Greening Climate Adaptation: Exploring the Use of Green Infrastructure as an Adaptation Strategy in Boston and Cambridge, MA
By
Sasha A. Shyduroff
BA in Anthropology
Reed College
Portland, OR (2008)
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Signature redacted
Author
Department of Urban Studies and Planning (May 16th, 2016)
Certified by ____________
Professor Terry Old
Department of Urban Studies and Planning
Thesis Supervisor
Signature redacted
Accepted by ____________
Assistant Professor P. Christopher Zegras
Chair, MCP Committee
Department of Urban Studies and Planning
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Submitted to the Department of Urban Studies and Planning on May 19, 2016 in Partial Fulfillment of the Requirements for the Degree of Master in City Planning

Abstract
Interest in green infrastructure as a potential strategy for addressing climate change has recently emerged in adaptation planning. Green infrastructure (GI), defined here as engineered systems that incorporate green space and natural systems to provide benefits to the public, can be used to address impacts such as sea level rise, storm surge, inland flooding, and urban heat island effect. GI can often be implemented at lower-cost and faster timelines than grey infrastructure. It also provides a myriad of aesthetic and public health benefits, and can be an attractive “no-regrets” adaptation solution for policy-makers.

Despite these benefits there is a lag in scaling up green infrastructure and formally connecting it to climate adaptation policy. The planning efforts of Boston and Cambridge, MA are used as case studies to explore the barriers and drivers of employing GI as a strategy to address increased urban flooding due to climate change. An historical ecological approach sets the foundation for the analysis of current and future challenges with stormwater management. This thesis uses a review of public planning documents and semi-structured interviews to explore how socio-political factors drive or prevent the use of GI. I found that path dependencies, navigating trade-offs in decision making, and shifting risk analysis act as barriers to using GI for adaptation. I also found that adaptive learning, knowledge networks, and collaboration might be used as strategies to overcome these and other barriers.

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Introduction

Hurricane Sandy, which caused $65 billion in damage, 195 deaths, and damaged 650,000 homes in 2012 (Rice & Dastagir 2013), was a wake up call to many along the Eastern Seaboard. Hurricane Sandy was unprecedented: it was nearly 1,000 miles across and the intensity of the storm was amplified by warmer than usual ocean waters caused by climate change (Abraham 2015). While much of the damage from Sandy was from storm surge, it also dropped 13 inches of rain on NY and NJ causing inland flooding. The volume of runoff, combined with storm surge, caused backwater effects where the water was unable to drain into the ocean. This storm came only one year after Hurricane Irene in 2011, which veered inland dropping eight inches of rain on Vermont and Western Massachusetts, causing massive amounts of damage from inland flooding. In the wake of Hurricane Sandy, cities along the Eastern seaboard began to take climate change more seriously and either launched or renewed efforts to adapt. One of the conversations that emerged was the potential for using green infrastructure as a strategy for climate adaptation (Hanscom 2013).

For the purposes of this thesis, green infrastructure (GI) will be used to mean: *engineered systems that incorporate green space and natural systems to provide benefits to the public.* Some of these benefits include restoring the natural hydrology of an area through filtration and infiltration, water storage, cooling air temperatures, and reducing wind. Since 2009, the Environmental Protection Agency (EPA) has pushed the use of green infrastructure as a viable alternative for cities reducing water pollution. Additionally, when green infrastructure is used in the right way and at the right scale, it can help mitigate urban flooding issues by infiltrating stormwater where it lands or storing it during peak flow times. Urban areas are particularly vulnerable to increased flooding from climate change due to the high percentage of impervious surfaces. Along with the other co-benefits this make green infrastructure an attractive part of climate adaptation planning. However, green infrastructure has been slow to scale up to a level that could help restore hydrology and reduce flooding. It has also been slow to be formally integrated into climate adaptation plans. This lag has led to the research questions:
1. What are the governmental barriers and drivers for early adapters employing green infrastructure as a strategy to adapt to climate change?

2. What would it take for cities to adopt green infrastructure on a larger scale?

This thesis will explore how socio political factors such as institutional norms, rules and regulations, and government structures either act as drivers or barriers for green infrastructure and adaptation planning.

**Scope of Thesis**

**Why urban inland flooding?**

While green infrastructure has the potential to be used for a wide-variety of climate impacts including mitigating storm surge and reducing urban heat island effect, I am choosing to focus on urban flooding for several reasons:

1. **Extreme precipitation is already affecting cities**

   Many urban areas in the United States are dealing with the impacts of increased precipitation and urban flooding associated with climate change. Urban grey infrastructure solutions are often designed for a “normal” rain event that is based on the region’s typical 10-year, 24-hour design storm (some infrastructure is built for the 25-year storm). Current infrastructure is not equipped to handle increased precipitation or extreme events. Massachusetts has already experienced a volume increase for the 10-year storm. One recent example of extreme precipitation was in 2010 when the city of Cambridge experienced a large amount of flooding due to a rainstorm that dropped 3.58 inches of rain in just an hour, which exceeded the capacity of the storm system. The historic likelihood of this event happening is between .5 and 1% change, also known as a 100 to 200 year storm. However, with climate change, the likelihood of these types of events is increasing and we are already beginning to feel those impacts. Urban flooding can cause damage to infrastructure, homes and businesses, and result in diseases or even death. Repeated nuisance flooding, like flooded basements, can cause mold and other health problems for residents.
2. Green infrastructure already used for water quality issues:

Many urban areas in the United States already are using green infrastructure to address issues of water quality, using it as a strategy for volume reduction would be an extension of its existing use. In 2009 the Environmental Protection Agency (EPA) began to push green infrastructure technology as a viable solution for cities needing to address Combined Sewer Overflows (CSOs), Municipal Separate Storm Sewer Systems (MS4) permits, and inadequate storm water infrastructure. This push was supported by research from National Research Council (NRC), which recognized the large percentage of impervious surfaces as a root cause to urban water quality issues. Municipalities were drawn to green infrastructure because it can be more cost effective than expensive grey piped systems and water treatment
plants. This trend towards green infrastructure for water quality improvements could be extended to deal with water volume and flooding.

3. Extreme precipitation and storm surge interact with each other

Coastal flooding can exacerbate inland flooding because the hydrological systems are connected. Storm surge can cause a backwater effect upstream whereby drainage systems and rivers cannot drain into the ocean because of heightened coastal waters. This means that infiltrating and storing water upstream becomes even more critical for coastal urban watersheds.

4. New vision for urban landscapes

Sea Level Rise and storm surge are major flood concerns in coastal cities like Boston and Cambridge, however green infrastructure in this realm is often seen through the lens of land conservation or restoration of wetlands and other critical ecosystems. By focusing on green infrastructure in the urban landscape there is an opportunity to rethink and reimagine what the streetscape and urban form looks like. Through a lens of green infrastructure we can make the argument that green space within the city is critical to the wellbeing of residents.

Why Boston and Cambridge?

1. Both are early climate adapters

Both Boston and Cambridge have been working on issues of climate change mitigation since the early 2000s and quickly realized they needed to incorporate climate adaptation and preparedness into their planning. While they have different approaches and are at different stages of their planning process, they both have staff and resources for this work. Thus, both cities have some experience and perspectives on the emerging challenges and best practices.

2. Share ecological and hydrological context

Boston and Cambridge have a shared ecological and development history, and have many shared climate impacts and hazards. Both have had a complicated
and rich history with urban water management, namely around the cleanup and restoration of the Charles River basin. Due to their history and challenge with water quality, both cities have emerging green infrastructure practices for stormwater management.

**Research Methods**

This thesis uses a mixture of methods to answer the research question, including semi-structured interviews with twelve key actors and a review of public planning documents. This analysis is situated within the region's ecological and historical development, which contextualizes the current issues derived from large percentages of impervious surfaces and urban water issues. I then look ahead to projected climate change impacts for the region and specific hazards Boston and Cambridge can expect to face. This analysis is understood within an emerging theoretical framework that combines green infrastructure and climate adaptation theories.

The semi-structured interviews were conducted in January and February 2016 using a snowball method. I first contacted municipal staff whose primary role work on water or climate. Those contacts then put me in touch with others whose work touched on green infrastructure or could give valuable perspectives on the climate adaptation process. That question yielded more contacts in each of the city, as well as non-profits that support work regionally. A set of ten questions was asked to each interviewee. Most of the questions remained consistent across interviews, but some of the questions were tailored towards either green infrastructure or climate change depending on their knowledge and expertise (See Appendix A). Interviews were done in person when possible, with only two out of twelve occurring via telephone.

In addition to the interviews, an analysis of documents of practice revealed how the cities are thinking about green infrastructure for climate change and how they communicate that to their departments and the public. Documents reviewed include Boston's *Greenovate Plan*, the *Open Space Plan*, and internal Boston Water and Sewer's research on climate change. For Cambridge, fewer documents were
available that covered the intersection of topics, but the *Vulnerability Assessment* was extensive. These documents contextualized the stakeholder interviews.

**Organization of Thesis**

Chapter 1 is a review of current literature on several streams of thought that merge in this thesis: stormwater management, green infrastructure, climate change adaptation, and risk management. In addition to understanding the definitions and concepts, the literature review outlines seminal and current research on the nexus of green infrastructure and climate change. Chapter 2 gives the historical ecological context for Boston and Cambridge urbanization impacts as well as looks to the future impacts of climate change. Chapter 3 provides an in depth case study of Boston and Cambridge and the primary drivers of their respective work on climate adaptation and green infrastructure. Chapter 4 analyzes the common barriers and some strategies for overcoming barriers that Boston and Cambridge have faced. This analysis is the foundation for recommendations for Boston and Cambridge, as well as other municipalities seeking to use green infrastructure for climate adaptation framed in the Conclusion. I also end with suggestions for future research to help build out this field of study.
Chapter 1: Literature Review

There is currently a growing interest by cities to use green infrastructure as a strategy to address climate change impacts. Research in Europe, Australia and Asia have led the way in looking at its feasibility and uptake in these countries. While research on climate adaptation in the US is more fully developed, connecting these efforts to green infrastructure is still fairly nascent. This literature review will give a broad overview of the converging streams of thought and develop a conceptual framework with which to analyze barriers and drivers for adopting green infrastructure as part of an adaptation strategy. The framework will provide an overview of physical, technical, and economic factors with an in-depth analysis of socio-political factors of green infrastructure for adaptation.

Climate Change

Along with warming the planet, climate change is fundamentally altering natural systems, including the earth’s hydrologic systems. Some areas will see an increase in drought, while others will see an increase in precipitation. Urban areas will experience climate impacts in unique ways due to the alteration of natural systems and large percentages of impervious surfaces. These impacts include the intensification of the urban heat island effect\(^1\), exacerbation of air pollution, inland and coastal flooding, landslides, drought, and water scarcity (IPCC 2014; 18). In North America, urban flooding is a risk that can lead to damaged infrastructure, disruptions to social and economic systems, public health issues, and loss of life.

The impacts associated with climate change can be addressed through mitigation and adaptation. Mitigation refers to the process of reducing the potential impacts of climate change by reducing greenhouse gas emissions. Adaptation refers to the work to reduce risk and vulnerabilities associated with the impacts of climate change. Adaptation planning is used to describe the process of understanding and predicting risks and vulnerabilities, creating plans and policies to address those risks, and implementation (Hansen et al. 2012). However, because of the changing

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\(^1\) Urban Heat Island effect is the phenomenon of urban areas comprised mainly of heat absorbing materials cause urban areas to be warmer than surrounding rural areas (EPA
risks and uncertainties, this process must be iterative (IPCC 2014). While climate change is a global problem, and many of the adaptation solutions must be localized, context specific, and work together across scales (local, regional, state, federal etc.).

Another term for this work is *resilience*, which borrows from ecology, systems thinking, and psychology, and refers to the ability of a system to absorb and adjust to shocks without flipping to another state (Tyler and Moensh 2012; Holling 1978). Resilience implies more flexibility and ability to address dynamic uncertainties than adaptation does. However, terms like “adaptive capacity” or “adaptive management” also highlight the fact that the process must be iterative and include a process of assessing and learning to incorporate new ideas.

For the purposes of this thesis *adaptation planning* refers to *activities undertaken to plan for climate change impacts, which includes both the phases of vulnerability assessments, planning adaptation projects, and implementation.* Adaptive capacity will refer to the likely increase in a city’s ability to respond and recover from a climate impact or crisis.

**Risk Management**

Risk management in the urban context is relevant to the discussion of climate change impacts and adaptation. The level of risk in an urban area is directly tied to the process of urbanization that leads to dense population centers and overlapping critical infrastructure systems. Disasters occur when there are cascading failures of multiple systems. *Hazard* describes the “potential harm to individuals or human systems” and can be endemic or episodic, where as *vulnerability* is the susceptibility or exposure to harm. *Risk* is described as the combination of hazard and vulnerability and explains the probability of exposure to the harm (Pelling 2003; 5). The common mnemonic formula is: \( DR = H \times V \) (where DR is disaster risk, H is hazard, and V is vulnerability). However, vulnerability has also been defined in other ways in the field of risk management. It is also useful to draw upon the work of Ben Wisner et al. who create a framework for understanding natural disasters in which vulnerability is defined as the “characteristic of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover
from the impacts of a natural hazard” (Wisner et al 2003; 11). In this framework vulnerability is seen as situated with in a progression of three factors including political structures, economic structures and social structures. Disaster Risk Reduction (DRR) is then reducing one’s exposure to hazards but also bolstering the ability to resist or recover. Climate change highlights the fact that so called “natural disasters” are not fully natural, in that they are influenced by “dynamically modified and constructed by human action” (Wisner et al 2012; 20). Human development patterns and histories have created unequal distribution of exposure to hazards and vulnerabilities.

Uncertainty plays a large role in risk management of climate change adaptation. Uncertainty in risk can come from the quality of data, the quality of the model, or the understanding of processes. In climate change assessments, uncertainty stems from uncertainty of future vulnerabilities and exposure to hazards (IPCC 2014). Not only are there multiple models to describe the hazards, population and demographic changes add to uncertainties associated with vulnerability. The challenge for urban planners is that when “uncertainty and disempowerment are felt by decision-makers there is a danger that investment in disaster preparedness and mitigation will be left outside of urban development strategy, with disaster management reverting to a focus on post-disaster humanitarian relief and rehabilitation” (Pelling 2003; 8). Decision-makers often have to make tough trade-offs when managing risk. They look for no-regrets decisions so that large investments of resources make an impact. Decision-makers often times accept a potentially catastrophic hazard if the probability of something going wrong is very low. These challenges are why “iterative risk management is a useful framework for decision making in complex situations characterized by large potential consequences, persistent uncertainties, long timeframes, potential for learning, and multiple climactic and non-climactic influences over time” (IPCC 2014; 9). A different type of risk management is needed when there is a high level of uncertainty or dynamic impacts.
Stormwater Management

Stormwater is broadly defined as the water generated by any storm, including rain, ice, or snow. Water that passes through engineered conveyance systems, such as ditches, gutters, or pipes is considered regulated stormwater (National Research Council 2009). Water that infiltrates where it lands or flows through natural systems usually falls outside urban stormwater regulation. Run-off is used to describe the stormwater that does not infiltrate immediately and is usually associated with impervious surfaces like roads, parking lots, roofs etc. Issues associated with stormwater and run-off include, degraded water quality thru pollution, increased temperatures of urban watersheds, and flooding. Flooding can lead to public health issues, damage to infrastructure and loss of life and property. Stormwater management is deeply embedded in the processes of urbanization, most notably that of changing land cover from vegetated surfaces to impervious surfaces and the construction of drainage networks. In the early development of US cities, small streams and rivers were enclosed to act as sewer systems, and raw sewage and waste would be released into local watersheds and oceans.

In the early 1900s, there was a shift towards building extensive piped drainage systems which were designed to move water and waste as far away as quickly as possible from streets and population centers. By the 1940s, cities like Boston only had primary sewage treatment, which allows solids to filter out. In many older cities, like Boston and Cambridge, that were developed in the late 19th to early 20th century stormwater shared drainage pipes with municipal sewage in combined systems that went to primary treatment. During a heavy rainfall these combined sewers could not handle the additional capacity and by-design overflowed raw sewage into local waterways, this is called a Combined Sewer Overflow (CSO). During a precipitation event run-off travels across streets and parking lots and picks up trash and pollutants like heavy metals, chemicals, gasoline and other road waste. Since roads and parking lots make up 70% of impervious surface land cover (National Research Council 2009), urban runoff has lead to many downstream waterways being heavily degraded and polluted. Many of these
problems persist today despite the creation of the Clean Water Act in 1972 and requirements to clean up urban watersheds. For many decades the way to address water quality issues was to install expensive grey infrastructure systems including separating sewer systems, installing larger pipes and storage, and building new treatment plants. However, this approach is often expensive for cities to implement and is out of reach to poorer cities whose ratepayers cannot bear the burden of increased water costs. In recent years, the EPA has pushed green infrastructure and other non-structural solutions for managing stormwater.

While the EPA has been the driver for water quality improvements, the Army Corps of Engineers and Federal Emergency Management Agency (FEMA) have mainly worked to address flooding issues. Similar to water quality issues, for decades solutions focused on the implementation of grey infrastructure: dams, levees and underground storage tanks.

**Green Infrastructure (GI)**

Green infrastructure, while not a new concept, is a term that remains contested, ambiguous, and evolving (Wright 2011; Matthews et al 2015). There are many different definitions of green infrastructure that range from large-scale open space preservation, constructed wetlands, street trees, engineered green spaces that infiltrate runoff, Low-Impact Development (LID), to Best Management Practices (BMPs). The term Blue-Green Infrastructure (BGI) is sometimes used when the focus is on restoring hydrologic systems through water infiltration, storage, and filtration (Dreiseitl et al 2015). As a contested term, green infrastructure runs the risk of losing meaning and its ability to convey information to the public, but at the same time can be positively dynamic (Wright 2011).

For the purposes of this thesis, green infrastructure will be used to mean: *engineered systems that incorporate green space and natural systems to provide benefits to the public*. Benedict and McMahon, in their 2006 book *Green Infrastructure: Linking Landscapes and Community* outline several key principles of good green infrastructure, including:
- May provide multiple co-benefits including improved water quality, increases water infiltration on-site, stores stormwater, cools water before entering the hydrological system, cooling of air-temperature, and reduction of wind speeds.
- Can include aesthetic, social and public health benefits associated with green space in urban areas.
- Should be seen as a critical part of urban infrastructure that provides necessary services and benefits to people.
- Can be implemented at many scales, but works best when thought of and used as a networked system.

Green infrastructure can help reduce run-off volumes and downstream flooding by storing water, infiltrating it into the soils, or slowing it down using vegetation (Zahmatkesh et al. 2015; Gill et al. 2009; Douglas 2010; Farrugia et al. 2013). Green infrastructure that includes vegetation, such as trees or green roofs, can help cool ambient air temperatures through the processes of evapotranspiration or in the case of trees providing shade (Bowler et al. 2010). Shading can in turn help reduce energy use and costs of buildings (Demuzere et al. 2014). In addition to physical benefits, green infrastructure can provide psychological and social benefits including improving public health and increasing local residents’ capacity to be environmental stewards (Demuzere et al. 2014). Green infrastructure can also provide financial benefits to cities beyond the cost savings of installing green infrastructure instead of grey infrastructure. Certain types of green infrastructure like green roofs actually reduce heating and cooling costs, and green infrastructure that reduces water flow volumes will reduce electricity costs of pumping water (Foster et al. 2011). Additionally, green infrastructure that is seen as a public amenity like parks, open space or street trees can increase property values (Foster et al. 2011).

Vegetated green open space is a form of green infrastructure that has a long history as part of land use planning and urbanization. Historically, the concept of green space as a critical piece of infrastructure began in the field of landscape architecture; it first appeared in Fredrick Law Olmsted’s Emerald Necklace in the
early 1900s, then it emerged again in Ian McHarg’s *Design with Nature* (1969) and the concept of Landscape Ecology, which took root in the 1970s. These landscape architects saw the critical need to develop land with natural systems in mind and preserve open space. By viewing open space as a type of green infrastructure, advocates “promote a strategic approach to land and water conservation that is systematic and well integrated” (Benedict and McMahon 2003; 12).

In 2009, the National Research Council (NRC) released an *Urban Stormwater Management* report at the request of the EPA. This report was a turning point for examining the root causes of stormwater issues in the US. They concluded that in an ideal world, stormwater would be managed by land use controls and stricter limits to quality and quantity of stormwater runoff. However, in lieu of seeing a comprehensive land use approach they recommended “non-structural SCMs (Stormwater Control Measures) such as product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning can dramatically reduce the volume of runoff and pollutant load from a new development” (NRC 2009; 9). They argued that using techniques, such as Green Infrastructure, to infiltrate and harvest water, as well as restore evapotranspiration processes were critical to address the volume and quality of stormwater runoff. Green infrastructure is not a new concept, but the 2009 report marked a huge shift in which not only was the EPA supportive of this technique, but also started to fund projects through grants to municipalities.

A few cities in the United States standout as leaders in green infrastructure installations mainly used for the purposes of water quality and CSO reduction. Philadelphia, PA launched Green Cities, Clean Waters in 2011 as part of their plan to reduce stormwater entering their combined sewer system. So far they have installed over 1,100 projects across the city and will save $5.6 billion by relying on green infrastructure instead of grey infrastructure (Philadelphia Water 2016). Washington DC and New York City, NY are also leaders in addressing CSOs through green infrastructure. Chicago, IL has green infrastructure for both stormwater and heat issues. In 2001, Chicago City Hall installed a 20,300 sq. foot green roof that has a reduced surface temperature of 56° C and also reduces 75% of runoff from a 1-inch
rainstorm (Foster et al 2011). In 2007, Chicago also installed 30 green alleys with permeable pavement and over 200 catch basins across the city. Portland, OR has also invested $8 million in green infrastructure to save $250 million in grey infrastructure in order to reduce CSO volume. Overall, these cities have found green infrastructure to be much more cost effective than traditional grey infrastructure and have additional financial benefits in the form of improved property values (Foster et al 2011).

**Toward a Conceptual Framework: GI for Climate Adaptation**

Green infrastructure has been touted as a possible solution to building adaptive capacity in urban areas for several key reasons: it can provide multiple co-benefits that would allow cities to address several issues at once and break down silo-based approaches (Carter et al 2015; Byrne and Yang 2015); it may be less expensive and politically favorable compared to typical grey infrastructure (Byrne and Yang 2009); it provides a localized solution to a global problem (Matthews, Lo, Byrne 2015). Despite this, uptake has been slow and research has been minimal. Adaptation itself is still in its nascent form in the United States, and most cities conducting an adaptation planning process are still considered early adopters (Anguelovski and Carmin 2011; Shi et al 2015). There are few formal rules, norms or policies shaping the adaptation process and outcomes. Also, the barriers and drivers for adaptation are not fully understood or researched, despite more cities undertaking climate adaptation planning.

This thesis borrows from Moser and Ekstrom's "A framework to diagnose barriers to climate change adaptation," in which limits and barriers are distinguished from one another. They define limits as the "obstacles that tend to be absolute in the real sense: they constitute thresholds beyond which existing activities, land uses, ecosystems, species, sustenance, or system states cannot be maintained" (Moser and Ekstrom 2010; 22026). Limits are often immutable constraints like amount of land or the ability of an ecosystem to survive. On the other hand, barriers are "obstacles that can be overcome with concerted effort, creative management, changes of thinking, prioritization, and related shifts in resources, land uses, institutions, etc." (Moser and Ekstrom 2010; 22027). Examples
of barriers are governance structures, socio-political factors and institutions. Barriers may slow, delay, or derail the process, but they are surmountable. In addition to examining barriers, this thesis will examine the internal and external drivers that push and motivate climate adaptation. By exploring the nexus of barriers and drivers for using green infrastructure as a climate adaptation strategy, I hope to gain a deeper understanding of how cities can overcome these barriers and get to the scale of green infrastructure needed to make an impact.

Australian researchers Jason Byrne and Jinjun Yang look at the role of green space in tackling climate change, including urban heat island and flooding. They provide a conceptual model to illustrate the factors that affect the ability for urban green space to be used for climate change adaptation. Their model includes biophysical and socio-political factors that shape and constrain capacity, including four realms: the biophysical realm, land use regulations, governance structures and decision-making, and resident perceptions of parks (Byrne & Yang 2009; 38).

Most recently, the 2015 concept paper written by Matthews et al. builds off the framework started by Byrne and Yang and tests their assumptions on seven municipalities in England. They are surprised that green infrastructure has been relatively slow to scale up given research that shows the potential of GI as a tool for climate adaptation and the myriad of co-benefits it provides (Matthews et al 2015; 156). This drove them to include additional factors such as the institutional environment, as well as the agency of climate change and nature itself on shaping the socio-political context (Matthews et al. 2015: 159). They argue that the concept of path dependencies has been overlooked in the research and that too much focus has been on the biophysical barriers and not enough attention has paid to socio-political factors.

Similar frameworks have been developed by those interested in adaptation planning in general, including a recent paper by Shi et al. (2015). They test 13 explanatory variables pulled from the literature on adaptation and look at 156 municipalities across the US to test assumptions. They find that only three variables are statistically significant in predicting status of adaptation planning including: municipal expenditure per capita, climate change impacts experience, and the
commitment of local officials (Shi et al. 2015). They especially highlight the role of leadership within a city and say that more research on institutional values, such as flexibility, openness to new ideas, and internal incentives, is needed.

In Hughes' 2015 *A Meta-analysis of Urban Climate Change Adaptation Planning in the US*, she finds that:

- Many adaptation proposals look for no-regrets options, which will be beneficial no matter what the timing or severity of climate change will be;
- Lack of coordination seems to be a barrier because climate planning remains highly sector specific;
- Financing and new partnerships are needed.

All of these factors can act as barriers to cities, but also point to areas of leverage for action. There is a need in climate adaptation planning to operate in complex governance structures because of the need to collaborate across sectors and vertically within a sector. However, this also means that there isn't always clarity on who is in charge of decision-making or who should be in charge. Along with leadership and collaboration, the need for developing social learning networks is critical (Bidwell et al. 2013). Learning or knowledge networks can help decision-makers deal with the changing levels of risk and uncertainty associated with climate impacts. These networks can also help scientists communicate complex ideas and enable important information to be more accessible to decision-makers and the public. The good news is that many of these socio-political barriers are surmountable with planning and creative problem solving.

The conceptual framework outlined in Table 1 builds off work from both the green infrastructure and climate change adaptation research fields. Green infrastructure and adaptation each have their own barriers and drivers, some of which are overlapping. Understanding how these barriers and drivers operate at the US municipal level will help planners and researchers implement green infrastructure at the scale that is needed for climate adaptation. This framework will be used to analyze the work of Boston and Cambridge in green infrastructure and climate adaptation.
Table 1 Framework of factors influencing the uptake of GI and climate adaptation planning.

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<td>Constraints on space and land</td>
<td>Maintenance</td>
<td>Staff and public perceptions</td>
<td>Cost of land; real and opportunity cost</td>
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<td>Soil</td>
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<td>Long-term efficacy</td>
<td>Path dependency towards grey infrastructure</td>
<td>Cost of maintenance</td>
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<td>Hydrology and water table</td>
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<td>Municipal boundaries do not match watersheds or waterscapes</td>
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<td>Lack of stormwater fees or other financing mechanisms</td>
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<tr>
<td>Natural systems (types of plants; grow cycle etc.)</td>
<td>Role of regulation at state and federal level (e.g. Clean Water Act compliance)</td>
<td>Costs of implementation and construction; lack of cost-over run projections</td>
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Adaptation planning | Space and land | Concerns over long-term efficacy of adaptation strategies | Institutional norms, rules, regulations and policies | Costs associated with staff time |
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<td>Not all impacts are spatial or can be mapped.</td>
<td>Scientific understanding and models of climate impacts (e.g. flood maps)</td>
<td>Culture of governance (perceptions and values)</td>
<td>Allocation of budget towards adaptation planning</td>
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<td>Uncertainty associated with future risks and vulnerabilities</td>
<td>Role of individual actors and leadership</td>
<td>Unknown costs of future disasters</td>
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In this framework, I use the term institution to mean “the prescriptions that humans use to organize all forms of repetitive and structured interactions” (Ostrom 2005; 3). This includes not only organizations and government, but also the rules (set of instructions) and norms (unwritten sets of expectations) that constrain them or provide opportunity. Many of these institutions are deeply ingrained and unconsciously followed, making it especially difficult for people to change or shift them. I am particularly interested in the social and political factors that have influenced Boston and Cambridge’s work around climate adaptation and green infrastructure including institutions and culture.
of decision-making. This thesis will look specifically at the socio-political factors including:

- Institutional norms and culture that allow for openness to new ideas within city government, as well as regional culture (non-profits, regional guidance outside city govt.)
- Rules and regulations that put pressure on municipal government.
- The role of leadership and structure in municipal government.
Chapter 2: Ecological History

The Boston metro region has always had a complicated relationship with water. The rivers and bay helped create what Boston is today, yet they have also caused challenges including flooding, storm surge, and of course water pollution. “Water is profoundly cultural” and cities are as much about the infrastructure that comprises them as they are about the ideas, values and beliefs that shape them (Smith 2013). Ideas and values around water are intrinsically tied to the values of the city. After centuries of water pollution, Boston Harbor and Charles River are held up as exemplary cases of urban water remediation. In Boston, how the city has dealt with water, has been intertwined with management of land use and the public realm. The waterscape itself of the Charles River basin and harbor are popular public amenities and symbols of the region. The Emerald Necklace, a chain of public parks, began as a way to treat and manage stormwater.

This chapter takes what Bevir calls a “radical historicism” approach to contextualizing the ecological and historical underpinnings of today’s challenges and solutions in relationship to water. By understanding how the ecology shaped the formation of Boston and Cambridge, we can better understand how future climate impacts may also shape the region in regards to water.

Urbanization: Changing the Land and Water

Boston, formerly known as Shawmut, is situated on a peninsula that juts out into a naturally protected harbor, with peninsulas to the north and south and islands across the middle. Early European settlers were drawn to the region for many of the similar reasons as the Algonquin Native Americans before them. European settlers moved to Boston from what is now Charlestown after discovering the freshwater spring on the peninsula. The peninsula consisted of just over 400 acres with three hills: Trimount, Copp’s Hill, and Fort Hill. Surrounding the peninsula was hundreds of acres of tidal mudflats and saltwater marshes. The river mouths were tidal estuaries too, with brackish water upriver for some distance. The natural surroundings made it an ideal place for both shipping and protection. As
Boston grew, the natural surroundings of the area were transformed through the processes associated with urbanization, including land creation and damming the rivers. Cambridge, first known as New Towne, was founded in 1601 up river from Boston.

Figure 2 Map of "Boston and its Environs" from 1806 by R. Phillips depicts the original area of Boston as a peninsula surrounded by tidal mudflats and wetlands.

Source: Boston Public Library.

Boston settlers attempted to harness the power of the tides by creating millponds around the coastline. However, these millponds would fill in with sediment over time and it was common practice to further fill them in to create new land. Similarly, because of the region’s large mudflats, long wharfs were needed to reach deep enough water for shipping and boating. Those wharfs also changed water flow patterns and caused sedimentation. By 1800, the city started to use the soils and rock from its hills to fill in the land for new real estate and transportation ventures. In 1857, the Mill Pond Corporation, after failing to recoup their costs as a Mill began the lengthy 40 year long process of filling in the pond to create land for
real estate, a much more lucrative investment. They transported tons of rock, soil and other materials by train from areas to the west. This new area added over 500 hundred acres of land to Boston and created needed residential and public space known as the Back Bay. Like Boston, Cambridge also participated in land creation along the Charles River.

Cambridge, MA is a much smaller city than Boston at only 6.26 square miles. Situated on the lower Charles River basin, what once was a coastal, tidal shoreline is now simply riparian. It’s a low-lying city with several hills that split the city between the Charles River watershed and Alewife Brook that flows into the Mystic River watershed in the north. Most of the shoreline on the Charles is created land including MIT’s campus and Cambridgeport. The area of Cambridge to the northwest was also a network of tidal salt marshes when the Alewife Brook and Mystic River were still tidal. However, around the late 1800’s the area between Fresh Pond and Alewife Brook was filled in so that Fresh Pond could act as a reservoir for Cambridge. Many of the brooks and tributaries in this area were eventually filled in or enclosed as sewer systems. In 1909, the Mystic River was dammed up, so it was no longer a tidal estuary. Between 1909 and 1912 the Alewife Brook was straightened and channelized in an effort to drain the wetlands, which lead to the loss of the natural water storage capacity of the wetlands.

**Early Examples of Green Infrastructure**

During the era of infill in Boston, the city undertook and effort to preserve and create public space to manage stormwater and flooding concerns that were developing as a result of the channelization and infill. In 1876 the City Council voted to purchase 100 acres of land from the Mill Pond Corporation in the middle of the newly filled in mudflats as part of a larger Back Bay Parks program as part of a project called the “Muddy River Project.” The city hired Frederic Law Olmsted to design a system to address some of the water issues:

A large masonry storm-water basin has long been part of the city’s plan for the Back Bay Park. Olmsted felt that a masonry storage basin big enough to hold floodwaters from Muddy River and Stony Brook would be excessively ugly and expensive. Instead he designed the entire park as a flood storage
basin with gently sloping banks covered by marsh grasses and other plants that could tolerate changing water levels. The resulting design was revolutionary, a synthesis of environmental engineering and aesthetics. (Spirn 2000; 7)

Along with the Muddy River project, the Fens were also created as constructed wetlands to deal with water storage and pollution. The entire park system of the Fens, the Muddy River, and Jamaica Pond connects with the Arboretum and Franklin Park, making it the first metropolitan-scale park system in the United States (Spirn 2000). The Fens and Olmsted Park began as a way to address stormwater issues, and it's use as a public space and additional amenities like walking and driving paths came later.

**Water Quality**

By the early 1900s pollution accumulated in the lower Charles, now adjacent to the Back Bay neighborhood. In 1911, at the urging of landscape architect Charles Eliot, an apprentice of Frederick Law Olmsted, a dam was built in order to cut off the river from ocean tides and permanently fill the basin with water. At the time, they believed this would help address the issue of polluted mudflats as well as create a recreational area for boaters. However, the problem of pollution persisted over the next century.

As the Boston area continued to grow and urbanize, water pollution became more of an issue as more and more sewage made its way into the waterways. By the 1960s residents knew they had a problem, the small wastewater treatment plant didn’t have enough capacity. In 1965, the Charles River Watershed Association (CRWA) formed in response to public concern. The sewer system in the Boston metro area is an old one, and it was designed so that municipal waste (sewage) was combined in the same pipes as stormwater runoff. While there was a primary treatment plant, it did not have a large enough capacity to treat water during heavy rainstorms. By design, during these heavy precipitation events, untreated wastewater would be released into the rivers at Combined Sewer Outfalls (CSO). There were hundreds of CSOs all along the Charles River, Mystic River, Neponset and Boston Harbor releasing untreated sewage and runoff into the watershed.
In 1972, Congress passed the Clean Water Act (CWA) and created the Environmental Protection Agency (EPA) to administer new environmental regulations. Despite these new regulations and citizen pressure, it was only in 1983 that the Conservation Law Foundation (CLF) sued the EPA and the state of Massachusetts on behalf of the City of Quincy\(^2\) for failure to comply with the CWA. The courts ordered the EPA to enforce the CWA and remediate the watershed. It was during this time that the Massachusetts Water Resources Authority (MWRA) was created. In 1991-1995 the new Deer Island Treatment plant was built. In 1997, a secondary treatment phase was constructed as well as a 9.5-mile long discharge tunnel into the Massachusetts Bay by 2000. However, this did not improve the issue of Combined Sewer Overflows, which still overflowed in heavy rainstorms. In 1995, the EPA launched the Clean Charles River Initiative (CCRI) to address the CSO issues. This multi-partner initiative successfully cleaned up the river from grade D to grade B+ by limiting CSOs and other sources of pollution.

Under legal pressure from the EPA, both Boston and Cambridge have worked to separate their sewer systems where they can and reduce instances of CSOs from 85 to 50 (MWRA). However, they are under current order to also reduce their phosphorus Total Daily Maximum Load (TDML) into the Charles River\(^3\). This external pressure has lead to the increase in green infrastructure, including three demonstration projects by Boston Water and Sewer and the Western Ave project in Cambridge.

**Flooding**

In the 1960s, planners began to better understand the role of wetlands as a flood buffer and retention tool. In 1974, another major green infrastructure project came in the form of wetland preservation in the upper Charles. The Army Corps of Engineers purchased 8,103 acres of wetland to help store floodwaters during heavy

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\(^2\) Quincy, a city south of Boston situated on Boston Harbor, bore the brunt of the pollution and raw sewage that was released into the Harbor.

\(^3\) In 2007 Mass DEP and EPA announced targets to reduce phosphorus and other nutrients in the Charles River. [https://www.epa.gov/charlesriver/environmental-challenges-charles-river](https://www.epa.gov/charlesriver/environmental-challenges-charles-river).
precipitation, which would be slowly released into the river naturally (EEA 2011; 68). The estimated cost of protecting these wetlands was $100 million dollars (in 1974 dollars). However, it is estimated that the wetlands helps prevent $40 million in flood damages every year including downstream (Foster et al 2011; 26).

Flooding has also been an issue in Boston along the border with Brookline, where the Muddy River captures much of the runoff. The original design of Olmsted Park and Muddy River, provided both improvements to water quality as well as relief from flooding using constructed natural system. However, in the 1950s a portion of the river was covered and pushed underground to make space for a parking lot for Sears Roebuck. The pipes that held the river were not large enough to manage big rain events. In 1996 a storm caused massive flooding as the Muddy River overflowed its banks causing the Green Line Kenmore Station to be shut down and damage to the Museum of Fine Arts and the neighborhood. Over $60 million in damage was done (Brady-Myerov 2013). It took nearly 20 years of planning and negotiating to get federal, state and city agencies to agree on a restoration project that would help add capacity to the river. Part of the issue was that many different agencies and levels of government were stakeholders in this plan, including historical and environmental preservation groups, which were nervous about changes. The current plan, which has been underway since 2013 and will cost $61 million, is to daylight 700 feet of the river, do additional dredging, and plant new vegetation (Abel 2015). Ultimately, the federal government is paying for 65% of the project and it is being managed by the Army Corps of Engineers. This green infrastructure required collaboration and a lot of funding to make the necessary improvements.

Another recent controversy in Boston was the remapping of the FEMA flood zones in 2013. FEMA released draft maps in 2013, which showed 18,000 homes and 4,000 businesses in the new flood zones versus 8,000 homes and 250 businesses in the previous maps (Fernandes 2013). This would require thousands of more people to get flood insurance than previously and would increase rates for some. Residents and the City of Boston appealed the flood maps, saying that the zones were inconsistent with those modeled by a third party consultant (Szaniszlo 2014). After
the appeal, the new maps were drawn which reduced the acreage of flood-zones. These flood zones went into effect March of 2016. Despite the changes in the FEMA flood zones, these maps only show current flood probabilities and not future flood risks. The zones will only continue to increase due to climate change. This controversy points to how difficult it is to plan for flooding and engage the public in thinking about risk management.

**Iconic Place**

The ecological history of both Boston and Cambridge is intertwined with its history of land development and management. Both cities spent hundreds of years fighting against the coastal tidal estuaries, creating dams and filling them in to build developable land. The relationship with the lower basin of the Charles River, a once tidal estuary shows a complicated relationship with water. The Charles River and its subsequent success story of a remediated urban watershed is an iconic image for both Boston and Cambridge. Many area universities, including MIT, Harvard, and Boston University use the river for recreational sports like rowing and sailing. Every year, thousands of boaters and spectators take to the river for the Head of Charles River, which bring rowers from all over the nation to compete.

**Future Impacts**

This ecological history and context, continues to have an impact on the urban landscape and sets the stage for the future impacts of climate change including sea level rise, storm surge, and flooding from precipitation. The state of Massachusetts, particularly coastal areas will face a variety of climate impacts including: increased precipitation cycled with periods of drought, increased high temperature days, and sea level rise. In 2008, Massachusetts passed the State Global Warming Solutions Act, which convened an advisory committee to analyze predicted impacts and strategies for adaptation. The committee released the Massachusetts Climate Change Adaptation Report in 2011, which downscaled some of the global impacts of climate change to the areas of Massachusetts and New England. They found that Massachusetts has already experienced some climatic changes including increases
in ambient air temperature, surface water temperature, precipitation increases and sea level rise (Executive Office of Energy and Environmental Affairs (EEA) 2011). Predictions for the future were based off a range of emission scenarios, which reflects the level of uncertainty of climate risks and future impacts.

One of the main concerns besides sea level rise and temperature is the change in hydrological patterns. In winter months, the northeast will see more precipitation as rain or ice instead of snow. Under a high emissions scenario Massachusetts could see a 14% increase in total annual precipitation with a slight decrease in summer precipitation, and as much as a 30% increase in winter precipitation amounts. This means there will be cycles of extreme precipitation followed by drought in the summer months (Hayhoe et al 2006). Under this scenario, ice storms also become a huge concern due to warmer and wetter winters. The report states:

These changes in hydrologic cycles would have profound impacts on water resources, including increased flooding and polluted overflows from stormwater and wastewater systems during high periods of flow, and increased stress on surface and ground drinking water sources during periods of drought and low flow. (EEA 2011; 18)

By 2100, Boston’s current 100-year storm (1% chance in any given year) could be felt every 2 or 3 years (50% chance in any given year). In this report, the authors recommend strategies for adaptation that could use infiltration and natural systems to deal with the impacts. They call these solutions “no regrets” because no matter the level of impacts, they would still make improvements in the hydrologic system and public safety, which appeal to voters and taxpayers. These impacts could have huge implications for fisheries and agriculture industries as well as damage to roads and critical infrastructure.

Similar to the processes of urbanization that dramatically shifted the natural landscape of the region, climate change will also cause shifts in ecology and urban infrastructure. During the past 100 years, the primary challenge for water in both Boston and Cambridge has been remediating the polluted watersheds. This challenge will likely continue, however the additional challenge of water volume and urban flooding will gain importance due to climate change. It is likely that flooding
will increase in frequency and volume in locations where it already exists. Both cities are in the process of understanding the risks and hazards associated with climate change and creating plans to adapt and increase resilience.
Chapter 3: Case Studies

I chose to focus my research on the two case studies of Boston and Cambridge for several reasons including their experience and proximity to each other. Both Boston and Cambridge have had policies and plans in place since the early 2000s addressing climate change mitigation and have recently started to address climate adaptation, preparedness and resilience. In comparison to other cities and towns in Massachusetts and New England, they are considered early adapters because many other places have only just begun to address these issues. I also thought it would be interesting to see how two cities on different sides of the same watershed (the Charles River) would address issues around water and flooding. They have a shared ecological context and history of remediating the water pollution in the Charles River. They both also have emerging green infrastructure components to their stormwater management practices, so they have some experience with the challenges and opportunities associated with this technology.

However, there are also some key differences between Boston and Cambridge: they are very different in size and population; have different cultures and political perspectives; and have different hydrological challenges despite being in the same watershed. These similarities and differences made for a rich backdrop in which to analyze the research question of understanding the barriers and driver for early adapters using green infrastructure as a strategy to adapt to climate change.

The following case studies were informed by two methodologies: a review of city public documents and plans, as well as a series of individual interviews with public employees and non-profits.

An analysis of documents of practice pulled out how the cities are thinking about green infrastructure for climate change and how they communicate that to their departments and the public. Documents reviewed include Boston's *Greenovate Climate Plan*, the *Open Space Plan*, and internal Boston Water and Sewer's research on climate change. For Cambridge, fewer documents were available that covered the
intersection of topics, but the Vulnerability assessment was extensive. These documents provided contextual support for the interviews I conducted.

The semi-structured interviews were conducted in January and February 2016 using a snowball method. I first contacted municipal staff that explicitly work on water or climate change. Those contacts then put me in touch with others whose work touched on green infrastructure or could give valuable perspectives on the climate adaptation process. That question yielded more contacts in each of the city, as well as non-profits that support work regionally. A set of ten questions were asked to each interviewee; Most of the questions remained consistent across interviews, but some of the questions were tailored towards either green infrastructure or climate change depending on their knowledge and expertise (See Appendix A). Interviews were done in person when possible, with only two out of twelve occurring via telephone. Interviews ranged from 30 minutes to 1.5 hours depending on the interviewee. I took extensive hand written notes during the interview as well as recorded them for the purposes of transcription later.

After transcription I compiled all of the responses to each question and looked for common themes across the answers, as well as unique components that raised an interesting new point or perspective. While I was particularly interested in the socio-political factors, I also heard a lot about the physical and technical barriers to green infrastructure that have been well documented and researched like maintenance issues. This shows that while both academics and practitioner understand those barriers, they are nonetheless still impediments that need strategies to overcome them. This chapter describes the history of both climate adaptation and green infrastructure in both cities and the drivers and barriers to using green infrastructure as an adaptation strategy. From there, I compare the two cases to find common challenges as well as strategies each city has used to overcome them.

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4 Originally Somerville, MA was planned to be part of the case studies, but I lacked enough information and access to local planners to interview. This is indicative to Somerville being both lower-resourced and also some research fatigue on their end.
Boston, MA

Boston, MA consists of 48.4 square miles of land and another approximately 40 square miles of water. It has a population of 645,966 and an annual city budget of $2.7 billion in 2014-2015 (Boston Office of Budget Management 2014). The City of Boston is operated under a strong mayor/weak council model. The former Mayor Tom Menino and current Mayor Marty Walsh have both been proponents of climate change mitigation and preparedness. This structure has allowed them to push through strong initiatives around climate change, including requiring city agencies to think about and incorporate climate adaptation and preparedness in their planning.

In 2007 Mayor Menino issued an Executive Order on Climate Action, which focused on creating a citywide greenhouse gas inventory, reducing emissions, and implementing other sustainability efforts like recycling and green buildings. In 2011, he issued A Climate Progress, which was Boston’s first community wide climate plan. A year later in 2012, Hurricane Sandy hit the eastern seaboard which Mayor Menino called “a gut check” on the realities of climate change, had the storm hit Boston just five hours earlier during the high tide, they too would have seen greater damage like New York City and New Jersey. There was a clear and urgent need to bolster Boston’s coastal protections and preparedness. Almost immediately, Mayor Menino created a Climate Preparedness Taskforce with the directive to better understand the vulnerabilities and hazards Boston faced with climate change including. The Taskforce quickly (within 9-months) turned around a report called Climate Ready Boston Municipal Vulnerability to Climate Change outlining the major hazards and vulnerabilities to climate change. This report aggregated existing data and studies from the National Climate Assessment, the Massachusetts Climate Change Adaptation Report (2011) and studies conducted by the Union of Concerned Scientists and Boston Harbor Association.

In 2014 Mayor Marty Walsh took office and continued to build off the foundation established by Mayor Menino. That year, the city released Greenovate Climate Action Plan, a detailed plan that outlines five key priority areas for the city
including: reducing greenhouse gas emissions, promoting healthy and equitable communities, preparing Boston for the impacts of climate change, increasing community engagement, and measuring progress of all of the priority areas. Each priority is further partitioned into 35 manageable goals and 98 actions that help guide efforts across different city departments and the community. In 2015, the city hired two full-time grant funded staff to work in the realm of preparedness and resiliency. In the Office of Environment, Energy and Openspace hired a Preparedness Fellow, Mia Goldwasser, who has been in this grant-funded position since September 2015. Her role is to manage coordinate efforts across the city and manage the consulting teams. The Mayors Office has also brought on a Resiliency Officer through a multi-year grant with the Rockefeller Foundation; the main focus of Dr. Attyia Martin’s work is on social and economic resilience and has less to do directly with the climate action plan. In order to better prioritize adaptation and preparedness efforts, the city has hired a contractor to conduct an in-depth vulnerability assessment that will use localized downscaled climate data.

**Green Infrastructure**

Throughout the *Greenovate Climate Action Plan*, green infrastructure of some kind is referenced in four of the 35 strategies including: energy efficiency in buildings, protecting and expanding green spaces, and expanding access to healthy and local foods. However, the primary strategy that addresses green infrastructure is “Expand green infrastructure and ecosystem-based approaches to address climate vulnerabilities” under the climate preparedness priority (*Climate Action Plan Update, Summary Report 2014; 22*). In this section the goals include expanding GI requirements, growing the urban tree canopy, exploring a stormwater fee, using neighborhood stormwater actions, and increasing support for urban agriculture. In this instance, green infrastructure is primarily seen thru the lens of stormwater or coastal protection. However from conversations with various offices, it is also apparent that Boston does not have a formal definition of green infrastructure, at least not one that employees were aware of.
Previous research has shown that the term green infrastructure is a contested term and has definitional ambiguity (Wright 2011). This is somewhat true in Boston, as there is no formal definition across or within city departments for the term "green infrastructure". Each department interviewed seemed to have a slightly different take on the concept, yet there was enough shared understanding across the departments that this definitional ambiguity didn’t seem to impede development. In fact, everyone seemed to acknowledge the multiple co-benefits of green infrastructure even if they were most concerned with their own department's priorities. This allows for space to work together and collaborate towards each other's goals. Boston Water and Sewer's (BWS) Chief Engineer, John Sullivan, and Project Coordinator for Stormwater Management, Kate England, had the most specific definition of using natural process in the built environment to infiltrate and manage stormwater. Yet, they also acknowledged GI could be used for urban heat island effect and within a complete streets framework as well.

Boston Parks and Recreation's (BPR) Allison Perlman, a Project Manager for green infrastructure, argued that the definition of green infrastructure is evolving. That while at its basic level it's about incorporating natural elements into engineered landscapes, it's also about layering in all of the co-benefits including stormwater capture, groundwater replenishment, flood reduction, urban heat reduction, and even making spaces more beautiful and engaging. Her role at BPR is to help plan and implement green infrastructure into park renovations. In regards to climate change, she argued that green infrastructure could be viewed through the lens of making landscapes more resilient and increase adaptive capacity for both the landscape and community. In addition to these departments green infrastructure is also seen as part of the Transportation Department’s complete streets initiative to make streets more accessible to all modes of transportation including walking, biking and public transit. Transportation often works in partnership with BWS on street renovations when stormwater management is involved.
Green Infrastructure for Property Protection

One of the initial reasons for experimenting with and installing green infrastructure was to improve groundwater levels that were affecting public and private property. Many buildings in the Back Bay, the South End, and other areas of Boston are built on in-fill and are situated on wood pilings. When the groundwater level is not at a high enough those pilings are exposed to air and being to rot, which lead to structural issues of the buildings. The Boston Groundwater Trust was formed in 1986 to address these issues and has created a specific Groundwater Conservation Overlay District (GCOD) where infiltration of stormwater to replenish the groundwater is critical. The Boston Groundwater Trust, in partnership with the City of Boston, the Charles River Watershed Association (CRWA) and Massachusetts Department of Environmental Protection (MassDEP) did a “green alley” with porous pavement in Boston’s South End between West Canton and Holyoke St. The porous pavement allows the water infiltrate into a larger gravel storage area below, which then in turn seeps into the groundwater system. Porous pavement also filters stormwater naturally. The CRWA, has been a leader in the region through their Blue Cities Initiative and have partnered on several other demonstration projects in the metro area. The City of Boston has also partnered with the Boston Architectural College to install a green alleyway near their campus in the Back Bay.

Green Infrastructure for Water Quality

The primary driver of green infrastructure installation in the past few years has been ongoing water quality issues regulated at the Federal and State level. The Environmental Protection Agency’s (EPA) uses the National Pollutant Discharge Elimination System (NPDES) to regulate point source pollution discharged in the waters of the United States. It is under NPDES that Total Maximum Daily Loads (TMDLs) of various nutrients, including phosphorus is regulated. After Boston had addressed its Combined Sewer Overflow (CSO) issues, Boston Water and Sewer was conducting a study to understand other sources of water pollution entering the Charles River and Boston Harbor. In 2010, Boston was sued for non-compliance with their NPDES permit on TMDLs. As part of the 2012 consent decree with the
EPA and Conservation Law Foundation (CLF), Boston is now required to install
three green infrastructure demonstration projects to address phosphorus discharge.
These projects include green infrastructure installations at Central Square in East
Boston, Audubon Circle in Fenway, and City Hall Plaza downtown. These projects
will be done in partnership with the Boston Transportation Department because
they involve street and sidewalk improvements. This consent decree came after the
EPA’s transition from pushing grey infrastructure to acknowledging the need for
green infrastructure. While grey infrastructure is also part of the consent decree,
green infrastructure makes sense since Boston has already undergone the lengthy
and expensive process of separating a majority of the CSOs and other grey solutions
such as larger storage pipes. Green infrastructure will be less expensive and faster
to install than investing in increased grey infrastructure. However, using green
infrastructure that incorporates trees and vegetation is also be seen as a symbolic
gesture of a shift towards more environmentally sustainable practices by the EPA.
The green infrastructure in these projects will be used to filter the “first flush” which
for Boston is the first inch of rainfall in which pollutants get picked up in the runoff.
Green infrastructure will be used to both filter the runoff naturally and infiltrate it
into the groundwater system, rather than the piped stormwater system. However,
all of the systems designed by BWS have a backup overflow system if the runoff is
too much after the first inch, it will be released into the standard storm sewer
system. It has been standard practice since the 1990s to infiltrate the first inch of
water because new development or redeveloped properties are required to manage
the first inch. However, this infiltration done in the private sector was not called
green infrastructure even though it helped recharge groundwater and filter water
without treatment. Boston Water and Sewer says there are over 1,600 projects in
the database tracking this information. This is an interesting point because other
cities like Philadelphia, PA, which are seen as leaders in green infrastructure
installments, have sited similar requirements as a driver for green infrastructure.
However, in Philadelphia, those requirements on development came after the push
for green infrastructure so the solutions that are leveraged often include vegetation,
bioswales, or the very least permeable pavement. Boston’s requirement is long-standing and came before the push nationally for green infrastructure technology.

In addition to these demonstration projects, BWS has many projects in the planning phase, including an extensive stormwater model examining three tributary areas for the Charles River and Neponset, which will help prioritize future projects for the next 30 years. There is also a 75-acre gravel wetland in the design phase, and they are working with the Boston Public School Dept. to identify five schoolyards to install green infrastructure in. While Boston has been slow to start green infrastructure, it is clear that they are preparing to scale up efforts. Sullivan says that in many ways this lag was on purpose; since Boston already separated their CSOs (a primary driver for green infrastructure in other cities) it gives them a luxury of waiting to see what successes and failures other cities have with green infrastructure. This will allow them to be smarter with their investments and hopefully not make any costly mistakes. Some of the cities they look towards are Philadelphia, PA, New York City, NY, and Washington DC. However, they were also quick to point out that Boston is in many ways different from these other places, in part because of the unique soil and hydrology.

For Boston Water and Sewer, the main driver for green infrastructure has been water quality, not to address flooding or extreme weather impacts. However, they have begun to incorporate climate projections into the future planning of the sewer system. Recently, BWS conducted a Wastewater Facilities Study of the entire sewer system, and within that included an extensive chapter on climate impacts, including the increase in precipitation volumes. One of the main shifts is figuring out what the new “design storm” should be for the entire system, which is often designed to the 10-year, 24-hour design storm (10% chance) for typical drainage systems. Major structures and culverts are designs to the 25-year, 24-hours storm (4% chance of occurring). Over the past 60 years, studies have shown there has already been increase in volume for the 10-year storm from 4.8 inches to 5.2 inches. Thus, BWS has already increased their design storm to the 5.2 inches volume and 1.65 inches of peak intensity to reflect this data (Wastewater Facilities Study 7-1). By 2100 scientists predict the 24-hour event will be 6.65 inches with peak intensity of
2.11 inches/hour. This presents a challenge because there are already areas of the city that have limited hydraulic capacity for the current volume of the 10-year storm. In this report, the recommendation is to use green infrastructure and other Best Management Practices (BMPs) to add "conveyance capacity and storage [...] to prevent street flooding due to surcharge should a significant rainfall occur during a storm surge event in the future" (BWS 7-3). This is considered a “no regrets” strategy because even if the predictions fail to materialize to such intensity, green infrastructure will provide lasting public benefits and be comparatively lower cost than building additional underground storage capacity. Despite these recommendations, when asked about instances of extreme weather Sullivan was clear that in his own opinion green infrastructure won't be able to handle major storm events and was skeptical that green infrastructure could be used to add additional storage. That’s in part because he’s been focused on capturing and filtering pollution from 90% of precipitation events, which have historically been less than 1 inch. He believes that grey infrastructure will still be the primary way to drain water and address flooding issues, because it becomes less of an issue around pollution and that of public safety. However, this may be partly a case of definitional differences because the Commission is also looking at potential natural areas as retention sites for flooding, which many would consider green infrastructure. There is also an element of path dependency because more is known how to plan capacity in the piped grey infrastructure system that has been around for more than 100 years. Less is understood about the long-term efficacy of green infrastructure so it makes them nervous to rely fully on it. Similarly, when green infrastructure includes vegetation and trees, the Parks Department actually does the maintenance on the greenery, so all of a sudden you have a Water and Sewer Commission that’s used to maintaining pipes having to think about living organisms.

**Green infrastructure as Critical Landscape**

Another primary driver of green infrastructure in Boston has been around the public benefits of open green space and the urban canopy. Boston Parks and Recreation and the Office of Environment, Energy and Open Space view green
infrastructure in the broad definition of services and public benefits associated with ecosystems. These benefits may include stormwater and water quality, but also heat mitigation/cooling, air pollution, and the public health benefits associated with public recreation space. In this framework, green infrastructure is viewed as a layered system of co-benefits that are an integral and critical part of the urban landscape. Allison Perlman, a Project Manager at PRD's, was hired three years ago as part of an effort to integrate green infrastructure into existing parks and open space. One of the recent park renovations they completed was at Elliot Norton Park off Tremont St. between the Theater District and South End. As part of a larger park/playground renovation, BPR installed an area of permeable pavement and a large rain garden at that site.

While BPR are aiming to address the first inch of stormwater on-site rather than have it enter the drainage system, they are also driven by Boston’s climate action plan. Perlman said they are looking at how to add adaptive capacity and resilient design into the parks for the benefit of the community. The Open Space Plan for 2015-2021 formalizes BPR’s commitment to climate resilience, arguing that:

Bolstering the city’s green infrastructure systems can help us withstand and temper the impacts of climate change through stormwater absorption, tree canopy benefits, and walkable access to active and passive recreational facilities. Expanded open space systems can provide physical buffers to increasingly powerful storms, support systems of non-vehicular transportation, and mitigate the health risks associated with warming urban environments. Parks and open spaces are central to the future health, resilience and livability of our city. (Boston Parks and Recreation 2015; 2)

This frames green infrastructure in a systems dynamic approach where open space is conceived as a networked system of public space that can support and connect with other critical systems like transportation. By framing open space in this way, it becomes equally critical to the wellbeing of residents as other infrastructure systems. This systems approach is also crucial when preparing for climate change and increasing adaptive capacity. Open space systems can build in redundancy—when transit systems are down, having a network of walkable pathways is key to getting people around. Similarly, parks with trees and shade provide important
cooling areas for outdoor workers, those who lack access to air conditioning, or during power outages when electric cooling is unavailable.

However, Parks and Recreation has found it challenging to layer in so many expectations and needs into a single open space. A public park has existing recreational uses which may include playing fields, tot-lots, senior areas etc... to then layer in stormwater management needs, more trees and other green infrastructure technology may compete with the same limited space. The key is finding a balance between all of the needs. Ideally however, green infrastructure can be used to help meet broader open space goals laid out in the open space plan.

**Analysis of Drivers**

The initial drivers for green infrastructure in Boston have been managing stormwater (as in the days of Olmsted Park), replenishing groundwater tables, and meeting regulations around water quality. The narrative around green infrastructure as part of a critical or resilient landscape has only emerged recently as climate change issues are being recognized. The majority of green infrastructure projects in Boston were motivated by federal and state regulations requiring improvements in water quality. Despite the priorities around green infrastructure listed in the *Greenovate Climate Plan*, this document lacks regulatory or policy power. These goals are seen merely as recommendations to plan around. Additionally, the *Greenovate Climate Plan* lacks funding to back it up, so unless the green infrastructure is seen as something mandated by the consent decree it is seen as something additional to be added onto a budget for a park or street project. However, there are many green infrastructure projects in the planning and design stages throughout the watershed that BWS have determined are critical for water quality. Both stronger regulatory drivers and funding sources will be needed to scale up green infrastructure.
Cambridge, MA

Cambridge, MA is a much smaller city than Boston at 6.26 square miles and 105,000 residents. However, due to the wealth of its residents associated with the elite institutions and tech industry it still has a significant Operating Budget of $524,401,800 and an additional Capital Budget of $31,954,025 for 2014-2015 (City Manager, Cambridge). The city uses a strong council model, with a city manager. The City Manager and Deputy City Manager oversees the operations of the city through various departments including Community Development and Community Maintenance. Community Development is where most of the municipal planning occurs through the division of Community Planning, Economic Development, Environmental and Transportation Planning, and Housing Departments, while Public Works is housed under Community Maintenance.

The City of Cambridge started addressing its own impacts on climate change in 2002 when the City Council adopted the Cambridge Climate Protection Plan that focused on reducing greenhouse gas emissions at the municipal level. About five years later, several studies came out about the potential impacts of climate change including the updated IPCC Fourth Assessment Report and a Union of Concerned Scientists (which is headquartered in Cambridge) report on sea level rise (SLR). Concerned about the potential impacts of SLR the City Council realized that it was not enough just to reduce their own contributions to climate change, but they had to also prepare for the broader impacts they would face due to a global change. In 2010, the Climate Protection Action Committee recommended the city conduct a vulnerability assessment in order to better understand the city’s vulnerabilities to climate hazards. This decision was fully backed by the City Manager, Bob Healy, and the City Council. Unlike Boston, which was primarily driven by a series of extreme weather events, emerging science and political pressure from constituents drove the decision to address adaptation and preparedness. Initially, when Cambridge was creating its Climate Action Plan in the early 2000s John Bolduc, the Environmental Planner who has worked in Cambridge for close to twenty years says that the City Council purposefully left out adaptation and instead focused on mitigation because
they worried adaptation would be seen as “conceding defeat” on slowing climate change (Bolduc 2016). However, several years later they quickly realized that a certain amount of climate change was “locked in” to the atmosphere and that they had to address concerns around sea level rise and storm surge in the region.

The vulnerability assessment is an interdepartmental effort managed by Mr. Bolduc and is wrapping up this year (all the technical work has been completed). In addition to Mr. Bolduc, the advisory committee is comprised of representatives from Public Works, Community Development and Public Health. They also hired an outside contractor, Kleinfelder, and other subcontractors to do the technical support for the assessment. While Environmental Planning manages the project, it was actually funded out of the Public Works Capital Budget to the tune of $1 million. The goal is that this report will help inform infrastructure and capital planning decisions. In addition to the internal advisory committee there are also two other groups that provided input into the process: the Expert Advisory Panel and the Technical Advisory Committee. The Expert Advisory Panel consists of local climate scientists and policy experts that guided the methodology of the study. The Technical Advisory Committee was comprised of business and institutional stakeholders, as well as local residents. This process is reflective of the fact that several elite institutions are located in Cambridge with many knowledgeable and engaged locals serving on these committees. The City also hosted an extensive public engagement process including several public meetings around the results of the assessment. The city has viewed the assessment as a “climate stress test” of critical infrastructure and vulnerable populations. In 2015, when the final Vulnerability Assessment was released there were several surprising outcomes. While sea level rise was a major driver for doing the assessment, the assessment found that extended heat waves and repeated urban flooding may a pose a larger concern to city. The next phase of the process for Cambridge is to create a detailed adaptation and preparedness action plan based off the findings. The Vulnerability Assessment provides the scientific foundation for understanding which strategies to prioritize.

While Cambridge has been an early adapter to climate change and has recently made large strides in green infrastructure projects they have yet to connect
the two formally in their planning. Many of the city departments that have been involved in the vulnerability assessment process have also been involved in the green infrastructure space including Transportation, Public Works and Public Health. The *Critical Assets and Community Resources* section of the *Vulnerability Assessment* connects issues of flooding to the high volume of impervious surfaces, although since the city is just beginning to plan solutions, there is no mention of green infrastructure. Similar to Boston, Cambridge is considering changes to their design storms looking ahead to predicted shifts that will occur in both 2030 and 2070.

**Cambridge Green Infrastructure**

Cambridge has made some significant investments in green infrastructure installations in just the past few years. Unlike in Boston, where green infrastructure is part of the climate strategy and the Open Space plan, Cambridge has yet to formalize its commitment to green infrastructure. However, several key projects have been completed in the past couple of years including: the Alewife Reservation Constructed Wetland (completed in 2013), the complete street on Western Ave (completed in 2015), and the sewer overhaul in the Huron Avenue Neighborhood (near completion/under construction). These three projects represent a growing commitment to managing stormwater using green infrastructure techniques such as permeable pavement, planters, and rain-gardens.

Similar to Boston, Cambridge lacks a formal citywide definition of green infrastructure. While in Boston, this definitional ambiguity seemed to support collaboration across departments; the ambiguity in Cambridge was more evident and may pose a problem. While many interviewees sited the co-benefits of stormwater management and heat mitigation as common goals, broader sustainability efforts like energy efficiency and green building materials were also mentioned. This suggests that green infrastructure could be used as a catchall term for all infrastructure that is somehow "green" or environmentally friendly. However, others, like the Public Works Department who are primarily responsible for installing and maintaining the green infrastructure viewed it very specifically in the
realm of Best Management Practices for infiltrating and filtering stormwater. Overall, green infrastructure is viewed as a tool to layer into existing street redesign or other projects. This means that it is still viewed as an add-on where the budget and space allows, and not seen as itself as critical infrastructure. Similar to Boston, there is no complete inventory of existing or planned green infrastructure projects, although Public Works is in the process of creating a Geographic Information Systems (GIS) map layer based off what Public Works has installed.

**Green Infrastructure for Water Quality**

The primary driver for Cambridge’s recent green infrastructure installations has been around water quality and permit compliance in the Mystic River and Charles River watersheds. While pollution and CSOs were largely addressed in the Charles River watershed in the 1990s and early 2000s, CSOs remained a large issue in the Mystic River for some time. Since the mid-2000s there has been a similar push by the EPA and local watershed organizations to remediate that watershed. While half of Cambridge falls in the Charles River watershed, the northern and western half fall in the Alewife Brook which is a tributary to the Mystic River watershed that eventually flows into the Boston Harbor. This area is still under consent decree to reduce the number and volume of CSOs in this watershed from the earlier 1997 ruling. The Massachusetts Water Resources Authority (MWRA) had the goal of reducing CSO volumes in the Alewife Brook in North Cambridge by 85% (from 1997 levels) by the end of 2015. While the MWRA is responsible for complying with this reduction goal, it is up to the local municipality (i.e. Cambridge) to do the actual sewer separation. Cambridge was initially concerned about reaching their reduction goals with only grey infrastructure and wanted to take a holistic look at the area, so they proposed layering in green infrastructure into project plans. This has motivated both the Alewife Reconstructed Wetland and the Huron Avenue neighborhood green infrastructure projects.
The Alewife Reconstructed Wetland is a large-scale, 3-acre wetland, which was built in partnership and jointly funded by the City of Cambridge, the state Department of Conservation and Recreation (DCR), and the MWRA. This area was already a publicly owned space since 1900, but had fallen into disrepair. The wetland reconstruction built special holding ponds and utilized various techniques to filter out sediment and pollution naturally before the water is released into the Alewife Brook. This allowed the city to reduce the amount of stormwater runoff that needs to be piped to Deer Island for treatment. Instead, it can be treated naturally and locally, bypassing the grey infrastructure. This project was necessary for the sewer separation in nearby Huron Avenue to take place, because even with new, larger pipes the city was concerned about the amount of volume needed. On average, constructed wetlands cost about $5.00 per gallon capacity versus $10.00 per gallon of capacity for conventional treatment (Foster et al. 2011; 26). This project was a cost effective way for Cambridge to manage stormwater in that neighborhood.

**Figure 3** The Alewife Constructed Stormwater Wetland helps with flood storage, water filtration and provides recreational space in Cambridge, MA.

In 2012, the design phase for Huron Avenue sewer separation and street level improvements started alongside the Alewife project. Originally, 28 bio-basins, 22 plantings, and permeable pavement on almost every street were proposed for this area of the city. The use of green infrastructure would help the city meet its CSO
reduction goals by infiltrating and treating water where it landed, and because the streets were already being excavated for the sewer separation, it made economic sense to layer this in. Now, four years later the sewers are separated and some of the green infrastructure installations are complete (other will be completed by the end of the year). The city has also plans to install porous pavement in parking lanes throughout the neighborhood, but this is also somewhat of an experiment for the city since they have only installed porous pavement on sidewalks and cycle tracks. The parking lanes will get less use than the driving lanes, but will also allow the city to get comfortable with maintenance and understand some of the challenges of working with this type of material. They underwent extensive hydraulic and soil modeling to understand the depth of the existing water table in this area. Basement flooding is already an issue in this area, and they were concerned that infiltrating more water where it landed would exacerbate those issues. The Huron Ave reconstruction is shaping up to be a success; but Public Works employees have been careful to call this project a sewer separation project and not a flood mitigation project. Despite the added capacity, this area of the city will still experience flooding especially as climate change increases precipitation volumes.

In addition to finishing up the CSO separation, Cambridge is under similar NPDES permit for TMDL of phosphorus in the Charles River as Boston. They have a current goal of reducing phosphorus by 65%, which was one of the drivers for experimenting with porous pavement and rain gardens in the Western Ave cycle track. Permeable pavement was used on the majority of the cycle track and rain gardens and other plantings were used. This project would probably not have moved forward if Cambridge hadn't already used permeable pavement experimentally on a previous project. It was first used experimentally on a sidewalk near Hasting Square in Cambridgeport along with stormwater street tree wells for the purpose of testing its effectiveness, especially in the cold New England winters. They found the permeable pavement to be very successful and that led them to be comfortable using it on the Western Ave cycle track. The Transportation

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5 A cycle track is a bicycle lane that is separated from traffic, in the case of Western Ave it is now on the sidewalk.
Department found that on warmer winter days when snow and ice started to melt, the water would infiltrate as designed. This meant there was less build up and less need for salting and sanding on the permeable pavement. They also found this infiltration particularly helpful because a cycle track extends the width of the sidewalk, which is a long way to pitch towards a gutter. Instead, the water would infiltrate into the porous pavement of the track, helping with overall drainage of the sidewalk (Deignan 2016). This project has allowed both the Transportation Department and Public Works to be more comfortable with porous pavement technology. Unlike putting permeable pavement on the actual streets, the cycle tracks will get less wear and tear, making this investment an easy one. It also has been used in areas around large street trees, in order to infiltrate more water to support their root systems.

**Figure 4 Cycle track along Western Ave uses permeable pavement to infiltrate water.**

**Urban Forest as Green Infrastructure**

The City of Cambridge is also well known for its urban forest and street trees. The City has 19,000 public trees and a program in which residents can request a street tree to be planted in their front yard if there is no space available on the
sidewalk. Like Boston, Cambridge has areas of dense, mostly 3-family homes with narrow sidewalks. If a sidewalk is redone, it must be American Disabilities Act (ADA) compliant on at least one side of the street. This had led to some challenges around planting new street trees and also preserving existing ones. Cambridge has started to do sidewalk bump-outs in order to preserve some of the largest street trees, which not only have the benefits of soaking up water, but also of cooling the air and providing shade. Street trees also can calm traffic in neighborhoods, improve the aesthetics, and improve public health. However, the bump-outs also compete with street parking, which has become a precious commodity in the City.

The urban forest is one type of green infrastructure that is explicitly covered in the climate Vulnerability Assessment. The Assessment cites the multiple co-benefits of street trees including: reducing storm runoff, conserving energy (by reducing the need for cooling in the summer), improving air quality, reducing wind speeds, reducing noise pollution, providing wildlife habitat, increasing real estate values, and enhancing visual aesthetics. However, they also anticipate that climate change will have an impact on the tree species themselves. Street trees already face so many stress factors they often have life expectancy of 8-15 years.

**Analysis of Drivers**

Similar to Boston, green infrastructure has primarily been driven by a need to comply with federal and state water quality regulations. However, the initial green infrastructure installations began more as experimentations and small demonstration projects with which the city could learn from. There is no plan or policy in Cambridge that explicitly pushes for green infrastructure use. However, since Cambridge has still been addressing CSOs and not just TMDLs, there are more financial resources that back the CSO projects from various partners including the MWRA, which is under consent decree to ensure this happens. The timeline for this last leg of CSO separation also came after the EPA’s internal shift in 2009 where green infrastructure was recognized as a Best Management Practice. Cambridge is also well resourced financially to be able to experiment with different technologies like the permeable pavement. Since they are less financially constrained in their
capital budget, they can afford to take more risks than a department that is always concerned about costs, as BWS seemed to be. Despite all of this, the city has yet to prioritize green infrastructure as a strategy for climate adaptation.
Chapter 4: Barriers and Strategies

Barriers to Using Green Infrastructure as a Climate Adaptation Strategy

Given that Boston and Cambridge both have made significant investments in climate change and green infrastructure, it is interesting that the two have not been more connected in either planning or practice. Boston has explicitly built green infrastructure into their formal climate plan, yet in practice this connection is loose. Water quality and groundwater infiltration remain the primary drivers for green infrastructure installations in Boston. Cambridge on the other hand, has no written or explicit commitment to use green infrastructure for adaptation, but has recently installed several projects that in the long run will likely increase adaptive capacity to their city. On a cursory look, once could say this is simply a timing issue, that while the cities have started planning for adaptation they have yet to invest in actual adaptation projects on a large scale. While this is part of it, there are other socio-political factors at play that are acting as barriers to using and scaling up green infrastructure for adaptation purposes. The interviews I conducted uncovered the following barriers:

1. Path dependencies toward grey infrastructure.
2. Making decisions around trade-offs, spatially and financially.
3. Changing or unknown risk associated with climate change projections.

This chapter will provide in-depth examples of the barriers experienced by city employees working on both climate and green infrastructure.

Path dependencies toward grey infrastructure

Previous research has shown that path dependencies are an institutional barrier for using green infrastructure for climate adaptation. Path dependencies impede institutional change and adoption of new technology or ideas because they “lock institutions into fixed patterns of thinking and decision-making and can reduce their ability to adequately or meaningfully respond to new problems” (Matthews et al 2015; 160). Path dependencies can be about the physical systems and built environment; the economic systems of how cities budget; or perspectives and
values of people. Physical path dependencies occur in several ways in the cases of Boston and Cambridge; green infrastructure is still a new technology to these cities and they have concerns about the long-term efficacy and viability of the technology in dealing with the issues associated with climate change. They also are concerned with scalability and what scale is needed to address climate change. These questions are legitimate, and it is true that more long-term research is needed. However, the issue of climate change is at an unprecedented scale, scope, and acceleration that new solutions will need to emerge. At the same time, many of the impacts of climate change at the urban level will exacerbate existing issues of flooding and heat. Because of this familiarity, there is a tendency to continue to address these issues as has been done historically. This path dependency is at play with the issue of urban flooding. Boston and Cambridge are used to a certain amount of urban flooding during heavy rainstorm events and the tendency is to continue to think about how to move stormwater as quickly away from property as possible through grey infrastructure. While there has been a shift in thinking towards utilizing green infrastructure for water quality, that same shift has not happened yet with flooding issues.

However, beyond the physical system constraints, there is also a lack of openness to new ideas and technology. Many of the people I interviewed did not believe that green infrastructure was an appropriate solution to flooding issues. They believed that while green infrastructure can be used to help infiltrate the first inch and improve water quality, it did not make sense to use it for flood storage or additional capacity. By in large, many of the people I interviewed saw green infrastructure narrowly as a water quality improvement technology and not as a technology for addressing water volume. This tension arises between grey solutions and green solutions, in part because engineers and policy-makers better understand grey solutions. Mia Goldwasser, the Preparedness Fellow for the City of Boston, acknowledged that:

Grey solutions for adaptation are really powerful because people see them as a quick fix: build walls and harden the infrastructure. Green infrastructure is seen as helping infiltrate the first inch... but ultimately if the job is to protect against this amount of flooding, then green infrastructure will only help so
much. People look at it as a one-to-one, how are you going to reduce this amount of flooding? (Goldwasser 2016). Grey solutions are also sometimes better understood and easier to communicate to the public: People understand the mechanisms of walls, levees, pumping and larger pipes in protecting against flooding. When it comes to large scale flooding (not just nuisance flooding) people want to know their families and property are protected.

Planners and engineers seem more comfortable with green infrastructure managing the first inch, but do not see it is an effective solution for managing a larger volume of water. Some types of green infrastructure are better suited to managing large volumes or storing water to let it infiltrate slowly- such as reconstructed wetlands or large bio-swales that have capacity to hold water. Engineers in charge of planning and building the infrastructure are often more familiar and comfortable with grey solutions than they are with green solutions. When talking about maintaining street trees and rain gardens, John Sullivan of Boston Water and Sewer remarked, “what do we know about plants?” This makes the maintenance of green infrastructure more complicated than grey, because there are both grey components like wells and pipes that need to be cleaned regularly and pavement that needs to be vacuumed, but there are also the natural components of plants needing to be cared for. In Boston, the Parks and Recreation Dept. are responsible for all city street trees. In Cambridge, the Public Works Department maintains everything, which allows for some streamlining. One interesting point is that grey infrastructure is also often underground, out of sight and out of mind. The general public does not have to think about flooding solutions on a daily basis. Green infrastructure on the other hand, while it has underground grey components, also has above ground components that people can see and touch.

Questions around scale also play a role in the path dependency towards grey infrastructure and discomfort with green infrastructure. Cities may not know how much green infrastructure they need to install to make a significant impact on flood reduction. When asked about the challenges of using green infrastructure for climate adaptation John Bolduc, Environmental Planner for Cambridge, said:

The big question for us is how much do you have to do to make a difference, so like we have some green roofs around the city, but not enough to make a
discernable difference. Especially in mitigating higher temperatures is a green roof going to mitigate temperatures on the street? We don’t have a good enough sense of the aggregate. (Bolduc 2016)

While they recognize that green infrastructure can have a positive impact for both flood reduction and temperature reduction they are unsure how much is needed to make a large enough impact. This makes it challenging to understand the cost-effectiveness of green infrastructure as a solution and how much of an investment will be needed over time. While efficacy and scale are critical questions city planners and engineers need to answer, these questions also hinders their ability to move forward at full speed with this technology. Furthermore, it makes them reluctant to invest resources in an unknown or less understood strategy.

Navigating Trade-Offs

All decisions at the city planning level include trade-offs; limited resources and space mean that a decision to go with one project will inevitably be incompatible with an alternative project. In many cases, green infrastructure can be layered into the existing urban landscapes or public space. Other times, green infrastructure will compete with other priorities for public space like recreation, transportation, parking, or even sidewalks. Both Boston and Cambridge are dense cities, that because of their age also have areas with very narrow streets, narrow sidewalks, and shallow or non-existent setbacks. Additionally, the space underneath the street is often already used to run utility lines. The majority of both cities were built up decades ago and with recent development booms, there are fewer vacant lots or redevelopment opportunities. In addition to public space and publicly owned parcels (schools, city hall etc....) cities look for opportunities to partner with private landowners (either residential or commercial). The limited space means that the trade-offs associated with green infrastructure have become a barrier to implementation.

The streetscape is a contested space between auto-oriented transportation, other public uses and green infrastructure. Even with the adoption and transition to Complete Streets policies, both Boston and Cambridge face challenges with combating auto-centric values. One of the largest places of tension with green
infrastructure is competing with people's street parking, which is seen as a sacred, untouchable thing. Both the projects on Western Ave and Huron Ave include reallocated space and taking away space for public parking and giving that space to rain gardens and street trees. When asked about challenges with green infrastructure, Bill Deignan, Cambridge Transportation Planner said, "our biggest challenge as projects move forward is that they require a reallocation of space... There are less people parking on our streets, but it will take more than that to change their attitudes" (Deignan 2016). Even in Cambridge, where vehicle miles traveled are down and use of alternative transportation is up, residents are concerned about parking for their personal vehicles. On a cursory level, this may look like a simple trade-off caused by constrained space, however these tensions are intrinsically tied to values and expectations around the use of public space. In order for these trade-offs to be more politically palatable for residents there will need to be a shift in culture, values and attitudes.

Figure 5 Example of curb bump out for street trees in Huron Ave Neighborhood.
Limited city budgets also lead to financial trade-offs as green infrastructure is not yet seen as a critical component to many projects or is seen as something required by the EPA. When a street is being reconstructed or a park is being updated, green infrastructure gets layered in as an optional addition. Advocates for green infrastructure need to make the case for why it should be included in the budget and project planning from the beginning. In addition to making the case for green infrastructure as a strategy, advocates also have to make the case for green infrastructure for climate change. This is a challenge when those making the budget may not understand the technology or its benefits. It's even more difficult when climate change is seen as something occurring far off in the future, versus impacting residents today. Perlman, of Boston Parks and Recreation pointed to this when she said, "the challenge is making the argument for larger budgets for green infrastructure or any design that will help reduce climate change impacts and making the argument that this is a public safety issue and a long-term goal (for the city)” (Perlman 2016). Climate adaptation has been made a priority by the city, but that doesn’t mean the funding has been attached to it yet. That means planners are put in the position of being advocates for green infrastructure and making the case to the budget offices why there is a need for it.

Luckily, much has been written about the cost effectiveness of green infrastructure and value of public parks. In 2008, the Trust for Public Land released a report called “How Much Value Does the City of Boston Receive from its Park and Recreation System?” TPL concluded that parks and recreation facilities increase property values by $8.3 million in 2007. They also attached monetary values to the clean air, clean water, tourism, direct use, health, property values and community cohesion benefits Boston receives from its park system. Environmental benefits of water pollution reduction were valued at $8.7 million in 2007. They found that Boston parks are 76.7% pervious surfaces compared to the rest of the city, which only has 34.9% pervious surface area. A large amount of value capture is available in the parks system. Another study released by the Center for Clean Air Policy in 2011 called “The Value of Green Infrastructure for Urban Climate Adaptation” evaluates the performance and benefits of green infrastructure solutions and compares many
of them to the typical grey infrastructure. They present examples from Portland, OR, New York City, NY and Chicago, IL as cities that have been able to save money by installing green infrastructure. The full monetary benefits of green infrastructure can be difficult to quantify because of the myriad of co-benefits and also the benefits of things like “community cohesion” in the TPL report, which are not naturally monetary. These types of studies help make the financial case for green infrastructure and take the conversation out of the realm of zero-sum trade-offs.

**Risk Now and in the Future**

One thing that is unique about climate change in particular is the changing levels and understanding of risks and hazards. In planning, the long lifetime of infrastructure means that planners often are making decisions today that will affect future residents. This has been fairly reasonable when risks around hazards and other impacts have been pretty stable. Now, risks associated with climate change are changing making it very difficult to plan for. Some cities rely heavily on technical and scientific data to try to determine exactly what this risk will be. However, with climate change there is a lot of shifting probabilities that come from differences in emission scenarios and incomplete scientific understanding of how complex systems (i.e. global hydrology, accelerated melting of ice caps, etc.) interact with each other on a warming planet. Cities have to operate with the best available data and ultimately make informed decisions on which scenarios and data to use based on what risks decision makers and residents can tolerate.

Shared understanding of climate impacts is critical to building a collective strategy for solutions. One thing happening in the Boston Metro region is a collaborative process to create a localized standard of climate models including sea level rise, storm surge and precipitation driven flooding that everyone can use. There is a recognition at the local, regional and state level that Boston, Cambridge and various state agencies like MassDOT should all be using the same data and models to base standards on. The process of determining the new design storm to build towards is ongoing.
Another element to risk assessment is the obligation to protect vulnerable people. Yet, it can be difficult to make the case to start building infrastructure now that will address the 100-year storm of the future, when people are already experiencing flooding with the 10-year storm today. However, what we do know is that climate change will exacerbate existing conditions, so that areas that flood now will flood more in the future, and additional new areas will experience flooding. Green infrastructure can be useful in helping to address these issues now, while building adaptive capacity and resilience for the future. However, there still seems to be a lack of urgency around implementation of adaptation projects. Part of this stems from need to do the vulnerability and planning stages first, and another part is that climate change impacts are still viewed as something that will happen in the future, not now.

**Strategies for Overcoming Barriers**

In addition to the barriers and challenges Boston and Cambridge have faced, this research also illuminated several strategies they have used to overcome barriers. Barriers are defined as obstacles or challenges that can be overcome with “concerted effort, creative management, changes of thinking, prioritization, and related shifts in resources, land uses, institutions, etc." (Moser and Ekstrom 2010; 22027). Both Boston and Cambridge have used adaptive learning and learning networks as a strategy that create new knowledge and modes of thinking. Additionally, both cities have collaborative processes that have reduced the siloing effect often seen in planning.

**The Role Adaptive Learning and Knowledge Networks**

The challenges of efficacy over long term and scalability fit into a path dependent model, where both municipal workers and decision makers are more comfortable with the protections that grey infrastructure provide. In Bidwell et al. 2013 commentary “Fostering knowledge networks for climate adaptation” the authors argue that planners need to accept some level of uncertainty with future climate predictions and instead use adaptive risk management (ARM) techniques
that will allow decision-makers to move forward with adaptation strategies. In ARM actions are based off best available date, but then through a process of tracking, analysis and learning, those actions will be altered and tweaked as new information becomes available. However, the challenge with ARM is that often decision-makers and scientists (who can help provide new information and analysis) are disconnected from one-another. Bidwell et al recommend creating “knowledge networks” between scientists and decision-makers to enhance social learning. They are quick to point out that “in climate adaptation, knowledge about the values and political calculations of policymakers can be as important as that about physical and ecological processes” (Bidwell et al 2013; 610). Cambridge has a robust knowledge network, which has been formalized through their vulnerability assessment processes and advisory committees that bring together experts, residents and policy-makers. There is also an emerging knowledge network regionally, in which city governments, non-profits and state agencies have come together to determine new standards for design storms and ensure that data is being shared at a regional level.

In the case of Boston, they are simultaneously looking to see what challenges early adopters like New York, Philadelphia, and Washington, DC are facing as they scale up their green infrastructure while also acknowledging that their city is different (soil types, hydrological, water table depth etc....). Learning from others is one-way cities may ultimately overcome their path dependencies. As Sullivan says, “Everyone has high hopes, but not everything works. We could let them (other cities) do it and learn from their mistakes and not have to spend a lot of money on it so we were lagging on purpose.” However, they can only learn so much from other cities, where the urban landscape, hydrology, and soil profiles are different. Boston is undergoing a process of installing three demonstration projects and looking at several more for water quality. They have purposefully hired three different consulting firms on these projects in order to maximize their own learning of new techniques and strategies. This will help them better be able to conduct a cost-benefit analysis so that the city can maximize their benefits for the least amount of money. Unlike other cities who advertise their green infrastructure, Boston Water
and Sewer is hesitant to do a large public engagement campaign for fear that residents will begin to request green infrastructure that the city can’t afford. When asked when they might start to advertise their work, Sullivan said it would most likely be rolled out with a larger plan to begin a municipal storm water utility, whereby landowners are charged a stormwater fee based on their impervious surface area. Other cities, like Philadelphia, have used this type of fee system to incentivize the private sector to reduce impervious surface as well as provide a revenue stream for public installments of green infrastructure.

Partnerships with non-profits have been a critical piece of learning and developing knowledge networks. The Charles River Watershed Association (CRWA) has played a critical role of cleaning up the Charles River and in local conservation in general. In 2005 they started researching green infrastructure for water quality and in 2008 they launched their Blue Cities Initiative. Pallavi Mande, Director of the Blue Cities Initiative, says CRWA looks at the watershed through a “water-centric urban design” lens that focuses not just on water quality but on a process of bringing in principals of urban development and how to “retrofit the watershed” (Mande 2016). As a watershed organization they work with both Boston and Cambridge and try to be a resource to both cities to make sure they are on the same page in terms of climate models that effect the Charles River Basin. In the specific area of green infrastructure, they aim to infiltrate and treat the first 1.5 inches, but also look for storage and volume reduction opportunities wherever possible. CWRA partnered with Boston on the first green alleyway mentioned in the case study, and has plans for several more green infrastructure projects.

Another partner who has been key to developing a deeper understanding of green infrastructure and climate change is the Trust for Public Land (TPL), which is a national non-profit with a local office in Boston. TPL has worked with the Metro Mayor’s Coalition (a local regional planning council) and the Metropolitan Area Planning Council (MAPC; a state regional planning agency) to create a Climate Smart Cities mapping tool. This tool will help local municipalities and nonprofits identify area for various green infrastructure and sustainable projects that will help connect, absorb, cool, and protect. Darci Schofield, who runs the Climate Smart Cities
program in Massachusetts and Rhode Island shared a holistic vision for how GI, can be used as a climate adaptation strategy:

What we want to do is help thinking about multi-benefits solutions with green infrastructure with climate resiliency. It’s not just about planting a rain garden; it’s about activating a space and getting a community together. And having a thoughtful conversation about what are some of the issues surrounding the neighborhood: Is it heat? Is it asthma? Is it air quality? Flooding? Health? How do we connect people to the land? How do we get people engaged in thinking about this space in an urban environment and educate those communities about the challenges we anticipate climate change. (Schofield 2016) In this perspective, green infrastructure isn’t simply just another piece of infrastructure, but also a valuable tool for engaging the community in urban planning and understanding the local perceptions and priorities regarding climate change. The interactive GIS decision-support tool they have created helps facilitate these conversations by layering together hazards with vulnerable populations and infrastructure to help cities identify areas where green infrastructure is needed. Boston is the third city to get this tool, and it has been used in Chattanooga, TN and New York City, NY. TPL’s goal is to provide the Climate Smart tool to municipalities and non-profits in order to help make decisions about prioritizing areas where investment in green infrastructure will make the biggest impact on vulnerable populations and ecosystems.

Collaboration

Cambridge and Boston are addressing these issues in similar ways, which include collaborative efforts across departments as well as engaging the public in their communities. This indicates the need to re-conceptualize public space as well as the benefits of collaboration between various departments and partnerships with the private sector. The pursuit of green infrastructure provides a unique opportunity to break down siloes in public government. As Darci Schofield, of Trust for Public Land said: “We all have to fulfill our job descriptions, but it’s a process of breaking down those barriers” (Schofield 2016). She acknowledges that everyone has their own departmental priorities they are responsible for carrying out in their work, but also that it is possible to come together around common goals.
The interdisciplinary nature of green infrastructure projects makes it necessary for these departments to work together. A street project that installs green infrastructure for stormwater may involve BWS, Transportation and Parks and Recreation. In fact, it is easier to make the argument for investing in green infrastructure when you can point to all of the various benefits. In Boston, one interviewee described the relationship between departments like that of a family, “sometimes you fight, but at the end of the day you’re all on the same page.”

Similarly, climate change is forcing city departments to work together collaboratively to identify collective vulnerabilities and potential solutions. In the City of Cambridge, most of the interviewees had been working for the city for around 20 years. They have a long history of working together and building trusted relationships, so building a collaborative team to address climate change was normal practice. Since Cambridge is a fairly small city, all projects usually involved various departments. Transportation planning may spearhead the project in the design phase, but Public Works will implement it. Public Health is often called in to support community engagement and respond to any issues that arise. A few of the departments interviewed prioritize public engagement with their projects, most notably Boston’s Parks and Recreation Dept. and Cambridge’s Transportation Department. They see public engagement as critical to every project they are implementing and the best scenarios include engagement from the design phase through implementation. For example, BPR found that community engagement is critical to understand localized impacts that may not be captured by scientific models, data, or scientific experts. Local residents, especially long-term residents, will have a richer understanding of localized flooding impacts and changes over time.
Conclusion: Implications for the Future

The cases of Boston and Cambridge provide a view of the drivers, barriers, and potential strategies for utilizing green infrastructure as a tool for climate adaptation. While both cities have recently started to scale up green infrastructure and both are under-going climate adaptation planning processes, the two concepts have not been fully married together. This is in part because the primary drivers for green infrastructure in Boston and Cambridge have largely been for them to address water quality issues that they are required to do under the mandate of the EPA. This follows trends seen across the country, where water quality issues and regulations have largely driven cities leading in green infrastructure such as Philadelphia, PA. There is not yet a similar regulatory framework for climate adaptation at the national or state level, which would push green infrastructure. The climate work of Boston and Cambridge has largely been driven by internal leadership and a growing recognition of climate impacts; however, because of absence of regulations there is a lack of urgency in project implementation.

While the drivers for green infrastructure as climate adaptation strategy are few, the barriers are high. My research and analysis focused on a socio-political framework to better understand how norms, roles, and leadership effect the implementation of green infrastructure. Three barriers and themes that emerged for both Boston and Cambridge were:

- Path dependencies towards grey infrastructure
- Understanding trade-offs and decision-making
- Understanding changing risks and risk management

At the same time, there were also commonalities between Boston and Cambridge in beginning to overcome these barriers including:

- Use of learning and knowledge networks
- Use of collaboration and partnerships

These findings continue to build upon a body of knowledge for both researchers and practitioners interested in climate adaptation planning. While green infrastructure seems to be a no-regrets policy decision for starting to address climate change, it has yet to be
formally linked and scaled up to meet adaptation goals. The path towards climate adaptation will be a difficult one especially if no strong regulatory or financial drivers exist. However, these cities are starting to develop strategies to overcome common barriers against implementing green infrastructure for climate adaptation.

**Recommendations for Other Municipalities**

Despite these challenges, Boston and Cambridge provide useful examples and strategies for overcoming barriers that other municipalities can learn from and build upon.

1. **GI provides an opportunity to find collaborative solutions**

   Green infrastructure in the realm of climate change adaptation provides an opportunity for municipalities and even regions to break down siloes between departments. The multiple co-benefits associated with many types of green infrastructure means that it can help bring together folks working on water, parks and open space, transportation, public health and more. Climate change presents a unique and unprecedented challenge, in that it will impact all systems of society in a complex and interconnected way. Green infrastructure, because of its many co-benefits and ability to address multiple issues, provide a useful lens and framework to address issues in a holistic way and break out of siloed thinking. Green infrastructure installations necessitate collaborative planning and decision-making. This also opens the potential for regional collaboration, public-private partnerships and work with local non-profits.

2. **Local learning helps people get comfortable with the technology**

   As early adapters they have both invested a lot of resources, time and money towards understanding their city’s vulnerabilities both in terms of critical infrastructure and populations. This has allowed them to lay the groundwork for their adaptation planning. However, *Greenovate Boston* also shows that cities do not need to have completely downscaled data to begin to set priorities for climate change. In many cases, such as urban flooding, city workers and residents already
know where the recurring flooding happens, as well as other hazards. Cities should work to address those now.

For green infrastructure specifically, Cambridge, MA has done a good job of layering in green infrastructure at varying scales and typologies across the city. This has allowed them to test new (to them) types of infrastructure and learn what works and what doesn’t work. Again, their water quality permits were the biggest driver of installing green infrastructure, but they’ve also found that places like the Alewife Wetland is now a valuable community amenity and a huge selling point for developers in that region. Boston’s approach has been slightly different, which is to focus on a subset of demonstration projects and working with several different consultants. Similarly, they are trying to learn as much as possible what will work for them.

3. Be prepared for the opening of policy windows:

While both Boston and Cambridge had set policies and plans around climate change since the early 2000s the experience of Superstorm Sandy forced the urgency of the issue. Since both cities had laid the groundwork for climate change planning, they were able to use the moment when natural disasters and flooding was on people’s mind to prioritize climate adaptation. Unfortunately, the public’s memory is fairly short, even when it comes to horrific disasters, so being able to build momentum when you can is critical. Policy makers and planners should be ready to capitalize on these events in the aftermath and build back stronger, but also funnel funding and resources into adaptation and resilience.

Recommendations for Boston and Cambridge

As Boston and Cambridge look to scale up their green infrastructure for both water quality and climate adaptation purposes they will likely have to develop new incentives for both public and private installations. There are several ways they can start to build momentum and develop these incentives:

1. Implement a Stormwater Utility
Many municipalities who are scaling up their green infrastructure are implementing a Stormwater Utility or Stormwater Fee in order to incentivize reducing impervious surfaces. Stormwater Fees redistribute more equitably the costs of stormwater management, so that those with more impervious surfaces will pay more for stormwater management (instead of being based on water usage, which typically has no bearing on stormwater). Both Boston and Cambridge should consider implementing this type of fee structure and explicit incentives for property owners to install green infrastructure on private land. This will give the municipalities revenue to build GI as well as give incentives to property owners.

2. **Start a Public Awareness Campaign**

One important step towards implementing a Stormwater Fee would be to build public support for it. The city should work with local non-profits to build a public awareness campaign around stormwater, climate change and potential solutions, like green infrastructure. Both cities should consider installing attractive signage at their green infrastructure sites, so the general public starts to understand what is happening. Boston’s Green Schoolyard projects and curriculum will be a great way to get school children and their parents involved. Both cities should get credit for the good work they are doing, but few people are aware of it.

3. **Track existing Green infrastructure projects across the city**

Both cities seem to be headed this direction, but it’s critical for cities to have good data and tracking of the existing and planned projects. Since various departments, non-profits, and other institutions have installed green infrastructure there is not comprehensive inventory that is easily accessible. A comprehensive inventory will help the cities track and learn from their projects over time, and help build awareness.

**Future Research**

There is a growing interest among city planners to utilize green infrastructure as a strategy for climate adaptation, but more research and data is
needed to help cities make informed decisions. More research is needed in the United States about what cities are already doing on this front and what successes have occurred. Climate change adaptation specialists should continue to look towards Europe, Australia and Asia where there is leadership on green infrastructure research. However, the United States provides a diverse set of ecological contexts as well as governance contexts, so we should continue to enlarge a US framework for research as well. On the technical side, more scientific modeling is needed to prove that green infrastructure can be scaled up to significantly reduce flooding, reduce air temperatures, and provide other climate benefits. Until that data is available, city engineers will still be hesitant that this is a solution that can work.

A large area of study that this thesis only touched on is the financial incentives and funding mechanisms needed for climate adaptation and green infrastructure. Lack of funding, or viewing green infrastructure as an extra spending line-item rather than critical infrastructure has been a challenge. Green infrastructure is still often seen within a narrow view of economic trade-offs. Yet, research shows that park systems and other green infrastructure can save money, increase property values and raise revenues. Beyond the Stormwater Fee model, there are other possible funding models that could tie green infrastructure with land use and development. Areas to explore in the future would be looking at what it would mean to create special climate districts or Tax Increment Financing districts where improvements to infrastructure could generate additional tax revenue for cities to pay for the infrastructure.

Linking climate adaptation, green infrastructure, spatial planning and land use will be a critical area of research in the near future as cities begin to grapple with these challenges. Planning mechanisms like zoning and building guidelines can be used to incentivize private developers to use green infrastructure, for instance giving a developer a FAR bonus for installing green infrastructure. Regulations, like the current water infiltration requirements on new development could be expanded and encouraged to use green techniques. Ultimately, with flooding issues cities will have to deal with tough issues of what is allowed to occur in flood zones. While this might not be a challenge for the next 15 years, it is certainly coming with climate
change. Cities should start research now how to manage development and retreat in flood zones and better regulate land use and impervious surfaces.

Ultimately, climate change will be an "all hands on deck" issue for urban planners. These case studies of Boston and Cambridge provide one look at how cities are beginning to grapple with the impacts and potential solutions for climate impacts. Water issues (from pollution, to drought, to flooding) will continue to grow in importance as climate change and increasing urbanization shift hydrological patterns. While more needs to be understood about green infrastructure and how to get it to scale, it provides a useful opportunity for researchers and planner to understand adaptation planning.
Bibliography


Appendix

Appendix A.
Interview Questions

1. What is your role at [city/dept.] and how long have you been in that role?

2. How does your office define green infrastructure?

3. What types of green infrastructure projects exist or are being planned in [city]?

4. If climate oriented: What were the primary reasons for [city] to start planning for climate change adaptation and resilience?

5. If water oriented: What motivated [city] to start using Green Infrastructure?

6. Does your office look at extreme weather, like heavy rainstorms and precipitation, when planning and implementing green infrastructure?

7. Does your department consider changing weather patterns due to climate change when planning and implementing green infrastructure?
   a. If yes, what types of information or models does the city use to plan for future risks?

8. How does your department interact with those planning for climate change and other departments? How are decisions made?

9. What have been some of the challenges to implementing green infrastructure? What about in relationship to climate change?

10. Is there anything else important that we have not covered yet?

11. Is there anyone else you think I should talk to?