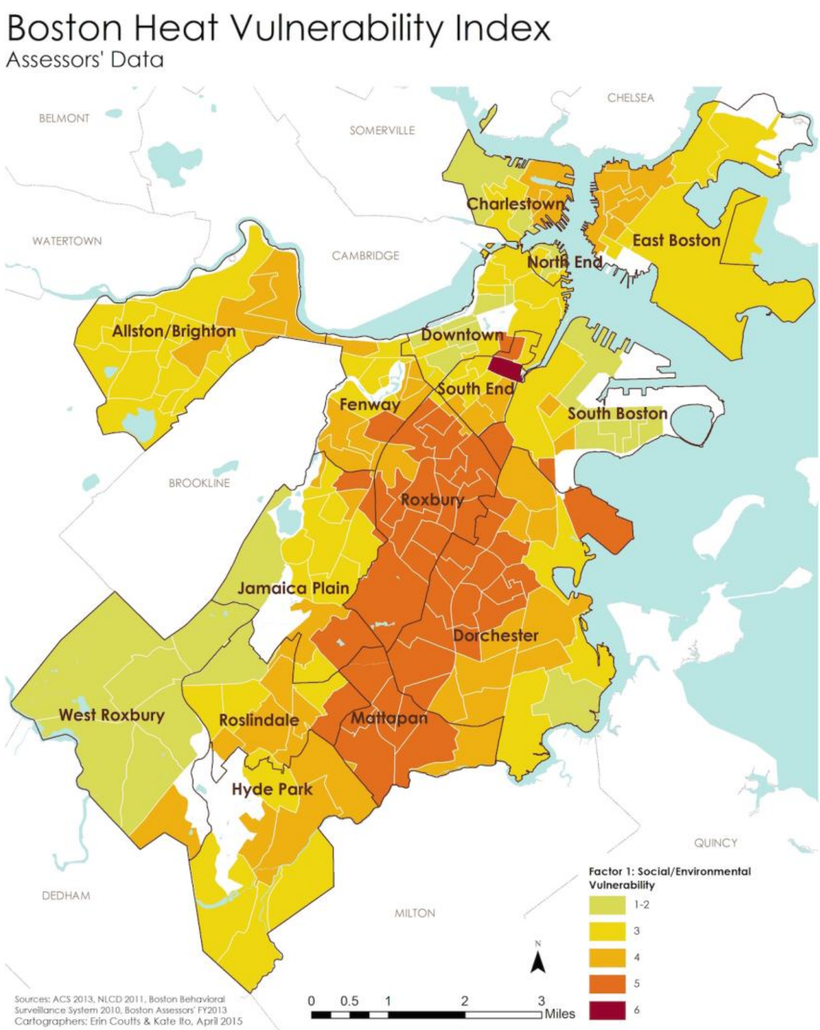

Figure 16: Factor 1 - Social/Environmental Vulnerability

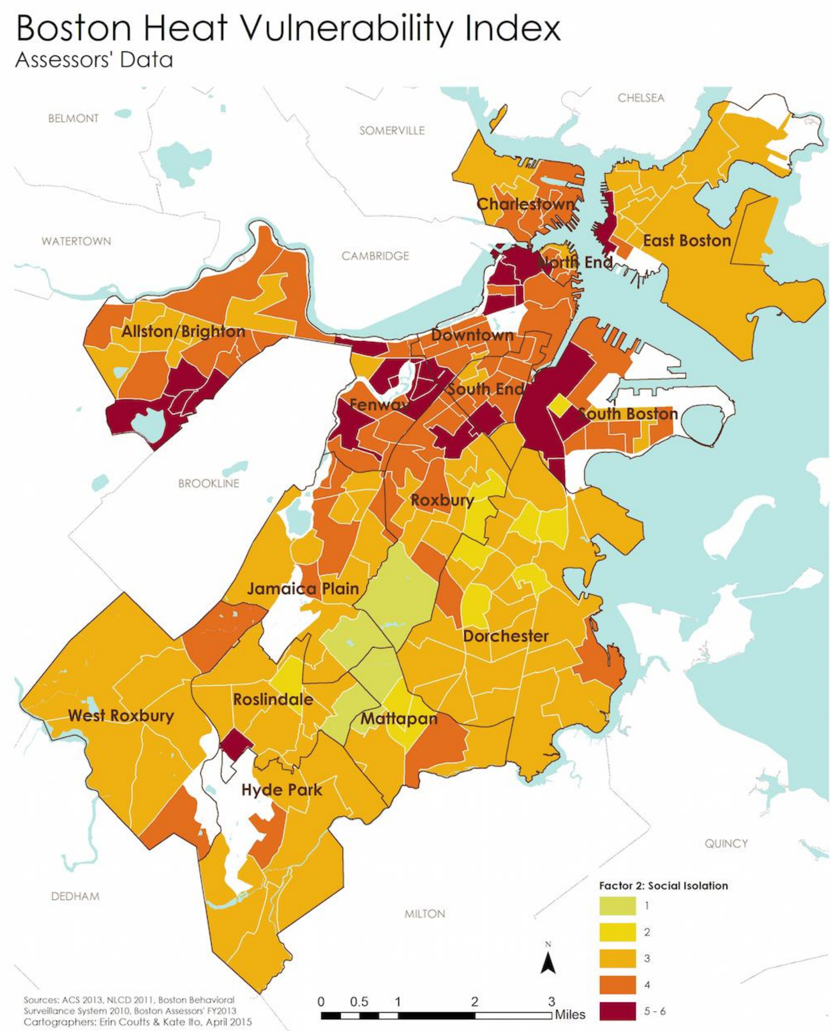

Figure 17: Factor 2 - Social Isolation

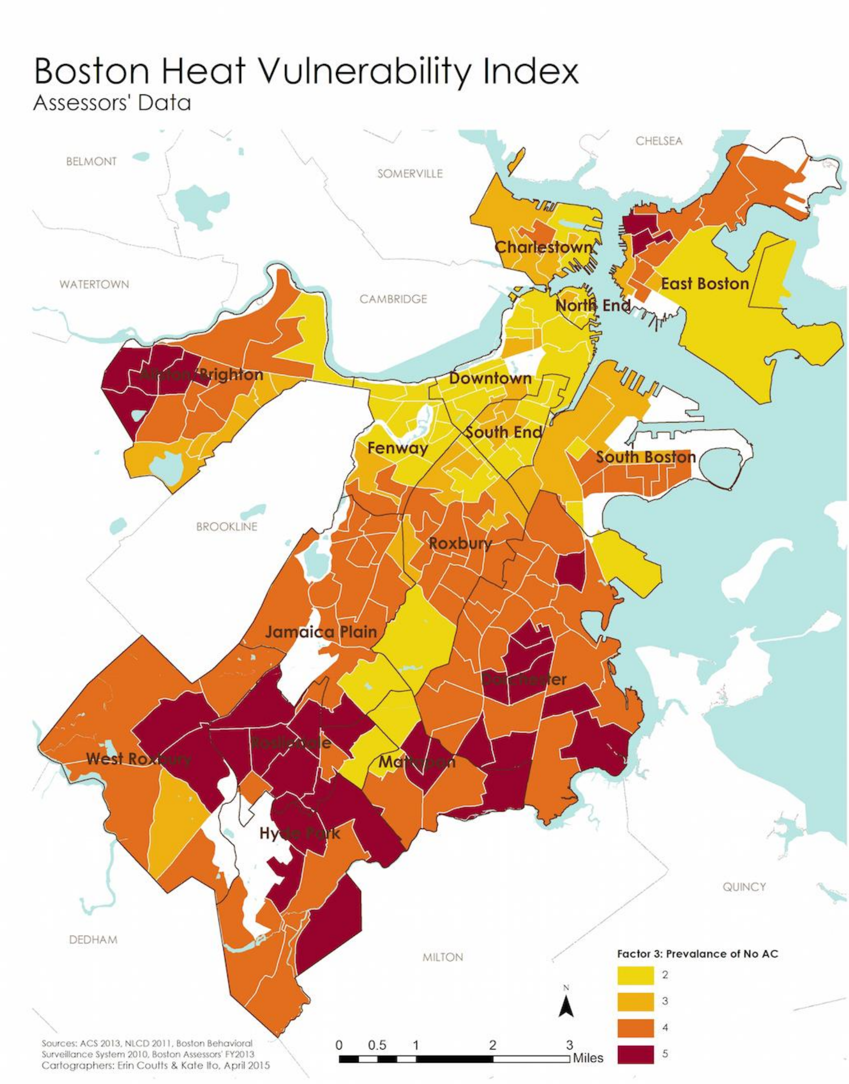

Figure 18: Factor 3 – Prevalence of No Air Conditioning

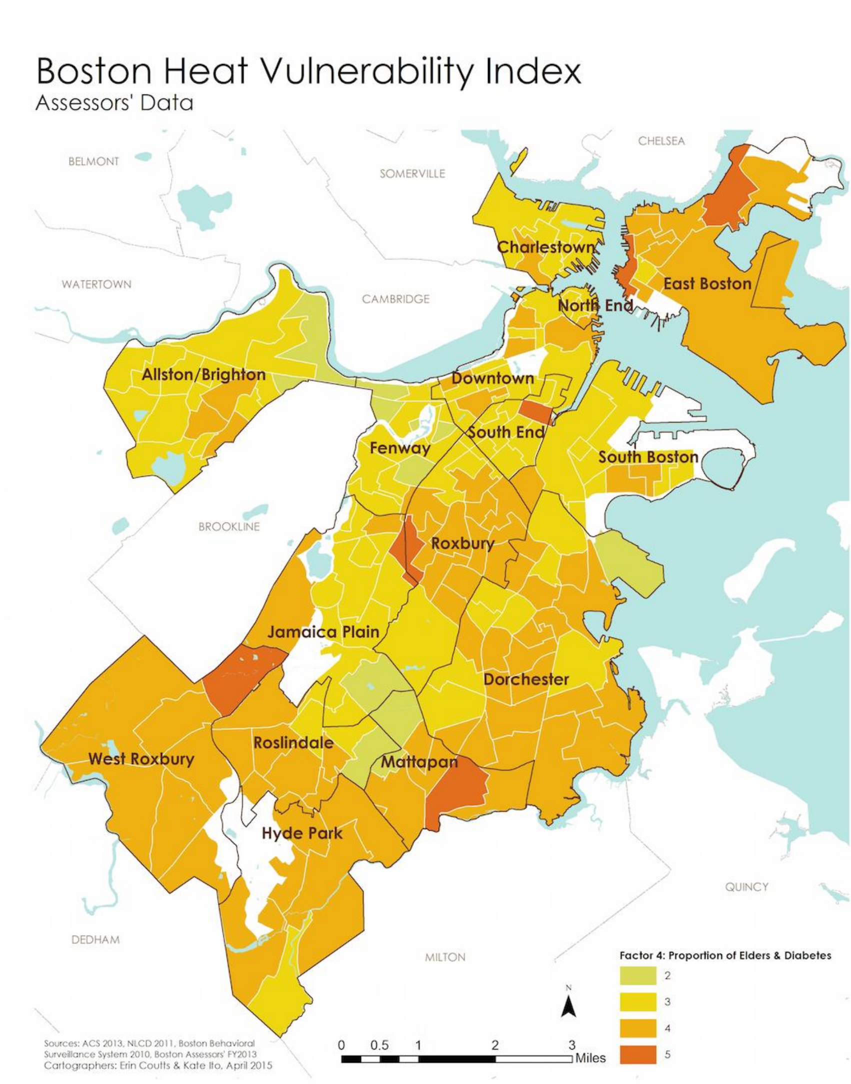

Figure 19: Factor 4 – Proportion of Elders/Diabetes

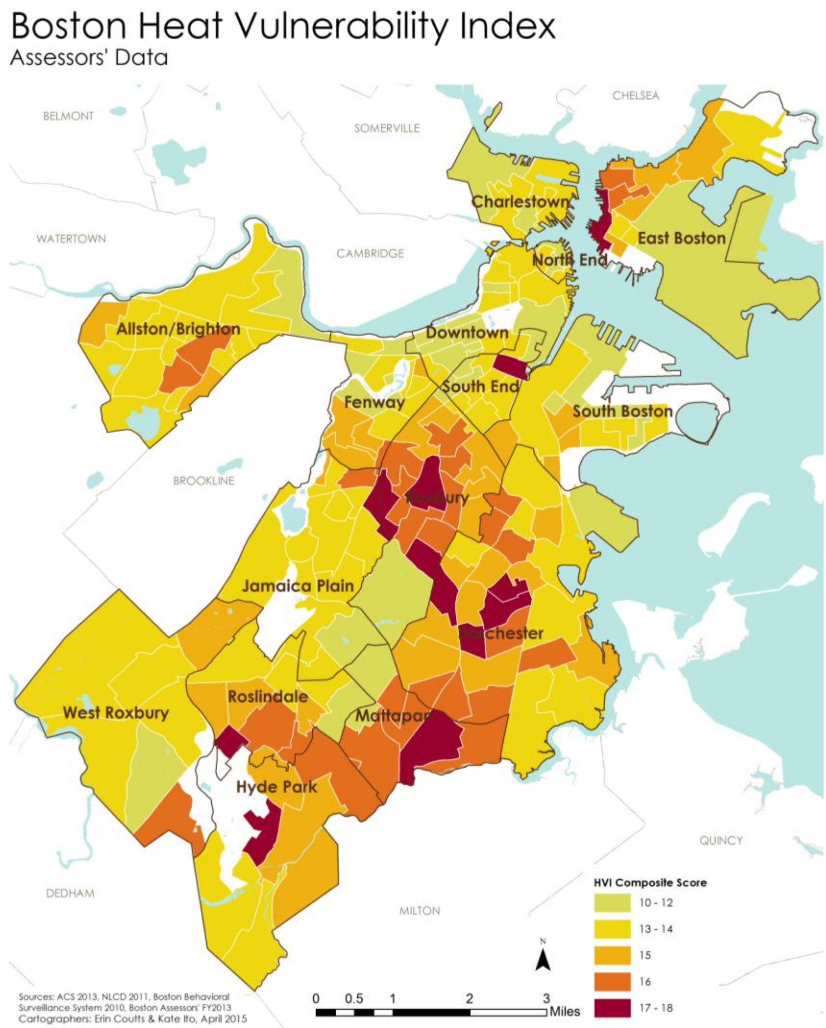

Figure 20: HVI Composite Score

Table 10 below shows the twelve most vulnerable census tracts, based on Assessor's data.

Table 10: Census Tracts with High HVI Scores based on Assessor's data

GEOID	Neighborhood	Population	HVI	Factor 1	Factor 2	Factor 3	Factor 4	High Factor Scores
25025101002	Mattapan	4933	18	5	4	4	5	- Social/Environ. Vulnerability - Proportion of Elders/Diabetes
25025050300	East Boston	2197	17	4	5	3	5	- Social Isolation - Proportion of Elders/Diabetes
25025070402	Chinatown (South End)	1718	17	6	4	2	5	- Social/Environ. Vulnerability - Proportion of Elders/Diabetes
25025081300	Roxbury	5382	17	5	4	3	5	- Social/Environ. Vulnerability - Proportion of Elders/Diabetes
25025081700	Roxbury	3277	17	5	4	4	4	- Social/Environ. Vulnerability
25025082100	Roxbury	4924	17	5	4	4	4	- Social/Environ. Vulnerability
25025090100	Dorchester	5005	17	5	4	4	4	- Social/Environ. Vulnerability
25025091700	Dorchester	3424	17	5	3	5	4	- Social/Environ. Vulnerability - Prevalence of No AC
25025092000	Dorchester	5226	17	5	3	5	4	- Social/Environ. Vulnerability - Prevalence of No AC
25025092300	Dorchester	3418	17	5	3	5	4	- Social/Environ. Vulnerability - Prevalence of No AC
25025140106	Roslindale	1961	17	4	5	4	4	- Social Isolation
25025140107	Hyde Park	2601	17	4	4	5	4	- Prevalence of No AC

11.2 Appendix B

Table 11: Existing Boston Programs

Program/ Initiative	Description	City Agency
	1. REGULATORY MECHANISMS	
Article 32: Groundwater Conservation Overlay District (GCOD)	Article 32 of the Boston Zoning Code regulates areas of the City that are at risk of water depletion. The statement of purpose is "to (a) prevent the deterioration of and, where necessary, promote the restoration of, groundwater levels in the city of Boston; (b) protect and enhance the city's historic neighborhoods and structures, and otherwise conserve the value of its land and buildings; (c) reduce surface water runoff and water pollution; and (d) maintain public safety." http://www.bostonredevelopmentauthority.org/getattachment/3742f956-eae0-453d-ae8a-805a094dde38 Inserted: February 15 2006 Additional information: http://www.bostonredevelopmentauthority.org/getattachment/7906045e-9472-440d-a109-be2db8ce8f66	BRA
Article 37: Green Buildings	Article 37 of the Boston Zoning Code requires any development project subject to large project review under Article 80 of the Zoning Code to meet LEED Certifiable requirements. The statement of purpose of this article is to "ensure that major building projects are planned, designed, constructed, and managed to minimize adverse environmental impacts; to conserve natural resources; to promote sustainable development; and to enhance the quality of life in Boston." http://www.bostonredevelopmentauthority.org/getattachment/7fb975b2-e811-4a5d-98cf-48c20469c70c Inserted: January 10 2007	BRA
Article 89: Urban Agriculture	Article 89 of the Boston Zoning Code regulates commercial agriculture in the City of Boston. Its Statement of Purpose is "to establish zoning regulations for the operation of Urban Agriculture activities and to provide standards for the siting, design, maintenance and modification of Urban Agriculture activities that address public safety, and minimize impacts on residents and historic resources in the City of Boston." http://www.bostonredevelopmentauthority.org/getattachment/a573190c-9305-45a5-83b1-735c0801e73e Inserted: December 20 2013	BRA
Article 29: Greenbelt Protection Overlay District (GPOD)	Article 29 of the Boston Zoning Code regulates development in the protected Greenbelt districts of the City. Its Statement of Purpose is "to preserve and protect the amenities of the city of Boston; to preserve and enhance air quality by protecting the supply of vegetation and open space along the city's Greenbelt Roadways; to enhance and protect the natural scenic resources of the city; to protect the city's Greenbelt Roadways from traffic congestion and to abate serious and present safety concerns." http://www.bostonredevelopmentauthority.org/getattachment/94599454-5fea-4235-85a6-a76cbf8d327a Inserted: June 1, 1987	BRA
Article 33: Open Space	Article 33 of the Boston Zoning Code regulates the protection of open space throughout the City. The Statement of Purpose is "to encourage the preservation of open space for community gardens, parkland,	BRA

Sub-Districts	recreation, shore land, urban wild, waterfront access area, cemetery, and urban plaza purposes; to enhance the quality of life of the city's residents by permanently protecting its open space resources; to distinguish different open space areas in order to provide for uses appropriate to each open space site on the basis of topography, water, flood plain, scenic value, forest cover, urban edge, or unusual geologic features; to prevent the loss of open space to commercial development; to restore Boston's conservation heritage of Olmsted parks; to coordinate state, regional, and local open space plans; to provide and encourage buffer zones between incompatible land uses and mitigate the effects of noise and air pollution; to promote and maintain the visual identity of separate and distinct districts; to enhance the appearance of neighborhoods through preservation of natural green spaces; and to ensure the provision of adequate natural light and air quality by protecting the supply of vegetation and open space throughout Boston." http://www.bostonredevelopmentauthority.org/getattachment/cf439d3c-76ed-42ea-89d0-eaf0917468c3 Inserted: March, 8 1988	
Climate Preparedness and Resiliency Checklist	All new development projects requiring Article 80 review from the Boston Redevelopment Authority must complete this checklist. The goal of the checklist is to "analyze project impacts on the surrounding environment that are attributable to forecasted climate conditions over the full duration of the expected life of the project. Utilizing the best available science, identify changes in the climate and environment and how such changes will affect the project's environmental impacts including the survivability, integrity and safety of the project and its inhabitants." http://www.bostonredevelopmentauthority.org/planning/planning-initiatives/climate-change-preparedness-and-resiliency Effective November 2013; asking for the data/results from the approximate year that this has been required could be interesting to see what heat related mitigation if any, has been documented	BRA
Stretch Code	The stretch code regulates the building energy efficiency standards for the City of Boston. The Commonwealth of Massachusetts regularly evaluates the statewide base building energy code; however, in 2009 Massachusetts became the first state to adopt an above-code appendix to the base code requirements known as the "Stretch Code." Local municipalities have the option to adopt the "Stretch Code" to supersede the base code. The Stretch Code requires new buildings to achieve approximately 20% better energy efficiency than the base code. http://www.cityofboston.gov/news/Default.aspx?id=4868 Adopted by City Council on November 17, 2010; effective as of July 1 2011 Additional information: http://www.mass.gov/eea/energy-utilities-clean-tech/energy-efficiency/policies-regs-for-ee/building-energy-codes.html	EE&OS
Parking Freeze	The Air Pollution Control Commission (APCC) of the City of Boston is responsible for administering parking freezes on off-street parking in three neighborhoods of Boston: Downtown, South Boston and East Boston. The overarching goals of the freezes according to the City of Boston are "to reduce vehicle miles traveled	APCC (EE&OS)

	in the Boston area, to promote the use of public transit, and to encourage transit-related development by restricting the number of off-street parking spaces." These parking freezes are part of the Massachusetts State Implementation Plan (SIP) aimed at improving air quality to meet federal requirements 74 according to the Clean Air Act. http://www.cityofboston.gov/environment/airpollution/parkingfreezes.asp Downtown freeze adopted in 1978, amended in March 2006; South Boston freeze adopted in 1993, amended in March 2006; East Boston freeze adopted in 1992. Only South Boston has available parking spots available in the parking bank. Additional information: http://www.cityofboston.gov/environment/AirPollution/	
	2. PLANNING AND GUIDELINES	
Boston Complete Streets	The Boston Complete Streets guidelines were published in 2013. The vision of the guidelines is "to improve the quality of life in Boston by creating streets that are both great places to live and sustainable transportation networks. The Complete Streets approach places pedestrians, bicyclists, and transit users on equal footing with motor vehicle users, and embraces innovative designs and technologies to address climate change and promote active healthy communities." http://bostoncompletestreets.org/	BTD/ PWD/ BRA
Go Boston 2030: Imagining Our Transportation Future	Go Boston 2030 is a current planning initiative led by the City of Boston's Transportation Department to envision transportation for the future of the City. Excerpted from the "Climate" section of the initiative description: "The plan will work to reduce greenhouse gas emissions from transportation by reducing the number of miles driven per person and increasing the number of trips made without a car. Transportation infrastructure should be prepared for extreme weather events." http://goboston2030.org/en/	BTD
Climate Action Plan	"The City of Boston's 2007 Executive Order on Climate Action calls for the City to have a climate action plan that is updated every three years. The Climate Action Plan serves as Boston's blueprint for reaching its goals of reducing greenhouse gas emissions 25% by 2020 and 80% by 2050, and making sure the city is prepared for the impacts of climate change. It also focuses on community engagement, social equity, and green jobs." http://www.cityofboston.gov/climate/bostonsplan/	EE&OS
Open Space Plan	The Parks and Recreation Department's citywide Open Space Plan seeks to protect Boston's existing parks and open space while exploring opportunities for the development and implementation of new open space infrastructure. A draft of the 2015-2021 Plan was released in the fall of 2014 and the final report is expected to be released in early 2015. http://www.cityofboston.gov/Parks/openspace/	Parks (EE&OS)
Greenovate	"Greenovate Boston is a community-driven movement to get all Bostonians involved in reducing the city's greenhouse gas emissions 25% by 2020 and 80% by 2050, as outlined in the City's Climate Action Plan. By laying out the necessary steps to reduce the causes of and to prepare for climate change, the Climate	EE&OS

	Action Plan gives Greenovate Boston a framework for building a greener, healthier, and more prosperous city." http://greenovateboston.org/about/	
	3. PROJECTS	
City Hall Green Roof Demonstration Project	"The City of Boston has initiated several green roofs projects on city-owned buildings. There is currently a green roof demonstration being exhibited on the 8th and 9th floors of City Hall. In addition, in cooperation with the Boston Schoolyard Initiative, the city has started a green roof at the Josiah Quincy School in Chinatown so students will have a great place to play and to learn about their environment." http://www.cityofboston.gov/images_documents/Green_Roof_Demon_tcm3-2745.pdf	COB
E+ (E Positive)	The E+ program in Boston have created housing in Boston which is energy positive. "In Boston, we are taking our green building and renewable energy efforts to the next frontier by creating ultra-efficient buildings that generate surplus clean energy. We are demonstrating that energy positive green homes and buildings can be constructed sustainably and cost-effectively, while enhancing the livability and vitality of Boston's neighborhoods now and into the future." http://www.epositiveboston.org/	DND/ BRA
	4. INFORMATIONAL	
City of Boston Webpage re: Urban Heat Islands	The City of Boston hosts a webpage on their website regarding urban heat islands. According to the page: "In summer, buildings, roads, and other structures in cities absorb heat from sunshine and slowly release it. As a result, urban areas are typically several degrees warmer than greener and less densely developed areas that surround them. The difference can be especially noticeable at night, when cities are much slower to cool off. This phenomenon is the urban heat-island effect." In addition, the page features a map from 2001 of the east coast, from Washington to Boston, which depicts the urban heat island effect. The page also features a temperature comparison between Boston, Worcester and Petersham, MA. http://www.cityofboston.gov/climate/urbanheatislandeffectboston.asp This page needs updating with more recent and relevant information on urban heat islands. Specific Boston context is important.	COB

Acronym Key	
APCC	Air Pollution Control Commission
BRA	Boston Redevelopment Authority
BTD	Boston Transportation Department

COB	City of Boston
DND	Department of Neighborhood Development
DPW	Department of Public Works
EE&OS	Environment, Energy and Open Space

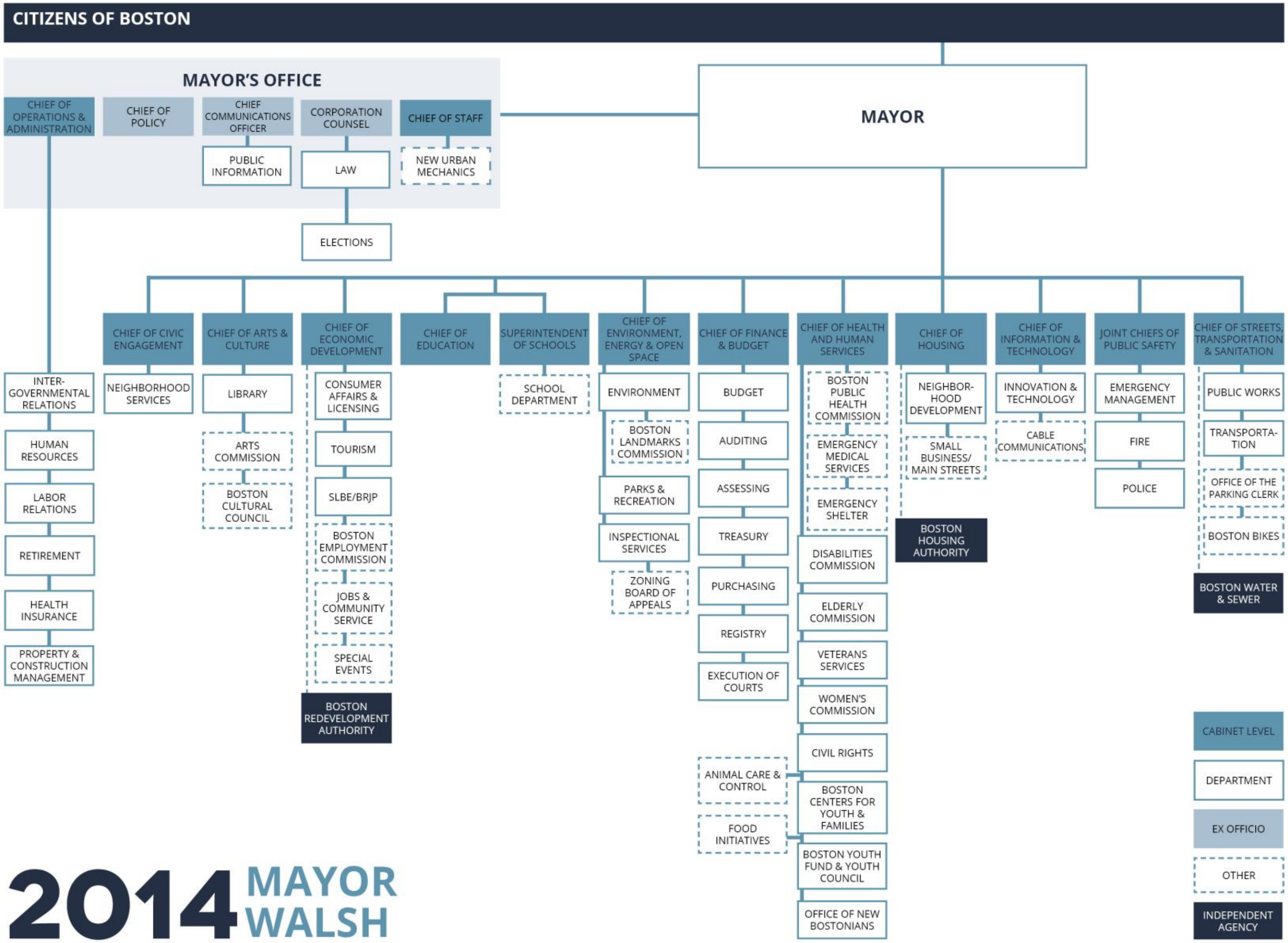

Figure 21: Structure of Boston Municipal Government