Critical Assets & Community Resources

CCVA

Climate Change Vulnerability Assessment

November 2015

City of Cambridge, Massachusetts

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For more information on the project, please visit the City's website at
http://www.cambridgema.gov/climateprep

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Executive Summary

In order to access the impact of climate change to the City of Cambridge, it was necessary to develop a compilation of critical assets and key community resources that would be assessed during the vulnerability and risk analysis. Key assets were determined based on their contribution to the overall functionality of the City as a whole and the level of consequence if they were to fail. Examples of critical infrastructure include electrical substations and hospitals. Key community resources were identified as those populations which might be particularly vulnerable to climate change (for example, the elderly and people living in poverty), as well as key facilities which supported the well-being of the community, such as daycare centers and affordable housing. A key finding of this report is that the City's infrastructure and social networks extend beyond the City's limits and will require engaging in regional coordination with key stakeholders.

The listing below represents the key systems and resources that were included in this analysis. A detailed discussion of each is included in the subsequent narrative.

Statement of Purpose

The City of Cambridge is poised to face the complex challenges presented by climate change. For over a decade, the City has been developing strategies and policies to reduce Cambridge's emission of greenhouse gases that contribute to climate change. Climate change science continues to reveal multiple lines of evidence that the global and U.S. climate is changing and the incidence of extreme weather events is increasing. For this reason, the City of Cambridge is undertaking a multi-faceted project to help prepare for climate change in our community. This project has two phases: first a vulnerability assessment; then a preparedness plan. The research and analysis effort for the vulnerability assessment is to be completed in 2015, and the preparedness planning phase is to start in 2015.

An evaluation of the City's vulnerability to local-scale impacts of climate change begins with an assessment of present resources, infrastructure, and most importantly, community resources. The report comprises a detailed review of the systems making up the built environment or City infrastructure and the facets of the local social environment, including its organizational landscape, municipal and physical resources, and finally an exploration of its rich social fabric.

The built environment section of the report focuses on identification of critical components that are integral to the normal function and support of the various systems of the City's infrastructure. Six major systems were studied for the built environment including: Energy, Transportation, Water, Telecommunication, Critical Services and the Urban Forest.

The City also studied the social environment including community resources to gain insight into social support structures. As a first step, the team focused critical affordable housing (focusing on the ones with larger number of units), schools, daycare centers as well as food shelters and pharmacies. Other municipal resources were also included and will be carried through the risk and vulnerability assessment.

This report provides an overview of the key feature of each of those systems and resources by documenting maps showing geographic extents and other important information such as ownership, type of facility etc., as well as readily-available information on key interdependencies among the various systems and facilities. This prioritized information identifying the City's key assets and resources will constitute the basis for conducting the vulnerability and risk assessment.

Key assets and vulnerable populations identified in this report will be ranked according to their exposure to a pre-identified climate change impact. Their sensitivity and adaptive capacity will be evaluated using qualitative and quantitative techniques to facilitate prioritization of planning areas for the City that will inform the Preparedness Plan.

The Built Environment

The overall functionality of a city is necessarily tied to its infrastructure, much of which is out of public view, or simply goes unnoticed until it ceases to function. Until now, infrastructure design guidelines have been based on past weather patterns and events. What happens when these trends change? Is the infrastructure sufficiently resilient to withstand changes? The following section outlines the key systems, assets and critical services that are analyzed as part of this study.

Energy

Energy drives the systems and services that support societies in the developed world, particularly in urban settings such as Cambridge. Without it, cities cease to function as designed, and populations become both physically and virtually stranded. Hurricanes Sandy and Katrina offer examples of just how fundamental and far-reaching that dependency can be.

After Hurricane Sandy, many customers in New York City remained without power for more than two weeks.[1] The failure of emergency back-up systems proved to be catastrophic for vulnerable populations, key industries and less obvious resources such as research labs, where thousands of lab animals perished representing decades worth of research. The reasons for the failures were complex and often interdependent, ranging from direct impacts to the energy system itself (e.g., felled wires), to flooded back-up power supplies and an inability to get liquid fuels onsite to power those systems that were still functioning. Both hurricanes resulted in significant and widespread damage and highlighted key vulnerabilities that will help Cambridge in identifying critical vulnerabilities and opportunities for resiliency.

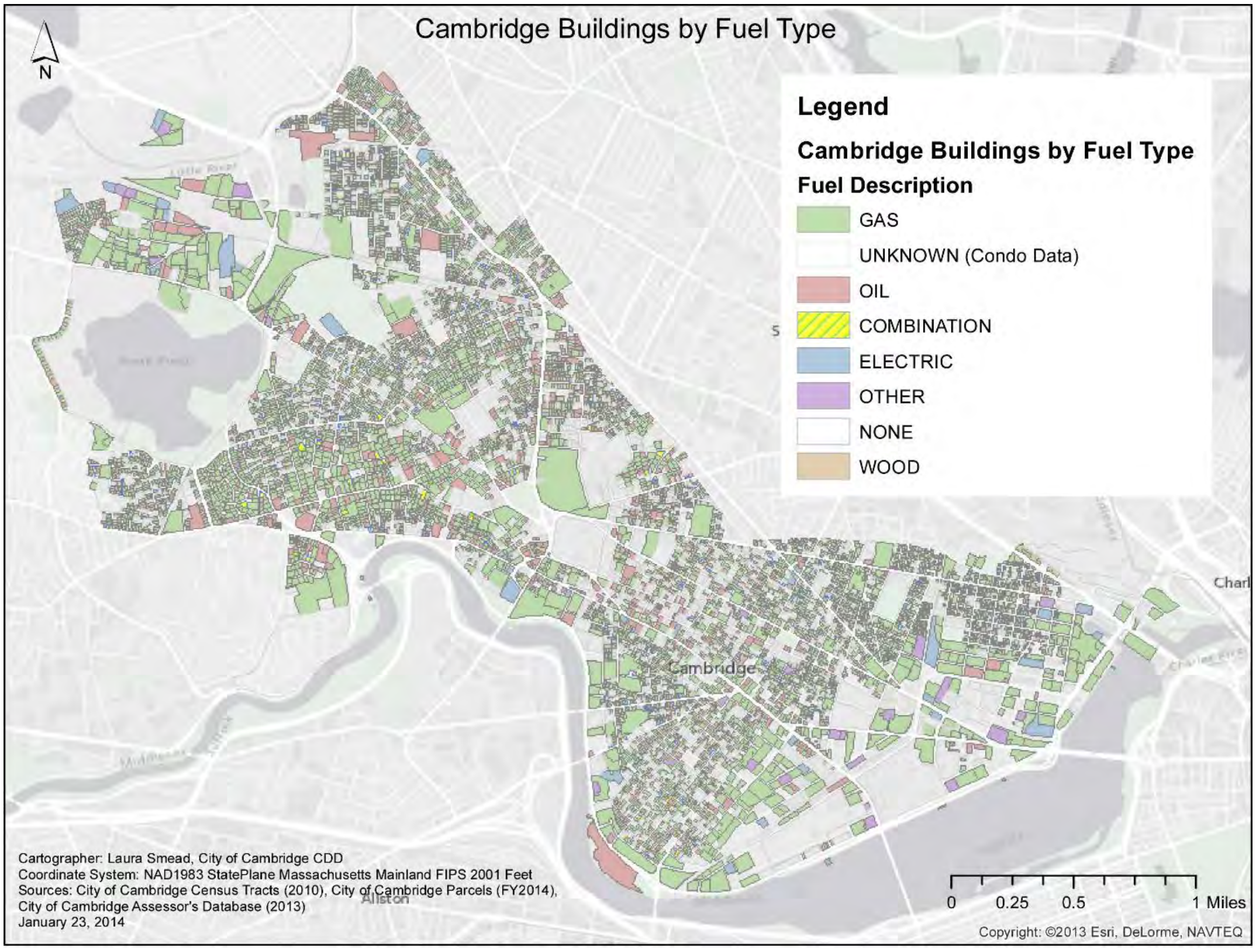
In Cambridge, there are four major sources of energy: electric power, natural gas, district steam and liquid fuels. Renewable energy plays a minor role with respect to the City's overall supply and demand, but it is considered here since both the Commonwealth and the City have recognized the need to further develop these sources of energy[2].

Key Energy Systems in Cambridge that are Part of this Assessment

- Electricity
- Natural Gas
- Steam
- Liquid Fuels
- Renewable Energy

[1] Source: PlaNYC A Stronger, More Resilient New York. Chapter 6: Utilities. http://www.northeastern.edu/kostas/wp-content/uploads/2013/08/Website-Version-2.pdf

[2] In 2008, Massachusetts enacted critical legislation that boosts energy efficiency and encourages investment in renewable energy. Known as the Green Communities Act, this law includes a number of provisions that are making Massachusetts a national leader in clean energy technology. It requires that 15 percent of electricity be supplied by new renewable power facilities by 2020. http://www.clf.org/our-work/clean-energy-climate-change/energy-efficiency/green-communities-act-ma/



Map E.1 Buildings by Heating Fuel Source, City of Cambridge [3] [4]

The City has documented the sources of heating fuel used by various buildings within the City (see Map E-1). This study will highlight the potential vulnerabilities to climate change of the different energy systems to allow the community to begin to prepare for potential changes in the predictability and functionality of those systems – both during extreme events, and for potential cumulative future impacts.

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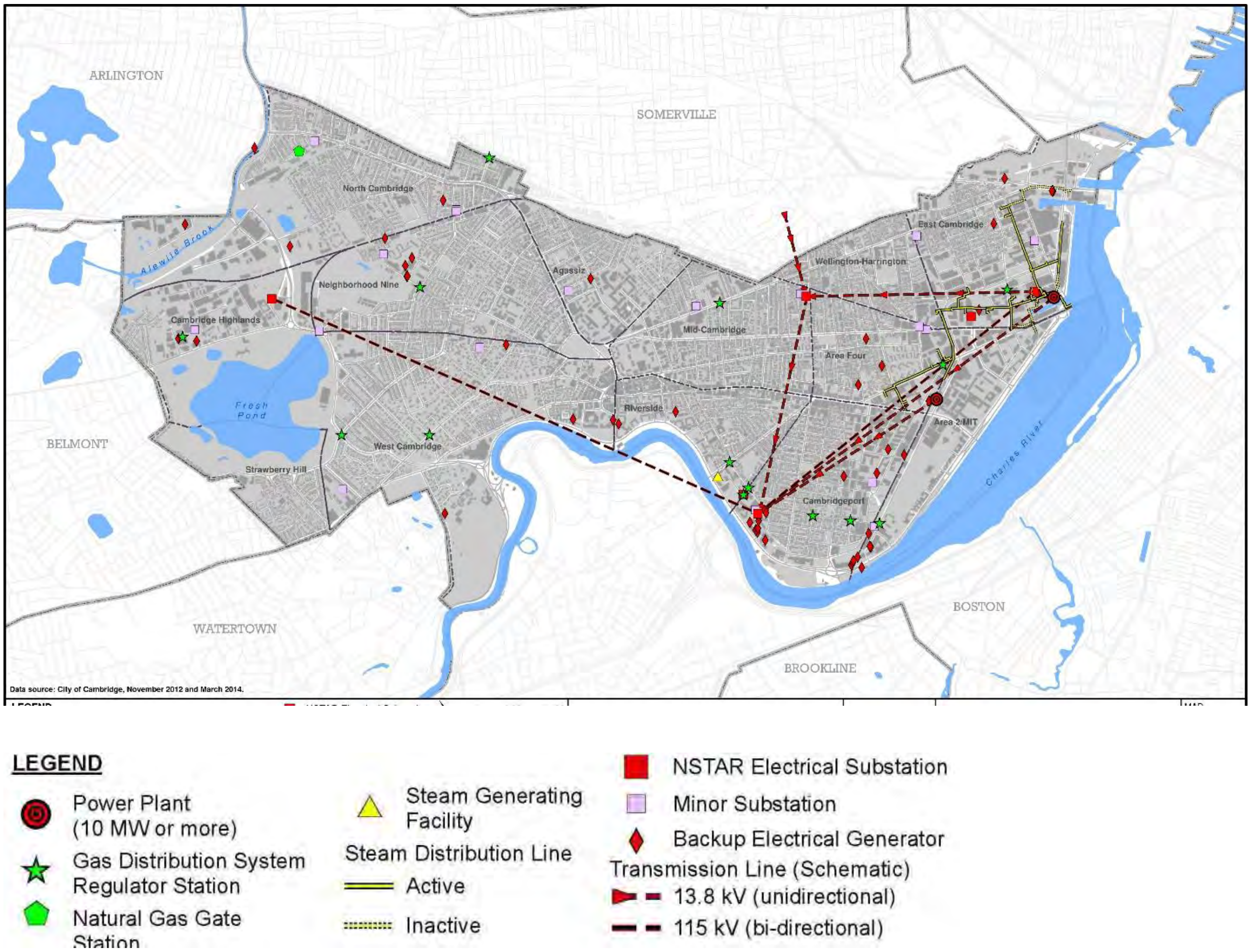
[3] Source: City of Cambridge Assessors Data, January 2014. Using FY2013 Cambridge Assessor's Database (residential, commercial, condo main and condo unit) "None" and "Unknown" are buildings with missing data for recording fuel type. Fuel used by non-profit institutions is not included as the Assessor's Database excludes tax-exempt properties.

[4] It is important to report that all buildings use more than one form of energy. The classification is for the main source of energy.



Map E.2 Energy Infrastructure Systems, City of Cambridge[5]

Electricity

The electrical grid is comprised of three major components: generation, transmission, and distribution. Electricity is generated in a variety of ways. Most of Cambridge's electricity is generated outside the City limits at natural gas or coal fired fossil-fuel plants and nuclear power plants. Eversource (formerly NStar) is the sole commercial distributor of electricity to Cambridge and is responsible for both transmission and distribution. A major local source of electricity is the Mystic Generating Station in Charlestown, a natural gas and oil fueled power generating plant,

[5] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012), Mass GIS and Eversource Electric Company (2004). System Impact Study Prepared for the NEPOOL Transmission Task Force. Online at: http://www.iso-ne.com/committees/comm_wkgrps/relblty_comm/relblty/mtrls/2004/jun212004/A3-2_EastCambSub.rpt.Complete.061504.pdf

which has a net summer capacity of 1,968MW. This is the largest active plant in Massachusetts. While it can sustain scheduled outage, in the case of extreme weather event, the failure of this plant would impact Cambridge.

Cambridge has one power plant that supplies electricity to the distribution grid: the Veolia-Kendall Station cogeneration plant[6]. This plant has a net summer capacity of 238MW and is fueled by natural gas or oil. In addition, the Massachusetts Institute of Technology (MIT), Harvard University, and BioGen own privately-run cogeneration plants that supply a portion of their respective electricity needs. MIT is able to produce about 20MW, and Harvard and Biogen[7] each have 5MW cogeneration systems for electrical power. There are an unknown number of small cogeneration units around the City, including at Watermark, 808 Memorial Drive, Cambridge Rindge and Latin School, and Iggy's Bakery. These cogeneration plants combined meet approximately 10% of Cambridge's electricity demand. As shown in Figure E-2, power plants producing 10MW or more are mapped: the Veolia, Kendall and MIT power plants.

To transmit electricity from generation plants to the transmission grid, it travels through a step-up transformer that boosts voltage to 400,000 volts. This allows electricity to be transmitted more efficiently over long distances.

Power lines transmit electricity into substations where step-down transformers change the very high voltage electricity back into lower voltage electricity[8]. Cambridge has four key substations located in North Cambridge, East Cambridge, Prospect Street and Putnam Avenue[9]. Electricity from these substations powers all facilities and systems including residential, commercial and

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[6] Cogeneration is a high-efficiency energy system that produces either electricity (or mechanical power) and valuable heat from a single fuel source. Cogeneration is sometimes known as 'combined heat and power', or CHP. It offers major economic and environmental benefits because it turns otherwise wasted heat into a useful energy source. This greater efficiency means carbon dioxide emissions are cut by up to two-thirds when compared with conventional coal-fired power stations. http://www.energy.nsw.gov.au/sustainable/efficiency/cogeneration.

[7] Biogen has on-site CHP plant to serve six buildings with electricity and five with high-pressure steam. This plant was completed in 2006. Today, the operation of the 5 megawatts (MW) of CHP capacity and 1 MW of back-up power capacity at Biogen Idec's Cambridge campus provides energy for its entire thermal load and for the majority of its electric load. http://www.sustainableplant.com/2012/06/cogen-forms-backbone-of-energy-strategy-at-biogen-idec/?show=all

[8] A substation is a part of an electrical generation, transmission, and distribution system. Substations transform voltage from high to low, or the reverse, or perform any of several other important functions. Between the generating station and consumer, electric power may flow through several substations at different voltage levels. Substations may be owned and operated by an electrical utility, or may be owned by a large industrial or commercial customer. Generally substations are unattended, relying on remote supervision and control. *http://en.wikipedia.org/wiki/Electrical_substation*

[9] Additional discussions with Eversource will be required to determine the degree of interdependency among these four (4) substations.

public services. The voltages typically range from 110 to 220 volts for residential use, with higher voltages for industrial, commercial and other uses.

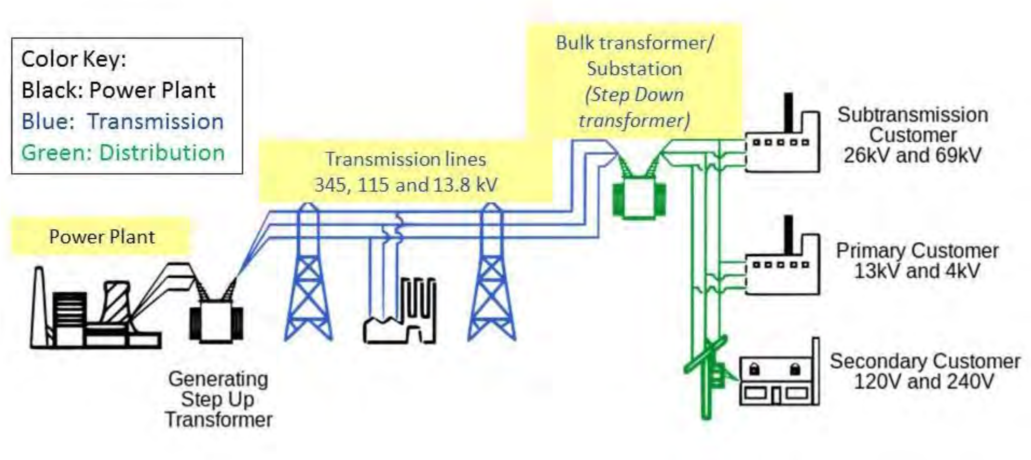

Figure 1: Diagram of Electricity Generation, Transmission, and Distribution[10]

In New England, major power generation, transmission, and distribution infrastructure is interconnected, forming a regional network, or grid. In theory, electricity supplied by a power plant at any point on the grid can be consumed by an electricity customer at any other point on the grid. However, some zones, such as the one Cambridge is in, are constrained in their ability to import power. This is because the transmission infrastructure serving the zone has limited capacity and redundancy compared to the area's overall demand. Local generation assets, therefore, are particularly important for Cambridge to have reliable electricity supply.

In Cambridge, most electric transmission lines are buried, but all transmission substations are above-ground. The electric power distribution system consists of both underground and overhead infrastructure (distribution lines, transformers, and related equipment). Overhead distribution systems are more vulnerable to storms, particularly ice storms or extreme winds. Underground lines typically use concrete duct banks and electrical manholes and vaults, which provide protection from some weather events but may be vulnerable to flooding and other underground utility failures.

[10] Adaptation for Cambridge of electrical system diagram included in the US Department of Energy (2004). Final Report on the August 14, 2003 Blackout in the United States and Canada. Online at: http://www.ferc.gov/industries/electric/indus-act/reliability/blackout/ch1-3.pdf

Key Electrical Assets to be Analyzed in the Vulnerability and Risk Assessment

Power Plants *(producing 10MW or more)*

- Mystic Generating Station (Charlestown/Everett) [11, 12] – fuel source: Natural Gas, Oil[13]
- Veolia-Kendall Station (Cambridge) – fuel source: Natural Gas[14]
- MIT Co-generation Plant (Cambridge) – fuel source: Natural Gas, Oil[15]

Bulk Transformers/Substations[16, 17]

- North Cambridge (fed by Mystic and Brighton substations; Mystic Generating Station; feeds Putnam Avenue substation)
- Putnam (fed by North Cambridge, East Cambridge, and Prospect Substations; MIT Power Plant and Veolia-Kendall Station)
- East Cambridge (fed by Putnam and Prospect Substations; Veolia-Kendall Station)
- Prospect (fed by Somerville, Putnam, and East Cambridge Substations; Veolia Kendall Station)

Major Transmission Lines[18, 19]

345 KV line[20]s (bi-directional)

- Mystic – North Cambridge

115 KV lines (bi-directional)

- Mystic - Somerville – Brighton – North Cambridge
- North Cambridge – Putnam
- Putnam – East Cambridge

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[11]As of 2010, the Mystic Generating Station relied entirely on the Everett LNG Terminal for its natural gas supply; http://www.naruc.org/international/Documents/Distrigas_Overview%20of%20LNG%20in%20New%20England_Katulak_Eng.pdf

[12] The Mystic Generating Station is not located in Cambridge, but it will be addressed in the context of regional issues.

[13] Massachusetts Department of Environmental Protection (2011). Final Air Quality Operating Permit for Mystic Station. Online at: http://www.mass.gov/eea/docs/dep/air/approvals/opp/op/op-constellationmystic.pdf

[14] Massachusetts Department of Environmental Protection (2013). Final Air Quality Operating Permit Renewal for GenOn Kendall/Kendall Square. Online at: http://www.mass.gov/eea/docs/dep/air/approvals/opp/op/op-genonkendall.pdf

[15] Massachusetts Institute of Technology. MIT Cogeneration Project. Online at: http://cogen.mit.edu

[16] Eversource (NStar) Electric Company (2004). System Impact Study Prepared for the NEPOOL Transmission Task Force. Online at: http://www.iso-ne.com/committees/comm_wkgrps/relblty_comm/relblty/mtrls/2004/jun212004/A3-2_EastCambSub.rpt.Complete.061504.pdf

[17] Eversource (NStar) Electric Company (2013). Transmission Operating Agreement, Schedule 2.01(b). Online at: http://www.oasis.oati.com/ISNE/ISNEdocs/IPS201ABL_Eversource.pdf

[18] Eversource (NStar) Electric Company (2013). Transmission Operating Agreement, Schedule 2.01(b)

[19] Eversource (NStar) Electric Company (2004). System Impact Study Prepared for the NEPOOL Transmission Task Force

[20] Bi-directional transmission lines can receive/send power from two directions which means that direction of feed can be reversed if needed.

13.8 KV lines (all unidirectional[21])

- Somerville to Prospect
- East Cambridge to Prospect
- Prospect to Putnam
- East Cambridge to Putnam
- Harvard to Putnam

Natural Gas

Like the electrical system, the natural gas system consists of three main components: supply, transmission and distribution. Gas is collected by suppliers at the source and transported across long distances via transmission pipelines or by ship. Massachusetts is the largest consumer of natural gas in New England (Commonwealth of Massachusetts 2011). The State's natural gas is supplied from production areas in the U.S. Gulf Coast and Canada; from natural gas storage sites in the Appalachian Basin region, which includes parts of New York, Pennsylvania, and Ohio; and from other international sources, including Trinidad (U.S. EIA 2012)[22]. Massachusetts receives 80% of its gas supplies via three interstate pipeline systems (e.g. Algonquin Gas Transmission Co., Maritimes/Northeast Pipeline Co. and the Tennessee Gas Pipeline Co.), entering the state from New York, Rhode Island and New Hampshire (U.S. EIA 2012).

Massachusetts also imports some of its natural gas via three liquefied natural gas import terminals: the Suez/Distrigas LNG Terminal is in Everett and two marine terminals located 11 to 13 miles offshore of Gloucester, MA (U.S. EIA 2012). Ships connect to buoys at the offshore terminals where the LNG is gasified then transported via undersea pipelines to the mainland (Commonwealth of Massachusetts 2011). Marine imports supply about 20 percent of New England's demand for natural gas; all other natural gas comes by pipeline (U.S. EIA 2012)[23].

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[21] Unidirectional is to be confirmed with Eversource

[22] Excerpt from the "Fuel distribution white paper _v3_092413" written by Laura Smead for the City of Cambridge. September 2013

[23] ibid

Figure 2: Regional Diagram of Algonquin Pipeline[24]

Gas is delivered to customers through 1,000 miles of underground transmission pipes and 21,000 miles of local distribution pipes (Commonwealth of Massachusetts 2011).

In Cambridge, natural gas travels at high pressure through transmission pipelines to two gate stations in the City, where custody of the gas transfers from the transmission company (Algonquin Gas) to the gas distribution utility (Eversource). The gas is received at a gate station where the pressure is reduced, then further reduced at district regulator stations. Gas is then distributed to customers via underground pipelines at one of three pressure ranges: high-pressure gas is typically used by industrial customers, intermediate-pressure gas is typically used by large buildings (both commercial and residential), and low-pressure gas is typically used by individual residences and small businesses.

[24] Source: Spectraenergy.com

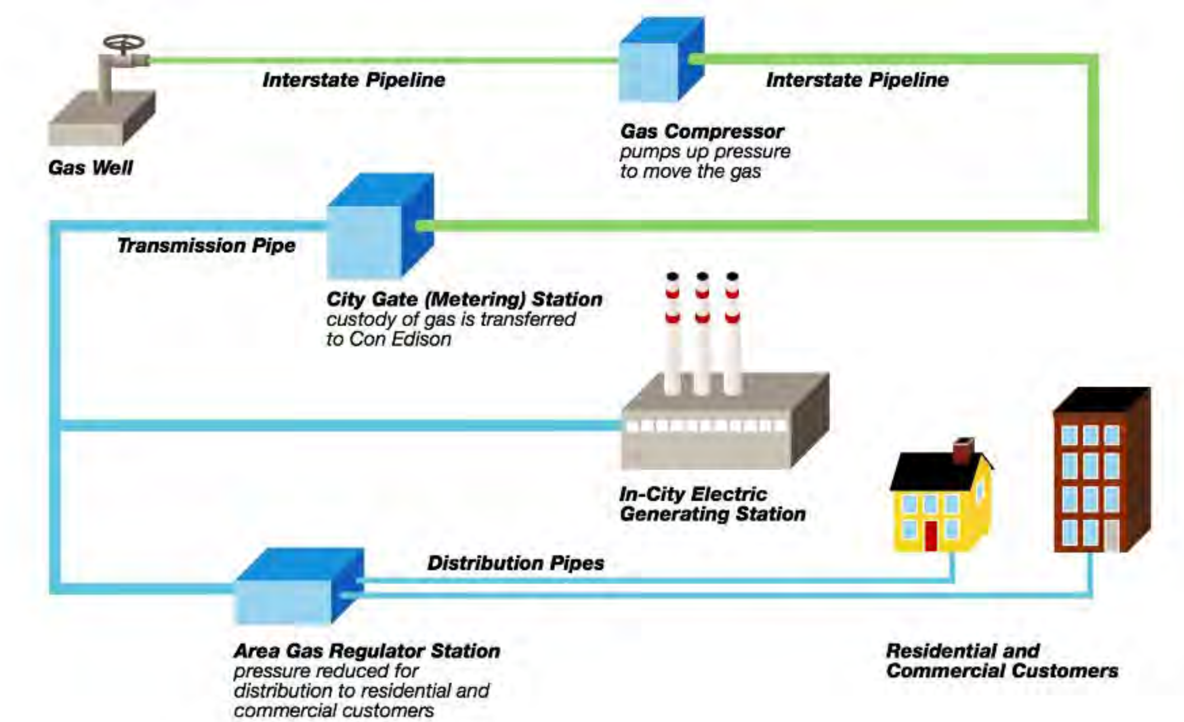

Figure 3: Diagram of a Gas System[25]

The natural gas distribution system operates at three pressures. These include 90-, 60-, and 10-PSIG systems which primarily feed large-volume commercial and industrial customers and feed distribution regulator stations that cut the pressure down to feed the low pressure distribution systems. Finally, low pressure distribution systems operate at a nominal 12 inches W.C.[26] and primarily feed residential neighborhoods. Areas of low pressure are a concern for possible water infiltration into the pipes, as this can cause corrosion in the distribution lines and damage components of customers' equipment, ultimately affecting safety and reliability.

City Gate Stations

The Cambridge natural gas distribution system is fed from two city gate stations (also referred to as "take stations") jointly owned and operated by a gas distribution company and an interstate natural gas pipeline company. One of these is the Brookford St. Take Station, located in North Cambridge. This station receives gas from a pipeline that runs along Route 128 to Route 2. The other is the Mystic Take Station in Medford, MA. The outlet of the Mystic Take Station feeds a nominal 320 PSIG pipeline that leads to the Third Street regulator yard. From here, this line feeds

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[25] source: ConEdison (2010). Gas Long Range Plan 2010-2030. Online at: http://www.coned.com/PublicIssues/PDF/GLRP1210c.pdf
[26] W.C. is an abbreviation for "Water Column" and is a standard pressure unit.

the Kendall Generating Facility and also feeds into two regulating stations operating at separate distribution pressures. Both take stations are fed from the Algonquin Gas Transmission Company (a division of Spectra Energy Corp. based in Houston, TX). EVERSOURCE Gas (a subsidiary of Northeast Utilities based in Springfield, MA) owns and operates the natural gas distribution system in Cambridge.

Key Natural Gas Assets to be Analyzed in the Vulnerability and Risk Assessment

Major Transmission Line

- Algonquin Transmission Line

Gate Stations

- Brookford Street Take Station (North Cambridge)
- Mystic Take Station (Medford, MA)

Distribution System Regulator Stations

There are seventeen natural gas distribution regulator stations in the City of Cambridge:

Station	Location
Third St. Intermediate Pressure Regulator Station	Third St. @ Linskey Way
Third St. Low Pressure Regulator Station	Third St. @ Linskey Way
Beech St. Regulator Station	Beech St. @ Elm St.
Blackstone St. Regulator Station	Blackstone St. @ River St.
Brattle St. Regulator Station	Brattle St. @ Elmwood St.
Cambridge St. Regulator Station	Cambridge St. @ Dana St
Cameron Ave. Intermediate Pressure Regulator Station	Cameron Ave. @ Fair Oaks St.
Cameron Ave. Low Pressure Regulator Station	Cameron Ave. @ Fair Oaks St.
Concord Ave. Regulator Station	Concord Ave. @ Sancta Maria
Huron Ave. Regulator Station	Huron Ave. @ Fresh Pond Pkwy.
Main St. Regulator Station	Main St. @ Albany St.
Pearl St. Regulator Station	Pearl St. @ Putnam Ave.
Putnam Ave. Regulator Station	Putnam Ave. @ River St.
Sidney St. Regulator Station	Sidney St. @ Putnam Ave.
Vassar St. Regulator Station	Vassar St. @ Audrey St.
Walden St. Regulator Station	Walden St. @ Sherman St.
Western Ave. Regulator Station	Western Ave. @ Putnam Ave.

Steam

Steam is generated at a utility plant by a steam boiler or a cogeneration unit, which recovers the heat that is given off as a byproduct of electrical generation and uses it to produce steam. The Veolia-Kendall cogeneration plant produces steam to generate electricity. The excess steam is distributed by Veolia to customers in Cambridge through a connection to the TriGen steam pipe network (owned by Veolia), to customers in Boston via a pipe over the Longfellow Bridge and a new steam and condensate return line along Cambridge Parkway into Boston.

Steam is used to run heating and cooling systems for large facilities, as well as to run steam generators that produce electricity. When used in heating and cooling, steam is generally distributed through below-ground piping to the systems and facilities it serves.

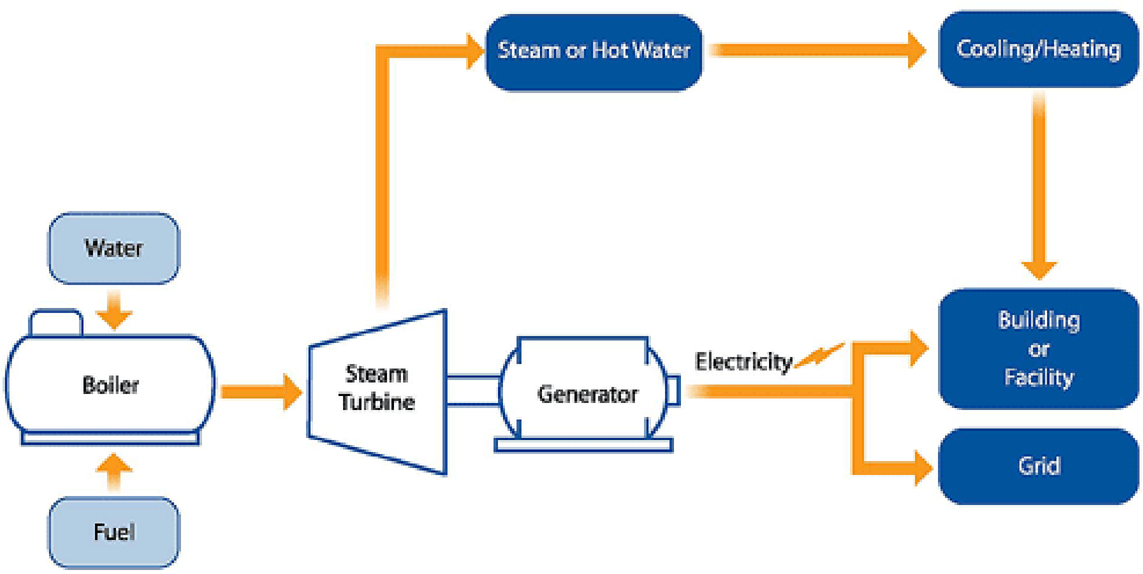

Figure 4: Typical Steam Generation System[27]

Private and institutional cogeneration plants produce steam and electricity for their owners. The Harvard Blackstone and MIT utility plants produce steam for institutional use. Steam produced at Harvard Blackstone provides 80% of campus heating services and 5MW of electricity. MIT uses steam to provide campus heating and cooling services, and sources some of its steam from a 20MW cogeneration unit that produces roughly 80% of its electricity. Multiple smaller cogeneration units also provide electricity for individual facilities including 808 Memorial Drive,

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[27] Source: http://www.epa.gov/chp/basic/index.html

Watermark, and the Cambridge Rindge and Latin School. Steam is an important source of heating, cooling, and process for Cambridge's biotechnology industry and medical facilities.

Key Steam Assets to be Analyzed in the Vulnerability and Risk Assessment

Steam Plants

- Veolia-Kendall Cogeneration (Electricity to Eversource Grid; Steam to Veolia)
- MIT Co-generation Plant[28]
- Harvard's Blackstone Plant

Liquid Fuels

Liquid fuels, such as gasoline, diesel, fuel oil, and jet fuel, supply a variety of energy services, including transportation, electric generation, and heating. Gasoline and diesel are primarily used to power personal and commercial vehicles, and during power outages, diesel is also widely used to power emergency generators. Fuel oil is used for building heating systems, and is also a back-up fuel for power plants that primarily run on natural gas.

Liquid fuels are produced, processed, transported, stored, and distributed by a global network of independent enterprises. These enterprises rely on public infrastructure, such as roads and ports, and private infrastructure, such as petroleum marine terminals, pipelines, and gas stations to deliver liquid fuels to consumers across the U.S.

Massachusetts does not have any liquid fuel production or processing facilities, so it imports all that it consumes, either from other states or from foreign countries. Liquid fuel supplies enter the State in bulk, primarily through private petroleum marine terminals located in the Port of Boston.[29] In 2011, Port of Boston petroleum terminals supplied 79% of the gasoline and 66% of the diesel consumed in the State.[30] Two small-capacity pipelines also carry liquid fuels from ports in Connecticut and Rhode Island to Springfield in central Massachusetts.[31] In addition to bulk supplies, liquid fuels are imported to western parts of the State by truck. Once in the State, liquid

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[28] MIT Co-generation Plant is also identified as a key electrical asset (power plant).

[29] US EIA (2013). Massachusetts State Energy Profile: Last viewed online at: http://www.eia.gov/state/print.cfm?sid=MA

[30] Massachusetts Department of Transportation (2013). The Ports of Massachusetts Strategic Plan, Technical Memorandum Number 2, Maritime Port System Infrastructure and Existing Operations.

[31] Ibid

fuels are transported to gas stations, residences, and large commercial and institutional consumers by rail or truck.[32]

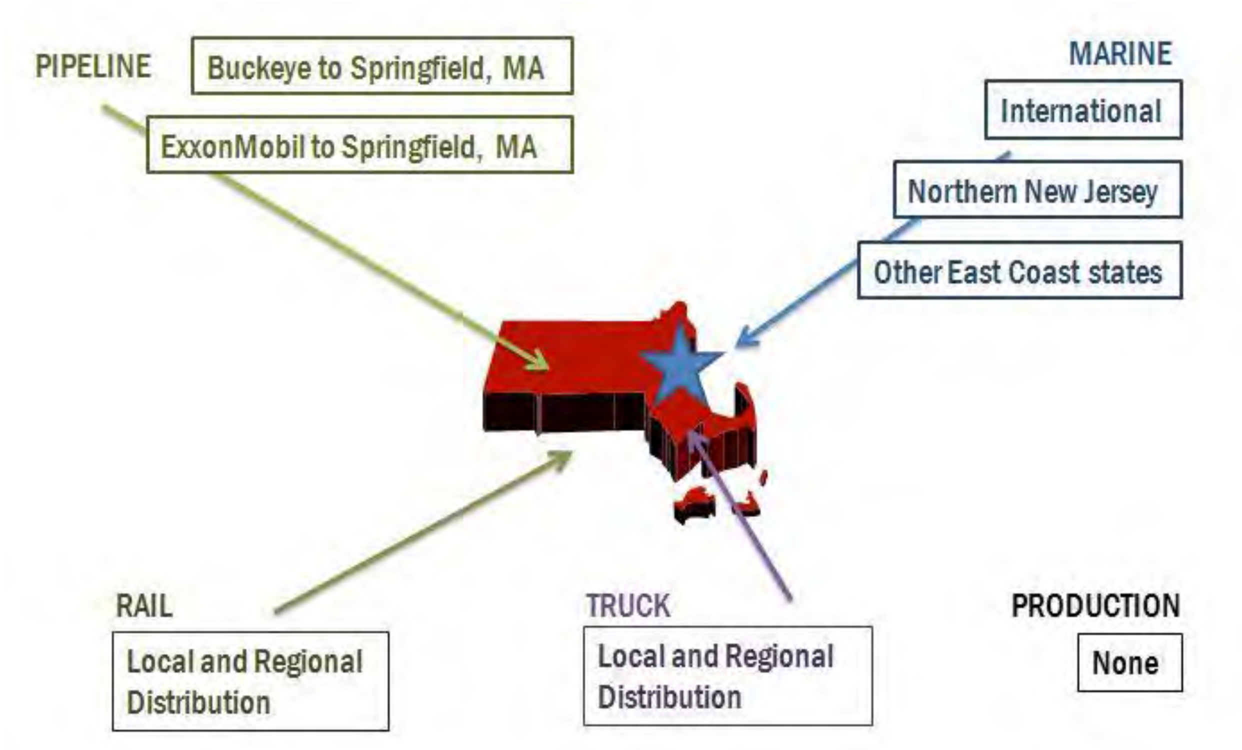

Figure 5: Schematic of the Boston Region's Supply of Transportation Fuels[33]

One of the nation's two Northeast Home Heating Oil Reserves storage sites, which are intended to cushion the effects of disruptions in the supply of home heating oil, is located in Revere (U.S. EIA 2012). This supply was first used in 2012 to offset the effects of Hurricane Sandy and the major snowstorm that followed. The Boston region's supply was largely unaffected by Hurricane Sandy. In part this was because Boston's port was unaffected by the hurricane, and could receive gas and oil supplies from other regions.[34] The storage site in Revere currently holds 500,000 barrels.

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[32] Commonwealth of Massachusetts. Massachusetts Climate Change Adaptation Report – Chapter 5. Key Infrastructure. Submitted by the Executive Office of Energy and Environmental Affairs and the Adaptation Advisory Committee, September 2011.

[33] Produced by the City of Cambridge. (Modeled on NYS Study 2012.). "Fuel distribution white paper _v3_092413" written by Laura Smead for the City of Cambridge. September 2013

[34] Excerpt from Fuel distribution white paper _v3_092413 written by Laura Smead for the City of Cambridge. September 2013

Key Liquid Fuel Assets to be Analyzed in Vulnerability and Risk Assessment

- Liquid Fuel Transmission Lines[35]

Renewable Energy

In Cambridge, renewable energy is primarily provided by solar photovoltaic (PV) and thermal systems. Wind turbines and biomass generators and boilers are not used at a significant scale. Some preliminary work has been done to track the use of solar power in the city[36]. The installation of solar PV systems has begun to accelerate in Cambridge as the price of solar panels declines and financial incentives remain strong. Based on staff estimates, in early 2014, there were about 2MW of solar PV in the City, which supplies a very small portion of electricity demand. However, there is significant potential for solar PV to be installed on buildings in Cambridge, and the City is working to support greater deployment. [37]

Figure 6: Estimate of Rooftop Solar Electric Potential in Cambridge (PV Panels)[38]

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[35] Not included in key liquid fuel assets are natural gas pipelines, which are included in key natural gas assets, and rail and truck distribution routes, which are addressed in the transportation section.
[36] City of Cambridge first estimated the square feet of PV solar panels in 2010, based on aerial photography interpretation, which was not field verified.
[37] A joint project between MIT, the City of Cambridge, and Mapdwell LLC has mapped the solar energy potential of buildings in Cambridge.[37]
[38] Source: http://en.mapdwell.com/cambridge#

While it may provide for an opportunity for increased resiliency in the future and deserving of additional consideration in the preparedness phase of this project, too little infrastructure currently exists to include it in the vulnerability and risk assessment.

Transportation

As with energy, transportation is an essential system for a city to function. It is fundamental to ensuring the efficient movement of people and goods, as well as enabling critical services and emergency response efforts. Disruptions to transportation systems directly affect citizens and businesses. During extreme events, transportation systems and roadways become critical assets for evacuation and emergency service providers. Public transit is also important to access hospitals, healthcare facilities, and shelters, especially for residents without access to a car. As an example, Hurricane Sandy resulted in the flooding of seven New York MTA subway tunnels under the East River and caused a full system closure for several days. Most major automobile tunnels and bridges were also closed. This resulted in the inability of employees to commute to work; critical fuel supplies could not reach back-up power facilities; rescue and emergency response efforts were significantly hampered; key provisions such as food could not be delivered; and businesses were forced to close for days to weeks. This resulted in billions of dollars of economic loss, in addition to the health and safety impacts[39].

Figure 1: Flooding at MBTA Alewife Station Garage and Access Road, July 2010

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[39] http://www.esa.doc.gov/Reports/economic-impact-hurricane-sandy

Even less severe events have the potential to cause considerable disruption. On July 10, 2010, heavy rain fell in Cambridge within a short period of time, creating local flooding that made streets impassable. The Nor'easter on January 2, 2014, dropped over a foot of snow in Boston and Cambridge, triggering a day-long travel ban and causing significant coastal flooding at high tides.

The transportation modes within Cambridge function as an integrated system. Within those modes, critical hubs or intersections (multiple arrival-departure sites) can be crucial for continued function. For example, while Harvard Square may be viewed as a public transit hub, disruption to the roadways or the Harvard Bridge causes traffic backups that affect bus schedules. A photograph of the access road to the Massachusetts Bay Transportation Authority (MBTA) Alewife parking garage (Figure E-8) illustrates how the failure of the road system can not only disrupt important arterial connections to Route 2 but also prevent commuters from accessing the Red Line.

Cambridge's ordinances contain stringent and enforceable mode share requirements linked to development that have successfully limited the number of single-occupancy vehicle trips.[40]However, 29% of Cambridge residents and 49% of the Cambridge workforce commute by driving. Public transit systems are in important means of mobility in the City. On a typical weekday, 150,000 and 85,000 passenger trips start or end in Cambridge's six subway stations and 33 public bus routes, respectively.

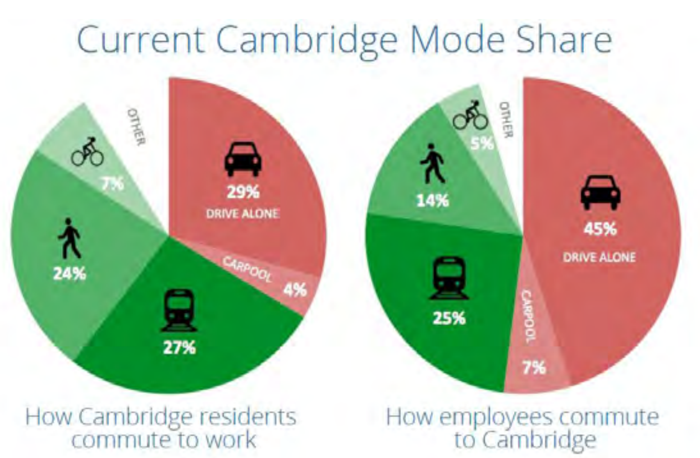

Figure 2: Current Cambridge Mode Share[41]

[40] http://www2.cambridgema.gov/CityOfCambridge_Content/documents/TransitInterReportJan2014.pdf

[41] Source: The City of Cambridge Strategic plan, Draft, January 2014http://www2.cambridgema.gov/CityOfCambridge_Content/documents/TransitInterReportJan2014.pdf

While acknowledging that transportation encompasses a variety of modes, this study will focus primarily on the movement of people and will address three main modes:

- Public Transit
- Roadways and Bridges/Tunnels
- Pedestrian and Bicycle Networks

Public Transit

Approximately 25% of people who live or work in Cambridge rely on public transit. Many residents who do not own cars rely on public transit as their primary means of transportation. Many more use it as a secondary means of transportation to work and for regular non-commuting purposes[42].

The MBTA is the primary operator of public transit for the City. Its systems and assets include the following critical components:

- Commuter Rail
- Subway System
- Bus System
- Service for the Disabled Population[43]
- Support Infrastructure[44]

Commuter Rail

The MBTA Commuter Rail provides crucial transportation for those who commute to Boston and Cambridge from outlying communities. Porter Square station, located at the junction of North Cambridge, Neighborhood Nine, and Agassiz, is the second-to-last inbound stop on the Commuter Rail's Fitchburg Line which terminates at North Station in Boston. The Fitchburg Line runs above-ground from Belmont through North Cambridge. At Porter Square Station[45], it travels under Massachusetts Avenue and then runs parallel to Somerville Avenue for half of a mile at a sub-grade elevation. It then continues through Somerville to Charlestown and across the Lechmere viaduct to North Station.

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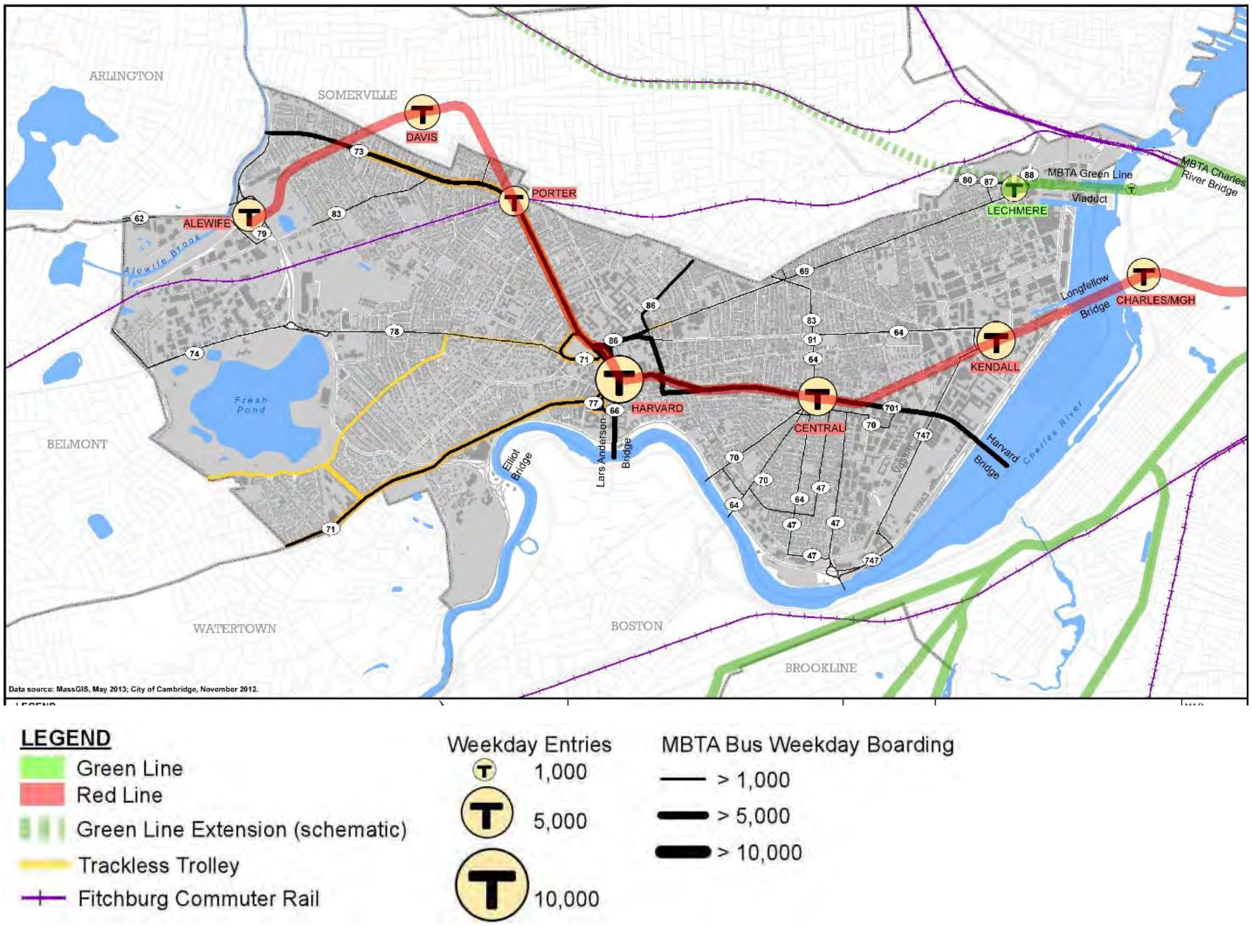
[42] Source: The City of Cambridge Transit Strategic Plan Update Report, January 2014aspx

[43] The Ride provides shuttle services to the disabled population and is operated for the MBTA by an independent provider. All other shuttles serving elderly and disabled populations, including Door2Door, are private and not covered in this report.

[44] Support infrastructure is defined here as energy infrastructure and storage and maintenance facilities owned or operated by MBTA that are needed to support the delivery of transit services in Cambridge.

[45] The subway Red Line also stops at Porter Square station, running underground beneath and perpendicular to the Commuter Rail tracks.



Map Tr.1: MBTA Transit Ridership, City of Cambridge

The commuter rail system relies on the Eversource electric power transmission and distribution network. MBTA has some redundant energy infrastructure with the capacity to support limited emergency service operations for specific routes and stations. Further coordination with MBTA will be required to identify and assess the criticality of redundant energy infrastructure that supports such capabilities in Cambridge.

Key Commuter Rail Assets to be Analyzed in the Vulnerability and Risk Assessment

- Fitchburg Commuter Rail Line
- Porter Square Commuter Rail Station

Subway System

Two MBTA subway lines serve the City: the Red Line and the Green Line. Impacts to any part of the subway have potential to affect the entire system; there is little redundancy within the subway lines.

The Red Line connects to South Station, the primary commuter rail hub for the region and the busiest MBTA subway station, while the Green Line connects to North Station, a smaller commuter rail hub. The Red Line enters Cambridge by crossing the Longfellow Bridge from the Charles/MGH Area of Boston. On the Cambridge side of the bridge, it enters a tunnel portal to Kendall station and then runs primarily underground for the rest of the route. It stops at five stations in Cambridge including Kendall, Central Square, Harvard Square, Porter Square station (which is also a Commuter Rail station), and Alewife station (the final stop on the Red Line). Harvard Square station is the busiest subway station within Cambridge, and the third busiest across the entire subway system, with over 20,000 entries on a typical weekday.[46]

All Cambridge stations are multi-modal, providing connections between the subway and public bus systems. The MBTA identifies Porter Square, Harvard Square, and Central Square as key stations that connect riders between subway and commuter rails or bus routes with frequent service.[47] Another key transfer point, Alewife station, connects park-and-ride commuters to the transit system.

The Green Line enters Cambridge by crossing the Lechmere viaduct from the Leverett Circle area. It then runs on surface tracks to the final stop on the E branch at Lechmere Station in East Cambridge. The Green Line extension project, currently under design, will slightly relocate Lechmere Station and extend the line to the towns of Medford and Somerville. Construction of the new lines is expected to be completed in 2019.

Alewife is the only Cambridge subway station with commuter parking, accommodating 2,733 motor vehicle spaces and 174 bicycle spaces. Commuter parking demand exceeds available spaces and the garage fills early on weekdays.

Key Subway Assets to be Analyzed in the Vulnerability and Risk Assessment

MBTA Red and Green Line Subway stations

- Alewife

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[46] Only includes entries. There are over 150,000 total entries and exits at all Cambridge subway stations on a typical weekday. (http://www.mbta.com/uploadedfiles/documents/2014%20BLUEBOOK%2014th%20Edition.pdf)
[47] see MBTA map at http://www.mbta.com/schedules_and_maps/subway/

- Porter Square
- Harvard Square
- Central Square
- Kendall
- Lechmere

Bus System

Buses, including trackless trolleys (electric buses), are important assets in the City's public transit network. Operating in or passing through Cambridge, 33 bus/trackless trolley routes carry approximately 85,000 riders each weekday. [48] In the MBTA system, 5 of the 20 bus routes with highest ridership are in Cambridge (#66, #1, #77, and #73).[49]

Four Cambridge trackless trolley routes rely on overhead electric wires. During a short-term power interruption, standard buses can replace these trolleys without disruption, if available. This option is less valid for long-duration outages.

Key Bus Assets to be Analyzed in the Vulnerability and Risk Assessment

- Harvard Square: More than 15 MBTA bus routes have stops in Harvard Square.
- Central Square: More than 8 MBTA bus routes have stops in Central Square.
- MBTA #66 bus route *(from Allston via Lars Anderson Bridge to Harvard Square)* has the highest ridership of Cambridge bus routes
- MBTA #1 bus route *(along Mass Ave across Harvard Bridge to Central Square & Harvard Square)* has the second highest ridership of Cambridge bus routes.
- MBTA #71 bus route *(Watertown Square - Harvard Station via Mt. Auburn St.)* has the sixth highest ridership of Cambridge bus routes.
- MBTA #70 bus route *(Cedarwood, No. Waltham or Watertown Sq. - University Park via Central Sq., Cambridge, Arsenal St. & Western Ave)* has the seventh highest ridership of Cambridge bus routes.

MBTA Services for Disabled Population (The Ride), Private Shuttles, and Additional Fleet

The MBTA also serves Cambridge's disabled population with The Ride, a service that provides pick-up and drop-off service in wheelchair-accessible vans to registered disabled customers and

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[48] http://www2.cambridgema.gov/CityOfCambridge_Content/documents/TransitInterReportJan2014.pdf
[49] MBTA 2014 Blue BookRidership

their caretakers. As of 2009, The Ride had 65,000 registered customers in its entire service area. The exact number in Cambridge is not known, but approximately 42,000 trips were taken in Cambridge in 2009. The number of trips has grown steadily since 2001[50].

In addition to public transit, a variety of private entities play an important role in the transportation network including private shuttles and operators of taxi and limousine fleets. Private shuttles include several operated by institutions such as MIT, Harvard University, and the Charles River Transportation Management Association (CRTMA)'s EZRide.

This report maps only the EZRide assets, since it serves a group of government, institutional, and private entities that represent the City's main employers (it is also available to the public for a cash fare[51]). EZRide links Cambridge employers and residents with commuter rail, bus, and rapid transit at key MBTA stations and institutional or commercial centers[52]. It carries approximately 2,500 passengers per day.[53]

While other private shuttle services are important resources, due to the diversity of assets, ownership, and the relatively small ridership, they are not included in the scope of this work for further assessment.

Support Infrastructure

The MBTA relies on a complex array of local and regional infrastructure, including energy, storage, and maintenance facilities, to support its system. The MBTA subway system relies on the electric power transmission and distribution network operated by Eversource for power. MBTA critical infrastructure has some redundant energy infrastructure in place for short-term shortage at subway stations.

To support its services, the MBTA operates storage and maintenance facilities[54], one of which is in Cambridge on Mass Ave.[55] The majority of the bus lines that stop in Cambridge use the Somerville facility as their primary garage[56].The MBTA also stores Red Line trains and buses outside of Cambridge at Cabot Yard (South Boston), Codman Yard (Dorchester), and

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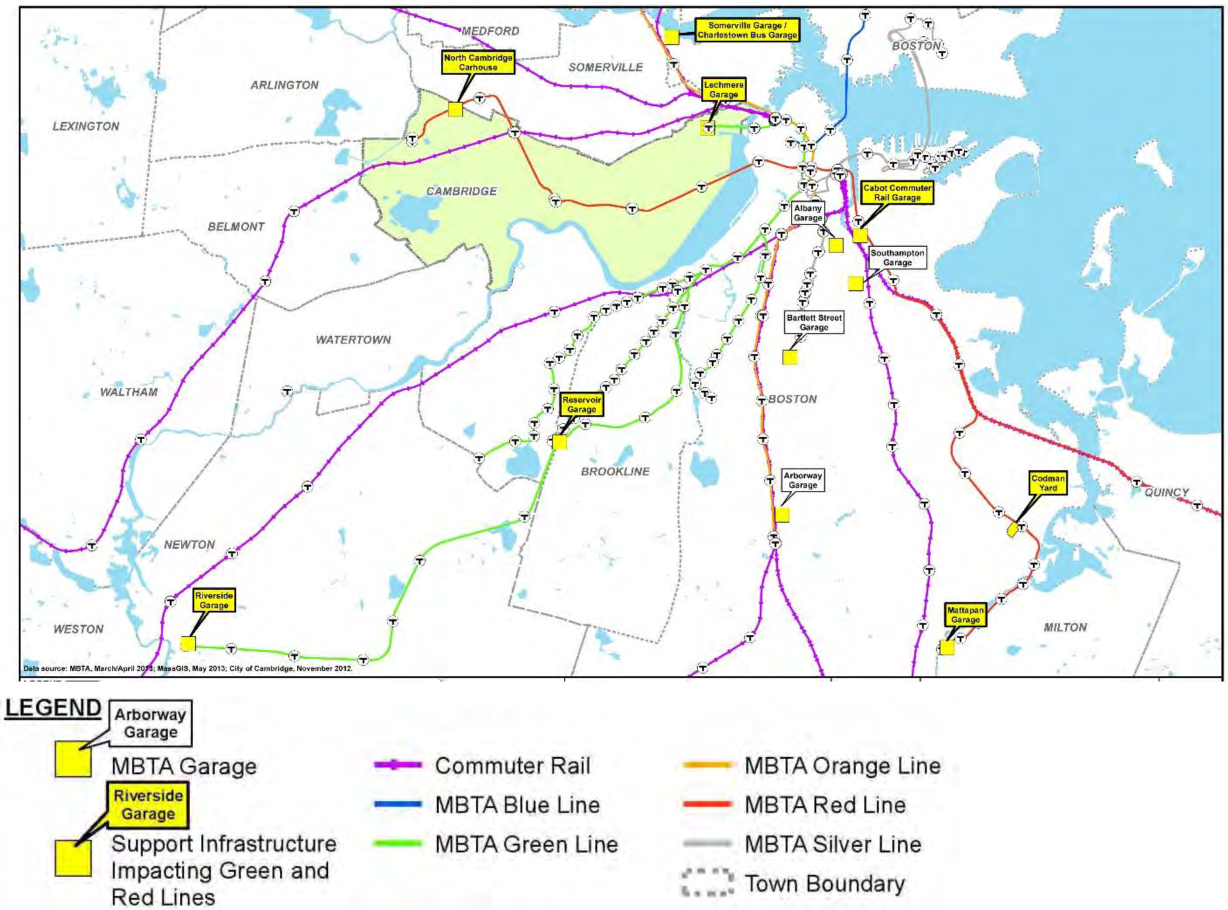
[50] Source: Interview with the MBTA, Fall 2012.
[51] http://www.charlesrivertma.org/charles-river-tma-members/
[52] http://www.cambridgema.gov/cdd/transportation/gettingaroundcambridge/bytransit.aspx
[53] http://www2.cambridgema.gov/CityOfCambridge_Content/documents/TransitInterReportJan2014.pdf
[54] MBTA 2010 Blue Book
[55] MBTA North Cambridge Carhouse for trackless trolleys.
[56] MBTA 2010 Blue Book

Charlestown Navy Yard (Charlestown).[57] Green Line trains are stored at Lechmere station in Cambridge, and outside Cambridge at Riverside (Newton) and Reservoir (Brookline) stations. The vulnerability of MBTA assets outside of Cambridge that are critical for supporting its Cambridge services will be assessed in the context of regional issues.



Map Tr.2: MBTA Support Infrastructure[58]

[57] According to MBTA 2001 Blue Book, there is a small 3-track underground yard at the terminus of the Red Line at Alewife station. However, this facility is not on the most recent list (2014) of MBTA maintenance and storage facilities.
[58] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

Road Systems

Cambridge is an urban mixture of housing, retail and other businesses and institutions, making it easy for most residents to make at least some trips without driving.[59] While commuting is often considered the primary reason for driving, only 45 percent of Cambridge employees drive to work alone. Since 2000, commuting alone has dropped 5.3 percent, whereas nationally, driving alone has risen[60].

This study considers the following components of the Roadway System:

- Major Roadways
- Key Intersections
- Bridges & Underpasses
- Large Public and Commercial Parking Garages (not including institutional or university parking)

Major Roadways

Several major roads lead to Cambridge, including Route 2, Route 16 and the McGrath Highway (Route 28). The Massachusetts Turnpike does not pass through Cambridge, but provides access by on and off ramps in nearby Allston. Both U.S. Route 1 and Interstate 93 also provide additional access on the eastern end of Cambridge at Leverett Circle in Boston. Route 2A runs the length of the city, along Massachusetts Avenue. Major regional connectors are located at the City's periphery and are limited in number. These are managed by state departments: the Massachusetts Department of Transportation (MassDOT) and the Massachusetts Department of Conservation and Recreation (DCR). At a local level, Cambridge has an irregular complex network of streets, many dating from the Colonial Era. The DCR-owned roads are also part of the state Historic Parkway system.

ADT (Average Daily Traffic) count values from the City of Cambridge and MassDOT road database were used to identify roads sections with highest traffic volumes. ADT counts record average annual 24-hour traffic volume. The following represent Cambridge highest ADT values organized into two tiers: exceeding 30,000 and 20,000 vehicles, respectively[61] .

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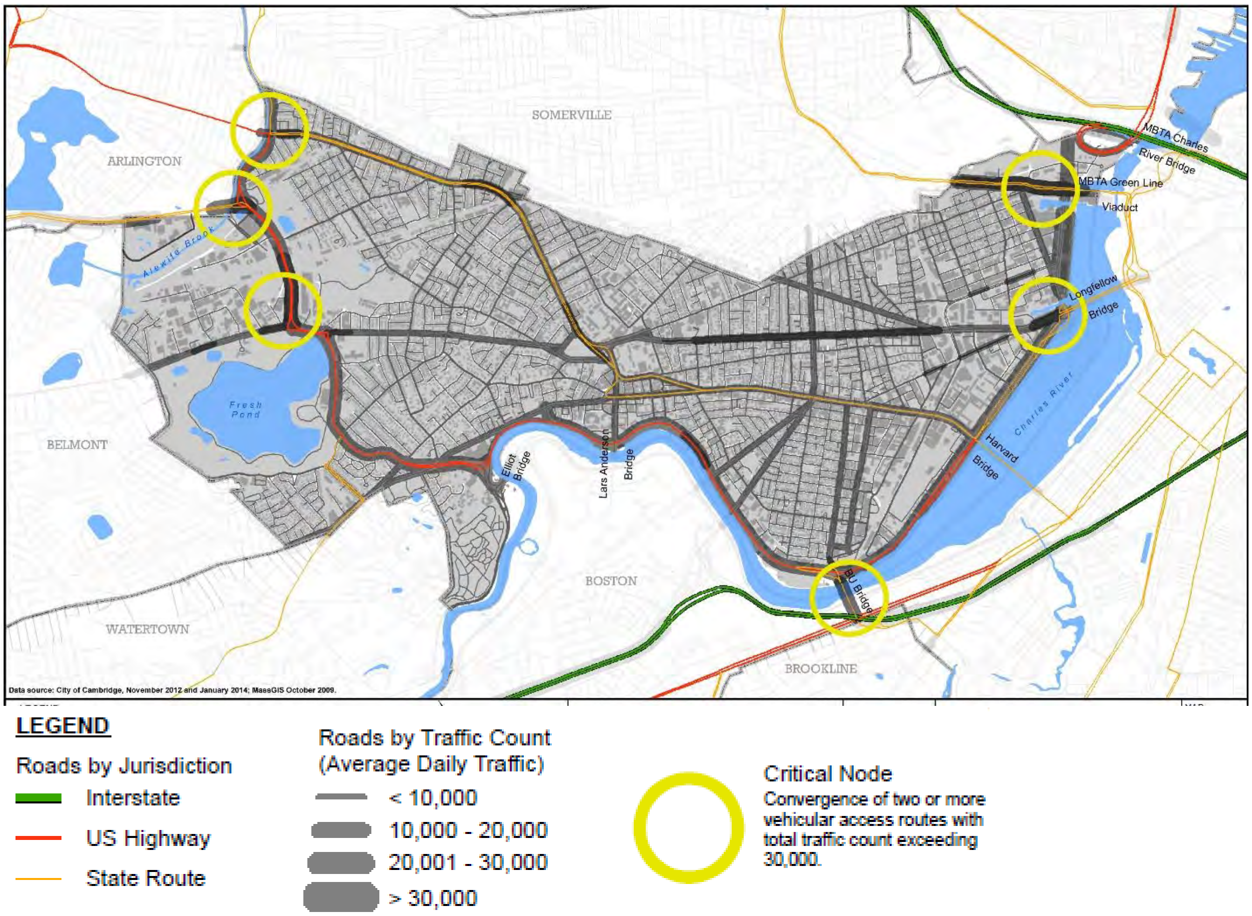
[59] https://www.cambridgema.gov/CDD/Transportation/gettingaroundcambridge.aspx

[60] 2000 Census, 2006-2010 American Community Survey. http://www2.cambridgema.gov/Traffic/Commuting.cfm

[61] Streets with additional location description provided in parenthesis are from the City of Cambridge ADT dataset and recorded as such.



Map Tr.3: Road System and Traffic Count, City of Cambridge[62]

Key Major Road Assets to be Analyzed in the Vulnerability and Risk Assessment

Over 30,000 Vehicles in 24 hours[63]

- Fresh Pond Parkway/Route 60
- Monsignor O'Brien Highway/McGrath Highway/Route 28
- Alewife Brook Parkway
- Concord Turnpike/Route 2
- Memorial Drive
- Broadway

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[62] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (October 2009),

[63] Memorial Drive, Broadway, and Mass Ave have some sections with less than 30,000 but greater than 20,000 vehicles in 24 hours, as shown on Map Tr.3.

- Mass Ave[64]
- Charlestown Avenue
- Land Boulevard

Over 20,000 Vehicles in 24 hours

- Concord Ave (East of Fawcett Street)
- Main Street (West of Memorial Drive)

Smaller roadways may also be critical for public transit. For example, JFK Street is critical for the #66 bus route, which is characterized as a critical asset because of its large number of riders. These routes with lower usage will only be considered on the basis of their criticality.

Key Intersections

Critical intersections include bridges, rotaries, and major highway intersection where two or more vehicular access roads converge and support high traffic volume (> 30,000).[65] These critical nodes in the roadway network are vital for vehicular accessibility not only within Cambridge but to and from the City.

Key Intersections Assets to be Analyzed in the Vulnerability and Risk Assessment

- BU Rotary/Reid Overpass
- Alewife Brook Parkway (including rotary at Concord Avenue and intersections with Route 2 and Mass Ave/Rt 16)
- Monsignor O'Brien Highway at Charlestown Ave/Land Boulevard

Bridges and Underpasses

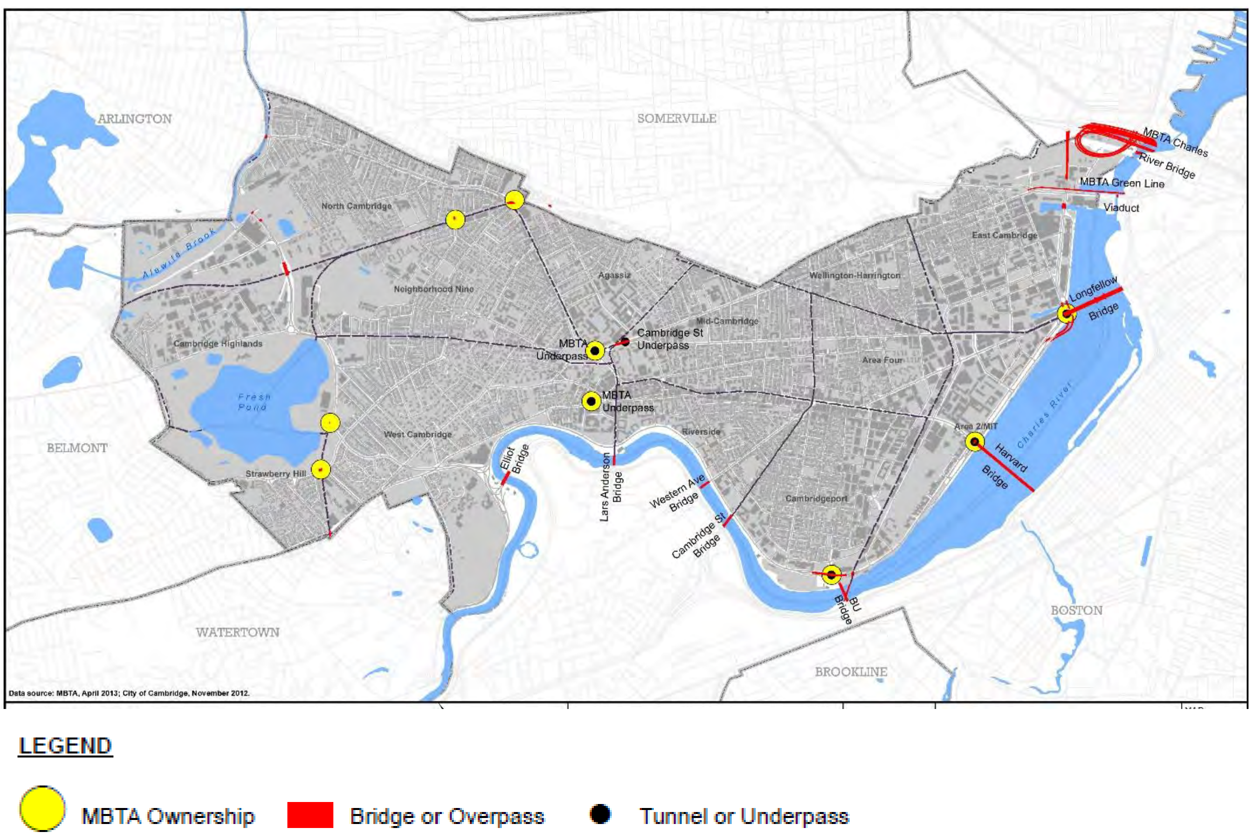
Of the 30 bridges in Cambridge documented in this report, 10 span railroads, 5 span roads, 2 span Alewife Brook, and 13 span the Charles River. The bridges over the Charles River provide key access routes to Boston and to the Mass Turnpike I-90.

In addition to being critical routes for the public, multiple bridges are critical components of the subway and rail systems and/or support bus routes. These dependencies are noted in the critical assets list below. Bridge ownership is also reported to identify key stakeholders in possible critical areas.

[64] Mass Ave is also a crucial road for MBTA #1 bus route, which has the second highest ridership in Cambridge.
[65] determined using spatial analysis

Key Bridge Assets to be Analyzed in the Vulnerability and Risk Assessment [66]

- Charles River Dam Bridge (Route 28) aka Lechmere Viaduct; critical for Green Line
- Longfellow Bridge (Route 3); critical for Red Line
- Harvard Bridge (Route 2A); critical #1 bus route support
- Boston University Bridge (Route 2)
- River Street Bridge
- Western Avenue Bridge
- Lars Anderson Memorial Bridge (N. Harvard Street/JFK Street); critical #66 bus route support
- Eliot Bridge (Route 2 to Fresh Pond Parkway)
- Cambridge Street Underpass
- Memorial Drive Underpasses



Map Tr.4: Bridges, Tunnels, and Underpasses, City of Cambridge[67]

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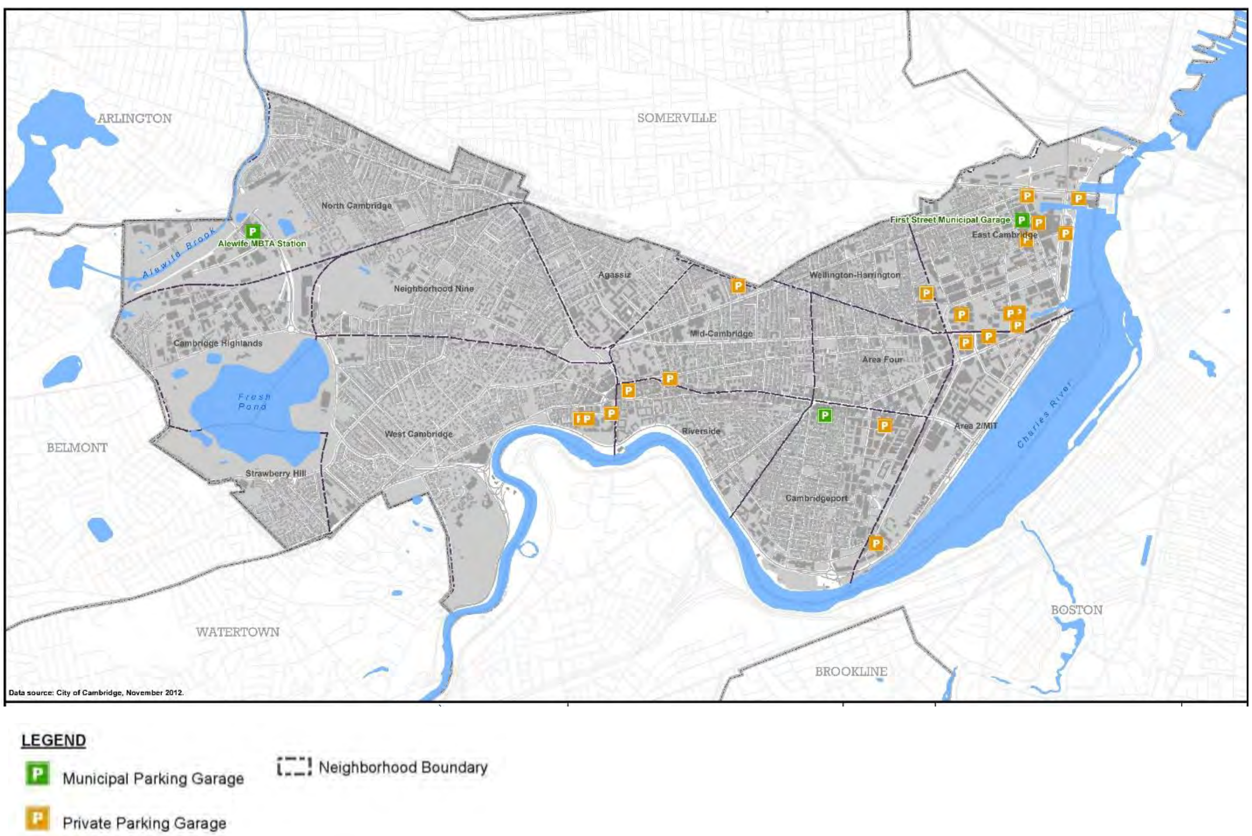
[66] http://en.wikipedia.org/wiki/List_of_crossings_of_the_Charles_River

[67] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

Parking

On-street parking and municipal and private parking garages are an important component of transportation. The Cambridge Traffic Department issues permits for residents to park in restricted on-street areas. Visitors to business areas use metered parking, which is monitored by Parking Control Officers, or park in one of 26 commercial parking lots and garages. The City operates two municipal garages in East Cambridge and Central Square. The City also manages nine metered, off-street parking lots.[68] Some local residential and commercial buildings have restricted parking lots or garages or below-grade garages. Public and private parking garages, both above-ground and below-ground, recorded on the City's GIS mapping database were mapped as they can support road management under extreme conditions. Parking garages are often co-located in commercial districts and in one instance by a major transit stops for park-and-ride commuters.



Map Tr.5: Parking Garages, City of Cambridge[69]

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[68] http://www2.cambridgema.gov/traffic/parking.cfm
[69] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

Key Parking Assets to be Analyzed in the Vulnerability and Risk Assessment

Public Parking Facilities[70]

Alewife MBTA Station	5-7 Cambridge Park Dr.	2750 sp
First Street Municipal Garage	11 Spring/51 First St.	1110 sp
Green Street Garage	260 Green St	290 sp
Municipal Lot #2	110 Mt. Auburn Street	42 sp

Private Garages/Open to the Public

Cambridgeside Galleria	78-90 First Street	2538 sp.
1 Kendall Square Garage	389 Binney Street / 205 B	1566 sp[71]
7 Cambridge Center	7 Cambridge Ctr	731sp
Cambridge Center Garage	115 Broadway	1170 sp
CRP Garage 1	354 Third Street	1409 sp
Shaw's Supermarket Garage	55 Franklin Street	1002 sp
Museum of Science	14 Msg OBrien Hwy	994 sp
4 Cambridge Center	4 Cambridge Ctr	875 sp.
Charles Square Garage	14 University Road	686 sp
University Place Garage	124 Mt. Auburn Street	450 sp
Hyatt	575 Memorial Drive	458 sp
MIT Badger Building	One Broadway	430 sp
Cambridge Hospital Garage	1493 Cambridge Street	210 sp
Eliot Street Garage	65 John F. Kennedy Street	208 sp
Royal Sonesta	5 Cambridge Parkway	180 sp
Monitor Building Public Garage	2 Canal Park	177 sp
Holyoke Center Parking Garage	17 Holyoke Street	109 sp
Bent Realty Trust	29 Charles Street	75 sp
The Inn At Harvard	1201 Massachusetts Avenue	50sp

Pedestrian and Bicycle Networks

Pedestrian and bicycle networks support "soft mobility,"[72] or non-motorized transport (human powered mobility). The pedestrian network in Cambridge is extensive. Almost all Cambridge streets have sidewalks and street lighting and a large percentage have bike lanes. Approximately

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70 Some facilities are a combination of commercial and non-commercial spaces.
71 Of the 1566 spaces, 1050 are commercial.
72 Soft mobility includes any non-motorized transport (human powered mobility), including pedestrian, bicycle, roller skate and skateboard trips. *Soft Mobility and Urban Transformation*. Rosa Anna La Rocca. TeMALab of Mobility, Land Use and Environment, e-mail: larocca@unina.it; web: www.dipist.unina.it
http://www.tema.unina.it/index.php/tema/article/viewFile/125/127

30% of Cambridge residents bike or walk to work. The City contains 46 miles of bike routes (off-road bike paths as well as streets with markers or design features that facilitate bike use), which almost completely mirrors the City's 48 miles of major roads. This reflects the importance of bicycle accessibility to Cambridge citizens.

In New York City post-Hurricane Sandy, pedestrians and bicyclists represented more than half the river crossings from New Jersey to Manhattan while the subway system was shut down and roads were congested[73]. In response, some 20,000 New Yorkers who usually used other forms of transportation commuted by bike[74]. This shows the role and viability of pedestrian and bicycle transport in emergency, especially in a city of neighborhoods like Cambridge.

Intersections with the Paul Dudley White bike path and the Charles River bridges represent the busiest pedestrian and bicyclist intersections in the City. Consequently, the bridges listed as critical assets within the roadway system are equally critical for the pedestrian and bicyclist networks.

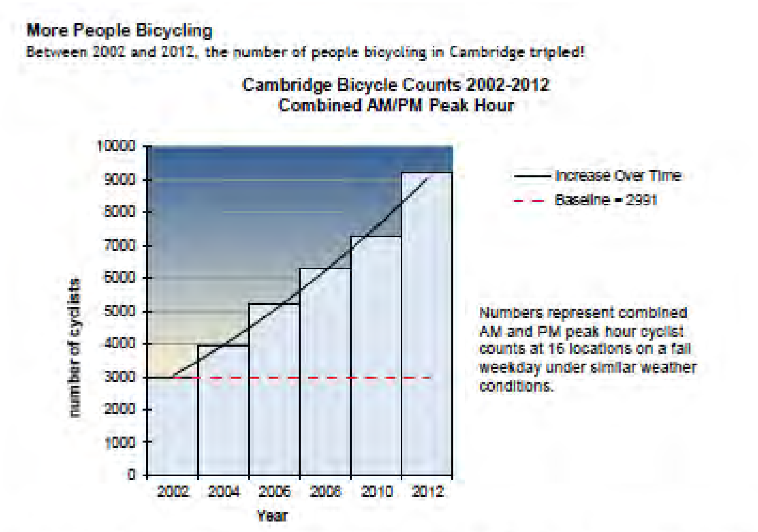

Figure 3: Cambridge Bicycle Counts 2002 - 2012[75]

Cambridge has built a reputation as one of the best cities for bicycling in the U.S. The City has actively invested in making cycling a priority, including establishing the Hubway bike share

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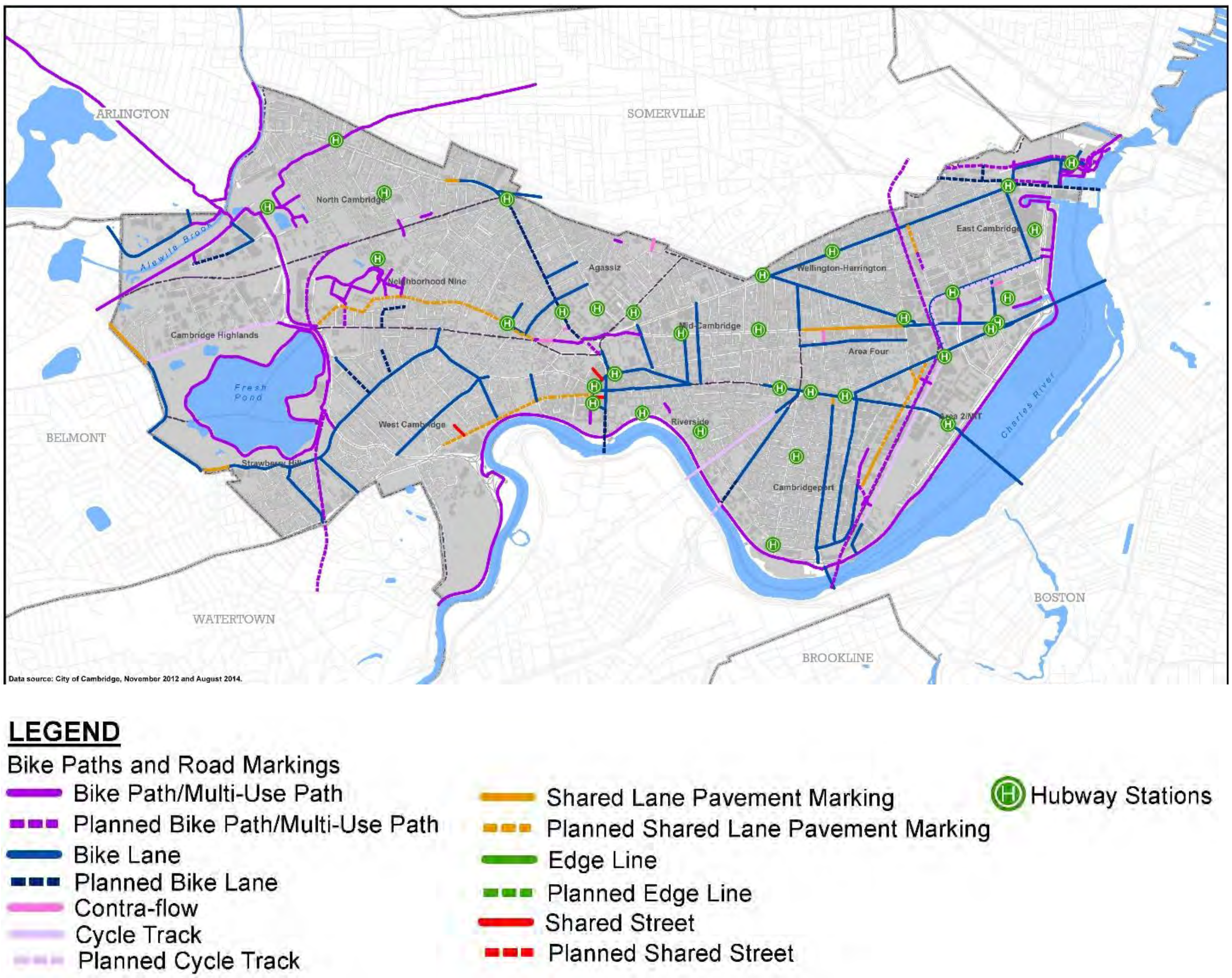
[73] PLANYC - A Stronger, More Resilient New York, Chapter 10, Transportation. July 2013 (page 187)

[74] Sandy Success Stories, New York, New Jersey, June 2013. Rockefeller Brothers Fund & Environmental Defense Fund.

[75] http://www.cambridgema.gov/~/media/Files/CDD/Transportation/Bike/bike_trends.ashx

program and creating an expansive network of bicycle facilities. The popularity of the bicycling culture in Cambridge is epitomized in such events as community bike rides.[76]

Hubway is the metro-Boston area's public bike share system, which operates in conjunction with the City of Cambridge Development Department. Hubway provides 27 bike sharing stations in Cambridge. The entire system in Cambridge, Somerville, Brookline, and Boston includes 129 stations. In 2013, Hubway piloted its first four-season operation of the bike share system in Cambridge.



Map Tr.6: Bicycling Infrastructure, City of Cambridge[77]

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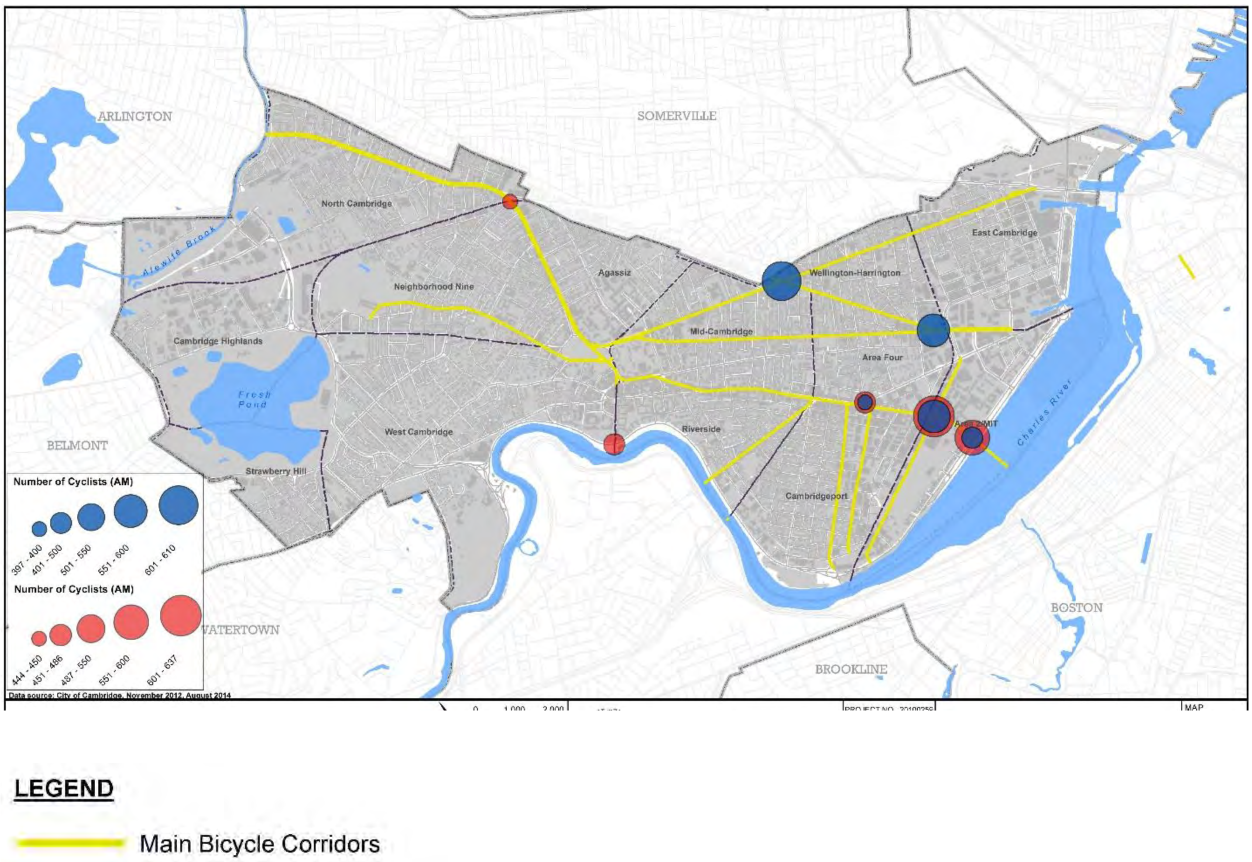
[76] Cambridge City Manager Robert Healy in its acceptance speech for the City's Gold BFC awarded by the League of American Bicyclists. http://www.cambridgema.gov/citynewsandpublications/news/2013/05/cambridgenamedagoldbicyclefriendlycommunity.aspx

[77] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012, (07/28/2014)

Current bike ridership is assessed using raw count data collected by the City at specifically intervals on designated roads. This information has yet to be analyzed but can provide a preliminary understanding of bike behavior in Cambridge. The City documented general trends in bicycling throughout a typical day that provide insight into bicycle usage for commuting, and highest bike ridership traffic areas by street. This information is used for a preliminary identification of critical bicycle assets to be updated as more comprehensive analyses are made available



Map Tr.7: Bicycling Critical Assets, City of Cambridge[78]

Latest available information on the bike share system is mapped, alongside bicycle facilities categorically including bicycle lanes, tracks, and other designated spaces on the roads for bike usage. As more Hubway stations are planned for installation in Cambridge, this information presents only current available information. Collectively, this map provides an overview of

[78] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012, (07/28/2014)

resources for bicyclists and residents who use the Hubway system for recreational or commute biking in the City.

Key Bicycling Resources to be Analyzed in the Vulnerability and Risk Assessment

The Key bicycling resources to be analyzed in the vulnerability assessment comprise main intersections and bicycle corridors associated with high bicycle ridership.

The main intersections are identified based on peak hour bicycle ridership in the 2012/2013 bicycle counts report. These are listed as:

- Inman Square
- Mass. Ave/Vassar St
- Broadway/Hampshire
- Mass Ave/Memorial Drive
- Lafayette Square
- Mass Ave/Vassar St
- Mass Ave/Memorial Drive
- JFK/Memorial Drive
- Lafayette Square
- Porter Square

Main Bicycle Corridors

- Mass Ave: entire way
- Dr. Paul Dudley White Bike Path (it is in Cambridge even if it isn't "ours" – we do have counts at JFK and Mass Ave intersections)
- Cambridge Street – Inman Sq – O'Brien
- Garden Street Corridor – Common - FPP
- Broadway – entire way
- Western Ave
- Brookline/Sydney
- Vassar Street
- JFK street from River to Harvard Square
- Hampshire Street to Porter Square

Water

Surface water bodies and built water infrastructure are fundamental to a city's livability and its functioning. Surface water bodies serve as sources of water supply; provide runoff storage, passive and active recreational uses, and cooling areas; and contribute to a city's aesthetics. The water infrastructure system is essential to treat and distribute potable water to residents and commercial facilities, provide flood protection, and collect stormwater and wastewater throughout the City. During extreme weather events, water infrastructure and operations can be significantly impacted. Hence it is of vital importance to understand the most critical assets in the natural and built environments, understand potential impacts, and identify strategies to mitigate those impacts.

This assessment includes many forms of water infrastructure including surface water bodies, drinking water reservoirs, water treatment and distribution system, wastewater collection system, and stormwater system. This section describes each of these systems, identifying the most critical water assets in the natural and built environments.

The water system in Cambridge is classified into two broad categories: (1) Natural environment that includes surface water bodies and wetlands, and (2) Built water infrastructure. The built infrastructure system is further comprised of three broad categories: (a) dams, (b) water supply, treatment and distribution system, and (c) wastewater, stormwater and combined wastewater collection system.

Surface Water Bodies

Some of the major surface water bodies within the City of Cambridge are:

- Charles River
- Little River/Alewife Brook
- Fresh Pond
- Wellington Brook
- Blair Pond

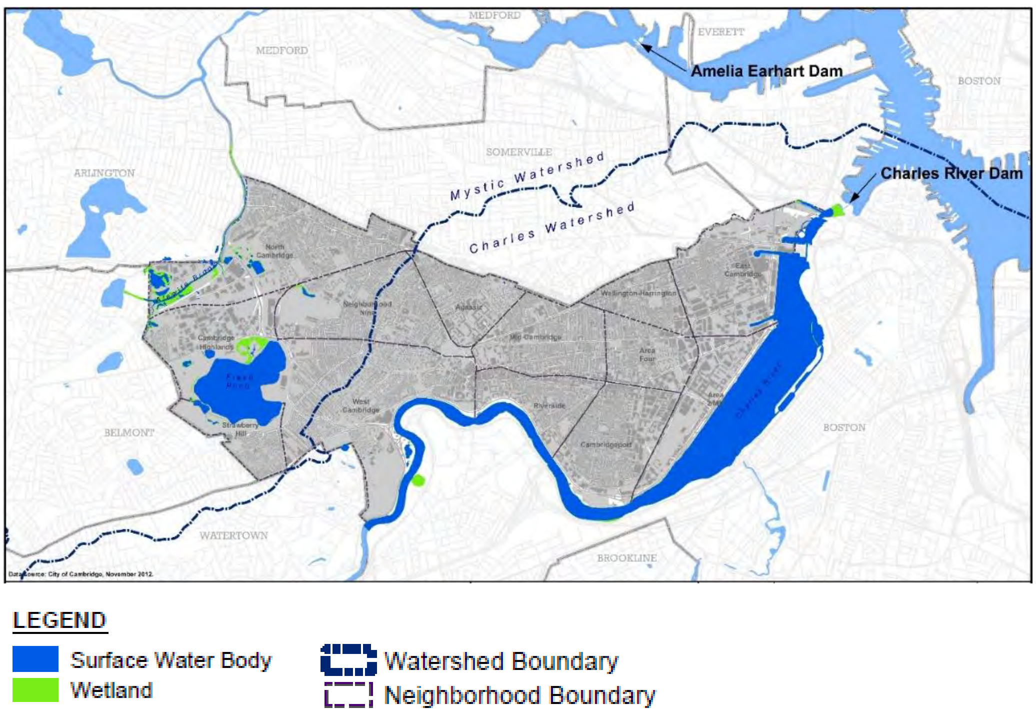
This section focuses on the Charles River, Alewife Brook and the Fresh Pond water bodies. The significance of these water bodies for the City of Cambridge is based on the following:

- Both Wellington Brook and Blair Pond contribute flows to the Alewife Brook. Approximately a third of the areas in North and West Cambridge discharge to Alewife Brook.
- Cambridge separated stormwater systems discharge to either the Charles River or Alewife Brook; approximately two thirds of the City of Cambridge discharge to the Charles River.
- In terms of water quality Fresh Pond, Blair Pond and Wellington Brook are not listed in the Section 303(d) (Cambridge Stormwater Management Plan, 2006), which is the list of waters impaired or threatened by a pollutant(s) determined by the EPA

- Both Charles River and the Alewife Brook are included in the Massachusetts Category 5 Waters list, which is the list of "impaired waters requiring a TMDL." Note that no Total Maximum Daily Loads (TMDLs) have been established for any segment of Cambridge water bodies at this time (2014). Hence, the City is required to monitor the combined sewer overflows which negatively impact water quality of these two water bodies.

Charles River

The eastern area of the City within the Charles River watershed comprises approximately 70% of the City (Cambridge Stormwater Management Plan, 2006). This portion of the Charles River watershed is also called the lower Charles River basin, which is the drainage area of the lower Charles River between the Watertown Dam and the New Charles River Dam. Map W-1 shows the major drainage areas within the City of Cambridge that are included in the Charles River and Mystic River basins.



Map W.1. Location of Surface Water Bodies, Wetlands, and Dams in Cambridge[79]

The Charles River in Cambridge receives discharges from the municipal separated storm sewer systems (MS4), as well as from combined sewer system overflows (CSOs) in the City during

[79] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

heavy rainfall events. There are six (6) combined sewer outfalls on the Charles River in Cambridge: one is permitted to the Massachusetts Water Resource Authority (MWRA) at cottage farm, and five are permitted to the City of Cambridge (Cambridge Stormwater Management Plan, 2006). Of the Cambridge-owned outfalls, CAM05, CAM07, and CAM17 are open and CAM09 and CAM11 are plugged. The stormwater system and the outfalls are discussed in greater detail in the built environment section on stormwater/combined wastewater infrastructure.

Since the Charles River serves as one of the main drainage discharge water bodies for the City of Cambridge, the elevations maintained in the lower Charles River are very critical in terms of operations of the stormwater and combined wastewater systems within the City. The elevation of the lower Charles River is maintained between 106.6 ft. MDC (0.07 ft. NVD88 or 11.72 ft. CCB) and 108.5 ft. MDC (2.07 ft. NAVD88 or 13.72 ft. CCB). 106.6 ft. MDC is the minimum elevation before piles become exposed. Typically, when the level at the lower pool reaches 108 ft. MDC, DCR turns on three pumps and progressively turns on more when levels get above that. At 108.5 ft. MDC, the system reaches the maximum elevation that prevents water from back-flowing into the Boston and Cambridge Marginal Conduits. Also, higher elevations in the Charles River will pose tail water restrictions to the City's drainage and combined wastewater system, which will cause capacity limitations and flooding/overflows in the City's sewer and drainage systems. The criticality of the Charles River Dam in maintaining the lower Charles River basin elevations is discussed in the next section.

Water-quality impact on the River during heavy rainfall events is another critical aspect of the Charles River as it relates to the City. Both primary (swimming) and secondary contact (boating, fishing) recreation activities are among the designated uses of the Charles River. The lower Charles River is currently listed by the EPA as a Category 5 water; it does not meet the water quality criteria for these uses. Heavy rainfall events result in increased discharge of both stormwater and wastewater loads in the Charles River from MS4 outfalls and combined sewer outfalls. This results in further impairment of water quality in the river from pollutants such as nutrients, pathogens, metals, priority organics, oil and grease. For example, approximately 0.2 Millions of Gallons per day (MGD of overflow to the Charles River was reported from the CAM 007 area during the heavy rainfall event on October 20, 2012, when over 2 inches of rain was recorded during a 24-hr period (2012 Annual NPDES Report).

Alewife Brook

The Alewife Brook starts at the outlet of Little Pond in Belmont and flows to the confluence with Mystic River in Somerville. The remaining approximately 30% of the City in West and North

Cambridge are part of the Mystic River watershed, which drains to the Mystic primarily through the Alewife Brook (Map W.1).

Similar to the Charles River, the Alewife Brook in Cambridge receives MS4 and CSO discharges during heavy rainfall events. There are seven (7) combined sewer outfalls on the Alewife Brook, of which one is permitted to MWRA, one to the City of Somerville, and the remaining five to the City of Cambridge. These are discussed in further detail in the built infrastructure section.

The elevations maintained in the Mystic River (and hence in the Alewife Brook) are critical in terms of operations of stormwater and combined wastewater systems that discharge to the Alewife Brook. The elevation of the Mystic River basin is maintained between 104.5 ft. MDC (-1.93 ft. NAVD or 9.72 ft. CCB) and 106.5 ft. MDC (0.07 ft. NAVD88 or 11.72 ft. CCB). However, there is some flexibility in terms of maintaining these elevations in the Mystic River basin compared to the lower Charles River basin. Also, the opportunities to drain the Mystic River basin are less. Higher elevations in the Alewife Brook will pose tail water restrictions to the City's drainage and combined wastewater system, which will cause capacity limitations and flooding/overflows in parts of the City's collection system that drain to the Alewife Brook.

The Alewife Brook is also listed as a Category 5 receiving water by the EPA, and its water quality is further impacted during heavy rainfall events. Heavy rainfall events lead to increased discharge of both stormwater and wastewater loads in the Alewife Brook, which further impair water quality with pollutants such as metals, nutrients, pathogens, organics, oil and grease. For example, approximately 6.6 MGD of overflow was reported to the Alewife Brook from the five combined sewer outfalls (CAM 001, CAM 002, CAM 401B, CAM 004, CAM 401A) during the heavy rainfall event on October 20, 2012, when over 2 inches of rain was recorded during a 24-hr period (2012 Annual NPDES report).

Fresh Pond

According to the Massachusetts Water Quality Standards 314 CMR 4.04, Fresh Pond is an "Outstanding Resource Water" because it is part of the drinking water supply system for the City of Cambridge. Fresh Pond is an ancient glacial pond approximately 155 acres in size. The Pond is surrounded by upland forests, meadows, wetlands and wildlife, and together this area is called the Fresh Pond Reservation. The topographic watershed of 1,297 acres is restricted to 229 acres by intercepting and redirecting local drainage in order to reduce the inflow of polluted stormwater runoff[80].Water from the Stony Brook Reservoir in Waltham is fed by gravity though a 7.7-mile underground pipeline to Fresh Pond. Capacity at full pool for the Fresh Pond is 1.5 billion gallons, most of which comes from the Stony Brook Reservoir via the conduit, with a small fraction coming from local groundwater sources.

Since Fresh Pond serves as the water supply source for the City, maintaining its water quality is very critical. Two isolated drainage areas contribute to Fresh Pond: one area adjacent to Weir Meadow and one area near Lusitania Field (City of Cambridge Stormwater Management Plan, 2006). Discharges to the Pond are regulated under the Massachusetts Surface Water Quality Standards. In 2001 the City adopted the Fresh Pond Reservation Master Plan to protect Fresh Pond's water quality. The City recognizes the Fresh Pond Reservation as a "unique irreplaceable resource" and considers it of vital importance in "protecting and enhancing both water quality of the Fresh Pond Reservation and its open space and naturalistic character" (Fresh Pond Master Plan, 2001). It is important to assess the extent of vulnerability of Fresh Pond in terms of both water quality and its impact as a natural resource under higher temperatures and flooding from extreme rainfall events.

Wetlands in Fresh Pond Reservation

Wetlands constitute 21.4 acres or 13% of the land area in the Fresh Pond Reservation and comprise five forested wetlands (17.4 acres), two scrub/shrub wetlands (3.3 acres) and one emergent wetland (0.7 acres). Wetlands in the Fresh Pond Reservation area are shown in Map W.1.

The wetlands in the Fresh Pond Reservation are critical to the City of Cambridge since they are a key component of the hydrological cycle and provide significant benefits in terms of both stormwater water storage and treatment. Wetlands serve as a slow infiltration system and through physical, chemical and biological processes they improve water quality by retaining and removing environmental contaminants such as heavy metals, phosphorous, and nitrogen. The enhanced infiltration system provided by the wetlands also reduces peak flows and helps mitigate downstream flooding impacts. Another critical function of the wetlands in the Fresh Pond Reservation is that they provide valuable ecological functions in terms of wildlife habitat. The vulnerability and risk associated with climate change impacts on the wetlands in the Fresh Pond

[80] (City of Cambridge Surface Water Supply Protection Plan, 2011).

Reservation will be assessed in a qualitative manner, both with respect to its function in improving water quality of stormwater runoff, as well as supporting wildlife habitat.

Key Surface Water Bodies to be Analyzed in the Vulnerability and Risk Assessment

- Charles River
- Alewife Brook
- Wetlands in the Fresh Pond Reservation

Built Water Infrastructure

This section on the built water infrastructure in Cambridge is subdivided into three main categories: (a) Dams, (b) Water supply, treatment and distribution infrastructure, and (c) Stormwater/combined wastewater collection infrastructure.

Dams

The two dams that are critical to flood control protection for the City of Cambridge are the New Charles River Dam on the lower Charles River and the Amelia Earhart Dam on the Mystic River in Somerville. It is important to note that neither dam is within the City boundary. However, the dam operations and control have a significant impact on the City's stormwater and combined wastewater collection systems that drain either to the lower Charles River or to the Alewife Brook.

New Charles River Dam

The New Charles River Dam was built in 1978. The primary functions of the dam are to maintain the lower Charles River basin elevation between 106.5 ft. MDC (0.07 ft. NVD88 or 11.72 ft. CCB) and 108.5 ft. MDC datum (2.07 ft. NAVD88 or 13.72 ft. CCB), as well as to prevent sea water from entering the lower basin during high tides. There are two 8' X 10' sluice gates that drain the lower basin by gravity when tide level is lower than basin level. The tidal elevations on the Harbor side typically fluctuate between 100 ft. MDC (-6.43 ft. NAVD88 or 5.22 ft. CCB) and 111 ft. MDC (4.57 ft. NAVD88 or 16.22 ft. CCB), but can rise as high as 18 ft. CCB. The top of the dam is at elevation of 118 MDC (11.57 ft. NAVD88 or 23.22 ft. CCB).

The dam contains three boat locks: two smaller ones (200 ft. in length and 25 ft. in width) used primarily by recreational vessels, and a larger boat lock (300 ft. in length and 40 ft. in width) used for recreational and occasionally by larger commercial vessels. The pumping station at the dam has six pumps, each of 1400 cfs capacity, so the total pumping capacity of the New Charles River Dam is 8400 cfs. The pump station buildings' elevation is 122 ft. MDC (15.57 ft. NAVD88 or 27.22

ft. CCB), so 4 ft. above the top of the dam. The primary fuel supply for these pumps is diesel, but they require electricity to function.

When a storm is forecast, the basin is pre-lowered to 106.6 ft. MDC (0.17 ft. NAVD88 or 11.82 ft. CCB) to increase the storage capacity of the basin by draining through the 8' X 10' sluice gates, and three or four of the six pumps at the Dam are activated. The pumps are in a vertical bell housing that maintains a constant head of 116 ft. MDC (9.57 ft. NAVD88 or 21.22 ft. CCB). The harbor side elevation has not exceeded 116 ft. MDC, so the pumps have always operated at a constant head of 116 ft. In a recent flooding event on March 8, 2013, the harbor-side tidal elevation reached 114.2 ft. MDC. When the storm passes, the basin is drained through the sluice gates by gravity drainage and the pumps are shut off.

According to the USACE 1971 Design Memorandum, the Charles River Basin Dam was designed based on a Project Design Flood (PDF) that caused a total inflow of 15,500 cfs, of which 2,100 cfs was contributed from the upper basin (at USGS Waltham gaging station) and 13,400 cfs was contributed from the lower basin. Review of flow records at the Waltham Dam revealed that the upper basin flows exceeded the PDF 2100 cfs for up to 11 events during the last 55 years. The lower basin flows have also increased as a result of new drainage outlets to the Charles River due to conveyance system improvements throughout the lower basin.

Because the New Charles River Dam is critical for flood control operations in the basin and in the tributary water bodies upstream, it is of vital importance to assess the extent of vulnerability of the Dam to flooding impacts from both extreme precipitation events, as well as from sea level rise and storm surge impacts. With respect to precipitation impacts alone, the following will need to be evaluated in the vulnerability assessment phase:

- Will the Dam be able to maintain its operational thresholds in terms of lower basin elevations under extreme precipitation events (for e.g. will the existing pump station operations/capacities be sufficient)?
- Will the design flows[81] at the Dam be exceeded due to higher inflows from the upper and lower basins?

With respect to sea level rise and storm surge impacts on the Dam, the following will need to be evaluated in the vulnerability assessment phase:

[81] The Design Peak Flows from the upper and lower Charles River Basin are presently 21000 cubic feet per second (cfs) and 13400 cfs respectively, indicating the maximum water flows the dam is designed to.

- How will the increase in tidal elevations on the harbor side, as a result of sea level rise and storm surge, impact the operations of the Dam (for example, will the pumps' capacity be limited due to higher operating head)?
- Could the Dam be overtopped and/or flanked as result of sea level rise and storm surge, to what depth and duration, and how will this impact flooding in Cambridge?
- Will the current Dam operations procedure be adequate for sea level rise and storm surge impacts in the future?
- Will service life issues impact the Dam, since it is 36 years old and will be in need of upgrading or replacement?

Amelia Earhart Dam

The Amelia Earhart Dam was built in 1966 and crosses the Mystic River about 1.6 miles above the mouth of the river. Similar to the New Charles River Dam, the primary functions of the dam are to maintain the Mystic River basin and its associated sub-basins elevation between 104.5 ft. MDC (-1.93 ft. NAVD or 9.72 ft. CCB) and 106.5 ft. MDC (0.07 ft. NAVD88 or 11.72 ft. CCB), as well as to prevent sea water from entering the lower basin during high tides.

The Dam is an earth-filled dam with three locks and no sluice gates. The largest lock, a commercial-vessel type, has a length of 325 feet, a width of 45 feet. Two smaller parallel locks just westward have lengths of 120 feet, widths of 22 feet[82] .The pumping station has three pumps, each of 1400 cfs capacity, so the total pumping capacity of the Amelia Earhart Dam is 4,200 cfs.

Because the Amelia Earhart Dam is critical for flood control operations in the Mystic River, including Alewife Brook, as well as in areas of North and West Cambridge that drain to the Alewife Brook, it is of vital importance to assess the extent of vulnerability of the Dam to flooding impacts from both extreme precipitation events, as well as from sea level rise and storm surge impacts. A vulnerability assessment similar to the New Charles River Dam will be conducted for the Amelia Earhart Dam in the vulnerability assessment phase.

[82] http://ma.usharbors.com

Water Supply, Treatment, and Distribution Infrastructure

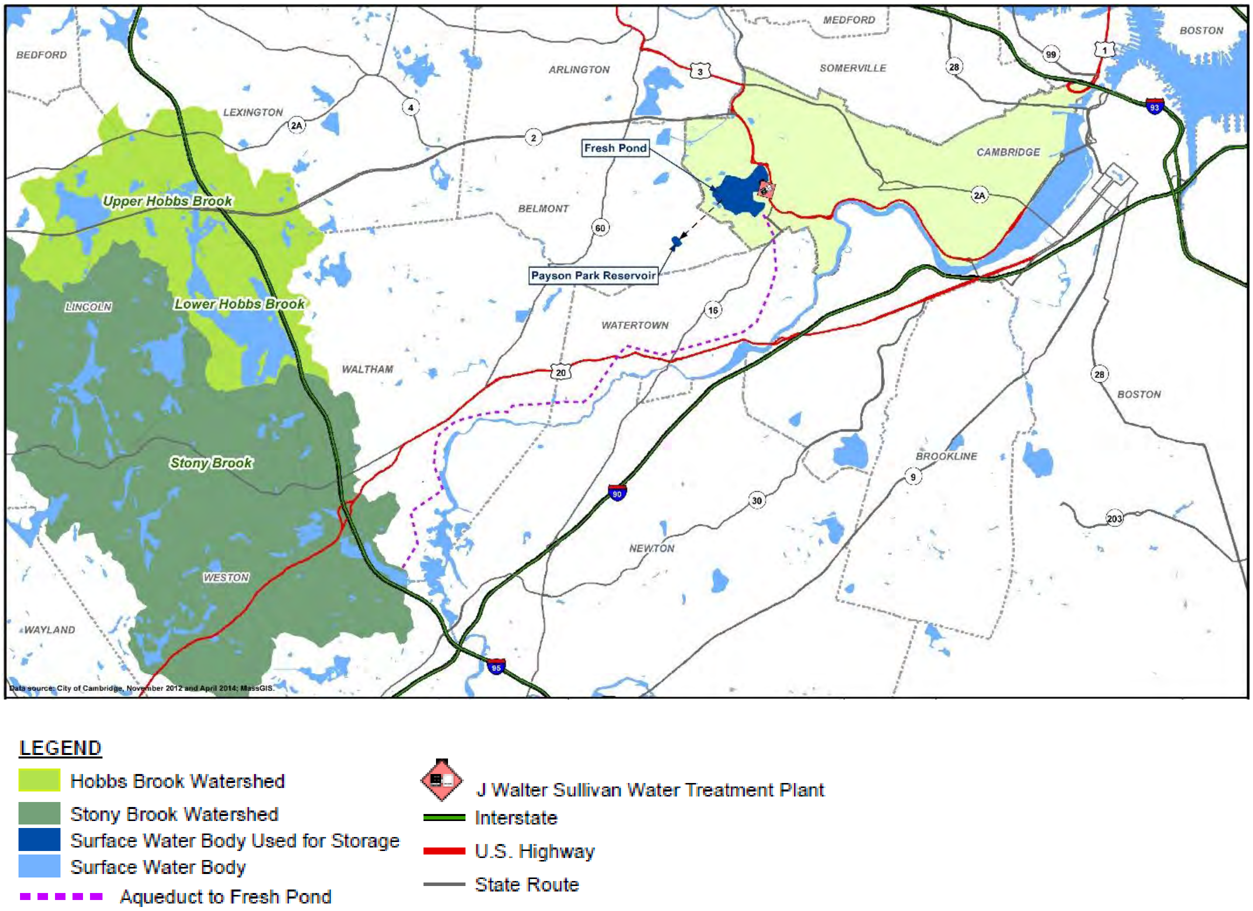
The drinking water supply, treatment and distribution infrastructure in Cambridge are part of the City's Water Department that serves over 100,000 permanent residents, businesses, institutions and government agencies in Cambridge. The impacts to the drinking water infrastructure system during extreme weather events could be negative impacts on the water quality of the supply source. These impacts could potentially be caused by:

- Contamination from polluted stormwater runoff from heavy rainfall events
- Decrease in water supply availability due to drought or extreme heat
- Flooding impacts to the treatment plant
- High-heat impacts to the unit operations in the treatment plant
- Flooding at entry points in the distribution system, such as the air-release blow-off valves
- Other impacts to the treatment plant under extreme weather events such as extended loss of power supply at the plant, equipment inoperability, or inability of plant staff to get to the plant.

Water Supply

The City of Cambridge obtains its water from the 24-square-mile Stony Brook watershed, which contains two impoundments, the Hobbs Brook and Stony Brook Reservoirs. Hobbs Brook Reservoir receives water from a seven-square-mile watershed and discharges into Hobbs Brook through a gatehouse on Winter Street in Waltham. Hobbs Brook joins Stony Brook further downstream, which flows into the Stony Brook Reservoir on the Weston-Waltham town line. The City owns less than 5% of the land in the Stony Brook watershed.

From the Stony Brook Reservoir, water is fed by gravity through a 7.7-mile underground pipeline to Fresh Pond located in the Mystic River Basin (City of Cambridge Surface Water Supply Protection Plan 2011). The location of the different water supply watersheds for the City is illustrated in Map W.2



W.2: Surface Water Supply Source Area, City of Cambridge[83]

The Stony Brook Reservoir has a limited storage capacity of 418 MG, while the Hobbs Brook Reservoir has approximately seven times the capacity of the Stony Brook Reservoir. Water supply in the system is maximized by holding back most of the water in Hobbs Brook Reservoir during winter and spring months, and by releasing to the Stony Brook Reservoir during summer and early fall periods.

Although the Hobbs Brook and Stony Brook Reservoirs are critical assets for the City's water supply system, a vulnerability and risk assessment of these reservoirs is outside the scope of this project, and will be addressed in a qualitative manner.

However, as indicated in the section on surface water bodies, the vulnerability and risk assessment will be conducted for Fresh Pond, which is within the City boundary and is also the terminal water supply reservoir for the City. The Fresh Pond Reservoir serves to improve the

[83] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

quality of water from the upper watershed by settling out solids, diluting dissolved pollutants, stabilizing pH, and decreasing turbidity and color of the incoming water. However, increased stormwater runoff to the reservoir from heavy rainfall events may lead to potentially exceeding its assimilative capacity and impacts to the water treatment facility[84]

Water Treatment

Water from Fresh Pond is pumped into the Walter J. Sullivan Water Purification Facility where it undergoes the following processes: pre-treatment with ozone, flocculation and clarification, disinfection with ozone, biological filtration, disinfection using chlorine, pH adjustment, and fluoride addition. Treated water is pumped uphill to two 16-million-gallon storage tanks on Payson Road in Belmont, to allow for optimum disinfection chemical contact time. This is critical to preventing potential public health issues related to contaminated water consumption. From there, water is fed by gravity to the distribution system. The water treatment facility is located within the Fresh Pond Reservation and its location along with the Payson Park Reservoir is shown in Map W.2.

The vulnerability and risk assessment will be conducted for the Walter J. Sullivan Water Purification Facility with respect to both extreme temperature and precipitation impacts. For example, higher temperatures of the source water will require higher dosage of disinfectant (ozone and chlorine) for the same contact time in the disinfection process. Similarly, decreased water quality of the source water from extreme flooding impacts will require higher dosage of chemicals to achieve the same levels of treatment. Also, the treatment plant itself may be vulnerable to flooding from heavy precipitation events and sea level rise/storm surge impacts in the Fresh Pond area from the Alewife Brook/Mystic River basin. Vulnerability and risk assessment of the Payson Park Reservoir will be conducted in a qualitative manner.

Water Distribution

Treated water from the storage tanks at Payson Park flows by gravity through the City's 190-mile distribution system. The water distribution system consists of transmission and water mains, hydrants, and valves. Although the water mains are generally buried underground and are not exposed to surface flooding, some components such as hydrants, valves, service access and meters could be exposed to flooding from extreme precipitation events. For example, some air-

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[84] City of Cambridge Surface Water Supply Protection Plan 2011

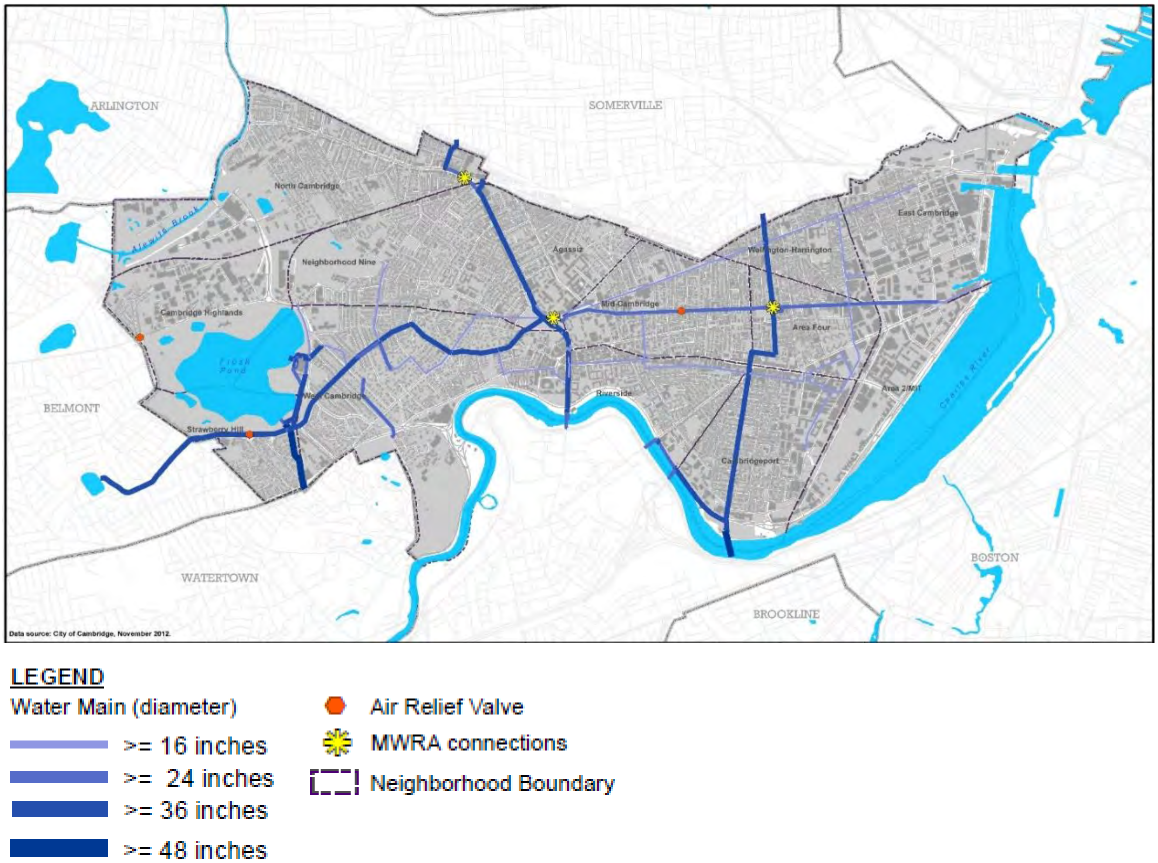
release blow-off valves in the City's distribution system are located in manholes. These valves would be vulnerable to flooding from heavy precipitation events, when they could act as inflows to flood water, and affect the water quality in the distribution system. The Massachusetts Department of Environmental Protection (DEP) has made relocation of such air-release valves mandatory and new valves must be placed at higher elevations on the streets in the form of "mushroom valves". The map W-3 shows the locations of the air-relief valves in the City's system, which could be vulnerable to flooding. Distributions mains in the City that are connected to these air-relief valves and are greater than 16 inches in diameter (Map W.3) are considered critical.

The City has three MWRA connections, which also serve as back-up to the City's potable water supply. The original MWRA 48-inch main connection to the City's distribution system at Cambridge Common was renewed and two additional connections were made in Porter Square and Norfolk Street in 1951. The Norfolk street connection links the City's system to a second 48-inch main, which runs roughly parallel to the first main. These MWRA connections are not used under normal conditions, but serve as back-up during periods of high-demand, stress on distribution system, and in emergencies.

The City of Cambridge has indicated that potable water supply is not an immediate concern because demand has been decreasing as a result of water efficiency efforts. Therefore, the vulnerability and risk assessment will be conducted in a qualitative manner for the assets in the potable water system.

Key Assets in the Drinking Water System to be Analyzed in the Vulnerability and Risk Assessment

- Fresh Pond Reservoir
- Walter J. Sullivan Water Purification Facility



W.3: Water Distribution System, City of Cambridge[85]

Stormwater/Sewer/Combined Wastewater Collection System

The collection system for Cambridge includes the sanitary sewer, combined sewer and separate stormwater collection systems. It also includes manholes, catch basins, pump stations, detention/retention structures and outfall structures. Separation of the sewer system began in the 1930s, and large areas of the combined collection system owned and maintained by Cambridge have been separated over the past 25 years. The City's sewer separation projects and stormwater management efforts have addressed localized flooding problems and stormwater quality issues for existing conditions. However, the City's collection system may be subject to vulnerability considering predicted increase in heavy precipitation events and flooding from sea level rise and storm surge.

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[85] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

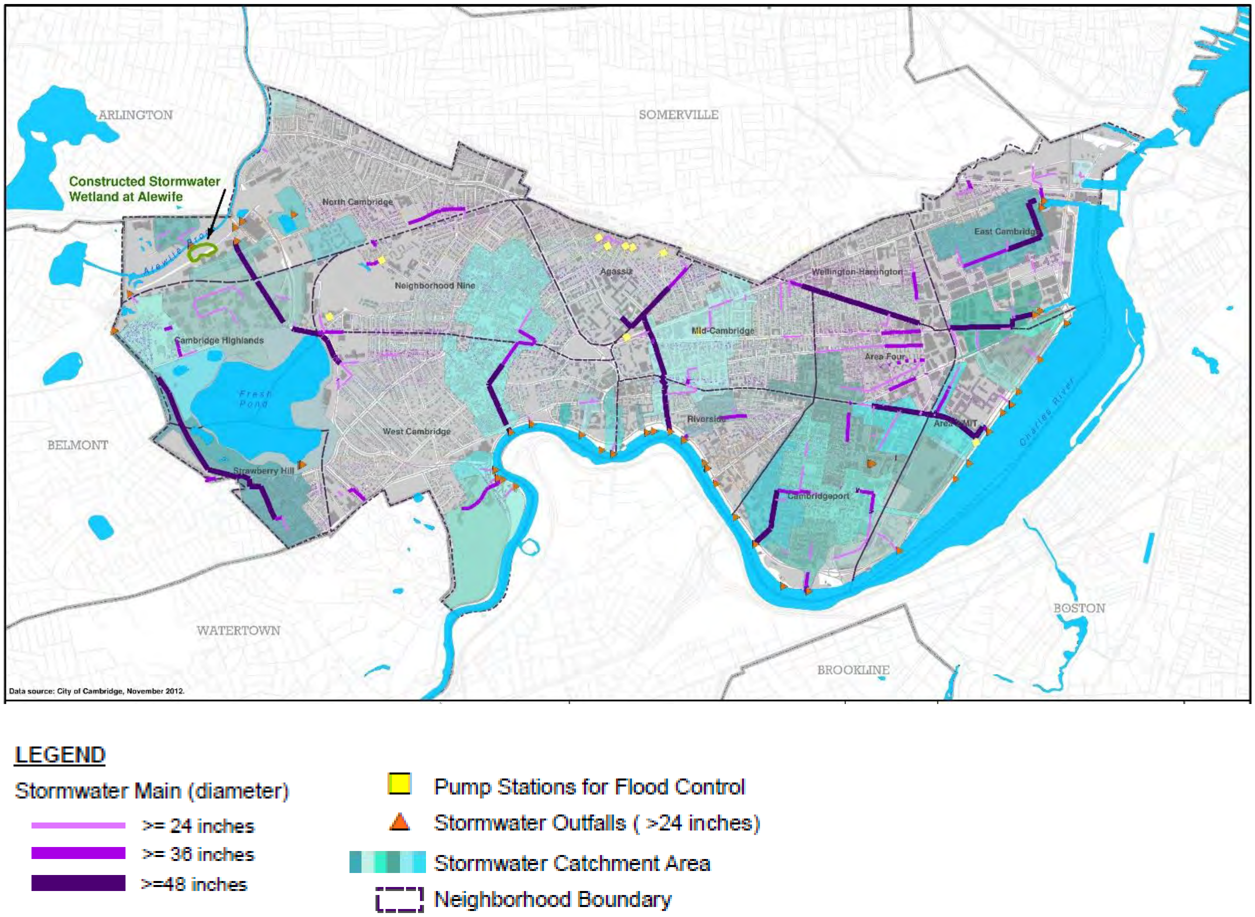
Stormwater System

The City has 94 miles of stormwater gravity mains (drainage pipes), over 6,000 catch basins, and approximately 4,000 drain manholes. The map of the stormwater collection systems (Map W.4) presents the stormwater gravity pipes that are equal to or greater than 18 inches in diameter considered as critical for analysis. There are ten stormwater pumps for flood control in the City, of which six are in the Agassiz neighborhood. These are distributed through New Street, Crescent Carver and Broadway and installed as part of the stormwater holding/retention tanks at these locations.

The retention tanks provide flood protection by storing stormwater overflows during heavy rainfall events. The pumps are critical because they drain stormwater from the retention tanks back into the drainage system when capacity is available in the pipes after the heavy rainfall has receded. There are two drainage pump stations at the Cambridge Street underpass and at the Memorial Drive underpass that are used to pump out stormwater under flooding conditions at these locations (Map W.4). In addition to these, there are another approximately 30 stormwater pump stations indicated on the City's GIS system, which may provide additional flood control relief. The vulnerability and risk assessment will be limited to the two main pump stations mentioned above as operation requirements are not factored in precipitation modeling as this requires a granular approach beyond the scope of this study.

The City stormwater outfalls discharge either to the Charles River (including Lechmere and Broad canals), Alewife Brook, Fresh Pond, Wellington Brook or Blair Pond. The stormwater outfalls associated with pipes greater than 24 inches in diameter are considered critical for this analysis and presented in Map W.4, and include the dedicated stormwater outfalls that were created as part of the City's recent combined sewer separation projects.

Another critical asset of the City's stormwater system that will be assessed in the vulnerability and risk assessment phase is the Stormwater Wetland Basin that was constructed as part of the drainage improvements in the Alewife Brook area (Map W.4). This constructed wetland basin, completed in 2013, will attenuate the stormwater flows and provide an additional level of water quality treatment prior to draining the stormwater to the Little River and Alewife Brook. It will be important to assess the extent to which this constructed wetland will provide flood protection or be vulnerable to flooding under future heavy rainfall events considering climate change impacts.



W.4: Stormwater Collection System, City of Cambridge[86]

The vulnerability and risk assessment of the assets in the stormwater system will be conducted based on the results of the City's hydraulic model for both the Charles River and the Alewife Brook basins. The model results with respect to manhole flooding, pipe surcharges, pump station capacity limitations, and increased flows at stormwater outfalls will dictate the specific assets to be analyzed.

Key Assets in the Stormwater System to be Analyzed in the Vulnerability and Risk Assessment

- Pump Stations associated with Flood Control Structures
- Stormwater Catchment Areas

[86] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

Combined Sewer/Sanitary Sewer System

The City has approximately 41 miles of combined sewer and 110 miles of separate sewer pipes, more than 1,100 combined-sewer manholes and more than 3,000 separate-sewer manholes, and 18 sanitary pump stations in the City (City of Cambridge GIS database, 2012; City of Cambridge Annual Report 2012/2013), illustrated in Map 5. This figure also presents combined sewer pipes equal to or greater than 18 inches in diameter and separated sewer pipes equal to or greater than 10 inches in diameter that are considered critical for analysis.

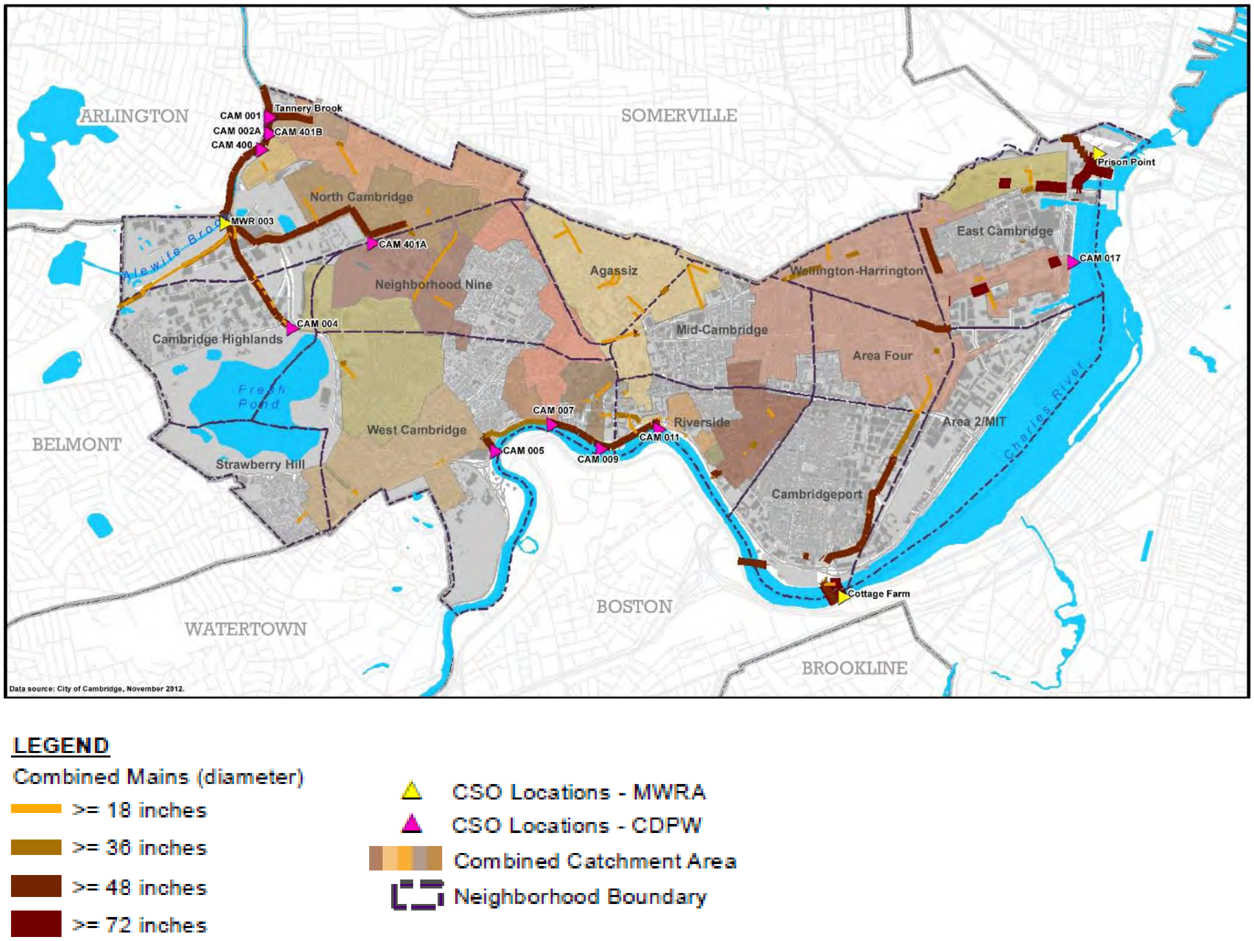
Approximately 40% of the collection system owned and maintained by Cambridge has been separated.[87] Sanitary sewers flow to the MWRA's high-capacity conveyance pipes and then to the MWRA Deer Island Treatment Plant.

Currently, the City has 12 permitted CSO locations associated with 11 CSO regulator structures (Map W.5). Of the 11 regulator structures, three have been temporarily plugged (CAM 002B, CAM 009, and CAM 011), and one was permanently closed and converted to a dedicated stormwater outfall (CAM400). The eight CSO outfalls that are currently metered are critical for analysis in terms of both frequency and volume of combined sewer overflows during heavy rainfall events, and will be assessed in the vulnerability and risk assessment phases.

Key Assets in the Combined Sewer/Sewer System to be Analyzed in the Vulnerability and Risk Assessment

- Sewer Pump Stations
- Combined and Sanitary Sewer Catchment Areas and Associated Conveyance Systems

[87] https://www.cambridgema.gov/theworks



W.5: Combined Sewer Collection System, City of Cambridge[88]

Impervious Surface

Impervious surface as defined by the Massachusetts Commonwealth GIS office (MassGIS) refers to constructed surfaces including buildings, roads, parking lots, brick, asphalt and concrete[89]. The impervious surface coverage in the City of Cambridge is documented as it is a significant contributor to surface run off, thereby impacting storm water management. The specific percentage of coverage in Cambridge by impervious surface has not been calculated but it is noted in this section of the report as a component to be address in the adaptation planning considerations for storm water management.

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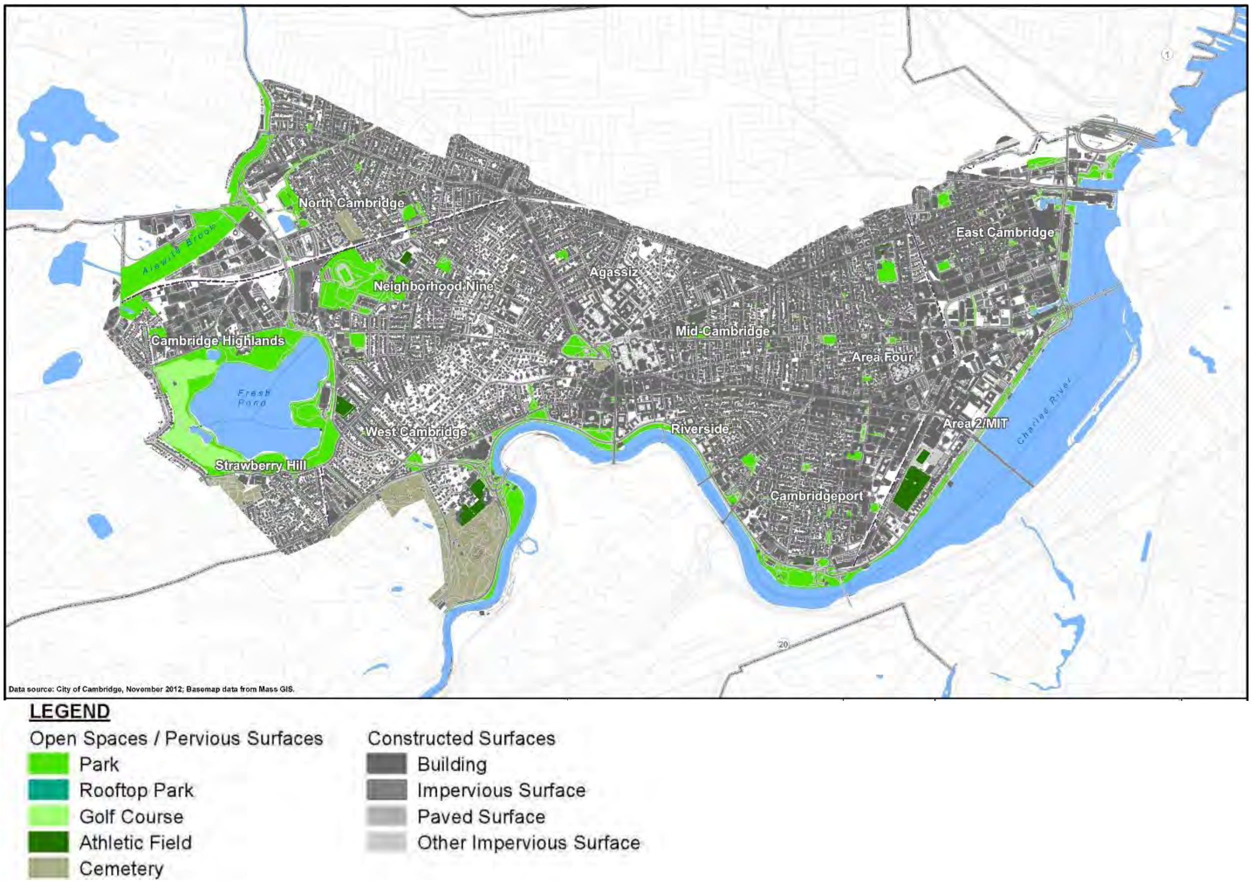
[88] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

[89] http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/impervioussurface.html



W.6: Impervious Surfaces, City of Cambridge[90]

Telecommunications

Telecommunications refers to the electronic transmission of information over distance including voice, data and images. Telecommunications networks are instrumental for information exchange and serve as crisis communication networks during a disaster. Local government and first responders were alerted to the criticality of wireless phone and data networks for disaster recovery during Hurricane Sandy when emergency services provision hinged on the relay of information to responders for health, public safety and support of vulnerable populations.

The primary causes for telecommunications infrastructure failure during disasters are a result of:

- Physical destruction of network components that are exposed to climate change hazards

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[90] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

- Disruption of the supporting network infrastructure such as to the electrical distribution system
- Network congestion[91]

Major disasters are the most intense generators of telecommunications traffic.[92] Because telecommunications providers share infrastructure in the form of network cabling and co-location centers, failure of an asset such as a cut cable or flooded facility can cause an outage for thousands of customers. Cambridge residents rely upon phone service, including that provided by voice over internet protocol, the internet, television, and radio to receive and share information during weather emergencies. This study of telecommunications infrastructure focuses on these consumer end points-–access to a telephone landline, cellular phone, internet, radio and television, and their shared or respective information transmission pathways–-to determine their vulnerability to specific climate change impacts. It is important to note instances of shared infrastructure supporting information transmission among several carriers for television, internet and wireless telecommunications devices (cellular phones, wireless internet). The following lists the major telecommunications providers in the City of Cambridge:

Major National Wireless Providers

- Verizon
- AT&T
- Sprint
- T-Mobile

Major Cable and Internet providers

- Comcast XFinity
- Verizon FiOS

Major Satellite Provider

- Dish Network

The lists above do not include smaller local exchange carriers that provide cable television, telephone and other services. The City of Cambridge also has its own IT service for security/safety providers, which provides the City more control in adapting its system to climate change. Telephone service availability is defined as the ability of the respondent to both make and receive

[91] http://www.nyu.edu/ccpr/pubs/NYU-DisasterCommunications1-Final.pdf
[92] ibid

calls.[93] As of 2003, cellular phones are considered part of telephone service. Only households whose service has been discontinued “for nonpayment or other reasons are not considered to have telephone service available”[94]. In Cambridge, the number of households without telephone service by census tract is not statistically significant (highest recorded percentage is 6%).

Telecommunications Critical Infrastructure

A telecommunications network is composed of critical components that can be organized into the three categories below[95]. This study focuses on the telecommunications facilities and equipment that support information transmission as listed below.

Terminals for Accessing the Network

- Device that is hooked up to a wireless or local area network (e.g., cellphone, telephone, computer)

Telecommunications Links that Form a Channel for Information Transmission

- Guided Media (e.g. overhead and underground cabling including coaxial cable and fiber optic cable)
- Wireless Media (e.g., terrestrial microwave, satellite transmission, radio transmission)

Telecommunications Facilities and Equipment

- Distribution and switching stations that house computer-controlled digital and fiber optic equipment
    - Co-location centers (carrier hotels) which co-locate network carriers and service providers
    - Telephone office and long-line switch[96]
- Cell sites, which rely on power supplied by a utility and have eight hours of battery backup
- Signal transmitting equipment (terminal devices) in homes, offices; from multiplexers[97] to customer modems *(Not included in this analysis)*

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[93] Telephone service is clearly a “telecommunications service” (it transmits your voice, unchanged, to the person at the other end of the line) and for several years the Commission also considered the transmission component of DSL service to be a “telecommunications service” (it transmits data, unchanged, from your computer to another computer). http://www.broadband.gov/legal-framework-glossary.html [issue with either font or font color]
[94] http://www.census.gov/acs/www/Downloads/survey_methodology/acs_design_methodology_ch06.pdf
[95] http://www.umsl.edu/~joshik/msis480/chapt07.htm
[96] A long line switch is a transmission in a long distance communication network
[97] A multiplexer is composed of analog or digital input signals that forwards the selected input into a single line

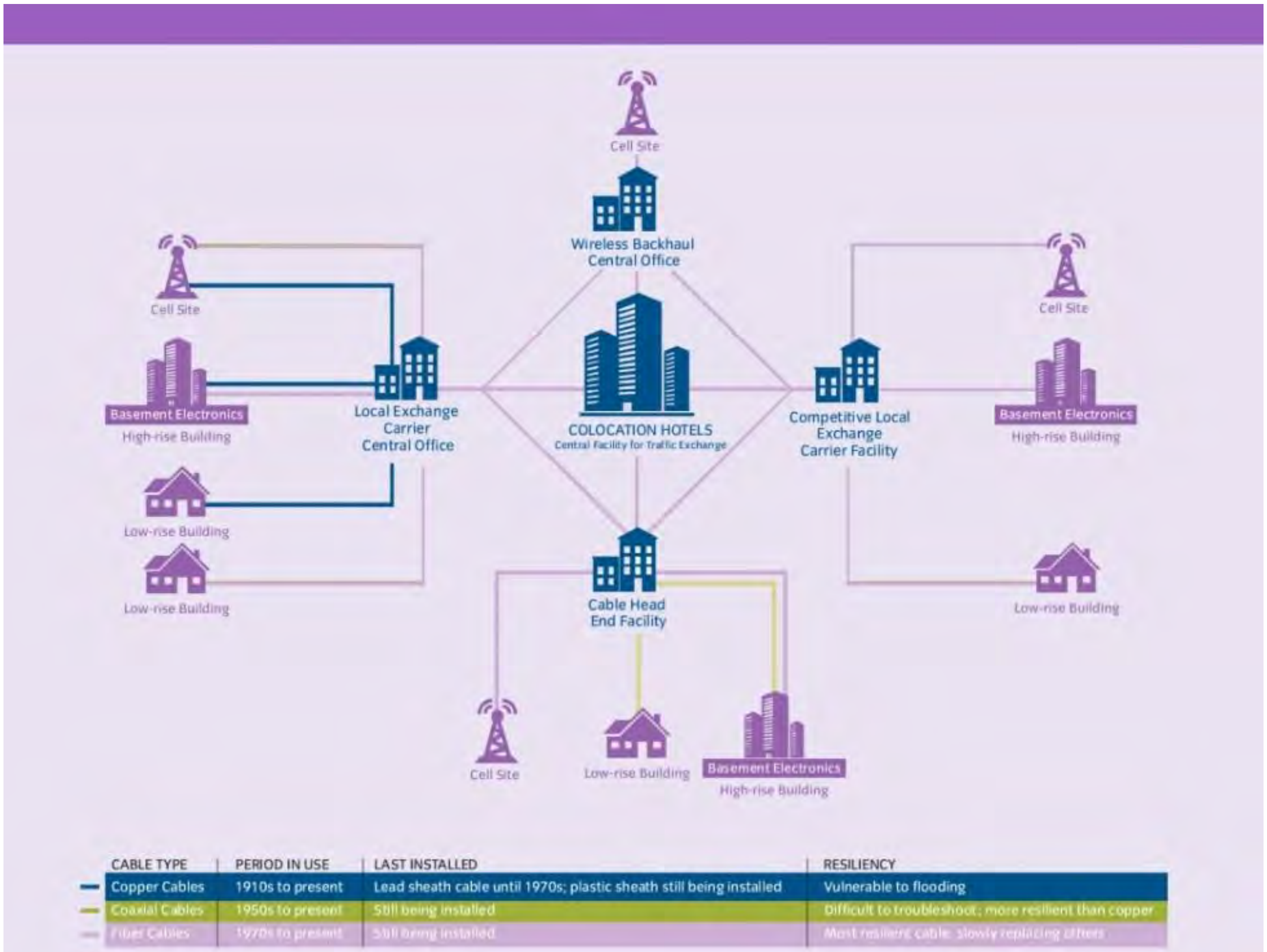


Figure 1: Diagram of Telecommunications Components[98].

Key Telecommunications Assets to be Analyzed in the Vulnerability and Risk Assessment

Based on data availability and consumer end points for accessing the telecommunications network, this assessment focuses on the following critical telecommunications infrastructure that supports service for cellular phones, landlines, cable television and internet. The following telecommunications infrastructure elements were mapped in GIS based on public information provided by the City of Cambridge and as well as publicly accessible data on the internet such as in the case of antenna towers:

Major Data Hubs and Co-location Centers

- 300 Bent St, Cambridge, MA
- 89 Fulkerson Street, Cambridge, MA

[98] Plan NYC More resilient, Chapter 9, Telecommunications

- 10 – 12 Moulton Street, Cambridge, MA (Data Hub)

Telephone Office and Long Line Switches

- 200 Bent St, Cambridge, MA
- 250 Bent St, Cambridge, MA
- 10 Ware St, Cambridge, MA

Cell Towers

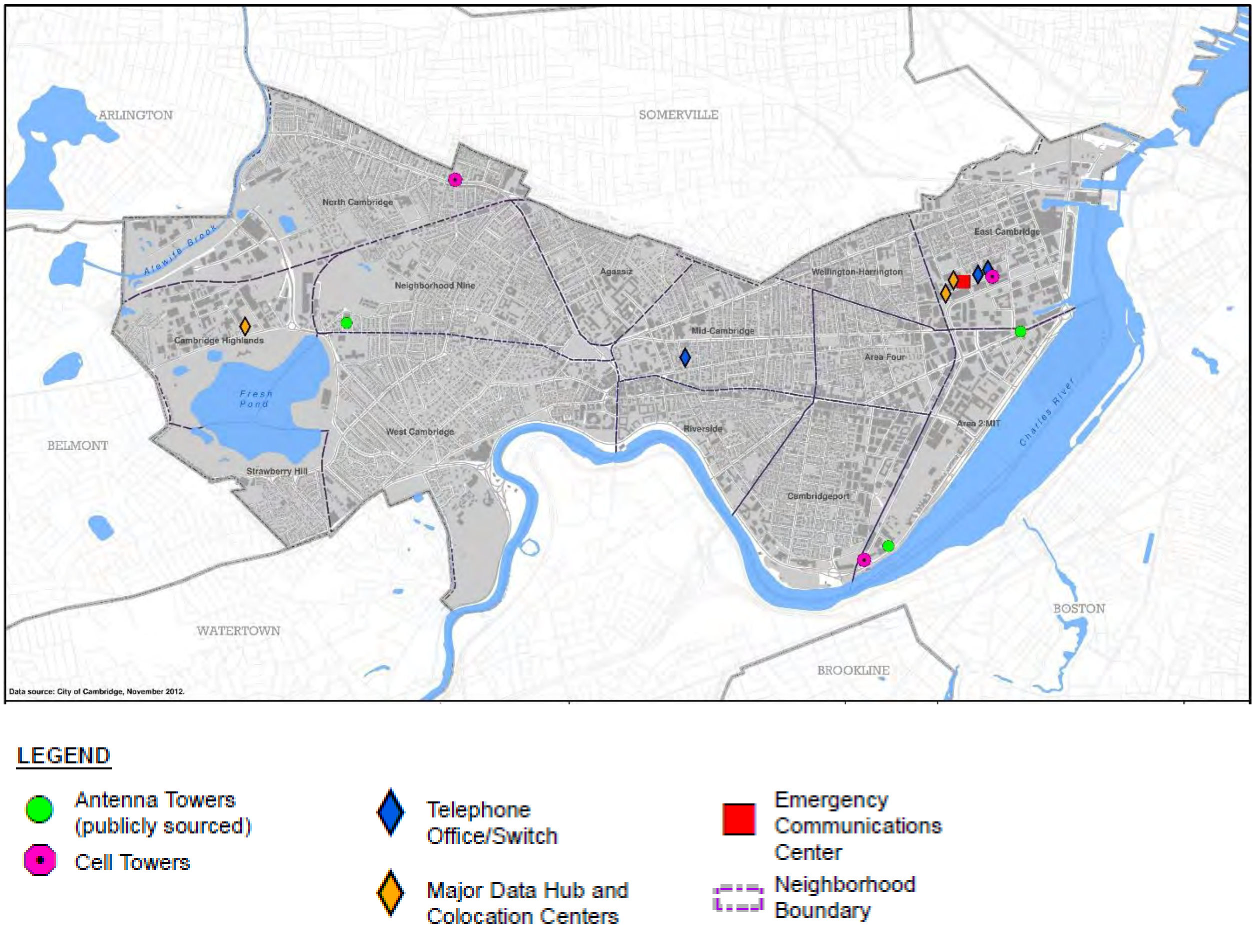
- 575 Memorial Drive, Cambridge, MA
- 210 Bent St, Cambridge, MA
- 2067 Massachusetts Ave, Cambridge, MA

Antenna Towers

- 210 Bent Street, Cambridge, MA
- 575 Memorial Drive, Cambridge, MA
- 443 Concord Ave, Cambridge, MA
- 60 Wadsworth St, Cambridge, MA

Emergency Communications Center

- 125 Sixth Street, Cambridge, MA



Te.1: Telecommunications Critical Assets, City of Cambridge[99]

Critical Services

Critical services are what we often think of in terms of emergency responsiveness and preparedness. These encompass assets and resources associated with public welfare, including health and safety. These include police, firefighters, EMTs, and community-based public health and outreach programs. The essential aspects of these services during emergencies are familiar.

This assessment will focus on municipally-owned assets that Cambridge residents could access in the event of an extreme event associated with projected climate change impacts. They broadly fall into the following groups:

- Police Headquarters

[99] Kleinfelder, 2014

- Fire Stations
- Emergency Shelters
- Health Facilities - Hospitals and Health Centers
- Cambridge Public Health Office

This survey of critical services focuses on City of Cambridge assets only, it does not consider the facilities belonging to the several higher education institutions in Cambridge, or that of the greater regional network. This assessment considers only the City's capacity to respond to Cambridge residents as a way to evaluate current emergency response capacity at a local scale. However, this layer of additional information on the extended capacity in the City of Cambridge could be integrated in coordination with key stakeholders such as the academic institutions in the area.

The emergency services assets identified below are the preliminary list of the City's response infrastructure. These assets must be functional, and access to and from these assets must also be evaluated to ensure services are available at all times, and especially during crisis, to Cambridge residents. The potential response needs of Cambridge residents is considered under the Community Resources section, through the preliminary identification of vulnerable populations in Cambridge. The information gathered through these venues helps to present an overview of the emergency services available to residents, and where these services may be especially in demand.

Key Critical Services Assets to be Analyzed in the Vulnerability and Risk Assessment

Police Stations

- Police Headquarters – 125 Sixth Street, Cambridge, MA

Fire Stations

- Fire Headquarters – 491 Broadway
- Fire Company 2 – 378 Mass Ave.
- Fire Company 3 – 175 Cambridge St
- Fire Company 4 – 2029 Mass Ave
- Fire Company 5 - 1384 Cambridge St
- Fire Company 6 – 176 River St
- Fire Company 8 – 113 Garden St
- Fire Company 9 – 167 Lexington Ave

Emergency Shelters

- Kennedy/Longfellow School - 158 Spring Street
- Peabody School - 70 Rindge Avenue
- Tobin School - 197 Vassal Lane
- Graham & Parks School - 44 Linnaean Street

- Cambridge Rindge and Latin - 459 Broadway
- Morse School - 40 Granite Street
- 136 Bishop Allen Drive
- 402 Massachusetts Ave

Hospitals and Health Centers

Hospitals

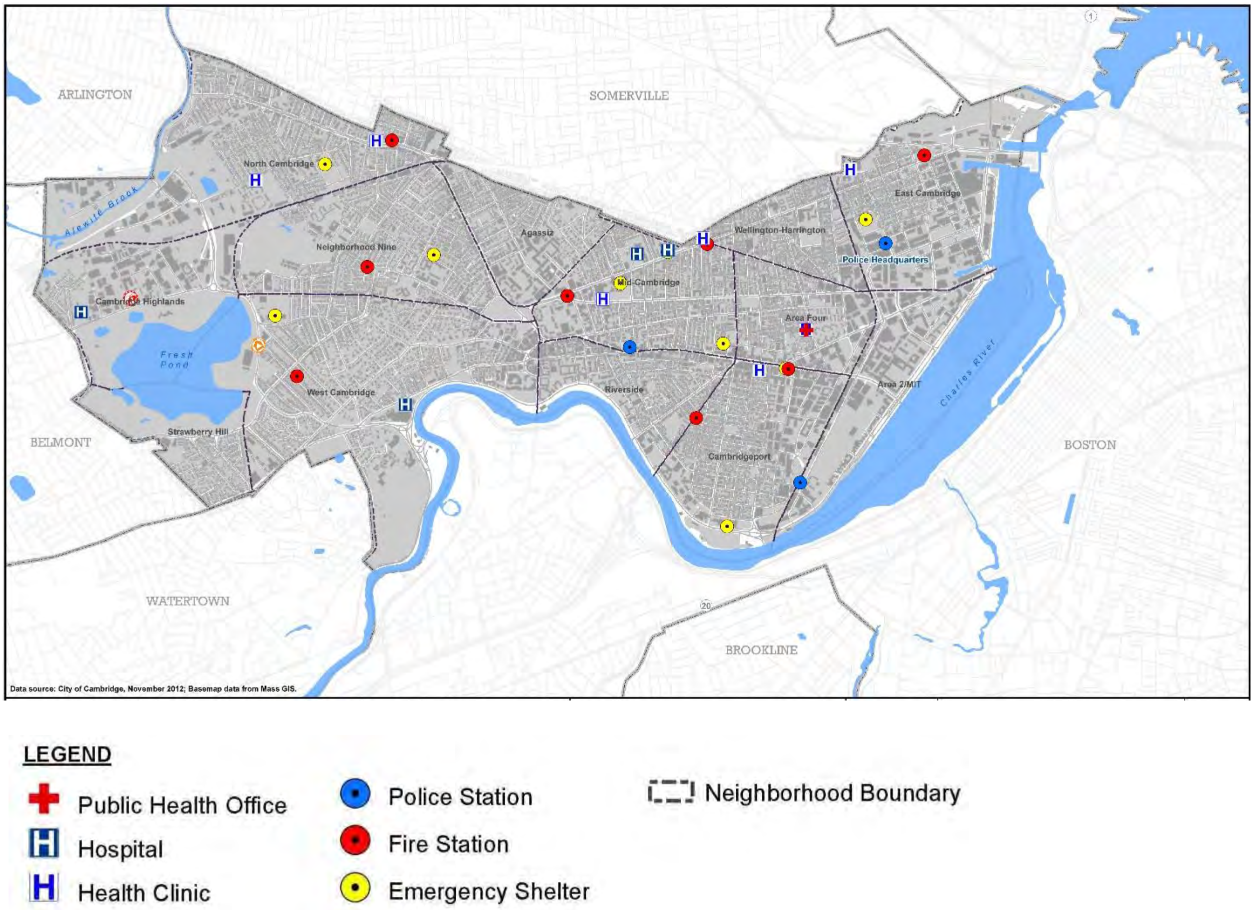
- Cambridge Hospital - 1493 Cambridge Street
- Youville Hospital - 1575 Cambridge Street
- Mount Auburn Hospital - 330 Mt. Auburn Street

Health Centers

- Cambridge Family Health - Inman Square, 237 Hampshire Street
- Cambridge Family Health North - Porter Square, 2067 Massachusetts Avenue
- North Cambridge Health Center - 266 B Rindge Avenue
- Senior Health Center - 806 Massachusetts Avenue
- Windsor Street Health Center/Public Health - 119 Windsor Street
- Teen Health Center at Cambridge Rindge and Latin - 459 Broadway
- East Cambridge Health Center - 163 Gore Street

Municipal Offices (public health/asset owners of water and other utilities)

- Public Health Dept. - 119 Windsor St



CS.1: Critical Services, City of Cambridge[100]

The anticipated outcomes of this spatial analysis are the identification of sensitive critical services and Cambridge residents that may be cut off from accessing these services. Subsequently, a qualitative assessment of the service or asset's resilience to specific impact scenarios can be developed, to anticipate potential lengths of service outages and their implications particularly for vulnerable populations in Cambridge.

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[100] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012),

The Urban Forest

The City of Cambridge places high value on its urban forest due to enhanced air quality, lower wind speeds, aesthetics, reduced energy consumption, reduced noise pollution, habitat provisioning, decreased runoff, and increased property values. A growing body of scientific research has begun to validate the importance of urban green space, showing that parks and street trees can ameliorate the negative physical and psychological impacts of the urban environment on city dwellers (De Ridder et al., 2004; Gill et al., 2007; Manning, 2008; Matsuoka and Kaplan, 2008; McPherson and Geiger, 2005; Tzoulas et al., 2007; Wilby and Perry, 2006).[101]

According to the Cambridge Municipal Ordinances, the urban forest serves to:

- Conserve energy by providing shade and evaporative cooling through transpiration
- Improve local and global air quality by absorbing carbon dioxide, ozone, and particulate matter, and producing oxygen
- Reduce wind speed and direct air flow
- Reduce noise pollution
- Provide habitat for birds, small mammals, and other wildlife
- Reduce storm runoff and the potential for soil erosion
- Increase real estate property values
- Enhance visual and aesthetic qualities that attract visitors and businesses

The changing climate will impact the number and species of trees that thrive in different locations. The Northeast Climate Impacts Assessment (Frumhoff et al. 2007) concludes that New England can expect significantly warmer temperatures, earlier springs and a shorter snow season. Downscaling by Hayhoe et al. (2008) indicates that inland and higher latitudes are expected to have the largest increase in temperature, but that coastal areas could be most prone to changes in the precipitation pattern.[102]

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[101] Daniel P. Bebber, Tegan Mortimer, Gitte Venicx, David Lefcourt, Mark Chandler, *Ecosystem service provision and change by urban trees in Cambridge, Massachusetts,* pending Earthwatch publication, 2013-2014

[102] Excerpt from The USACE Corps of Engineers vulnerability assessment of the Cambridge Urban Forest funded through a Planning Assistance grant to States. [April 2014] Permission was granted by the USACE Chief of Engineers to publish this material. The views and opinions expressed in this paper are those of the individual authors and not those of the US Army, the City of Cambridge, MA or other organizations

Overview of Existing Urban Forest

Cambridge's urban forest is composed of fairly young trees, given that the life expectancy of a street tree is estimated at 8-15 years. The "turn-over" of the entire forest is estimated to be every 50 years. The Department of Public Works has developed and maintains a comprehensive tree inventory of public street and park trees[103]. The inventory includes a catalogue of all of the city's public trees, including species, diameter at breast height (DBH), number of trunks, and general condition. The GIS layer, "DPW_StreetTrees", is available online (Cambridge MA, 2014). Using these data, the City was able to determine the species that encompass at least 90% of the identified trees in Cambridge: 34 species were included in a vulnerability assessment completed in 2012. In total, there are 20,507 trees in the DPW database, of which 1,810 (8.8%) were species infrequent enough to be assessed. Of the included trees, 923 (4.5%) were characterized in the database as "unknown" species; these trees were also not assessed.[104] The most common species[105] referred to here by their common names are species of maple (14.6%), the thorny locust (10.5%), the red maple (8.3%), the pin Oak (6.8%), little leaf linden (5.5%) , and the pear (5.2%)[106]

The outlook for the urban forest of Cambridge is good, with stable or increasing tree cover, tree diversity, and ecosystem service provision. Invasive exotics such as *A. platanoides, the most common at 14.6%,* and pear (including Callery Pear, *P. calleryna*) are declining in number. Annualized mortality rates are somewhat smaller than those reported in other studies (Lawrence et al., 2012; Nowak et al., 2004), and the decline in urban tree cover seen in many U.S. cities has not been detected (Nowak and Greenfield, 2012).[107]

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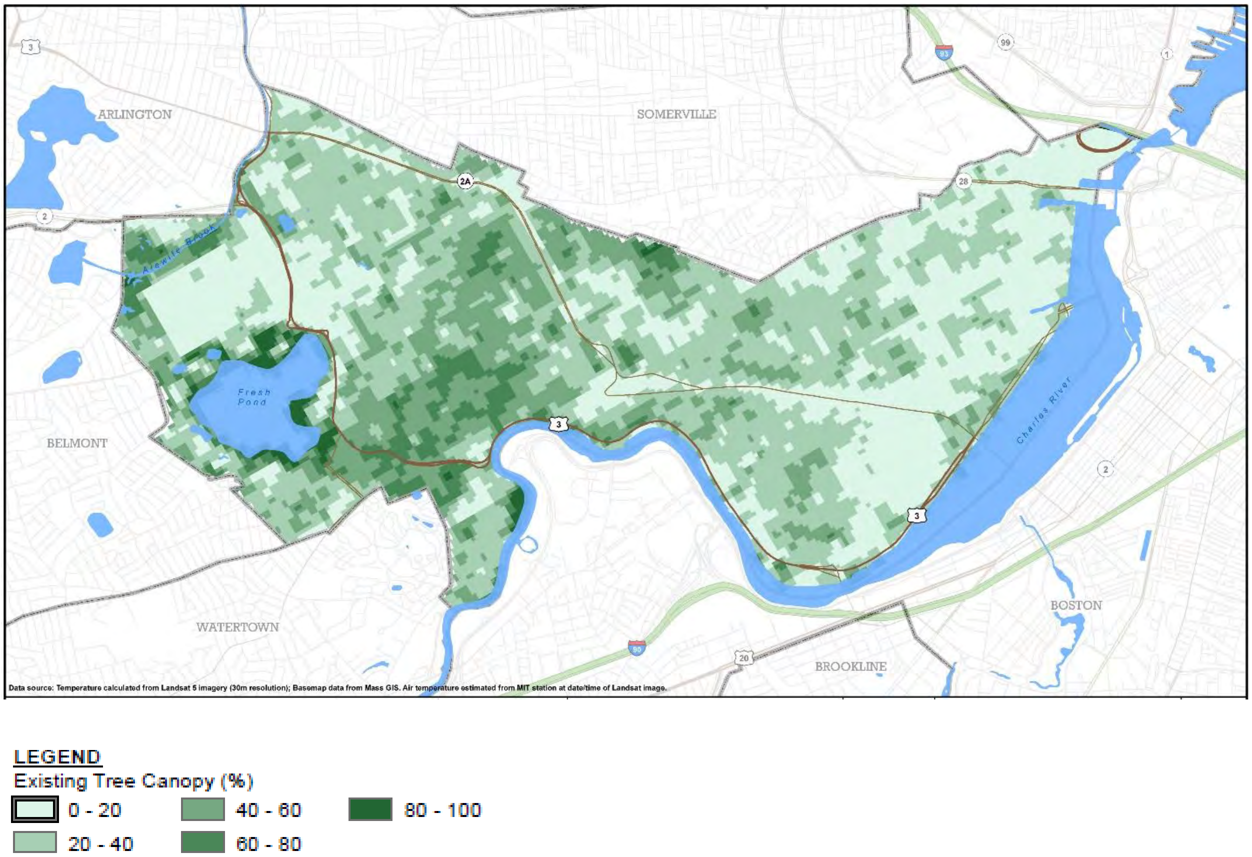
[103] (Cambridge Department of Public Works, 2011)

[104] The USACE Corps of Engineers received funding to perform a vulnerability assessment of the Cambridge Urban Forest through a Planning Assistance to States Agreement with the City of Cambridge, MA. Findings in this section are excerpts from the draft report summarizing existing conditions of Cambridge urban forest. Permission was granted by the USACE Chief of Engineers to publish this material. The views and opinions expressed in this paper are those of the individual authors and not those of the US Army, the City of Cambridge, MA or other organizations [this footnote is very repetitive w/ footnote 73

[105] Daniel P. Bebber, Tegan Mortimer, Gitte Venicx, David Lefcourt, Mark Chandler, *Ecosystem service provision and change by urban trees in Cambridge, Massachusetts,* pending Earthwatch publication, 2013-2014

[106] *Acer platanoides* (14.6 % of trees), *Gleditsia triacanthos* (10.5%), *A. rubrum* (8.3 %), *Quercus palustris* (6.8 %), *Tilia cordata* (5.5 %) and *Pyrus* spp. (5.2 %).

[107] Daniel P. Bebber, Tegan Mortimer, Gitte Venicx, David Lefcourt, Mark Chandler, , *Ecosystem service provision and change by urban trees in Cambridge, Massachusetts,* pending Earthwatch publication, 2013-2014



Map UF.1: Percentage of Tree Canopy in Cambridge[108]

Overview of the Urban Forest to be Analyzed in the Vulnerability and Risk Assessment

The vulnerability assessment will study the loss of tree species in response to a set of climate-driven scenarios[109]:

- Projected Heat Increase Impact on the Urban Forest
- Tolerance to Flooding, including Salinity
- Insect Infestation

The health of the urban forest will inform the heat vulnerability assessment part of the Social Environment Section as the health of the urban forest might mitigate expected changes for

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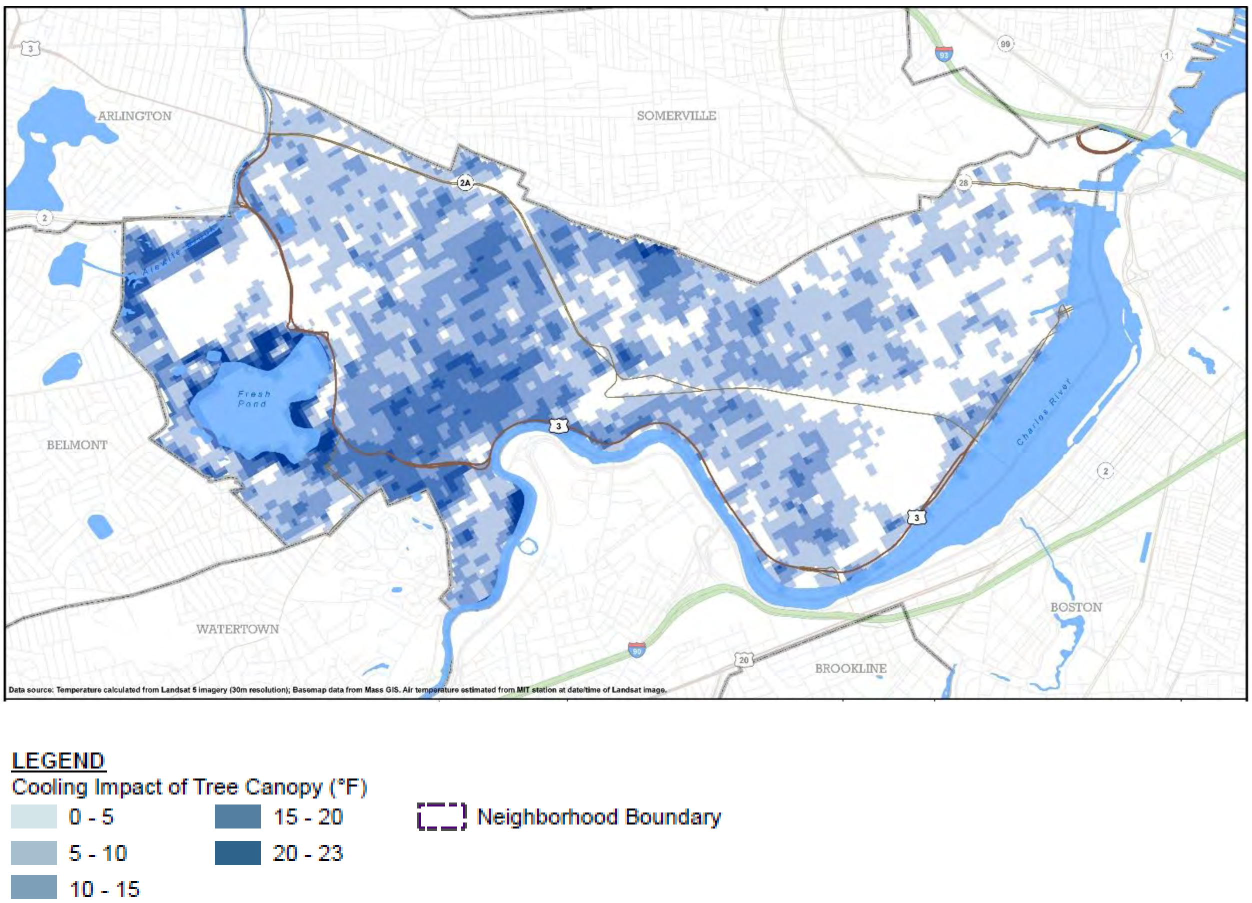
[108] Produced by Kleinfelder based on the City of Cambridge report on Existing and Potential Tree Canopy, DPW in Collaboration with the University of Vermont, 2012. The University of Vermont calculated the tree canopy percentage. Tree canopy was mapped using aerial photography and LiDAR data. The city of Cambridge was divided into a grid of 250-foot-wide squares, and the tree canopy percentage was calculated per square.

[109].Permission was granted by the USACE Chief of Engineers to publish this material. The views and opinions expressed in this paper are those of the individual authors and not those of the US Army, the City of Cambridge, MA or other organizations.

increased temperature. It has been documented that trees and vegetation lower surface and air temperatures by providing shade and through evapotranspiration. Shaded surfaces, for example, may be 20–45°F (11–25°C) cooler than the peak temperatures of unshaded materials[110]. An extensive study conducted by the New York City Regional Heat Island Initiative concluded that vegetation plays a more important role than albedo or other features of the urban physical geography (e.g. building heights, road density) in determining heat island potential in New York City.[111]



Map UF.2: Cooling Impact of Trees in Cambridge[112]

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[110] (http://www.epa.gov/heatisland/mitigation/trees.htm)
[111] MITIGATING NEW YORK CITY'S HEAT ISLAND WITH URBAN FORESTRY, LIVING ROOFS, AND LIGHT SURFACES. NEW YORK CITY REGIONAL HEAT ISLAND INITIATIVE. FINAL REPORT 06-06. [not in caps]https://cmsapps.nyserda.ny.gov/EMEP/project/6681_25/06-06%20Complete%20report-web.pdf
[112] Produced by Kleinfelder based on the City of Cambridge report on Existing and Potential Tree Canopy, ["by"??] DPW in Collaboration with the University of Vermont, 2012. The average adjusted land surface temperature was calculated for each 250-foot-wide tree canopy grid square. Average temperature and tree canopy percentage data were exported for analysis in Excel. A linear regression model relating tree canopy percentage and temperature was developed. The model was applied to the tree canopy percentage data to estimate the cooling impact of the trees

The Social Environment

Despite the upsurge of interest and an increasing number of publications focused on this important issue, a clear and comprehensive definition of the "social environment" has proved elusive. We would like to suggest and adapt the encompassing definition offered by Barnett and Casper, 2001, where "human social environments encompass the immediate physical surroundings, social relationships, and cultural milieus within which defined groups of people function and interact"[113] and includes but is not limited to the "built infrastructure; industrial and occupational structure… social and economic processes, wealth; social, human, and health services; power relations; government; race relations" of that environment. In this extensive consideration of the social environment, Barnett acknowledges the dynamic, and multiple scales at which the social environment can be experienced, "often simultaneously, including households, kin networks, neighborhoods, towns and cities[114]", and the interdependencies at these different scales.

Our Approach

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[113] Barnett, Elizabeth, PhD, Casper, Michele, PhD A Definition of "Social Environment" American Journal of Public Health, March 2001, Vol. 91, No. 3.http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1446600/pdf/11249033.pdf
[114] ibid

For the purpose of our assessment, we focus on the local social environment in the City of Cambridge, and the social, human and health services, cultural practices, religious institutions and practices that shape the community landscape, as well as the physical resources such as community resources providing affordable housing, day care facilities and schools, water resources and recreational areas that Barnett regards as “at least partially configured by human social processes”[115]. While Barnett subsumes the built infrastructure into the social environment, we distinguish the built or physical environment to engage with it separately. However, the built environment is re-visited consistently and acknowledged as the supportive framework that enables a thriving social environment.

The built environment, from transit systems to tunnels and bridges, serves to supports a thriving social environment. The social environment is at the center of the existing conditions assessment undertaken to better understand the vulnerabilities of Cambridge communities. The following section presents an overview of the City of Cambridge’s social environment, with a preliminary consideration of its vulnerable communities as informed by, an identification of vulnerable population by building uses and identification of community facilities--municipal resources and community-based organizations— contributing to the support network for a City’s residents through their mission and provision of social services. This assessment attempts to capture these various channels of support that may be available to residents, especially potentially vulnerable groups.

Community Resources

Identification of Vulnerable Populations Based on Building Use

Vulnerable populations were identified based on building use, such as schools and buildings that operate as facilities for a vulnerable segment of the population. These groups are highlighted because of various socioeconomic and physical characteristics that can potentially heighten their sensitivity, lower their adaptive capacity and therefore increase their vulnerability. For example, the elderly population being more prone to physical disability and other ailments may have mobility concerns and lower resistance to cope with environmental and other stressors. Similarly, children of a very young age, as associated with daycare facilities, would present similar concerns because of their age and dependence on adult caretakers for support.

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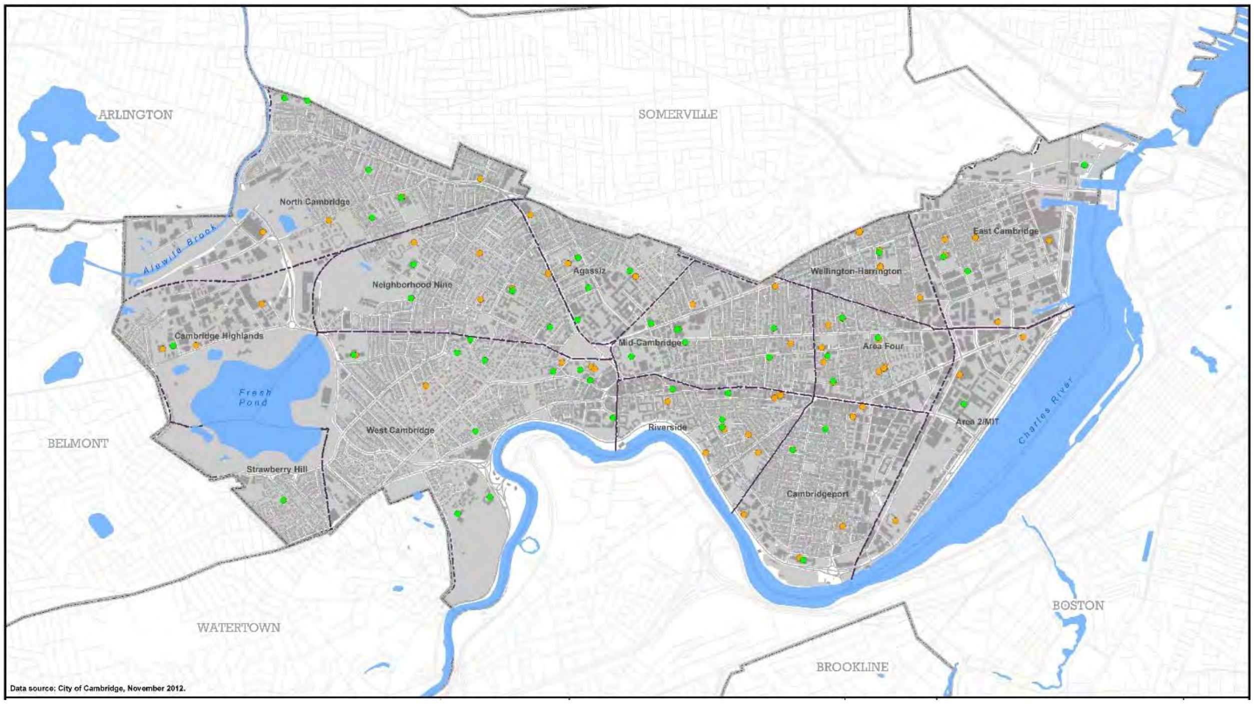
[115] ibid

Schools and Day Care Facilities

Highlighting the locations of buildings occupied by school-age children, or low-income families housed in affordable housing, presents a spatial visualization of potential emergency planning hotspots and provides the City information that may be vital for preparedness initiatives.



LEGEND

- School - K-12 Public or Private
- School - Day Care
- Neighborhood Boundary

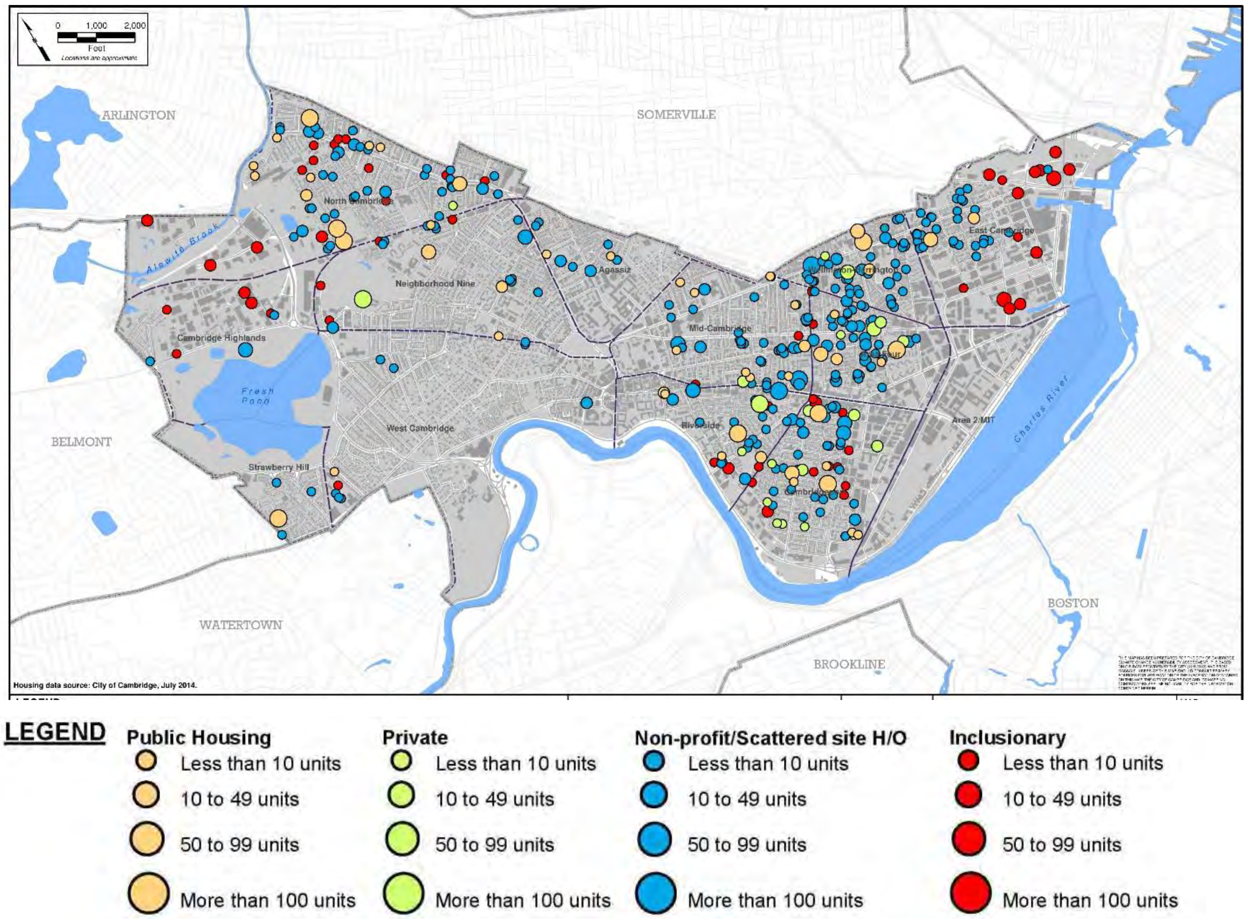
CR.1: K-12 Schools and Day Care Facilities[116]

K-12 schools appear to be evenly distributed, with a higher relative density of schools located in the Mid-Cambridge, Agassiz and Area Four neighborhoods. In this map, schools are not distinguished by their size (number of students enrolled) nor if they are private or public schools.

[116] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012) and base map data from MassGIS

Elderly Care Facilities and Affordable Housing

Affordable housing is displayed in terms of ownership – public housing, private housing (managed by a private company), non-profit and inclusionary, which refers to inclusionary zoning for generalized programs. Locations of affordable housing buildings are symbolized using a graduated point symbol to indicate the relative size of the building by number of units. These affordable housing sites are more densely located in the Eastern neighborhoods of Cambridge. This information is especially relevant for evacuation purposes, when emergency responders may need additional or special facilities to support these populations. The affordable housing facilities of a substantial size, exceeding 50 family dwellings or units, appear to be in the North Cambridge, Strawberry Hill, Riverside neighborhoods in addition to the neighborhoods cited previously. These may be home to families with small children, single parent households, or both. As mentioned earlier in this assessment, in cases where families are already living below the poverty line, the presence of small children--especially under the age of five--reduces the disposable income available to mitigate vulnerability.



CR.2: Elderly Care Facilities and Affordable Housing[117]

The buildings in the map above (CR.2) are identified based on their use by elderly persons who are above the age of 65, minors (children below the age of 18 according to the State of Massachusetts[118]), and families with low income qualifying for affordable housing. Housing is considered "affordable" when the tenant or homeowner pays no more than 30% of their gross income for housing costs. Affordable housing in Cambridge serves low-, moderate-, and middle-income households, with most programs targeted to households earning less than 80% of Area Median Income adjusted for household size[119].

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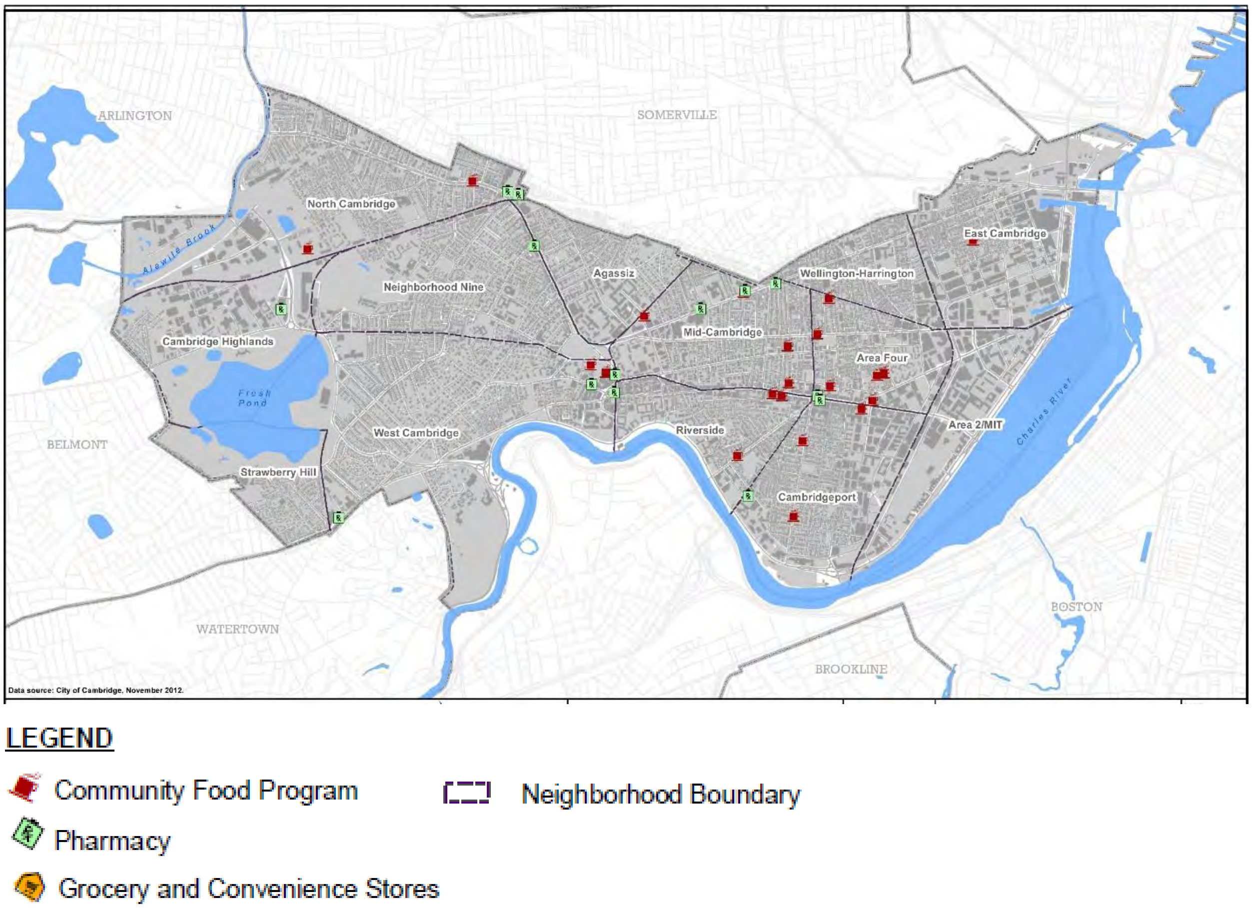
[117] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (7/21/2014) and base map data from MassGIS

[118] https://malegislature.gov/Laws/GeneralLaws/PartI/TitleI/Chapter4/Section7

[119] http://www.cambridgema.gov/cdd/housing/resourcesandadditionalinformation/whatisaffordablehousing.aspx

Pharmacies and Food Assistance

As essential community resources for most vulnerable populations, Pharmacies, Food Assistance, and Municipal Resources facilities were also mapped based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts.



CR.3: Pharmacy and Community Food Programs[19]

Key Building Assets by Use to be Analyzed in the Risk Assessment

- Daycare Facilities
- Elderly Facilities
- K- 12 Schools
- Affordable Housing
- Pharmacies & Food Assistance

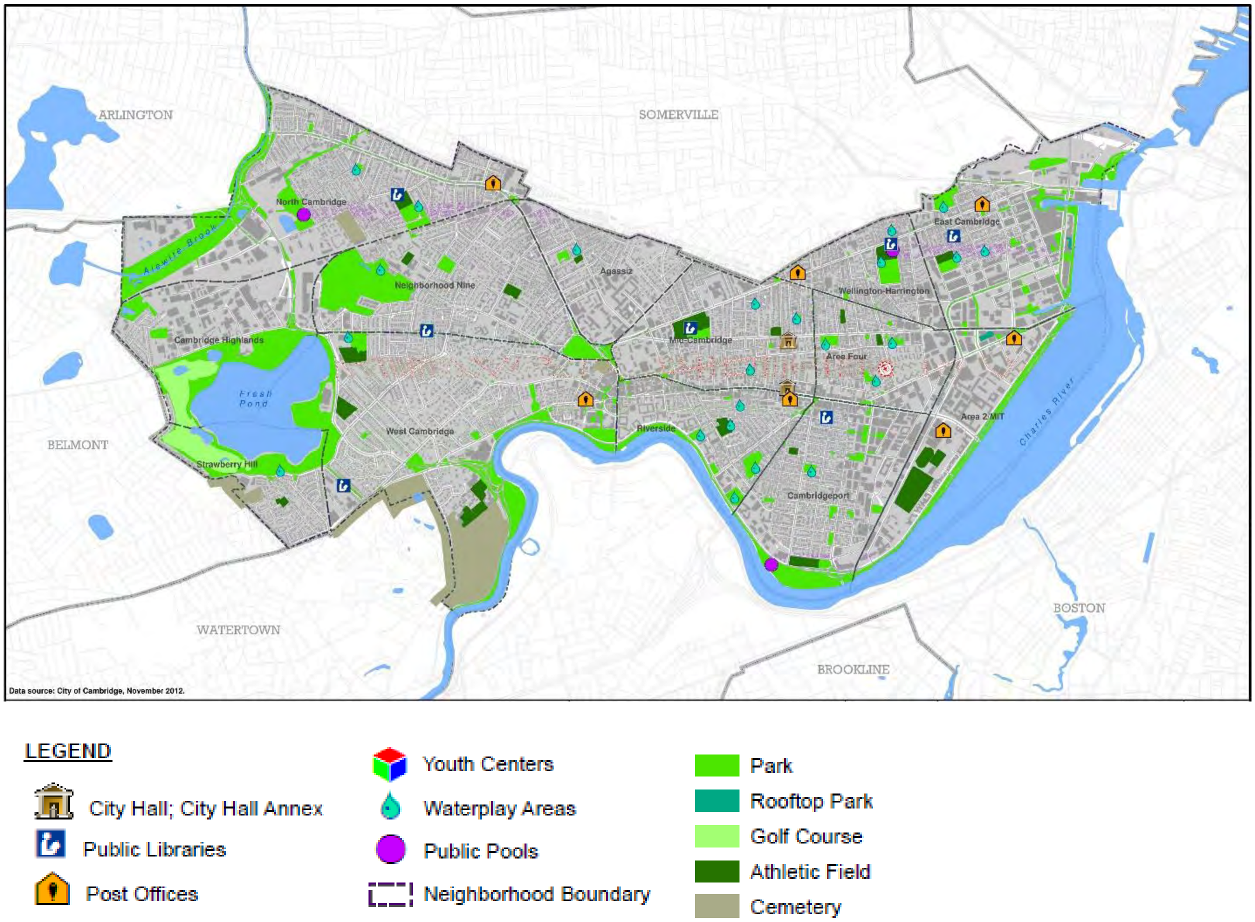
Municipal Resources

Municipal buildings such as City Hall and its satellite offices have the capacity to provide operational and logistical support outside of their normal functions during emergencies. Public libraries and post offices have historically been places for public notices that enabled members of the community to receive and ask for help. This has been proven to be vital especially when conventional modes of communication are inaccessible. The Cambridge Department of Human Service Programs administers several programs that support diverse population needs, including potentially vulnerable sections of the population. The extensive list of programs and services administered under the purview of the City are an important feature in the community landscape that need not be re-iterated in the list below.

Key Sites to be Analyzed in the Risk Assessment

- City Hall and City Hall Annex
- Post Offices
- Public Libraries

Public pools, water play areas and open spaces have also been identified as they are publicly available resources that constitute places of gathering for residents and their families, These types of resources can be accessed by sections of the population (families with children for example), to mitigate the impact of a heat emergency. This could constitute a proxy for adaptive capacity for certain vulnerable segments of the population as determined by their ability to access such resources. Therefore, elderly and disabled members of the community may represent differently in terms of their vulnerability to heat because accessing open space and waterplay areas may not be feasible. Other forms of adaptive capacity such as central air conditioning will thus be more applicable depending on the segment of the population focused on.



CR.4: Municipal Resources[120]

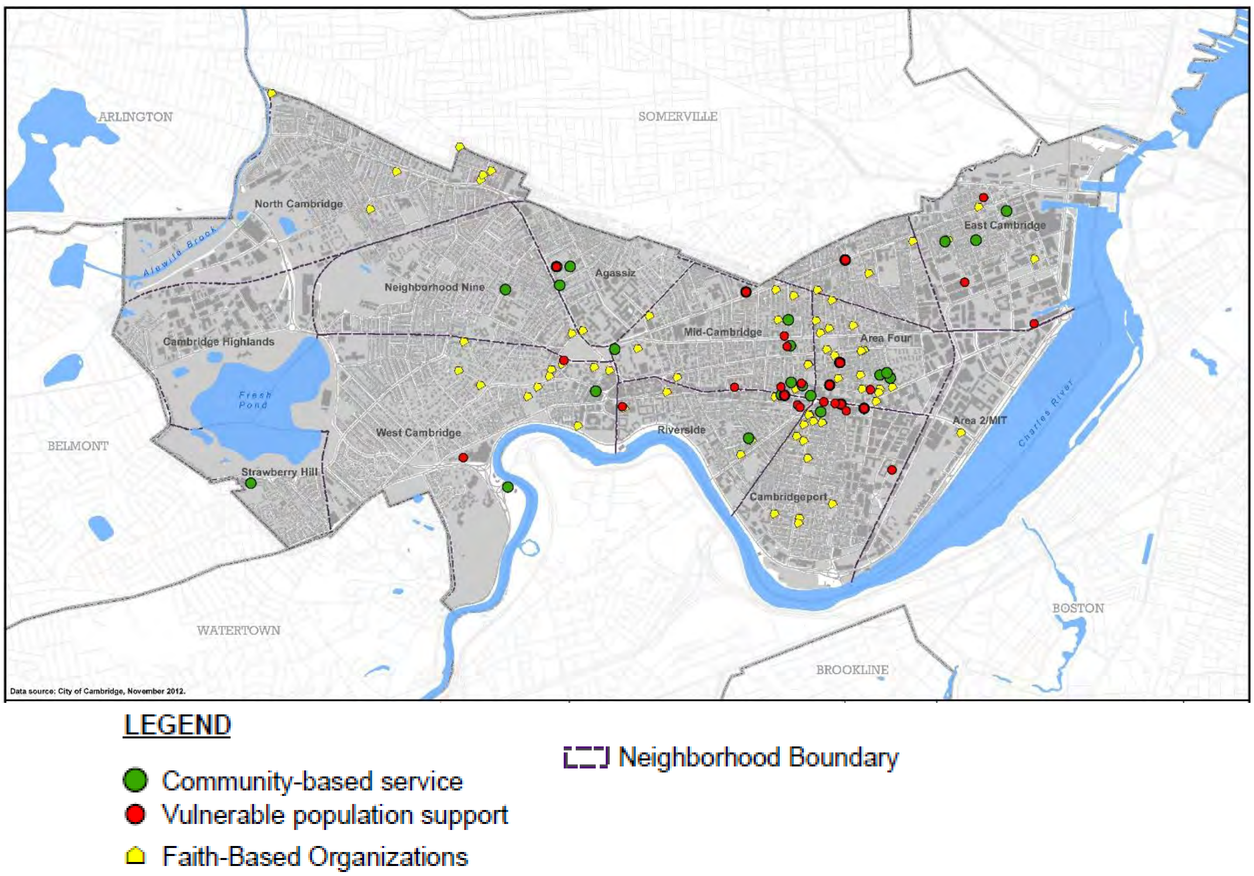
Community-based Organizations

Community-based organizations and services, including agencies provide dedicated support to various vulnerable sections of the community. These contribute to community adaptive capacity by improving access to resources and information, and fostering informal social relationships among the community (Nelson et al. 2007; Pelling, et al).

These civil society organizations and groups with a community-serving function support a community's ability to access processes that mitigate their exposure to climate change impact, and also provide resources in a time of need. They can be spatially represented by the buildings from which they operate or provide services regularly; these often coincide with faith-based

[120] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012) and base map data from MassGIS

organizations, schools and community centers. Therefore, these building serve multiple functions and can become vital to the community in several ways. Identifying these organizations will require further research and collaboration with the City to elucidate the community-based organizations that serve configuring roles in the larger community. Presently, we have a draft map locating the faith-based organizations and community resources in Cambridge.



CR.5: Community-Based Organizations and Services[121]

Cambridge is home to a diverse array of places of worship and other faith-based organizations. These are a critical supportive network for residents and families for whom these organizations are not only places of worship but opportunities to connect with other families in the same religious and often linguistic community. The concentration of faith-based organizations is evident in Area Four as well as towards the center of the City, between West Cambridge, Agassiz and Neighborhood Nine. The communities that form around faith-based organizations, and other types

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[121] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012) and base map data from MassGIS

of community-based organizations, are often based on other cultural, linguistic, and immigration-based bonds. These forms of community relationships and linkages can be only elucidated with community participation and further research.

This information is retrieved from online directories managed by the City of Cambridge and Somerville, and refers to resources such as the Cambridge Somerville Resource Guide. When updated, the key sites to be analyzed in the vulnerability and risk assessment will include sites regrouped into three main categories; faith-based organizations and places of worship, vulnerable population support programs and community based services.

Key Sites to be Analyzed in the Vulnerability and Risk Assessment

- Faith-based Organizations and Places of Worship
- Vulnerable Population Support Programs
- Community-based Services

Hazardous Materials Sites

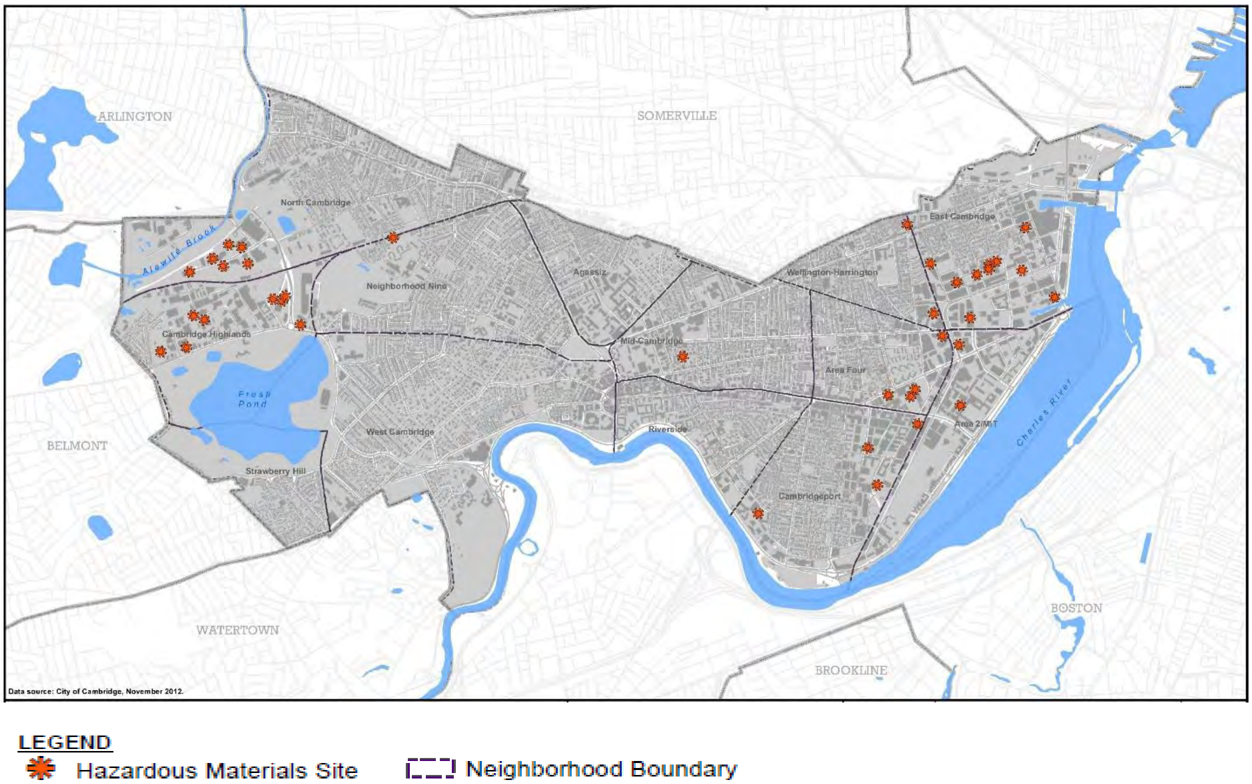
Cambridge is home to numerous high-tech and life-sciences research facilities, which generate an important component of the hazardous materials assessed in this study. The importance of these research facilities to the Cambridge economy highlights the significance of the discussion around the safe containment of hazardous materials, and development of emergency action plans which are undertaken by the Cambridge Local Emergency Planning Commission. The City of Cambridge also requires a specific permit for biotechnology research and development; this permit process must be completed prior to the initiation of research that uses DNA[122] technologies and requires that companies form an Institutional Biosafety Committee (IBC) as an internal mechanism for research oversight and the point of contact for the City of Cambridge Biosafety Committee (CBC).[123]

Hazardous materials identified in the Superfund Amendments and Reauthorization Act (SARA) Title III include chemical hazards such as pesticides and propane[124] that must be reported according to the requirements outlined in Section 3 of Title III. This information supports identification of potential public health risk associated with disruption of safe containment of

[122] Deoxyribonucleic acid
[123] http://www.cambridgebiostart.org/biosafety.php4#faq
[124] Cambridge Biostart: Hazardous Materials (http://www.cambridgebiostart.org/haz_mat.php4)

hazardous materials, and vulnerable communities and areas in proximity to these containment sites.

The map below (CR.6) locates the hazardous sites throughout the City as provided by the City of Cambridge. Information on the location of these sites is shared with the local emergency planning commission and Cambridge Fire Department. The reporting requirements set within the industry at the federal level and by the City of Cambridge enable the mapping of these hazardous material sites.



CR.6 Hazardous Material Sites[125]

[125] Produced by Kleinfelder, 2014 Using information provided by the City of Cambridge – GIS base information (11/08/2012) and base map data from MassGIS

Areas for Further Research

The social environment as explored in our report extends to the traditional, built communication infrastructure in the City of Cambridge. However, the telecommunications network in the form of landlines, while a mainstay in the communications network of a city does not capture the reality of today's social connections or how people communicate on a day-to-day basis. The vast majority of communication now takes place at all times, on cellular phones that people own with monthly subscriptions or pay-as-you-go access. Coupled with cellular communication, social media presence has a variable but discernible influence on the development of social networks and critical nodes in the relay of information within these networks.

The City of Cambridge may begin to engage with this 'fourth dimension' more extensively by exploring the patterns of communication embedded in cellular phone use and the multitude of social media channels relevant to Cambridge. Among these channels, Twitter, Reddit and Facebook are ubiquitous social media websites with popular use by a spectrum of the population. The first layer of inquiry may be to use anonymized data of incoming and outgoing calls to gain insights into the diverse Cambridge population. Potential indicators such as frequency of phone calls, the origin and destination of those calls, as well as at specific times such as during and after an emergency, can provide rich information on social relationships, responses and the informal channels of information transmission within a community.

Social media websites such as Facebook, Twitter and Reddit have strong integration into many social networks; in Cambridge, the high percentage of college-going and young educated professionals is likely to be users of one or more of these sites. Each site provides geotagging, particular ways of visualizing one's social network, and unique platforms for the aggregation of user-generated information. Often small businesses and organizations use these sites to reach out to the communities and markets they serve; therefore, it is possible to also witness similar types of social networks translating from the physical social landscape to the cyber social landscape. Community organizations with a social media presence are indicative of a community with internet access and reasonable comfort with multiple modes of communication. General trends may be elicited with statistical analysis of the key words and phrases emerging in internet traffic and social RSS feeds. Both internet and cellular traffic can be correlated to major events, positive or negative, and present an overarching picture of social response in a given community, and the critical nodes shaping its network.