Ranking Reports
Critical Assets and Community Resources

Climate Change Vulnerability Assessment

City of Cambridge, Massachusetts

November 2015

Acknowledgments

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

Ranking Reports

Critical Infrastructure & Community Resources

The City of Cambridge has evaluated numerous assets, systems, and vulnerable populations to compare their relative vulnerability to climate change and identify the City's most critical and urgent needs. Since resources available to address climate vulnerabilities are finite, it is important to prioritize, and the risk assessment process facilitates that sorting. The City will focus on addressing the most at-risk elements in the subsequent *Climate Change Preparedness and Resilience Plan*.

In order to ensure the City's resources are focused on demographic groups, assets, and systems most at risk of harm from climate stressors, planning-level vulnerability analyses were performed for nearly 1,000 resources, social factors, assets, and critical services. A standardized methodology was applied to each item in a system (e.g., energy infrastructure) to rate its vulnerability and compare it to other items in seemingly disparate categories (e.g., energy infrastructure and public health) to assess interdependencies. The vulnerability ranking methodology included quantitative, qualitative, and map-based criteria.

Vulnerability and risk assessment findings and methodologies for the systems that were evaluated are compiled in Technical Memoranda, attached to this report. Each Technical Memorandum includes a summary of key findings and identifies "High Risk Priority Planning Areas". They explain the processes used to assess each system's assets and summarize the results of the vulnerability and risk assessments for extreme heat and inland flooding hazards. Those findings form the basis for a city-wide comparison and analysis of vulnerabilities and risks, the results of which are described in the City of Cambridge Climate Change Vulnerability Assessment (CCVA) final report. The summary maps and tables provided below highlight the most at risk Critical Infrastructure and Community Resources identified in the assessment.

Due to a variety of considerations, including cost, time, and available methodologies, the City chose to focus on assessing and comparing the vulnerability of a specific set of assets, populations, and systems. While a large number of assets and factors were assessed, many more could also have been assessed. Additional systems and factors that could be assessed in the future include supply chains for food, fuel, and medication, as well as regional health care system capacity.

Critical Infrastructure

Figures 1 shows the location of Critical Infrastructure most at risk from extreme heat and flooding, including energy, critical services, telecommunications, transportation, and water/stormwater assets. Figure 2 provides a legend, listing the individual assets shown in Figure 1 and summarizing, in tabular form, the hazards and time horizons under which they pose a high risk.

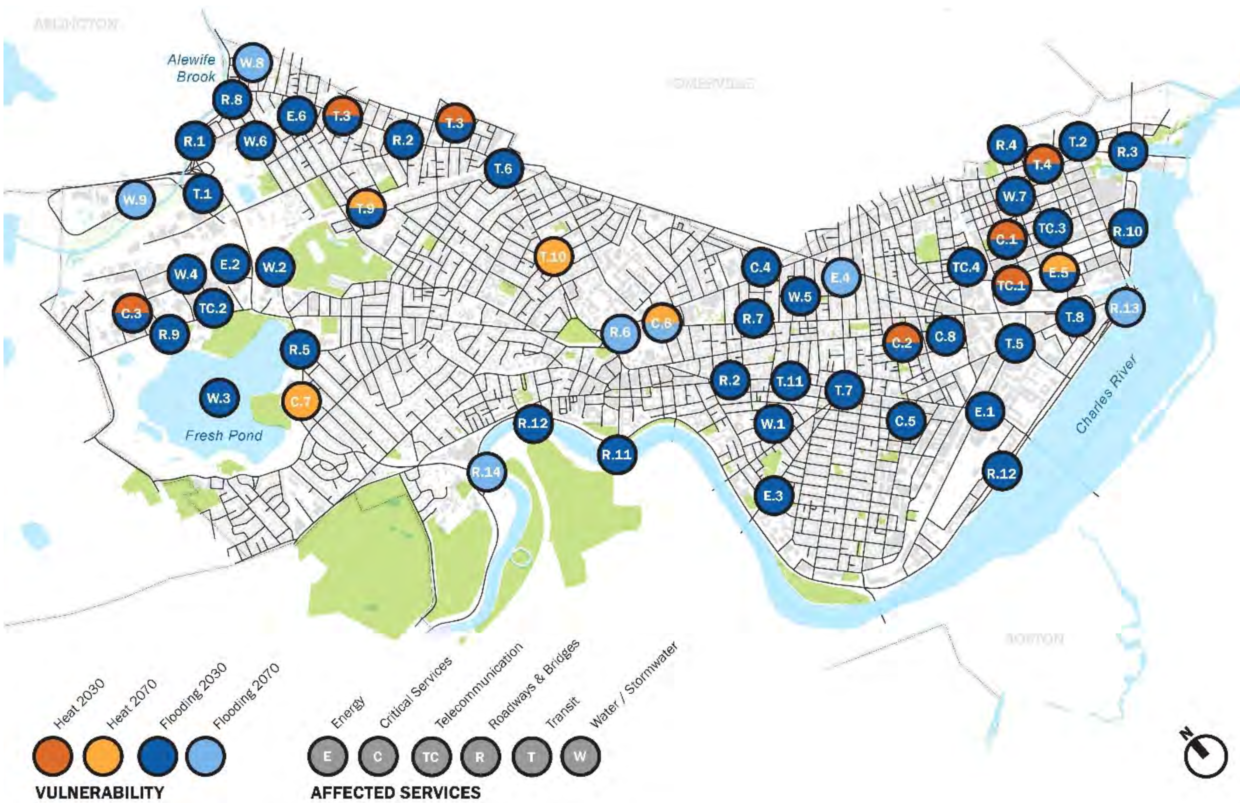


Figure 1: Most at Risk Infrastructure (Source: Kleinfelder, November 2015)

	Asset		Heat		Flood	
			2030	2070	2030	2070
Energy	E.1	MIT Co-generation Plant				
	E.2	North Cambridge Substation				
	E.3	Putnam Substation				
	E.4	Prospect Substation				
	E.5	Third Street Regulator Station – natural gas				
	E.6	Brookford Street Take Station – natural gas				
Critical Services	C.1	Police Department headquarters				
	C.2	Public Health Department office				
	C.3	Professional Ambulance Services				
	C.4	Youville Hospital				
	C.5	Fire Company 2				
	C.6	Fire Department headquarters				
	C.7	Water Department building / City's Emergency Operations Center				
	C.8	Windsor Street Health Center				
Telecom	TC.1	City Emergency Communications Center (Police HQ)				
	TC.2	BBN Technologies data hub				
	TC.3	AT&T telephone office/long-line switch				
	TC.4	AT&T data hub/co-location center (CO-LOC)				
Roadways & Bridges	R.1	Alewife Brook Parkway				
	R.2	Massachusetts Ave				
	R.3	Monsignor O'Brien Highway at Charlestown Ave/ Land Boulevard				
	R.4	Monsignor O'Brien Highway / McGrath Highway / Route 28				
	R.5	Fresh Pond Parkway / Route 60				
	R.6	Cambridge St Underpass				
	R.7	Broadway				
	R.8	Alewife Brook Parkway - intersections with Rt. 2 and Mass Ave/Rt. 16				
	R.9	Concord Turnpike/Route 2				
	R.10	Land Boulevard				
	R.11	Lars Anderson Bridge				
	R12	Memorial Drive				
	R.13	Longfellow Bridge				
	R.14	Eliot Bridge				
Transit	T.1	Alewife Station (Red)				
	T.2	Lechmere Station (Green)				
	T.3	Alewife – Davis – Porter Rail Line (Red)				
	T.4	Lechmere – Science Park Rail Line (Green)				
	T.5	Central – Kendall Rail Line (Red)				
	T.6	Porter Square Subway / Commuter Rail Station (Red)				
	T.7	Central Square Station (Red)				
	T.8	Kendall Station (Red)				
	T.9	Fitchburg Commuter Rail Line				
	T.10	Porter – Harvard Rail Line (Red)				
	T.11	Harvard - Central Rail line (Red)				
Water/Stormwater	W.1	Western Flagg (Charles, Separated)				
	W.2	New Street Pump Station				
	W.3	Fresh Pond Reservoir				
	W.4	CAM 004 (Alewife, Separated)				
	W.5	CAM 017 (Charles, Combined)				
	W.6	CAM 400 (Alewife, Separated)				
	W.7	Lechmere (Charles, Separated)				
	W.8	CAM 001 (Alewife, Combined)				
	W.9	D46 (Alewife, Separated)				

Figure 2: Most at Risk Infrastructure Legend (Source: Kleinfelder, November 2015)

Community Resources

Figures 3 shows the location of Community Resources most at risk from extreme heat and flooding, including affordable housing, pharmacies, food assistance providers, municipal resources, public schools, daycares, and youth centers. Figure 4 provides a legend, listing the individual facilities shown in Figure 1 and summarizing, in tabular form, the hazards and time horizons under which they pose a high risk.

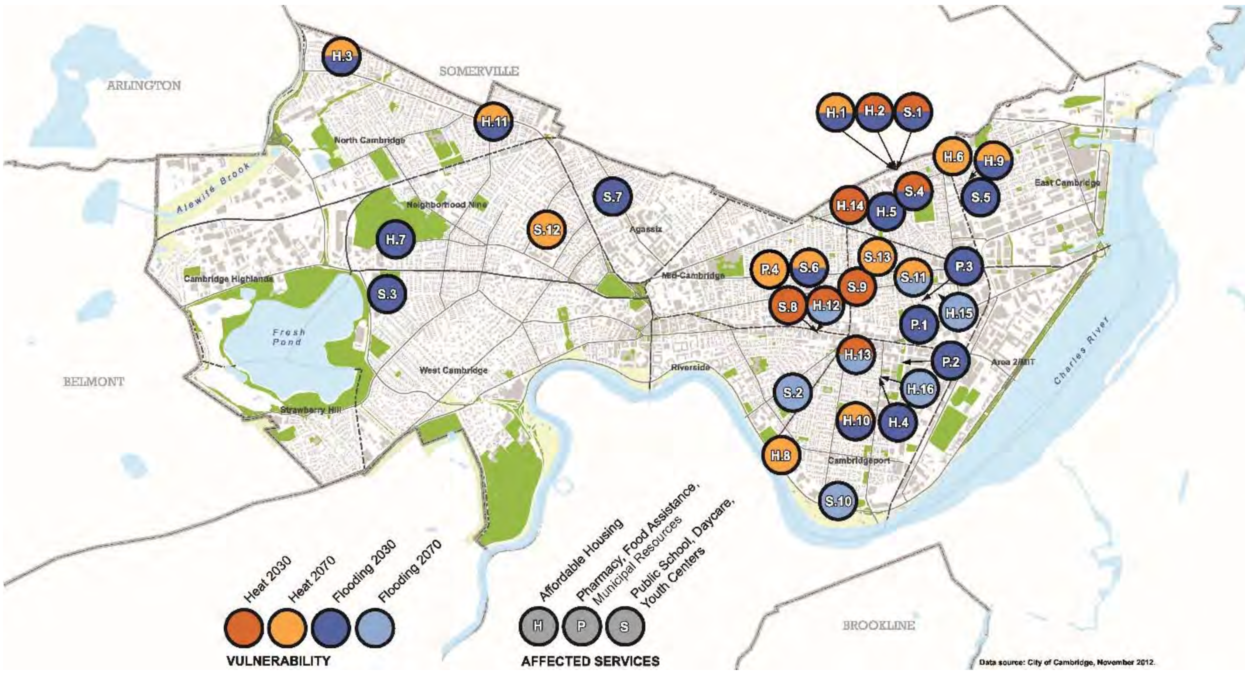


Figure 3: Municipal Resources Community Resources Priority Areas (Source: Kleinfelder, November 2015)

		Asset	Heat		Flood	
			2030	2070	2030	2070
Affordable Housing (H)	H.1	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units				
	H.2	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units				
	H.3	Daniel F. Burns Apt (50 Churchill Ave), 198 units				
	H.4	Auburn Court I (80 Auburn Park), 77 units				
	H.5	Harwell Homes (1 Citizens Place), 56 units				
	H.6	Miller's River Apts (15 Lambert St)				
	H.7	Briston Arms (247 Garden St), 105 units				
	H.8	808 Memorial Dr (808-812 Memorial Dr)				
	H.9	Truman Apts (25 Eighth St), 60 units				
	H.10	Johnson Apts (150 Erie St), 180 units				
	H.11	2050 Mass Ave/ Leonard J. Russell Apts, 51 units				
	H.12	YMCA (820 Mass Ave), 128 units				
	H.13	Manning Apts (237 Franklin St), 199 units				
	H.14	Inman Sq Apts (1203-1221 Cambridge St), 116 units				
	H.15	Washington Elms (131 Washington St), 175 units				
	H.16	Auburn Court II (80 Brookline St), 60 units				
Public Schools, Daycare, and Youth Centers (S)	S.1	Daycare at Roosevelt Towers (14 Roosevelt Towers)				
	S.2	Moore Youth Center & Daycare				
	S.3	Tobin School & Daycare				
	S.4	King Open School & Daycare (850 Cambridge St)				
	S.5	Kennedy / Longfellow School & Daycare				
	S.6	CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway)				
	S.7	Baldwin School & Daycare (28 Sacramento St)				
	S.8	Daycare at YMCA (820 Mass Ave)				
	S.9	Area IV Youth Center & Daycare (243 Harvard St)				
	S.10	Morse School & Daycare (40 Granite St.)				
	S.11	Fletcher/Maynard Academy & Daycare (225 Windsor St)				
	S.12	Graham & Parks School & Daycare (44 Linnaean St)				
	S.13	Cambridgeport School & Daycare (89 Elm St)				
Pharmacy, Food Assistance, Municipal Resources (P)	P.1	Margaret Fuller Neighborhood House (71 Cherry St				
	P.2	Salvation Army / Daily Lunch (402 Mass Ave)				
	P.3	WIC Program Services (119 Windsor St - Public Health Dept)				
	P.4	Human Services Department (51 Inman St)				

Figure 4: Community Resources Priority Areas Legend (Source: Kleinfelder, November 2015)

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA)

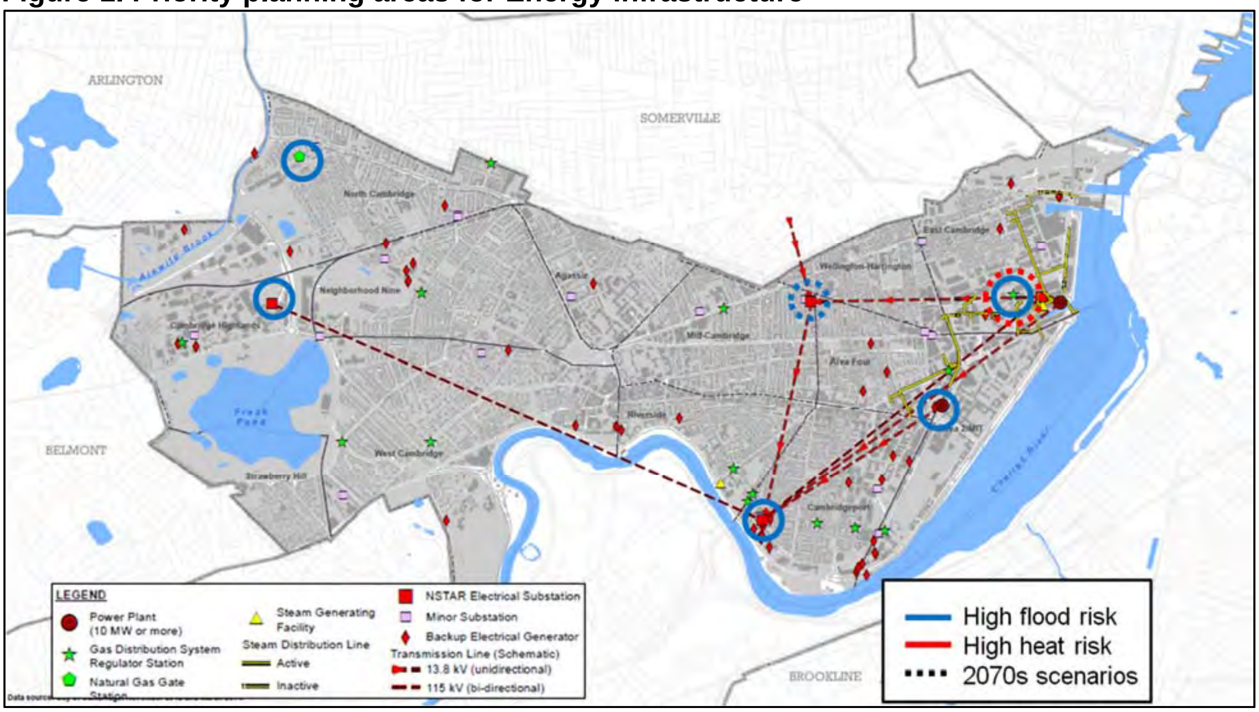
Technical Memorandum: Energy Infrastructure

Prepared by Kleinfelder, 2-26-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

The summary of the high-risk priority planning areas for Energy infrastructure is presented in Figure 1. Only assets with high risk scores are highlighted (R3 or R4). Those with solid circles around them were identified as high risks for heat (red) or inland flooding (blue) in the 2015-2044 (2030s) scenarios, while those surrounded by dashed circles were only identified as high risks in the 2055-2084 (2070s) scenarios. These priority planning areas should be addressed in the development of the City's Climate Change Preparedness Plan.

Figure 1. Priority planning areas for Energy infrastructure



The City's Energy infrastructure is significantly more vulnerable to flooding than heat. NStar's **North Cambridge Substation (R4)** and **Putnam Substation (R3)** are the highest risk assets for the Energy system due to their vulnerability in the Inland Flooding 2030s scenarios and their high consequences of failure, including cascading impacts on other energy infrastructure.

Cascading failure stemming from the North Cambridge Substation vulnerability in the Inland Flooding 2030s scenario (10-year 24 hour storm) caused the **Brookford Street Take Station** – a critical natural gas assets – to also be considered highest risk **(R4)**, even though it was not directly exposed to flooding in the scenario. Brookford Street Take Station is directly exposed to flooding in the 2070 100-year 24 hour storm scenario.

Other high risks / high priorities for preparedness planning are as follows:

Inland Flooding – 2030s

- MIT Co-generation Plant (R3)
- Third Street Regulator Station – natural gas (R3)

Inland Flooding – 2070s

- Prospect Substation (R3)

Heat – 2070s

- Third Street Regulator Station – natural gas (R3)

Key Findings – Electrical Transmission/Distribution:

Multiple sources of electrical supply (transmission in to North Cambridge, transmission in to Prospect, and transmission from within-city generation) provide some level of transmission redundancy to the city, varying based on the scenario. Since the bulk of supply is from transmission in to North Cambridge, this substation is particularly important. There is redundancy in the system but it should be noted that failure at any given bulk substation would impact local distribution and failures at multiple substations would reduce transmission redundancy.

In the past, extreme heat has been a greater concern than flooding for NSTAR in Cambridge. Centralized infrastructure has not been exposed to flooding in Cambridge before. Meanwhile extreme heat events more routinely impact peak load and have the potential to cause equipment failures. As a result, more resources have been devoted to managing extreme heat risks.

B. Summary of Assessment Process and Methods

Selection of Assets

Energy infrastructure in Cambridge, including power plants, bulk electrical substations, electrical transmission lines, steam plants, and natural gas gate stations and regulator stations were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. Assets were screened to ensure that the vulnerability assessment focused on the most important assets in the system. For example, only power plants with a generating capacity of 10MW or more were included. Bulk substations were used as a vulnerability proxy for underground transmission lines, which were assumed to be free from exposure to heat and flooding hazards except where they emerged at bulk substation locations. Other important assets were outside of Cambridge and therefore could not be assessed quantitatively using the geographically-limited heat and flooding scenarios. The final list of assets assessed in this study is the result of iterative review and revision by the project team and stakeholders, including the City's Electrical Department, NStar Electric, and NStar Gas.

Vulnerability and Risk Scoring

The methods and assumptions for scoring the vulnerability and risk of assets were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

Vulnerability of each asset was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.

- Exposure was assessed based on scenario maps developed for the project (see Attachment 1).

- Sensitivity of assets was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the asset to fail to function (see Attachment 2).
- Adaptive capacity was assessed based on whether assets had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure (see Attachment 2).

Sensitivity and Adaptive capacity of the electrical assets have been reviewed by NSTAR and updated to factor in current measures being implemented.

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.

- Probability was assessed based on whether assets were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- Consequence was assessed based on the scale of the service disruption caused by an asset's failure (entire city vs. neighborhood vs. locality) and the potential for their failure to cause cascading impacts on other assets within or across systems.

Specific protocols for Energy infrastructure were developed to standardize assumptions for scoring assets' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge (see Attachment 2).

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed assets were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 3).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Energy infrastructure were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC), and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The latest feedback from a workshop with City stakeholders on October 6, 2014, a meeting with TAC members on December 11, 2014, a focus group with NStar Electric and City representatives on December 17, 2014, as well as subsequent follow-up has been incorporated. Participants included the City's Electrical Department, Department of Public Works, NStar Electric, and NStar Gas, among others.

Attachments 1-3 and the results reported in this memorandum reflect the latest understanding and assumptions.

Sections C & D below report the heat and inland flooding vulnerability and risk assessment results for Energy infrastructure.

Section E compiles the risk scores for only highly vulnerable assets.

C. Heat Vulnerability and Risk Assessment

Overall, Cambridge's critical Energy infrastructure is not highly vulnerable to heat. This is primarily due to relatively high adaptive capacity of Energy assets.

Extreme heat is an ongoing concern for NSTAR. They are primarily concerned about increased peak electricity demand during heat events exceeding the capacity of transformers and other equipment. Such a scenario could lead to load shedding events. NSTAR seeks to avoid load shedding as a priority through routine monitoring, inspection and maintenance programs, and capital planning. However, electricity demand and supply modeling was not conducted for this assessment to determine whether the heat scenarios developed could result in the electrical transmission capacity in Cambridge, or the broader region, being exceeded.

Highly Vulnerable Assets

The only asset identified as being highly vulnerable and high risk from heat was the Third Street Regulator Station (natural gas) (R3). At this location, the critical threshold for damage to heat-sensitive equipment was exceeded, due to a high heat island effect in the 2070 scenario. If this asset failed, there would be no alternative means of supplying its service area with natural gas. Due to the lack of redundancy, it was considered highly vulnerable.

Adaptive Capacity

North Cambridge Substation, Putnam Substation, and MIT Co-generation Plant, were all exposed to high heat island effects in the 2030s and 2070s heat scenarios. However, all had high adaptive capacities and were therefore not considered highly vulnerable.

MIT Co-generation plant was assumed to have temperature monitoring and controls as well as HVAC to prevent damage from high temperatures. If it did fail, there would be redundancy in that the sites it powers could still access electricity from the grid.

NSTAR's major substations are designed to have redundancy in terms of individual equipment failures caused by heat. Transformers and transmission line connections to them are vulnerable to degradation from heat over time. However, the substations are designed to be able to operate at full peak load with one transformer offline. That means if a single transformer failed due to heat, the others would presumably be able to provide full backup.

NSTAR also has emergency response measures to reduce the ambient heat of substation equipment, such as misting and other technologies, which would be deployed during extreme heat events to reduce the stress on equipment and decrease the risk of failure. Emergency management is organized state-wide and company-wide, extending from NSTAR to Northeast Utilities (parent company). NSTAR has a member in the MEMA command center during emergency situations, improving access for coordinating response plans and resources.

Through regular inspections, maintenance, and capital planning, NSTAR replaces equipment that over time has been degraded by heat. Design standards may evolve over time to adapt to the changing environmental conditions. NSTAR conducted a recent survey to standardize equipment and found that the transformers being installed today far exceed standards and are designed for 40°C (104°F) ambient conditions. In this assessment, assets were considered highly sensitive to ambient temperatures above 110°F.

Vulnerability from Cascading Impacts

In general, heat will lead to surges in demand for energy services. However, cascading impacts from failures in other systems are not likely a key factor in the vulnerability of Energy infrastructure to heat.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 1: Energy infrastructure vulnerability and risk from heat
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Heat - 2030		Heat - 2070	
Type	Name	Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
Power Plants (>10MW)	Veolia-Kendall Cogeneration Station	V0		V0	
	MIT Co-generation Plant	V0		V1-V2	
Bulk Transformer/ Substations	North Cambridge	V0		V1-V2	
	Putnam	V0		V1-V2	
	East Cambridge	V0		V0	
	Prospect	V0		V0	
Natural Gas City Gate Stations	Brookford Street Take Station (N. Cambridge)	V1-V2		V1-V2	
Natural Gas Distribution Regulator Stations	Third St. Intermediate/Low-Pressure Regulator Station	V1-V2		V3-V4	R3
Steam Plants	Harvard Blackstone Plant	V0		V0	

D. Inland Flooding Vulnerability and Risk Assessment

The City's Energy infrastructure is significantly more vulnerable to flooding than heat and may pose a risk from failure during future extreme rainfall events (Tables 2a and 2b). Asset failures would likely be due to direct exposure of sensitive equipment to localized flooding as well as cascading impacts from other infrastructure failures (e.g., energy or transportation). Because energy is a lifeline service, such scenarios represent a high consequence for other infrastructure systems as well as the economy of Cambridge.

Highly Vulnerable Assets

10-year 24 hour storms, 2030s and 2070s
The North Cambridge Substation (R4) would be highly vulnerable in the 10-year 24 hour storm scenarios for 2030 and 2070. Localized flooding would come in direct contact with outdoor equipment above critical thresholds, causing failure. As a direct consequence, large areas of western Cambridge would lose power. There would also be significant cascading impacts.

Critical infrastructure in these areas would lose power, including Brookford Street Take Station (R4), which is one of two entry points for the city's natural gas supply. While Brookford Street Take Station would not be directly exposed to flooding in these scenarios, its lack of adaptive capacity to cope with power failure (no emergency generator) makes it highly vulnerable. There is some limited redundancy in that the Third Street Regulator Station, which primarily serves a large area in eastern Cambridge, could backfeed to some of its customers. Nevertheless, its failure would have high consequences, especially if the power outage was for an extended period of time or during seasonal periods of high natural gas demand.

In addition, because North Cambridge Substation generally provides transmission for the bulk of electricity that is imported to and used in Cambridge, it is possible that demand from the rest of the city could exceed the remaining supply and result in larger areas being without power. It may be possible to supply the balance of power demands from imports transmitted through Prospect Substation and/or from un-impacted generation within the city (e.g. at the Veolia-Kendall Co-generation Station). However, it is uncertain whether such a balance could be enacted and, if so, how long it would take.

MIT's Co-generation Plant (R3) would be directly impacted by flooding in the 10-year storm scenarios, so additional grid and in-city generation would be needed to make up for the loss of supply that it generally provides (~20MW).

100-year 24 hour storm, 2030s
The 100-year 24 hour storm scenario in 2030 would be even more disruptive than the 10-year storms in terms of impacts to the city's Energy infrastructure. In addition to the heightening of vulnerabilities and risks described above, due to increased exposure, there are several new assets that would become highly vulnerable and high risk.

In the 2030s scenario, Putnam Substation (R3) would be highly vulnerable, with direct exposure that would exceed its critical threshold. Failure of Putnam Substation would result in a large, densely populated area of the city losing power. Hence, the consequences of such and event were assessed to be high.

The Third Street Regulator Station (natural gas) (R3) was also assessed to be vulnerable in the 2030s scenario, although it is not as highly exposed. The impacts would be to roadways that are used to access the facility. Despite the relatively limited exposure, the station lacks adaptive capacity (no floodproofing or emergency generator) and was therefore considered vulnerable according to the scoring protocol.

100-year 24 hour storm, 2070s

The impacts of the 2070s 100-year storm scenario on energy infrastructure are extremely severe.

The main additional impact is that Prospect Substation (R3) would be highly vulnerable to flooding, and thus a high risk. If Prospect Substation failed, another large area of the city would lose power. That would mean three of the city's four bulk substations, and its only two pathways for importing electricity into Cambridge would be out of service in this scenario. Only customers served by the Veolia-Kendall Generation Station, smaller-scale generation (including co-generation and emergency generators), and the East Cambridge Substation may still be able to access electricity.

Another significant issue is that North Cambridge Substation would be more broadly exposed to higher depths of flooding than in the other scenarios. This could increase the amount of time it takes to recover from the flooding impacts due to more widespread equipment damage.

Brookford Street Take Station (R3) would also be directly exposed to flood levels that would potentially damage electrical systems and controls in this scenario, in addition to the impacts of cascading power failure. In other scenarios it would only be vulnerable to cascading impacts.

Other vulnerabilities

Although it was not assessed directly in this study, low pressure natural gas distribution systems in Cambridge may be vulnerable and at risk from flooding as well. Most of Cambridge is served by low pressure systems, which consists of cast iron mains that may be susceptible to flooding, and district regulator stations. NStar Gas has plans to replace the mains in Cambridge over the next 20 years. When mains are replaced the meters are then susceptible to damage and also need to be replaced. The regulator stations are below ground and, where possible, have vent lines located in or on traffic boxes to avoid pressurization of the system in the event of water entry. In some cases, vent lines may not be present.

Adaptive Capacity

Recent flooding in NStar and broader Northeast Utilities service areas outside of Cambridge caused by extreme storms like Irene and Sandy have raised concerns about flooding which are spurring additional planning and investments in those areas. NStar bulk substations in Cambridge have not been exposed to flooding before. However, equipment located at customer sites have been impacted by street flooding in the past. NSTAR is working with the Cambridge Fire Department to facilitate permitting of more elevated off-street electrical equipment to protect customer-side equipment from street level flooding.

Electrical Transmission Redundancy

Multiple sources of electrical supply (transmission in to North Cambridge, transmission in to Prospect, and transmission from within-city generation) provide some level of transmission redundancy to the city, varying based on the scenario. Since the bulk of supply is from transmission in to North Cambridge, this substation is particularly important. However, failure at any given bulk substation would impact distribution over a large area. In addition, failures at multiple substations would reduce transmission redundancy.

NSTAR Electric Operational Preparedness

NSTAR's emergency management includes emergency response plans for different scenarios, integrated command structure, training for employees who serve different roles during emergencies. Irene, Sandy, and the blizzard that followed Sandy were catalysts for NSTAR to further strengthen their communications and operations for natural disaster response.

Emergency management is organized state-wide and company-wide, extending from NSTAR to Northeast Utilities (parent company). NSTAR has a member in the MEMA command center during emergency situations, improving access for coordinating response plans and resources. It has also been involved in regional efforts. After Sandy, for the first time NSTAR/Northeast Utilities sent substation technicians to the Rockaways to assist with response and recovery. Underground technicians were also sent to New York to help deal with salt exposure in underground electrical vaults after streets flooded.

NSTAR has emergency flood response capabilities for protecting equipment from flood damage. They could deploy sandbags or other flood protection devises (e.g., tiger dams). However substation flooding is not currently an issue for NSTAR's key assets in Cambridge, so resources would have to be brought in from elsewhere. Multiple substations being subjected to flooding in the same event would present a more difficult challenge to respond to.

If key equipment could not be prevented from flooding, NSTAR would do controlled shut-downs of the facilities to avoid catastrophic failures. Drying out the flooded equipment would take several days. The capability to shut down and avoid catastrophic equipment damage depends on the substation being staffed or accessible during the event. If all access routes were flooded by 1 ft. or more, accessing a substation may not be possible with their current fleet. However, if there was advanced notice of a flood risk, personnel might be pre-staged at the facilities to preclude inaccessibility. This capability would be tempered by NSTAR's primary concern for the safety of their employees. In addition, other types of capabilities (e.g. vehicles that could access the sites in flooded conditions) could be brought to bear through mutual aid partners during response and recovery.

NSTAR expects that if flooding becomes more prevalent into the future, their adaptive capacity will increase accordingly such that by 2030 they are able to prepare for more severe flooding.

Vulnerability from Cascading Impacts / Regional Issues

Due to the high level of interdependency among Energy system infrastructure, it is possible that failures outside of Cambridge could cause cascading impacts on the Energy system within the city.

For example, all of the city's natural gas comes from the Algonquin Pipeline. If locations upstream in the pipeline are damaged by flooding, it is possible that the flow of natural gas to Cambridge would be temporarily disrupted.

Similarly, if upstream electrical generation or transmission facilities, such as at the Mystic Generation Station, were impacted it could disrupt a large source of electrical supply that the city depends on.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 2a: Energy infrastructure vulnerability and risk from inland flooding by 2030s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Power Plants (>10MW)	Veolia-Kendall Cogeneration Station	V1		V1-V3	
	MIT Co-generation Plant	V5	R3	V5	R2
Bulk Transformer/ Substations	North Cambridge	V4	R4	V4	R3
	Putnam	V1-V3		V4	R3
	East Cambridge	V1-V3		V1-V3	
	Prospect	V1-V3		V1-V3	
Natural Gas City Gate Stations	Brookford Street Take Station (N. Cambridge)	V3-V5	R4	V3-V5	R3
Natural Gas Distribution Regulator Stations	Third St. Intermediate/Low-Pressure Regulator Station	V2		V3-V5	R3
Steam Plants	Harvard Blackstone Plant	V1-V3		V1-V3	

Table 2b: Energy Infrastructure vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Power Plants (>10MW)	Veolia-Kendall Cogeneration Station	V1		V1-V3	
	MIT Co-generation Plant	V5	R3	V5	R2
Bulk Transformer/ Substations	North Cambridge	V4	R4	V4	R3
	Putnam	V1-V3		V4	R3
	East Cambridge	V1-V3		V1-V3	
	Prospect	V1-V3		V4	R3
Natural Gas City Gate Stations	Brookford Street Take Station (N. Cambridge)	V3-V5	R4	V5	R3
Natural Gas Distribution Regulator Stations	Third St. Intermediate/Low-Pressure Regulator Station	V2		V3-V5	R3
Steam Plants	Harvard Blackstone Plant	V1-V3		V1-V3	

E. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 3a and 3b below. Assets with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

In Table 3a, the “High Probability” column indicates which assets are highly vulnerable and their corresponding risk scores under the 2030s heat scenario. The “Low Probability” column contains the same information but corresponds with the 2070s heat scenario.

In Table 3b – Risk ranking summary for inland flooding – the “High Probability” column indicates which assets are highly vulnerable and their corresponding risk scores under the 10-year 24 hour storm scenarios of the 2030s and 2070s. The “Low Probability” column contains the same information but corresponds with the 100-year 24 hour storm scenarios of the 2030s and 2070s. Assets with “(2070)” next to their names were assessed to be highly vulnerable in the 2070s scenario, but not the 2030s.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 3a: Risk ranking summary for heat
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	Score R3 • Third St Regulator Station	Score R4
	Medium	Score R2	Score R3
	Low	Score R1	Score R2

Table 3b: Risk ranking summary for flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	Score R3 • North Cambridge Substation • Putnam Substation • Prospect St Substation (2070) • Brookford St Take Station • Third St Regulator Station • MIT Co-generation Plant	Score R4 • North Cambridge Substation • Brookford St Take Station
	Medium	Score R2	Score R3 • MIT Co-generation Plant
	Low	Score R1	Score R2

*(2070) indicates that an asset is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

Attachment 1 – Scoring Protocol for Energy Infrastructure V&R Assessment

Attachment 1 - Energy System: Vulnerability & Risk Assessment Scoring Protocol

Sensitivity to Heat: Extent to which the asset's functionality will be affected by high temperatures it is exposed to in the scenario

Critical Threshold	Score	Description		Direct Impact - based on level of demand and stress on system (°F)
S0	S0	Not affected	Equipment failures due to heat and increased demand unlikely	<90
S1-S2	S1	Minimally affected	Equipment failures due to heat and increased demand possible	90-110
	S2	Somewhat affected		
S3-S4	S3	Largely affected	Equipment failures due to heat and increased demand likely	>110
	S4	Greatly affected		

Assumptions:

- Transformers and transmission line connections will experience accelerated degradation under higher local heat conditions, raising the risk of component failure during the event and over time with cumulative exposure (according to City of Cambridge Electrical Department, during heatwave lasting longer than 3 days, vulnerability of electrical equipment to failure increases).
- Assumed that there will generally be increased demand for energy services especially electricity and chilled air/water during the scenario, putting stress on the system, and resulting in more heat generated from generation and transmission equipment. This raises the risks of component failures and fires.

Sensitivity to Flooding: Extent to which the asset's functionality will be affected by flooding it is exposed to in the scenario

Critical Threshold	Score	Description	Direct Impact - based on location of critical equipment		Indirect Impact - based on dependencies	
			Exterior (ft)	**Inside Building - direct flood contact (ft)**	**Access - local roads (ft)**	**Energy**
S0	S0	Not affected	0	0	<0.5	If upstream energy system is V1-V3
S1-S3	S1	Minimally affected	<0.5	0-1	>0.5	If upstream energy system is V4-V5
	S2	Somewhat affected				
	S3	Largely affected				
S4	S4	Greatly affected	>0.5	>1	NA	NA

Assumptions:

- Exterior
  - Assumed that equipment is raised 0.5 ft above ground. Flooding >0.5 will lead to critical equipment failure.
- Inside building
  - Assumed that equipment is raised 1 ft above ground (building first floor 0.5 ft above ground, equipment raised 0.5 ft above first floor). Flooding >1 ft in direct contact with the building will lead to critical equipment failure.
- Access
  - Access must be maintained for full functionality. Access flooding impairs functionality when >0.5 ft. However access impacts alone are insufficient to "greatly affect" functionality.
- Energy
  - Electricity is needed for critical functions of power plants, substations, natural gas gate stations, and steam plants. If power loss is expected, the facility will not fully function, but upstream energy impacts alone are insufficient to "greatly affect" the functionality. Redundancy in terms of emergency generation will be accounted for in Adaptive Capacity.
  - Natural gas is needed for power plants and steam plants to fully functions. If natural gas gate stations are impacted, these facilities will function at lower level.

Redundancy in fuel supplies (i.e. fuel oil) is accounted for in Adaptive Capacity, since natural gas is assumed to be the primary fuel.

Adaptive Capacity: Extent to which the asset will be able to accommodate or adjust to the impact

Score	Description	Criteria
AC2	High	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing energy services ARE available
AC1	Medium	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover OR 2. Alternative means for obtaining or providing energy services ARE available
AC0	Low	1. Physical/operational measures NOT in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing energy services are NOT available

Vulnerability

		Sensitivity: Low → High				
		S0	S1	S2	S3	S4
Adaptive Capacity: Low ↓ High	AC0	V2	V3	V4	V5	V5
	AC1	V1	V1	V2	V3	V4
	AC2	V0	V0	V0	V1	V2

Consequence

	Criteria
High	1. Impacts a large number of people **OR** large area of the city **AND** 2. Impacts other critical assets/systems
Medium	1. Impacts a large number of people **OR** large area of the city **AND** 2. Does not impact other critical assets/systems
Low	1. Does not impact a large number of people **OR** large area of the city **AND** 3. Does not impact other critical assets/systems

Probability

- Heat
  - o High: 4-day >90°F heatwave (2030 scenario)
  - o Low: 5-day >90°F heatwave with 3 days >100°F (2070 scenario)
- Flooding
  - o High: 10 year 24-hour storm (2030 and 2070)
  - o Low: 100 year 24-hour storm (2030 and 2070)

Risk

		Probability	
		Low	High
Consequence	High	R3	R4
	Medium	R2	R3
	Low	R1	R2

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA)

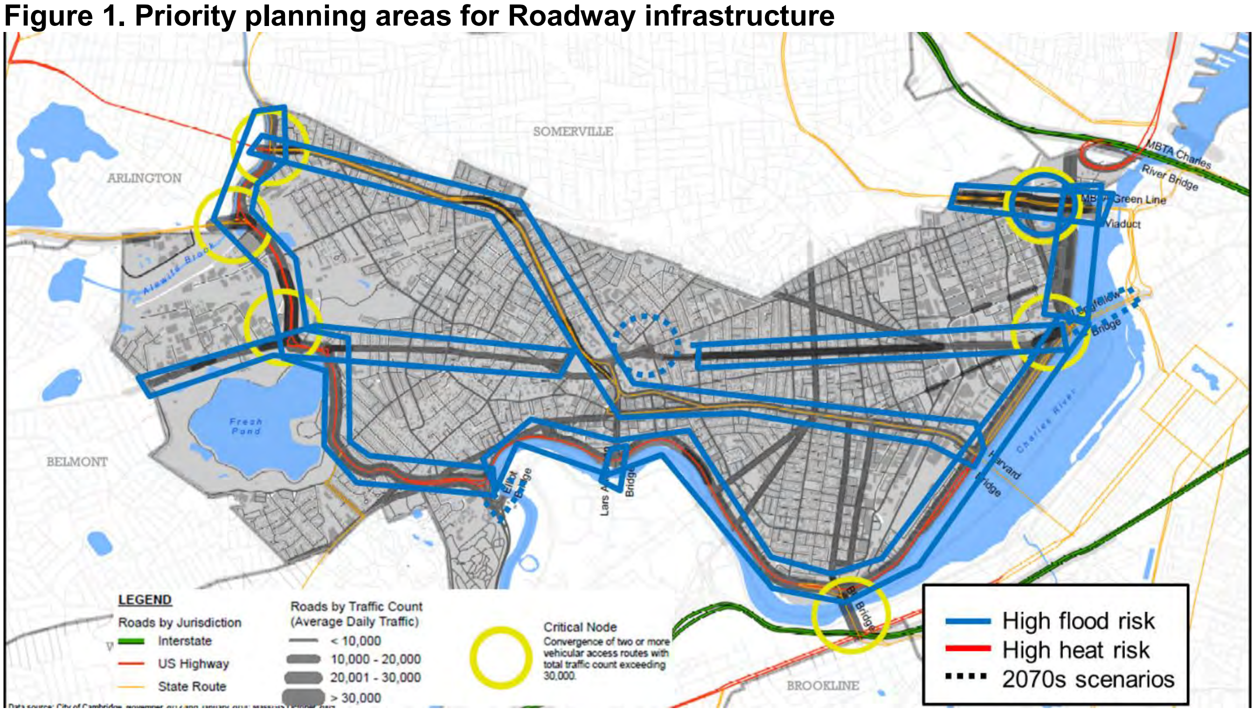
Technical Memorandum: Roadways & Bridges

Prepared by Kleinfelder, 11-3-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

The summary of the high-risk priority planning areas for Roadway infrastructure is presented in Figure 1. There are no identified high risks to the Roadway system being exposed to increased heat. There are however identified high risks of inland flooding scenarios for 2030s and 2070s. Only assets with high risk scores are highlighted (R3 or R4). Those with solid circles around them were identified as high risks for heat (red) or inland flooding (blue) in the 2015-2044 (2030s) scenarios, while those surrounded by dashed circles were only identified as high risks in the 2055-2084 (2070s) scenarios. These priority planning areas should be addressed in the development of the City's Climate Change Preparedness Plan.

Figure 1. Priority planning areas for Roadway infrastructure



The City's Roadway infrastructure is highly vulnerable to flooding, but not highly vulnerable to heat. The highest priorities for planning are the following assets with the highest risk scores (R4) in the Inland Flooding – 2030s scenario:

- Alewife Brook Parkway
- Memorial Drive
- Massachusetts Ave
- Monsignor O'Brien Highway at Charlestown Ave/Land Boulevard
- Monsignor O'Brien Highway / McGrath Highway / Route 28
- Fresh Pond Parkway / Route 60
- Broadway

- Alewife Brook Parkway - intersections with Rt. 2 and Mass Ave/Rt. 16
- Concord Turnpike / Route 2

Other high risks / high priorities for preparedness planning are as follows:

Inland Flooding – 2030s
- Land Blvd (R3)
- Lars Anderson Memorial Bridge (R3)

Inland Flooding – 2070s
- Longfellow Bridge (R3)
- Eliot Bridge (R3)
- Cambridge St Underpass (R3)

B. Summary of Assessment Process and Methods

Selection of Assets
Roadway infrastructure in Cambridge, including major roadways, major intersections, bridges and underpasses, parking facilities, and bicycle routes were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. Assets were screened to ensure that the vulnerability assessment focused on the most important assets in the system. For example, only roadway segments with average daily traffic greater than 30,000 vehicles were included. A limited number of key bicycle routes and parking facilities (public lots or garages with more than 1,000 spaces) were also included. The final list of assets assessed in this study is the result of iterative review and revision by the project team and stakeholders.

Vulnerability and Risk Scoring
The methods and assumptions for scoring the vulnerability and risk of assets were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

Vulnerability of each asset was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.
- Exposure was assessed based on scenario maps developed for the project (see Attachment 1).
- Sensitivity of assets was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the asset to fail to function (see Attachment 2).
- Adaptive capacity was assessed based on whether assets had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure (see Attachment 2).

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.
- Probability was assessed based on whether assets were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- Consequence was assessed based on the scale of the service disruption caused by an asset's failure (entire city vs. neighborhood vs. locality) and the potential for their failure to cause cascading impacts on other assets within or across systems.

Specific protocols for Roadway infrastructure were developed to standardize assumptions for scoring assets' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge (see Attachment 2).

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed assets were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 3).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Roadway infrastructure were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC), and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The latest feedback from a workshop with City stakeholders on October 6, 2014, a meeting with TAC members on December 11, 2014, as well as subsequent follow-up has been incorporated. Participants included the City's Department of Public Works and Community Development Department (Transportation Planning).

Attachments 1-3 and the results reported in this memorandum reflect the latest understanding and assumptions.

Sections C & D below report the heat and inland flooding vulnerability and risk assessment results for Roadway infrastructure.

Section E compiles the risk scores for only highly vulnerable assets.

C. Heat Vulnerability and Risk Assessment

Overall, Cambridge's Roadway infrastructure is not highly vulnerable to heat. This is primarily due to the low sensitivity of roadways to heat (high critical threshold for damage).

The critical variable affecting the sensitivity of roadways to heat is the asphalt binder maximum operating temperature. MassDOT specifications for asphalt used in roadways call for a binder that can withstand up to seven consecutive days with a maximum pavement temperature of 147°F temperature. Climate models do not show these temperatures ever being exceeded in Cambridge in the time period of study, though temperatures on dark surfaces close to the ground may be higher than general ambient air temperature projected by models. Other factors contributing to accelerated pavement failure include traffic loads and the integrity of the underlying layers (base, sub-base, and sub-grade).

Bridges and garages may be more sensitive to heat, based on whether or not their expansion joints can accommodate the greater thermal load (higher extreme temperatures). The specific thermal loads incorporated in the designs of bridges and garages in Cambridge were not reviewed as part of this analysis.

Bicycle routes, particularly bicycle lanes (built to same standards as roadways they are part of), are similarly insensitive to the heat exposure scenarios and were therefore not found to be highly vulnerable to heat. However, user behavior was not integrated in the analysis of vulnerability and risk of Roadway infrastructure in order to ensure cross-comparability of results within and across systems. It is reasonable to infer that bicyclist behavior would likely be negatively impacted in general, and specifically on routes with high urban heat island effects.

Highly Vulnerable Assets

Several assets were exposed to high heat (>110°F) in the 2070s scenario, including Alewife Brook Parkway, Massachusetts Ave, Monsignor O'Brien Highway, First Street Municipal Garage, and Green Street Garage. However, due to low sensitivity, no Roadway assets were assessed as being highly vulnerable to heat.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 1: Roadway infrastructure vulnerability and risk from heat
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Heat - 2030		Heat - 2070	
		Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Major Roads (ADT >30,000)	Fresh Pond Parkway / Route 60	V2		V2	
	Monsignor O'Brien Highway / McGrath Highway / Route 28	V2		V2	
	Alewife Brook Parkway	V2		V2	
	Concord Turnpike / Route 2	V2		V2	
	Memorial Drive	V2		V2	
	Broadway	V2		V2	
	Mass Ave	V2		V2	
	Charlestown Avenue	V2		V2	
	Land Boulevard	V2		V2	
Key Intersections	BU Rotary/Reid overpass	V2		V2	
	Alewife Brook Parkway - intersections with Rt. 2 and Mass Ave/Rt. 16	V2		V2	
	Monsignor O'Brien Highway at Charlestown Ave/Land Boulevard	V2		V2	
Bridges and Underpasses	Charles River Dam Bridge / Lechmere Viaduct (Rt. 28 and MBTA Green Line)	V1		V1	
	Longfellow Bridge (Rt. 3 and MBTA Red Line)	V1		V1	
	Harvard Bridge (Rt. 3 and MBTA Red Line)	V1		V1	
	Boston University Bridge (Rt. 2)	V1		V1	
	River Street Bridge	V1		V1	
	Western Ave. Bridge	V1		V1	

Critical Assets		Heat - 2030		Heat - 2070	
Type	Name	Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
	Lars Anderson Memorial Bridge (N. Harvard St./JFK St and MBTA #66 Bus Route)	V1		V1	
	Eliot Bridge (Rt. 2 to Fresh Pond Parkway)	V1		V1	
	Cambridge Street underpass	V1		V1	
	Memorial Drive underpasses	V1		V1	
Parking Facilities	Alewife MBTA Station	V2		V2	
	First Street Municipal Garage	V1		V1	
	Green Street Garage	V1		V1	
Key Bicycle Routes and Intersections	Broadway Bicycle Route	V1		V1	
	Hampshire St Bicycle Route to Porter Sq	V1		V1	

D. Inland Flooding Vulnerability and Risk Assessment

Roadway system infrastructure in Cambridge is vulnerable to flooding, and may pose a risk from failure during future extreme rainfall events (Tables 2a and 2b). Asset failures would be due to direct exposure to localized flooding, whereby the asset becomes impassable or inaccessible, as well as the cumulative and cascading impacts of multiple critical transportation assets (including transit) flooding or failing during the same extreme event.

Highly Vulnerable Assets

Many of the major roadways and intersections included in this assessment were highly vulnerable and highest risk (R4) from flooding in the 10-year 24 hour scenarios. Levels and extents of vulnerability and risk increased over time and with the severity of the scenarios, such that in the 2070s 100-year storm scenario almost all critical roadways and intersections were highly vulnerable and high risk (R3).

A limited number of bridges and underpasses were highly vulnerable, and mostly only in the 100-year 24 hour storm scenario for the 2070s. The most vulnerable and high risk bridge was the Lars Anderson Memorial Bridge (R3) in the 100-year 24 hour storm of the 2030s.

The three parking facilities assessed were all highly vulnerable in the 2070s 100-year storm scenario. Only one of them – MBTA Alewife Station Garage – was highly vulnerable in less severe flooding scenarios, and it was vulnerable across all the scenarios. Parking facilities were considered a relatively low risk because they do not serve a large area of the city or proportion of its population, and their failure does not impact the functions of other critical infrastructure.

Both of the key bicycle routes would be highly vulnerable to flooding under the 2070s 10-year 24 hour storm scenario.

Adaptive Capacity

Roadways and their stormwater systems have largely not been designed or adapted to the levels of inland flooding modeled in these scenarios. For example, there is no excess stormwater storage or pumping capacity to further mitigate flooding of roadways, as these were all included in the modeling results and flooding was still extensive. This factor contributed to the low adaptive capacity and high vulnerability of exposed assets.

Major roadways were considered to have very low adaptive capacity, also due to limited redundancy. It was assumed that the cumulative traffic volumes from all of the highly exposed major roadways would not be accommodated through re-routing on more minor roads, which could also be flooded but were not specifically assessed. This effectively meant that six moderately exposed and sensitive roadways in the 2030s 10-year 24 hour storm scenario, and two in the 2070s 10-year storm scenario, were considered highly vulnerable.

In contrast, moderately exposed and sensitive bridges and underpasses were not considered highly vulnerable. As opposed to major roadways, it was assumed that there was redundancy among the various bridges and land-based access points to and from Cambridge, despite the challenges associated with re-routing traffic. There was not a critical mass of bridges and underpasses affected by flooding to suggest that there would effectively be no redundancy.

Vulnerability from Cascading Impacts

Flooding could also impact lifeline systems such as energy and telecommunications, without which some roadway infrastructure (traffic signals, lighting, ITS) may not be able to properly function. Critical Services, such as law enforcement and emergency medical services, are also vulnerable to flooding, limiting their ability to manage traffic and ensure public safety before, during, or after an event.

The failure of Roadway infrastructure also has cascading impacts on other critical infrastructure systems, particularly those that rely on vehicle access for full functionality. These include Critical Services and Energy facilities, among others.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 2a: Roadway infrastructure vulnerability and risk from inland flooding by 2030s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Major Roads (ADT >30,000)	Fresh Pond Parkway / Route 60	V3-V5	R4	V5	R3
	Monsignor O'Brien Highway / McGrath Highway / Route 28	V3-V5	R4	V5	R3
	Alewife Brook Parkway	V5	R4	V5	R3
	Concord Turnpike / Route 2	V5	R4	V5	R3
	Memorial Drive	V3-V5	R4	V3-V5	R3
	Broadway	V3-V5	R4	V5	R3
	Mass Ave	V3-V5	R4	V5	R3
	Charlestown Avenue	V2		V2	
	Land Boulevard	V2		V3-V5	R3
Key Intersections	BU Rotary/Reid overpass	V2		V2	
	Alewife Brook Parkway - intersections with Rt. 2 and Mass Ave/Rt. 16	V5	R4	V5	R3
	Monsignor O'Brien Highway at Charlestown Ave/Land Boulevard	V3-V5	R4	V5	R3
Bridges and Underpasses	Charles River Dam Bridge / Lechmere Viaduct (Rt. 28 and MBTA Green Line)	V1		V1	
	Longfellow Bridge (Rt. 3 and MBTA Red Line)	V1		V1	
	Harvard Bridge (Rt. 3 and MBTA Red Line)	V1		V1-V3	
	Boston University Bridge (Rt. 2)	V1		V1	
	River Street Bridge	V1		V1	
	Western Ave. Bridge	V1		V1	

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	Lars Anderson Memorial Bridge (N. Harvard St./JFK St and MBTA #66 Bus Route)	V1		V4	R3
	Eliot Bridge (Rt. 2 to Fresh Pond Parkway)	V1		V1	
	Cambridge Street underpass	V1		V1-V3	
	Memorial Drive underpasses	V1		V1	
Parking Facilities	Alewife MBTA Station	V5	R2	V5	R1
	First Street Municipal Garage	V1		V1	
	Green Street Garage	V1		V1	
Key Bicycle Routes and Intersections	Broadway Bicycle Route	V1		V4	R1
	Hampshire St Bicycle Route to Porter Sq	V1		V4	R1

Table 2b: Roadway Infrastructure vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Major Roads (ADT >30,000)	Fresh Pond Parkway / Route 60	V5	R4	V5	R3
	Monsignor O'Brien Highway / McGrath Highway / Route 28	V5	R4	V5	R3
	Alewife Brook Parkway	V5	R4	V5	R3
	Concord Turnpike / Route 2	V5	R4	V5	R3
	Memorial Drive*	V3-V5	R4	V3-V5	R3
	Broadway*	V5	R4	V5	R3
	Mass Ave*	V5	R4	V5	R3
	Charlestown Avenue	V2		V2	
	Land Boulevard	V2		V5	R3
Key Intersections	BU Rotary/Reid overpass	V2		V2	
	Alewife Brook Parkway - intersections with Rt. 2 and Mass Ave/Rt. 16	V5	R4	V5	R3
	Monsignor O'Brien Highway at Charlestown Ave/Land Boulevard	V5	R4	V5	R3
Bridges and Underpasses	Charles River Dam Bridge / Lechmere Viaduct (Rt. 28 and MBTA Green Line)	V1-V3		V1-V3	
	Longfellow Bridge (Rt. 3 and MBTA Red Line)	V1		V4	R3
	Harvard Bridge (Rt. 3 and MBTA Red Line)	V1		V1-V3	
	Boston University Bridge (Rt. 2)	V1		V1	
	River Street Bridge	V1		V1	
	Western Ave. Bridge	V1		V1-V3	
	Lars Anderson Memorial Bridge (N. Harvard St./JFK St and MBTA #66 Bus Route)	V1		V4	R3

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	Eliot Bridge (Rt. 2 to Fresh Pond Parkway)	V1		V4	R3
	Cambridge Street underpass	V1		V4	R3
	Memorial Drive underpasses	V1		V1	
Parking Facilities	Alewife MBTA Station	V5	R2	V5	R1
	First Street Municipal Garage	V1		V4	R1
	Green Street Garage	V1		V4	R1
Key Bicycle Routes and Intersections	Broadway Bicycle Route	V4	R2	V4	R1
	Hampshire St Bicycle Route to Porter Sq	V4	R2	V4	R1

E. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 3 below. Assets with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

As no Roadways assets were assessed as being high risk, no summary table for heat risk is included.

In Table 3, the "High Probability" column indicates which assets are highly vulnerable and their corresponding risk scores under the 10-year 24 hour storm scenarios of the 2030s and 2070s. The "Low Probability" column contains the same information but corresponds with the 100-year 24 hour storm scenarios of the 2030s and 2070s. Assets with "(2070)" next to their names were assessed to be highly vulnerable in the 2070s scenario, but not the 2030s.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 3: Risk ranking summary for flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3** • Alewife Brook Parkway - intersections with Rt. 2 and Mass Ave/Rt. 16 • Alewife Brook Parkway • Concord Turnpike / Route 2 • Broadway • Fresh Pond Parkway / Route 60 • Land Boulevard • Lars Anderson Memorial Bridge • Monsignor O'Brien Highway at Charlestown Ave/Land Boulevard • Monsignor O'Brien Highway / McGrath Highway / Route 28 • Memorial Drive • Massachusetts Ave • Longfellow Bridge (2070) • Eliot Bridge (2070) • Cambridge St Underpass (2070)	**Score R4** • Monsignor O'Brien Highway at Charlestown Ave/Land Boulevard • Monsignor O'Brien Highway / McGrath Highway / Route 28 • Memorial Drive • Massachusetts Ave • Fresh Pond Parkway / Route 60 • Broadway • Alewife Brook Parkway - intersections with Rt. 2 and Mass Ave/Rt. 16 • Alewife Brook Parkway • Concord Turnpike / Route 2
	Medium	**Score R2**	**Score R3**
	Low	**Score R1** • Hampshire St Bicycle Route to Porter Sq • Broadway Bicycle Route • Green Street Garage • First Street Municipal Garage • Alewife Station Garage	**Score R2**

*(2070) indicates that an asset is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

Attachment 1 – Scoring Protocol for Transportation Infrastructure V&R Assessment

Attachment 1- Transportation System: Vulnerability & Risk Assessment Scoring Protocol

Sensitivity to Heat: Extent to which the asset's functionality will be affected by high temperatures it is exposed to in the scenario

Threshold	Score	Description		Direct Impact - based on stress on equipment/components: Rail Lines[1] (°F)	Roadway Infrastructure including underpasses, traffic signals (°F)	MBTA Stations, Bus Routes
S0	S0	Not affected	Functional capacity or usability is not likely affected	<80	< 147	<100
S1-S3	S1	Minimally Affected	Functional capacity or usability may be affected, degree of sensitivity to be vetted with stakeholders	80 - 100	> 147	100 - 110
	S2	Somewhat Affected				
	S3	Largely Affected				
S4	S4	Greatly affected	Functional capacity likely to be affected at this temperature	>100		<110

Assumptions:

- Upper bound of neutral temperature range for MBTA rail is 110°F; noting temperature differential between rail and ambient air temperature is approximately 30°F[2], the threshold above which some impact is expected is therefore assumed to be 110°F – 30°F = 80°F ambient air temperature.
- At the same ambient temperature, above ground rail lines are assumed to be more sensitive because they experience higher relative temperatures than underground rail

[1] https://www.mbta.com/uploadedfiles/Business_Center/Bidding_and_Solicitations/Design_and_Construction/Track-MaintandSafety-Standards-Green-Line.pdf
[2] https://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task3/task_3.2/task2phase3.pdf

- Roadway asphalt will experience accelerated degradation during the event and over time with cumulative exposure from daily traffic loads.
- Transformers and transmission line connections will experience accelerated degradation under higher temperatures, raising the risk of electrical failure during the event and over time with cumulative exposure. This may affect subway stations and third rail, main intersection traffic signal functioning.
- Bridge expansion may be not be accommodated if structure is not designed to greater thermal load (higher extreme temperature)

Sensitivity to Flooding: Extent to which the asset's functionality will be affected by flooding it is exposed to in the scenario

<table>
<tr><th rowspan="2">Threshold</th><th rowspan="2">Score</th><th rowspan="2">Description</th><th colspan="3">Direct Impact - based on location of critical equipment</th></tr>
<tr><th>MBTA T Stations and Rail (above ground) (ft.)</th><th>MBTA T Stations (below ground), Underpasses (ft.)</th><th>Bus Hubs, Bus Routes, Roadways, Bridges (approaches), Intersections, Parking Facilities (ft.)</th></tr>
<tr><td>S0</td><td>S0</td><td>Not affected</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="3">S1-S3</td><td>S1</td><td>Minimally affected</td><td rowspan="3"><0.5</td><td rowspan="3">N/A</td><td rowspan="3">0-1</td></tr>
<tr><td>S2</td><td>Somewhat affected</td></tr>
<tr><td>S3</td><td>Largely affected</td></tr>
<tr><td>S4</td><td>S4</td><td>Greatly affected</td><td>>0.5</td><td>>0</td><td>>1</td></tr>
</table>

Assumptions:

· Below ground vs. above ground
  - Below ground assets (T stations, underpasses) are assumed to be highly sensitive to even low levels of flooding (as measured at their above ground points of entry) because water will flow to and accumulate in the below ground areas of the infrastructure.

· MBTA T Stations and rail lines
  - Assumed that third rail will be deactivated/damaged (below ground) and/or the top of rail will be exceeded at >0.5 ft. flooding (above ground), rendering the station temporarily unusable and potentially causing equipment damage.

· Bus Hubs, Bus Routes, Roadways, Bridges (approaches), Intersections, Parking Facilities

- Above 1> ft. flooding would reach vehicle undercarriages, rendering the transportation asset unusable.
- Bridge scour during flooding can compromise structural integrity

Adaptive Capacity: Extent to which the asset will be able to accommodate or adjust to the impact

Score	Description	Criteria
AC2	High	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing transportation services ARE available
AC1	Medium	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover OR 2. Alternative means for obtaining or providing transportation services ARE available
AC0	Low	1. Physical/operational measures NOT in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing transportation services are NOT available

Vulnerability

		Sensitivity: Low → High				
		S0	S1	S2	S3	S4
Adaptive Capacity: Low ↓ High	AC0	V2	V3	V4	V5	V5
	AC1	V1	V1	V2	V3	V4
	AC2	V0	V0	V0	V1	V2

Consequence

	Criteria
High	1. Impacts a large number of people **OR** large area of the city **AND** 2. Impacts other critical assets/systems
Medium	1. Impacts a large number of people **OR** large area of the city **AND** 2. Does not impact other critical assets/systems
Low	1. Does not impact a large number of people **OR** large area of the city **AND** 3. Does not impact other critical assets/systems

Probability

- Heat
  - o High: 4-day >90°F heatwave (2030 scenario)
  - o Low: 5-day >90°F heatwave with 3 days >100°F (2070 scenario)
- Flooding
  - o High: 10 year 24-hour storm (2030 and 2070)
  - o Low: 100 year 24-hour storm (2030 and 2070)

Risk

		Probability	
		Low	High
Consequence	High	R3	R4
	Medium	R2	R3
	Low	R1	R2

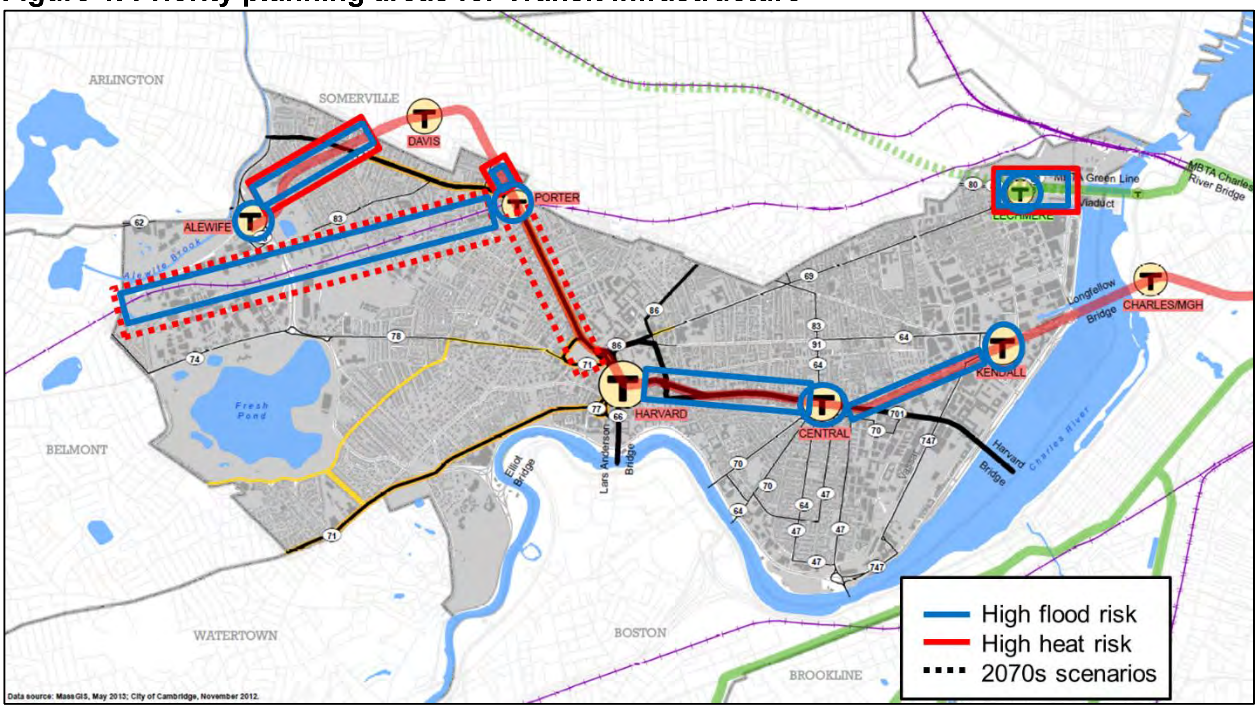
Technical Memorandum: Transit Infrastructure

Prepared by Kleinfelder, 11-3-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

The summary of the high-risk priority planning areas for Transit infrastructure is presented in Figure 1. Only assets with high risk scores are highlighted (R3 or R4). Those with solid circles around them were identified as high risks for heat (red) or inland flooding (blue) in the 2015-2044 (2030s) scenarios, while those surrounded by dashed circles were only identified as high risks in the 2055-2084 (2070s) scenarios. These priority planning areas should be addressed in the development of the City's Climate Change Preparedness Plan.

Figure 1. Priority planning areas for Transit infrastructure



Transit infrastructure in Cambridge is at high risk from both inland flooding and heat. In the 2030s, including the more extreme flooding scenario (100-year 24 hour storm), five of the city's six T stations, four of its five T rail lines, its only commuter station and rail line, and its two of its four most critical bus routes and hubs would be highly vulnerable to inland flooding and/or heat.

Two MBTA subway (T) lines enter and end in Cambridge: the Red Line and the Green Line. Their terminal rail line segments were among the assets with the highest risk scores (R4) in the Inland Flooding and Heat in the 2030s scenario:

- Green Line: Lechmere – Science Park Rail Line
- Red Line: Alewife – Davis (Somerville) – Porter Rail Lines
- Red Line: Central – Kendall Rail Line

Other high risks / high priorities for preparedness planning are as follows:

Inland Flooding – 2030s
- Alewife Station (Red) (R4)
- Lechmere Station (Green) (R4)
- Harvard – Central Rail Line (Red) (R3)
- Porter Square Subway (Red) and Commuter Rail Station (Red) (R3)
- Central Square Station (Red) (R3)
- Kendall Station (Red) (R3)
- Fitchburg Commuter Rail Line (R3)

Inland Flooding – 2070s
- Porter Square Subway (Red) and Commuter Rail Station (Red) (R4)
- Kendall Station (Red) (R4)
- Fitchburg Commuter Rail Line (R4)

Heat – 2070s
- Porter – Harvard Rail Line (Red) (R3)
- Fitchburg Commuter Rail Line (R3)

B. Summary of Assessment Process and Methods

Selection of Assets
Transit infrastructure in Cambridge, including MBTA subway and commuter stations and rail lines, bus routes and hubs, maintenance and storage facilities were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. Assets were screened to ensure that the vulnerability assessment focused on the most important assets in the system. For example, only bus routes with daily ridership greater than 10,000 were included. Information about some support infrastructure, particularly energy systems that support the MBTA system, were not publicly available and thus were not assessed. Other important assets were outside of Cambridge and therefore could not be assessed using the geographically-limited heat and flooding scenarios. The final list of assets assessed in this study is the result of iterative review and revision by the project team and stakeholders.

Vulnerability and Risk Scoring
The methods and assumptions for scoring the vulnerability and risk of assets were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

Vulnerability of each asset was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.
- Exposure was assessed based on scenario maps developed for the project (see Attachment 1).

- Sensitivity of assets was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the asset to fail to function (see Attachment 2).
- Adaptive capacity was assessed based on whether assets had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure (see Attachment 2).

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.

- Probability was assessed based on whether assets were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- Consequence was assessed based on the scale of the service disruption caused by an asset's failure (entire city vs. neighborhood vs. locality) and the potential for their failure to cause cascading impacts on other assets within or across systems.

Specific protocols for Transit infrastructure were developed to standardize assumptions for scoring assets' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge (see Attachment 2).

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed assets were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 3).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Transit infrastructure were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC) – which MBTA is a member of, and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The latest feedback from a workshop with City stakeholders on October 6, 2014, a meeting with TAC members on December 11, 2014, as well as subsequent follow-up has been incorporated. Participants included the City's Department of Public Works and Community Development Department.

Attachments 1-3 and the results reported in this memorandum reflect the latest understanding and assumptions.

Sections C & D below report the heat and inland flooding vulnerability and risk assessment results for Transit infrastructure.

Section E compiles the risk scores for only highly vulnerable assets.

C. Heat Vulnerability and Risk Assessment

Transit infrastructure in Cambridge, particularly subway and commuter rail lines, are vulnerable to heat and may pose a risk from failure during extreme heat events in the future (Table 1). Asset failures would likely be due to rail exposure to extreme heat which could result in damage to rails (rail buckling, sun kinks) or supporting electrical equipment.

Transit user behavior may also be affected by extreme heat, though it was not assessed in this study. Extreme heat could lead to more people driving or taking public transit rather than walking or bicycling to avoid exposure to outdoor heat. This surge in demand could put additional stress on the transit system. In addition, T stations and bus stops are not air conditioned and some bus stops are not covered, so these may still not be preferred modes of transportation during extreme heat events.

Highly Vulnerable Assets

Rail line is the Transit infrastructure asset type that is most sensitive to heat, and due to its high exposure and limited adaptive capacity, most vulnerable as well.

The rail used in MBTA subway lines is conditioned to operate optimally at maximum ambient temperatures of around 80°F[1], above which the risk of buckling or "sunk kinks" increases as heat rises., The critical threshold used in this assessment for the ambient air temperature at which rails become highly vulnerable was 100°F, as documented in Attachment 2 (Scoring Protocol). Vulnerabilities could increase if more conservative critical thresholds were used.

Two above ground rail lines are highly vulnerable to heat under the 2030s scenario: Alewife-Davis-Porter (Red Line) and Lechmere-Science Park (Green Line). These assets were all considered highest risk (R4) due the large number of people that depend on them for daily transit. In the 2070s heat scenario, two additional rail lines are highly vulnerable and high risk (R3): Porter-Harvard (Red Line), and the Fitchburg Commuter Rail Line.

The rail line routes for Harvard-Central and Central-Kendall segments of the Red Line were also highly exposed to heat. However, as these line segments are entirely underground, it was assumed that they would be less sensitive and therefore less vulnerable.

Adaptive Capacity

There is some adaptive capacity in the rail system (stations and rail lines) to deal with heat impacts. At ambient temperatures above 90°F, MBTA may reduce speeds to enable trains to safely cross over lightly-buckled track sections. However, the line could be shut down if buckling is severe as has occurred in the past (e.g., Orange Line in July 2010 and 2011). Commuter rail is also impacted by heat and operates at reduced speed when rail are overheated by extreme temperature.

When a section of rail or a station is shut down due to heat, trains may be single tracked or shuttle buses may be provided between stations, increasing transit time for riders. However, shuttle busing is only a feasible short term solution if a limited number of rail segments are impacted, as there is limited additional bus capacity.

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[1] Maximum MBTA neutral rail temperature is 110°F (Massachusetts Bay Transportation Authority, Maintenance of Way Division. 2000. Green Line – Light Rail Transit Track Maintenance and Safety Standards: CWR Installation Guide and Track Buckling Countermeasures. Pages 47-52. Accessed November 2014. https://www.mbta.com/uploadedfiles/Business_Center/Bidding_and_Solicitations/Design_and_Construction/Track-MaintandSafety-Standards-Green-Line.pdf).
Rail temperature is assumed to be 30°F higher than the ambient temperature in hot weather (Federal Railroad Administration, Office of Safety Analysis. 2013. Continuous Welded Rail Generic Plan: Procedures for the Installation, Adjustment, Maintenance and Inspection of CWR as Required by 49 CFR 213.118. Page 15. Web, Accessed November 2014. http://safetydata.fra.dot.gov/OfficeofSafety/publicsite/cwr/).

Critical bus routes and hubs were not highly vulnerable, despite being highly exposed and sensitive in the 2070s scenario, due to their adaptive capacities. Their technical and operational systems to mitigate the impact of high exposure and sensitivity included air conditioning and redundancy in terms of buses' ability to take modified routes if necessary to avoid impacted areas.

Vulnerability from Cascading Impacts

Transit service to Cambridge rail stations and bus routes could be impacted by failures in the MBTA system outside of Cambridge. This could include heat-related impacts to rails on the Red Line or Green Line, or impacts to MBTA's supportive electrical infrastructure, which may be sensitive to heat.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 1: Transit infrastructure vulnerability and risk from heat
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Heat - 2030		Heat - 2070	
		Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Subway Stations	Alewife Station (Red Line)	V2		V2	
	Porter Square Subway Station and Commuter Rail (Red Line, Fitchburg Line)	V2		V2	
	Harvard Square Station (Red Line)	V2		V2	
	Central Square Station (Red Line)	V2		V2	
	Kendall Station (Red Line)	V2		V2	
	Lechmere Station (Green Line)	V2		V2	
Rail Lines (Subway and Commuter)	Fitchburg Commuter Rail Line	V1-V3		V4	R3
	Alewife-Davis-Porter (Red)	V4	R4	V4	R3
	Porter - Harvard (Red)	V1-V3		V4	R3
	Harvard - Central (Red)	V1-V3		V1-V3	
	Central - Kendall (Red)	V1-V3		V1-V3	
	Lechmere-Science Park (Green)	V4	R4	V4	R3
Bus	Harvard Square hub	V0-V1		V2	
	Central Square hub	V0-V1		V2	
	MBTA #66 Bus Route (from Allston via Lars Anderson Bridge to Harvard Square)	V0-V1		V2	
	MBTA #1 Bus Route (along Mass Ave across Harvard	V0-V1		V2	

Critical Assets		Heat - 2030		Heat - 2070	
		Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	Bridge to Central Square & Harvard Square)				

D. Inland Flooding Vulnerability and Risk Assessment

Transit infrastructure in Cambridge is highly vulnerable to flooding and may pose a high risk from failure during future extreme rainfall events (Tables 2a and 2b). Asset failures would likely be due to direct exposure to localized flooding. Based on the results of this assessment, flooding could also impact lifeline systems such as energy, roadway, and telecommunications without which Transit facilities may not be able to properly function.

Highly Vulnerable Assets

10-year 24 hour storm, 2030s
Critical transit assets on the Red Line and Green Line in Cambridge would be highly vulnerable to flooding in this scenario.

Alewife Station and the rail lines between Alewife and Porter Square Stations, and Central and Kendall Stations would be highly vulnerable and highest risk (R4) from flooding. As Alewife is the final stop on the Red Line and the last stop in Cambridge, it would not necessarily have a cascading impact on other Red Line stations in the city, though it would likely lead to delays. Due to flooding of bus loading areas at Alewife Station, Red Line passengers including commuters who parked at the MBTA Alewife Garage could not easily be shuttle bussed to and from other stations.

Lechmere Station and the rail lines from Lechmere to Science Park Station in Boston would also be highly vulnerable to flooding and highest risk (R4) as well. Failure of these assets would prevent passengers from transiting to and from Cambridge on the Green Line.

10-year 24 hour storm, 2070s
The 2070s 10-year 24 hour storm scenario could be significantly more severe in terms of flooding impacts to Transit infrastructure in Cambridge. In addition to those assets described above, two additional Red Line stations (Porter Square and Kendall) and the Fitchburg Commuter Rail Line and Station (Porter Square) would be highly vulnerable and highest risk (R4) from flooding. With

Kendall (Red Line) and Lechmere (Green Line) Stations out of service, there would be no access via the T from Cambridge to Boston.

100-year 24 hour storm, 2030s and 2070s

The 2030s and 2070s 100-year storm scenarios are very similar to the 2070s 10-year scenario in that essentially all key Transit infrastructure assets are highly vulnerable. These include five of the city's six T stations (all but Harvard), four of its five T rail lines, its only commuter station and rail line, and, in this case two of its four most critical bus routes and hubs.

Two key bus assets, MBTA #66 Bus Route and MBTA #1 Bus Route, would be highly vulnerable to flooding. These routes are interdependent on the Red Line, given the prominence of Red Line stations on their routes and ridership data. However, bus assets were assessed as having a lower consequence of failure than T station and rail lines, given their more limited ridership and routes.

Assets are also more broadly exposed to higher flood depths in the 100-year scenarios than in the 2070s 10-year storm scenario. For example, in the 100-year scenarios, riverine flooding from Alewife Brook results in flooding of significantly broader extent and higher depth at Alewife Station (Red Line) and on the Fitchburg Commuter Rail Line. This could result in a more costly, challenging, and lengthy recovery period for the Transit system.

Adaptive Capacity

Transit assets have some adaptive capacity, in that the transportation system is multi-modal. If trains stop running on a segment of rail due to flooding, passengers can be shuttled by bus. If a bus route is flooded, buses can re-route around the flooded area. However, when multiple modes are impacted those redundancies break down. For example, in certain scenarios flooding at most T stations is sufficient to prevent passenger boarding of buses at the normal locations.

In addition, the understanding from this assessment is that transit systems in Cambridge were not designed or adapted to cope with the significant exposure to inland flooding in these scenarios. Pumping systems are likely inadequate, there are few if any temporary or permanent barriers to limit the penetration of flood waters into sensitive areas, and equipment (e.g., rails) may not be sufficiently raised off the ground.

When a section of rail or a station is shut down due to flooding, trains may be single tracked (if only one track is flooded) or shuttle buses may be provided between stations. Both options increase transit time for riders. Shuttle busing is only a feasible short term solution if a limited number of rail segments are impacted, as there is limited additional bus capacity.

Vulnerability from Cascading Impacts

The Transit system could be impacted by failures in other systems due to flooding. Flooding could impact key systems such as energy, roadways, and telecommunications, without which some Transit infrastructure (signals, switches, third rail, station HVAC, etc) and operations may not be able to properly function.

Transit service to Cambridge rail stations and bus routes could be impacted by failures in the MBTA system outside of Cambridge. This could include flooding-related impacts to rails on the Red Line or Green Line, or impacts to MBTA's supportive electrical infrastructure or train and bus storage and maintenance facilities, which may be impacted by flooding.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 2a: Transit infrastructure vulnerability and risk from inland flooding by 2030s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	**Name**	**Vulnerability**	**Risk**	**Vulnerability**	**Risk**
Subway Stations	Alewife Station (Red Line)	V5	R4	V5	R3
	Porter Square Subway Station and Commuter Rail (Red Line, Fitchburg Line)	V1		V4	R3
	Harvard Square Station (Red Line)	V1		V1	
	Central Square Station (Red Line)	V1		V3-V5	R3
	Kendall Station (Red Line)	V1		V5	R3
	Lechmere Station (Green Line)	V5	R4	V5	R3
Rail Lines (Subway and Commuter)	Fitchburg Commuter Rail Line	V1		V3-V5	R3
	Alewife-Davis-Porter (Red)	V1		V5	R3
	Porter - Harvard (Red)	V1		V2	
	Harvard - Central (Red)	V2		V3-V5	R3
	Central - Kendall (Red)	V4	R4	V5	R3
	Lechmere-Science Park (Green)	V5	R4	V5	R3
Bus	Harvard Square hub	V1		V1	
	Central Square hub	V1		V1-V3	
	MBTA #66 Bus Route	V1		V4	R2
	MBTA #1 Bus Route	V1-V3		V4	R2

Table 2b: Transit Infrastructure vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Subway Stations	Alewife Station (Red Line)	V5	R4	V5	R3
	Porter Square Subway Station and Commuter Rail (Red Line, Fitchburg Line)	V5	R4	V5	R3
	Harvard Square Station (Red Line)	V1		V1	
	Central Square Station (Red Line)	V2		V3-V5	R3
	Kendall Station (Red Line)	V4	R4	V5	R3
	Lechmere Station (Green Line)	V5	R4	V5	R3
Rail Lines (Subway and Commuter)	Fitchburg Commuter Rail Line	V5	R4	V5	R3
	Alewife-Davis-Porter (Red)	V5	R4	V5	R3
	Porter - Harvard (Red)	V2		V2	
	Harvard - Central (Red)	V2		V5	R3
	Central - Kendall (Red)	V4	R4	V5	R3
	Lechmere-Science Park (Green)	V5	R4	V5	R3
Bus	Harvard Square hub	V1		V1	
	Central Square hub	V1		V1-V3	
	MBTA #66 Bus Route	V1		V4	R2
	MBTA #1 Bus Route	V1-V3		V4	R2

E. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 3a and 3b below. Assets with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

In Table 3a, the "High Probability" column indicates which assets are highly vulnerable and their corresponding risk scores under the 2030s heat scenario. The "Low Probability" column contains the same information but corresponds with the 2070s heat scenario.

In Table 3b – Risk ranking summary for inland flooding – the "High Probability" column indicates which assets are highly vulnerable and their corresponding risk scores under the 10-year 24 hour storm scenarios of the 2030s and 2070s. The "Low Probability" column contains the same information but corresponds with the 100-year 24 hour storm scenarios of the 2030s and 2070s. Assets with "(2070)" next to their names were assessed to be highly vulnerable in the 2070s scenario, but not the 2030s.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 3a: Risk ranking summary for heat
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	**Score R3** • Alewife – Davis – Porter Rail Line (Red) • Porter – Harvard Rail Line (Red) • Lechmere – Science Park Rail Line (Green) • Fitchburg Commuter Rail Line	**Score R4** • Alewife – Davis – Porter Rail Line (Red) • Lechmere – Science Park Rail Line (Green)
	Medium	**Score R2**	**Score R3**
	Low	**Score R1**	**Score R2**

Table 3b: Risk ranking summary for flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3** • Alewife Station (Red) • Porter Square Subway (Red) and Commuter Rail Station (Red) • Central Square Station (Red) • Kendall Station (Red) • Lechmere Station (Green) • Alewife – Davis – Porter Rail Line (Red) • Harvard – Central Rail Line (Red) • Central – Kendall Rail Line (Red) • Lechmere – Science Park Rail Line (Green) • Fitchburg Commuter Rail Line	**Score R4** • Alewife Station (Red) • Porter Square Subway (Red) and Commuter Rail Station (2070) • Kendall Station (Red) (2070) • Lechmere Station (Green) • Alewife – Davis – Porter Rail Line (Red) • Central – Kendall Rail Line (Red) • Lechmere – Science Park Rail Line (Green) • Fitchburg Commuter Rail Line (2070)
	Medium	**Score R2** • Central Square Bus Hub • MBTA #66 Bus Route (from Allston via Lars Anderson Bridge to Harvard Square) • MBTA #1 Bus Route (along Mass Ave across Harvard Bridge to Central Square and Harvard Square)	**Score R3**
	Low	**Score R1**	**Score R2**

*(2070) indicates that an asset is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

Attachment 1 – Scoring Protocol for Transportation Infrastructure V&R Assessment

Attachment 1- Transportation System: Vulnerability & Risk Assessment Scoring Protocol

Sensitivity to Heat: Extent to which the asset's functionality will be affected by high temperatures it is exposed to in the scenario

Threshold	Score	Description		Direct Impact - based on stress on equipment/components		
				Rail Lines[1] (°F)	Roadway Infrastructure including underpasses, traffic signals (°F)	MBTA Stations, Bus Routes
S0	S0	Not affected	Functional capacity or usability is not likely affected	<80	< 147	<100
S1-S3	S1	Minimally Affected	Functional capacity or usability may be affected, degree of sensitivity to be vetted with stakeholders	80 - 100	> 147	100 - 110
	S2	Somewhat Affected				
	S3	Largely Affected				
S4	S4	Greatly affected	Functional capacity likely to be affected at this temperature	>100		<110

Assumptions:

- Upper bound of neutral temperature range for MBTA rail is 110°F; noting temperature differential between rail and ambient air temperature is approximately 30°F[2], the threshold above which some impact is expected is therefore assumed to be 110°F – 30°F = 80°F ambient air temperature.
- At the same ambient temperature, above ground rail lines are assumed to be more sensitive because they experience higher relative temperatures than underground rail

[1] https://www.mbta.com/uploadedfiles/Business_Center/Bidding_and_Solicitations/Design_and_Construction/Track-MaintandSafety-Standards-Green-Line.pdf

[2] https://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task3/task_3.2/task2phase3.pdf

- Roadway asphalt will experience accelerated degradation during the event and over time with cumulative exposure from daily traffic loads.
- Transformers and transmission line connections will experience accelerated degradation under higher temperatures, raising the risk of electrical failure during the event and over time with cumulative exposure. This may affect subway stations and third rail, main intersection traffic signal functioning.
- Bridge expansion may be not be accommodated if structure is not designed to greater thermal load (higher extreme temperature)

Sensitivity to Flooding: Extent to which the asset's functionality will be affected by flooding it is exposed to in the scenario

Threshold	Score	Description	Direct Impact - based on location of critical equipment		
			MBTA T Stations and Rail (above ground) (ft.)	MBTA T Stations (below ground), Underpasses (ft.)	Bus Hubs, Bus Routes, Roadways, Bridges (approaches), Intersections, Parking Facilities (ft.)
S0	S0	Not affected	0	0	0
S1-S3	S1	Minimally affected	<0.5	N/A	0-1
	S2	Somewhat affected			
	S3	Largely affected			
S4	S4	Greatly affected	>0.5	>0	>1

Assumptions:

· Below ground vs. above ground

- Below ground assets (T stations, underpasses) are assumed to be highly sensitive to even low levels of flooding (as measured at their above ground points of entry) because water will flow to and accumulate in the below ground areas of the infrastructure.

· MBTA T Stations and rail lines

- Assumed that third rail will be deactivated/damaged (below ground) and/or the top of rail will be exceeded at >0.5 ft. flooding (above ground), rendering the station temporarily unusable and potentially causing equipment damage.

· Bus Hubs, Bus Routes, Roadways, Bridges (approaches), Intersections, Parking Facilities

- Above 1> ft. flooding would reach vehicle undercarriages, rendering the transportation asset unusable.
- Bridge scour during flooding can compromise structural integrity

Adaptive Capacity: Extent to which the asset will be able to accommodate or adjust to the impact

Score	Description	Criteria
AC2	High	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing transportation services ARE available
AC1	Medium	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover OR 2. Alternative means for obtaining or providing transportation services ARE available
AC0	Low	1. Physical/operational measures NOT in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing transportation services are NOT available

Vulnerability

		Sensitivity: Low → High				
		S0	S1	S2	S3	S4
Adaptive Capacity: Low ↓ High	AC0	V2	V3	V4	V5	V5
	AC1	V1	V1	V2	V3	V4
	AC2	V0	V0	V0	V1	V2

Consequence

	Criteria
High	1. Impacts a large number of people **OR** large area of the city **AND** 2. Impacts other critical assets/systems
Medium	1. Impacts a large number of people **OR** large area of the city **AND** 2. Does not impact other critical assets/systems
Low	1. Does not impact a large number of people **OR** large area of the city **AND** 3. Does not impact other critical assets/systems

Probability

- Heat
  - High: 4-day >90°F heatwave (2030 scenario)
  - Low: 5-day >90°F heatwave with 3 days >100°F (2070 scenario)
- Flooding
  - High: 10 year 24-hour storm (2030 and 2070)
  - Low: 100 year 24-hour storm (2030 and 2070)

Risk

		Probability	
		Low	High
Consequence	High	R3	R4
	Medium	R2	R3
	Low	R1	R2

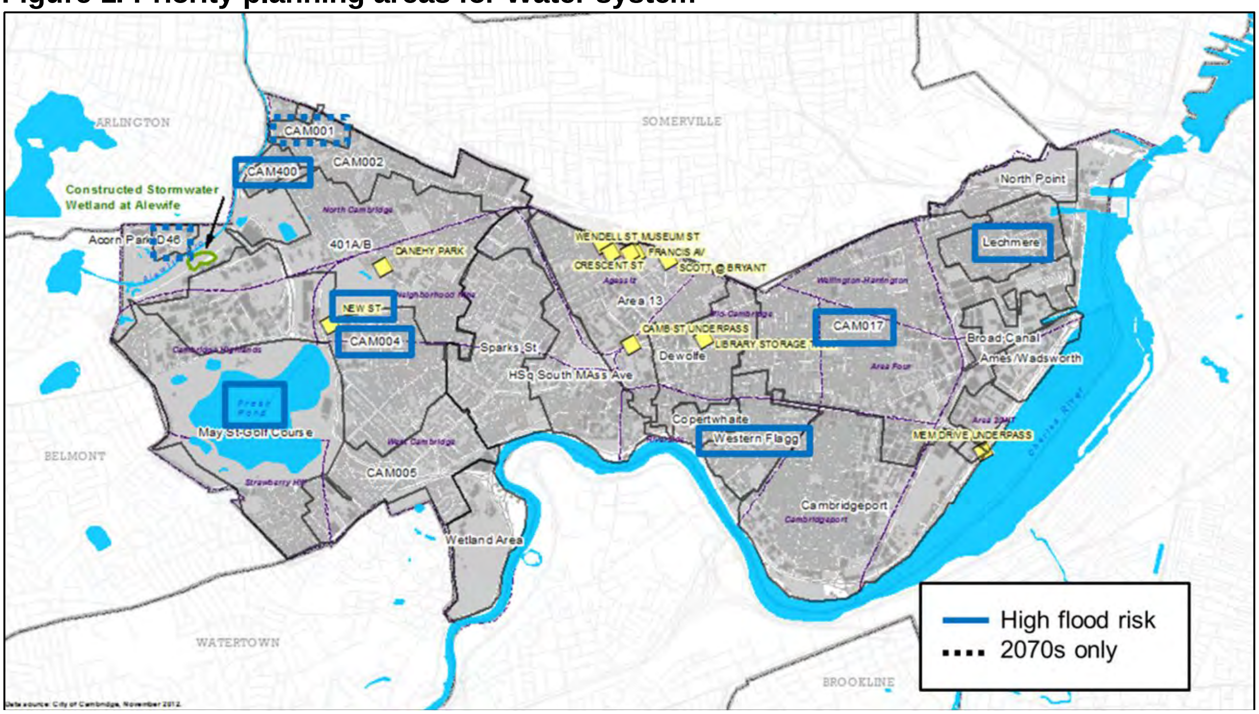
Technical Memorandum: Water / Stormwater

Prepared by Kleinfelder, 11-6-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

The summary of the high-risk priority planning areas for the Water system is presented in Figure 1. There are no identified high risks to the water system being exposed to increased heat. There are however identified high risks of inland flooding scenarios for 2030s and 2070s. Only assets or areas with high risk scores are highlighted (R3 or R4). Those with solid boxes around them were identified as high risks in the inland flooding (blue) in the 2015-2044 (2030s) scenarios, while those surrounded by dashed circles were only identified as high risks in the 2055-2084 (2070s) scenarios. These priority planning areas should be addressed in the development of the City's Climate Change Preparedness Plan.

Figure 1. Priority planning areas for Water system



In the 2030s and 2070s, Water system assets, resources, and stormwater and combined storm-sewer catchment areas in Cambridge are highly vulnerable and high risk from inland flooding.

High priorities, considering potential impacts on critical infrastructure, populations, and public and environmental health include **CAM 004** (Alewife, Separated), **Fresh Pond Reservoir**, and **CAM 017** (Charles, Combined). These areas are most vulnerable and at risk in the 100-year 24 hour storm scenarios of the 2030s and 2070s. However, critical infrastructure impacts are also present in the 10-year storm scenarios due to manhole flooding.

According to the methodology described in Section B, high risks / high priorities for preparedness planning are as follows:

2030s – Inland Flooding – 10-year 24 hour storm scenario
- New Street Pump Station (R3)

2030s – Inland Flooding – 100-year 24 hour storm scenario
- Fresh Pond Reservoir (R3)
- CAM 004 (Alewife, Separated) (R3)
- CAM 017 (Charles, CSO) (R3)
- CAM 400 (Alewife, Separated) (R3)
- Lechmere (Charles, Separated) (R3)
- Western Flagg (Charles, Separated) (R3)

2070s – Inland Flooding – 10-year 24 hour storm scenario
- CAM 001 (Alewife, CSO) (R3)
- D46 (Alewife, Separated) (R3)

2070s – Inland Flooding – 100-year 24 hour storm scenario
- All of the above

B. Summary of Assessment Process and Methods

Selection of Assets

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. Water infrastructure assets and areas were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. Assets were screened to ensure that the vulnerability assessment focused on the most important assets in the system. The final list of assets assessed in this study is the result of iterative review and revision by the project team and stakeholders.

Vulnerability and Risk Scoring

The methods and assumptions for scoring the vulnerability and risk of assets, such as stormwater pump stations, were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

Vulnerability of each asset was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.
- Exposure was assessed based on scenario maps developed for the project (see Attachment 1).
- Sensitivity of assets was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the asset to fail to function (see Attachment 2).
- Adaptive capacity was assessed based on whether assets had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure (see Attachment 2).

One major difference with how this assessment was conducted, in comparison to others, was that the assessment focused on the performance of the associated conveyance system (piped infrastructure) for the stormwater and combined sewer catchment areas corresponding to the key outfalls. Vulnerability assessment and ranking was standardized using maximum flood volume per catchment area, rather than depth of flooding at the outfall locations.

Maximum flood volumes from riverine overbank flooding and flooding from drainage/combined sewer system capacity issues (reported in million gallons MG or acre-feet) were normalized by size of the catchment area to give a standardized unit ranking by area (reported in acre-feet/acre). The maximum flood volume calculations for riverine overbank flooding from the HEC-RAS model and for piped infrastructure flooding from the ICM-2D model were provided by VHB and MWH, respectively on December 5th, 2014.

The use of acre-ft/acre as an indicator of exposure and sensitivity is valuable for ranking the relative performance of different catchment areas and associated conveyance systems. However, it can mask the vulnerability of larger catchments which may have higher overall flood volumes.

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets and areas that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.

- Probability was assessed based on whether assets and areas were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- Consequence was assessed based on the scale of the service disruption caused by an asset's failure (entire city vs. neighborhood vs. locality) and the potential for their failure to cause cascading impacts on other assets and areas within or across systems.

Specific protocols for Water infrastructure were developed to standardize assumptions for scoring assets' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge (see Attachment 2).

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed assets and areas were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 3).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Water infrastructure were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC), and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The latest feedback from a workshop with City and State agency stakeholders on October 6, 2014 and a meeting with TAC members on December 11, 2014, as well as subsequent follow-up has been incorporated. Participants included the City's Water Department and Department of Public Works and the Massachusetts Water Resources Authority and Department of Conservation and Recreation.

Attachments 1-3 and the results reported in this memorandum reflect the latest understanding and assumptions.

Sections C & D below report the heat and inland flooding vulnerability and risk assessment results for Water system assets and areas.

Section E compiles the risk scores for only highly vulnerable assets and areas.

C. Heat Vulnerability and Risk Assessment

Overall, water system assets and areas are not highly vulnerable to heat (as presented in Table1), and consequently no high risks from heat for the water systems have been identified.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 1: Water infrastructure vulnerability and risk from heat
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Heat - 2030		Heat - 2070	
		Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Surface Water Bodies	Charles River	V2		V2	
	Alewife Brook	V2		V2	
Dams	New Charles River Dam	V1		V1	
	Amelia Earhart Dam	not assessed		not assessed	
Drinking Water System	Fresh Pond Reservoir	V0		V0	
	Walter J. Sullivan Water Purification Facility	V0		V0	
Stormwater Pump Stations	New Street Pump Station	V2		V2	
	Cambridge St Underpass pump station	V3		V3	
Combined Sewer/Sanitary Pump Stations	Sewer pump station: Prison Point	V3		V3	
	Sewer pump station: Cottage Farm	V2		V2	
Separated Stormwater Catchment Areas	CAM 400 (Alewife)	no interaction		no interaction	
	D46 (Alewife)	no interaction		no interaction	

Critical Assets		Heat - 2030		Heat - 2070	
Type	Name	Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
and Associated Conveyance Systems	CAM 004 (Alewife)	no interaction		no interaction	
	May Street Golf Course (Alewife)	no interaction		no interaction	
	Sparks St (Charles)	no interaction		no interaction	
	Harvard Sq (Charles)	no interaction		no interaction	
	Area 13 (Charles)	no interaction		no interaction	
	Coperthaite (Charles)	no interaction		no interaction	
	Dewolfe (Charles)	no interaction		no interaction	
	Western Flagg (Charles)	no interaction		no interaction	
	Cambridgeport (Charles)	no interaction		no interaction	
	North Point (Charles)	no interaction		no interaction	
	Lechmere (Charles)	no interaction		no interaction	
	Ames Wadsworth (Charles)	no interaction		no interaction	
	Wetland Area (Charles)	no interaction		no interaction	
Combined Sewer/Sanitary Catchment Areas and Associated Conveyance Systems	CAM 001 (Alewife)	no interaction		no interaction	
	CAM 002 (+ CAM 002a for manhole flooding) (Alewife)	no interaction		no interaction	
	401 A/B (Alewife)	no interaction		no interaction	
	CAM 005 (Charles)	no interaction		no interaction	
	CAM 017 (Charles)	no interaction		no interaction	

D. Inland Flooding Vulnerability and Risk Assessment

In the 2030s and 2070s, stormwater and combined storm-sewer catchment areas in Cambridge are highly vulnerable to inland flooding.

Highly Vulnerable Catchment Areas and Assets

Alewife River Catchment Areas and Assets
High risk (R3) Alewife River catchments areas D46, CAM 001 (a combined sewer system), CAM 400, and CAM 004 are highly vulnerable to riverine flooding and/or manhole flooding. In addition, New Street Pump Station, located in CAM 004, is also highly vulnerable and high risk (R4). The 100-year 24 hour storm scenarios result in the most extensive and highest volumes of flooding in these catchments due to riverine flooding. In these scenarios, Fresh Pond Reservoir is also highly vulnerable and a high risk (R3).

Of these catchment areas, CAM 004 could be of highest concern due to the location of numerous critical, highly vulnerable infrastructure assets within it, including the city's most important electrical facility, its only ambulance company, only commuter rail line, major roads and intersections, an emergency shelter, and New Street Pump Station, among others. It is a relatively large catchment area and therefore only surfaces as a highly vulnerable catchment area in the 100-year 24 hour storm scenarios when large enough volumes of flooding are present to result in a relatively high acre-ft/acre score. However, manhole flooding in the 10-year 24 hour storm scenarios was sufficient to impact critical electrical, ambulance, and roadway assets as well as the New Street Pump Station.

Another key concern for the City, related to Alewife River flooding, is the potential flooding impacts to Fresh Pond Reservoir in the 100-year 24 hour storm scenarios. Fresh Pond is an "Outstanding Resource Water" because it is part of the drinking water supply system for the City of Cambridge. Discharges to Fresh Pond are therefore regulated by water quality standards. In the 100-year storm scenarios, significant untreated discharges could occur once the Pond's elevation exceeds the point at which it no longer becomes isolated from surrounding areas. The area that the Pond could effectively be connected to includes railway and areas zoned for industrial uses, which may contain hazardous materials.

Charles River Catchment Areas and Assets
High risk Charles River catchments areas CAM 017 (a combined sewer system) (R3), and separated catchment areas Lechmere (R3) and Western Flagg (R3) are highly vulnerable to manhole flooding. An important finding of this assessment is that the Charles River Dam is capable of largely preventing riverine flooding in Cambridge along the Charles River. As would be expected, the higher the rainfall associated with the storm scenario, the more extensive and higher depth the resulting manhole flooding is.

Flooding in CAM 017 could be of highest concern due a number of factors. It is a combined sewer system, so flooding could pose a public health and environmental risk. It is also a large, high-density area, so flooding could result in significant impacts to buildings, including sewer back-ups into homes and businesses without backflow controls. Importantly, it also contains a significant number of critical, highly vulnerable infrastructure assets within it, including the City's Police Department headquarters (also the City's Emergency Communications Center), Public Health Department offices (also a critical health center), telecommunications company offices, a major electrical substation, and major roadways. Like CAM 004, it is a large catchment area and therefore is only assessed as highly vulnerable in the 100-year 24 hour storm scenarios when its acre-ft/acre exposure is high enough to overcome the bias against its larger size. However, it has among the highest overall flood volumes in Cambridge. Manhole flooding in the 10-year 24 hour storm scenarios was sufficient to impact several critical facilities.

Tables 2a and 2b indentify other assets and catchment areas that are highly vulnerable to inland flooding scenarios, based on their relatively high acre-ft/acre exposure, sensitivity, and their adaptive capacities.

Adaptive Capacity

Adaptive capacity of stormwater and combined sewer systems was assumed to be highly limited, given that all available stormwater management capabilities (e.g., storage, pumping, dam operations) were already taken into account in the flood modeling scenarios. The potential to build adaptive capacity may be greater in less developed catchment areas of the Alewife River, where additional storage capacity could be built more easily. However, some of these areas are expected to develop more rapidly in the near to medium term future.

The Water Supply and Distribution system was assessed as having a relatively high adaptive capacity due to back-up supply systems linked to regional MWRA infrastructure.

Vulnerability from Cascading Impacts / Regional Issues

There are upstream failure points in the water supply and distribution system and downstream failure points in the waste water system that could not be quantitatively assessed due to their locations outside of the flood model boundaries (i.e. outside of Cambridge). These include Hobbes Brook and Stony Brook Reservoirs and their dams; MWRA's Delauri, Alewife, and Ward Street pump stations; and the Deer Island Waste Water Treatment Plant. Impacts to these assets and resources could negatively affect Cambridge, including by eroding redundancy in its systems.

The vulnerability of such assets could not be directly assessed in the same way as other assets in this study because flood and heat modeling and mapping were limited to Cambridge. However, this could be an area for more regional scale investment in vulnerability assessment.

In addition, the accuracy of the model results for stormwater and combined sewer flooding depend upon the operation of the Amelia Earhart Dam on the Mystic River as assumed in the modeled scenarios. Assumptions related to how the Amelia Earhart Dam and Charles River Dam operate, and how they influence modeling results are documented in the Climate Projections – Scenario Development Report.

Due to the vulnerabilities of energy infrastructure in Cambridge to flooding, identified in the assessment of the Energy system, some Water system facilities in Cambridge such as pump stations and the City's water treatment plant may be forced to operate without grid electricity. Most of these facilities have emergency generators, so this will only be a major issue if electricity is unavailable for an extended period of time.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 2a: Water infrastructure vulnerability and risk from inland flooding by 2030s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	**Name**	**Vulnerability**	**Risk**	**Vulnerability**	**Risk**
Surface Water Bodies	Charles River	V1		V1	
	Alewife Brook	V1		V3	
Dams	New Charles River Dam	V1		V1	
	Amelia Earhart Dam	V1		V2	
Drinking Water System	Fresh Pond Reservoir	V0		V4	R3
	Walter J. Sullivan Water Purification Facility	V0		V1	
Stormwater Pump Stations	New Street Pump Station	V5	R3	V5	R2
	Cambridge St Underpass pump station	V2		V2	
Combined Sewer/Sanitary Pump Stations	Sewer pump station: Prison Point	V2		V2	
	Sewer pump station: Cottage Farm	V2		V3	
Separated Stormwater Catchment Areas and Associated Conveyance Systems	CAM 400 (Alewife)	V3		V5	R3
	D46 (Alewife)	V5	R2	V5	R2
	CAM 004 (Alewife)	V3		V5	R3
	May Street Golf Course (Alewife)	V3		V5	R1
	Sparks St (Charles)	V3		V3	
	Harvard Sq (Charles)	V3		V3	
	Area 13 (Charles)	V3		V4	R2
	Coperthaite (Charles)	V3		V4	R2
	Dewolfe (Charles)	V2		V3	
	Western Flagg (Charles)	V2		V4	R3
	Cambridgeport (Charles)	V3		V4	R2
	North Point (Charles)	V3		V3	
	Lechmere (Charles)	V3		V4	R3

Critical Assets		Flooding - 2030			
Type	Name	10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
		Vulnerability	Risk	Vulnerability	Risk
	Ames Wadsworth (Charles)	V3		V3	
	Wetland Area (Charles)	V2		V3	
Combined Sewer/Sanitary Catchment Areas and Associated Conveyance Systems	CAM 001 (Alewife)	V3		V5	R2
	CAM 002 (+ CAM 002a for manhole flooding) (Alewife)	V3		V3	
	401 A/B (Alewife)	V3		V4	R2
	CAM 005 (Charles)	V3		V4	R2
	CAM 017 (Charles)	V3		V5	R3

Table 2b: Water Infrastructure vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 year 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Surface Water Bodies	Charles River	V1		V1	
	Alewife Brook	V1		V3	
Dams	New Charles River Dam	V1		V1	
	Amelia Earhart Dam	V1		V2	
Drinking Water System	Fresh Pond Reservoir	V0		V4	R3
	Walter J. Sullivan Water Purification Facility	V0		V1	
Stormwater Pump Stations	New Street Pump Station	V5	R3	V5	R2
	Cambridge St Underpass pump station	V2		V2	
Combined Sewer/Sanitary Pump Stations	Sewer pump station: Prison Point	V2		V2	
	Sewer pump station: Cottage Farm	V2		V3	
Separated Stormwater Catchment Areas and Associated Conveyance Systems	CAM 400 (Alewife)	V3		V5	R3
	D46 (Alewife)	V5	R3	V5	R2
	CAM 004 (Alewife)	V3		V5	R3
	May Street Golf Course (Alewife)	V3		V5	R1
	Sparks St (Charles)	V3		V4	R1
	Harvard Sq (Charles)	V2		V3	
	Area 13 (Charles)	V3		V4	R2
	Coperthaite (Charles)	V3		V4	R2
	Dewolfe (Charles)	V3		V3	
	Western Flagg (Charles)	V3		V4	R3
	Cambridgeport (Charles)	V3		V5	R2

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 year 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	North Point (Charles)	V3		V3	
	Lechmere (Charles)	V3		V4	R3
	Ames Wadsworth (Charles)	V3		V3	
	Wetland Area (Charles)	V2		V3	
Combined Sewer/Sanitary Catchment Areas and Associated Conveyance Systems	CAM 001 (Alewife)	V4	R3	V5	R2
	CAM 002 (+ CAM 002a for manhole flooding) (Alewife)	V3		V4	R2
	401 A/B (Alewife)	V3		V4	R2
	CAM 005 (Charles)	V3		V4	R2
	CAM 017 (Charles)	V3		V5	R3

E. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the asset or area failing as a result. Only assets or areas that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 3 below. Assets or areas with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

As no Water system assets or areas were assessed as being high risk, no summary table for heat risk is included.

In Table 3, the "High Probability" column indicates which assets, resources, or catchment areas are highly vulnerable and their corresponding risk scores under the 10-year 24 hour storm scenarios of the 2030s and 2070s. The "Low Probability" column contains the same information but corresponds with the 100-year 24 hour storm scenarios of the 2030s and 2070s. Assets with "(2070)" next to their names were assessed to be highly vulnerable in the 2070s scenario, but not the 2030s.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 3: Risk ranking summary for flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**

Consequence	**High**	**Score R3**
		• Fresh Pond Reservoir
		• Separated Catchment Areas and Conveyance:
		  • CAM 400 (Alewife)
		  • CAM 004 (Alewife)
		  • Western Flagg (Charles)
		  • Lechmere (Charles)
		• Combined Sewer/Sanitary Catchment Areas and Conveyance:
		  • CAM 017 (Charles)
			Score R4

	Medium	**Score R2**
		• New St Pump Station
		• Separated Catchment Areas and Conveyance:
		  • D46 (Alewife)
		  • Area 13 (Charles)
		  • Coperthaite (Charles)
		  • Cambridgeport (Charles)
		• Combined Sewer/Sanitary Catchment Areas and Conveyance:
		  • CAM 001 (Alewife)
		  • 401 A/B (Alewife)
		  • CAM 005 (Charles)
		  • CAM 002/a (Alewife) (2070)
			Score R3
			• New St Pump Station
			• Separated Catchment Area and Conveyance:
			  • D46 (Alewife) (2070)
			• Combined Sewer/Sanitary Catchment Areas and Conveyance:
			  • CAM 001 (Alewife) (2070)

	Low	**Score R1**
		• Separated Catchment Area and Conveyance:
		  • May Street Golf Course (Alewife)
		  • Sparks St (Charles) (2070)
			Score R2
			• Separated Catchment Area and Conveyance:
			  • D46 (Alewife)

*(2070) indicates that an asset is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

Attachment 1 – Scoring Protocol for Water Infrastructure V&R Assessment

Attachment 1- Water / Stormwater: Vulnerability & Risk Assessment Scoring Protocol

Sensitivity to Heat: Extent to which the asset's functionality will be affected by high temperatures if it is exposed to this scenario

Critical Threshold	Score	Description	Direct Impact - based on impacts to the functionality of the system (°F)
S0	S0	Not affected	<90
S1-S2	S1	Minimally affected	90-110
	S2	Somewhat affected	
S3-S4	S3	Largely affected	>110
	S4	Greatly affected	

Assumptions:

- Pump Stations and Water Treatment facilities require electricity for operation of key equipment. Vulnerabilities to the energy system will affect their functioning.
- Increase in temperature can affect water quality in the Charles River, Alewife Brook and Fresh Pond. Water quality impacts are particularly more pronounced during summer months, with reduced dissolved oxygen concentrations. Also, higher temperatures cause more thermal stratification in water bodies, which results in lower mixing of dissolved oxygen in summer.
- High temperature impacts on the Charles River, Alewife Brook and Fresh Pond from heat wave scenarios for both 2030 and 2070 have been analyzed qualitatively. Since the temperature increase on the water bodies (based on LandSat data) is not significant from heat island effects in the City corresponding to the two scenarios, it is assumed that water quality parameters, such as dissolved oxygen, nutrient (e.g. nitrogen, phosphorous) concentrations will not be affected under these scenarios. However, higher water temperatures on surface water bodies from more intense and longer duration heat wave events may cause water quality impairment (e.g. DO concentration falls below the designated water quality standard for Charles River). Under such scenarios, these surface water bodies will be assigned a higher vulnerability score.
- There are no known high temperature impacts under the 2030 and 2070 heat wave scenarios to the drainage and combined sewer catchment areas and their associated conveyance system. Hence these areas have not been ranked for the heat scenarios.

Sensitivity to Flooding for Point Assets: Extent to which the asset's functionality will be affected by flooding if it is exposed to in this scenario. The sensitivity scores for the water treatment facility in Cambridge and at the Fresh Pond Reservoir have been analyzed by considering the critical elevations at the water treatment plant and operating levels of Fresh Pond.

- The normal operating level of Fresh Pond is 16 ft CCB (4.35 ft NAVD88), and the maximum operating level of Fresh Pond 17 ft CCB (5.35 ft NAVD88).
- The Stony Brook flow is fed to the plant through a chamber with a weir to avoid flooding the plant, and the weir height is 18 ft CCB (6.35 ft NAVD88). However, if Fresh Pond elevation is above 18 ft CCB (6.35 ft NAVD88) it cannot be isolated from the Stony brook flow.
- The first floor slab of the treatment plant is at 24 ft CCB (12.35 ft NAVD88). Flooding above this level will have the potential of flooding the treatment plant. However, much of the process equipment, such as filter controls, compressors, DAF recirculation pumps, etc. are located below elevation 24 ft (12.35 ft NAVD88).

The sensitivity scores for the pump stations and the dams have been ranked using the flood depth table below include the.

Critical Threshold	Score	Description	Direct Impact - based on location of critical equipment		Indirect Impact - based on dependencies
			Exterior (ft)	**Inside Building - direct flood contact (ft)**	**Access - local roads (ft)**
S0	S0	Not affected	0	0	<0.5
S1-S3	S1	Minimally affected	<0.5	0-1	>0.5
	S2	Somewhat affected			
	S3	Largely affected			
S4	S4	Greatly affected	>0.5	>1	NA

Assumptions:

- Exterior
  - Assumed that equipment is raised 0.5 ft above ground. Flooding >0.5 ft will lead to critical equipment failure.
- Inside building
  - Assumed that equipment is raised 1 ft above ground (building first floor 0.5 ft above ground, equipment raised 0.5 ft above first floor). Flooding >1 ft in direct contact with the building will lead to critical equipment failure.
- Access
  - Access must be maintained for full functionality. Access flooding impairs functionality when >0.5 ft. However access impacts alone are insufficient to "greatly affect" functionality.

Sensitivity to Flooding for Catchment Areas: Extent to which the asset's functionality will be affected by flooding if it is exposed to in the scenario

Critical Threshold	Score	Description	Flood volume normalized by catchment area (Acre-feet per Acre)
S0	S0	Not affected	0
S1-S3	S1	Minimally affected	<0.05
	S2	Somewhat affected	0.05 to 0.15
	S3	Largely affected	0.15 to 0.35
S4	S4	Greatly affected	>0.35

Assumptions:

- Flood volumes have been reported for a total of 15 drainage areas and 5 combined sewer areas. Please refer to the map in the package called "FloodReportingAreas_122313.pdf" for a delineation of these areas.
- Flooding outside of these reporting areas (mostly river flooding) are not included in the reported volumes. All flood volumes (nuisance and damaging) are accounted for in the reported volumes.
- Used flood volumes for each catchment area corresponding to maximum flood extent and depth (maximum of manhole flooding and riverine flooding) recorded at each grid point throughout the reporting period irrespective of timing.
- Used relative ranking of flood volume per acre to determine the areas that are most impacted in comparison to the others.
- There is no direct physical basis for the flood volume per area thresholds (0.05 acre-ft/acre, 0.15 acre-ft/acre, 0.35 acre-ft/acre). However, the resulting sensitivity ratings are informed by knowledge of areas that are more affected by flooding than others. The higher sensitivities match historically flood-prone areas.

Adaptive Capacity: Extent to which the asset will be able to accommodate or adjust to the impact

Score	Description	Criteria
AC2	High	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing water supply, treatment, and wastewater/stormwater conveyance services ARE available
AC1	Medium	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover OR 2. Alternative means for obtaining or providing water supply, treatment, and wastewater/stormwater conveyance services ARE available
AC0	Low	1. Physical/operational measures NOT in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing water supply, treatment, and wastewater/stormwater conveyance services are NOT available

Vulnerability

		Sensitivity: Low → High				
		S0	S1	S2	S3	S4
Adaptive Capacity: Low ↓ High	AC0	V2	V3	V4	V5	V5
	AC1	V1	V1	V2	V3	V4
	AC2	V0	V0	V0	V1	V2

The assets that are ranked with vulnerability scores V4 or V5 are further assessed for risk scores by analyzing the consequence and probability of impact under a given climate change scenario.

Consequence

	Criteria
High	1. Impacts a large number of people **OR** large area of the city **AND** 2. Impacts other critical assets/systems
Medium	1. Impacts a large number of people **OR** large area of the city **AND** 2. Does not impact other critical assets/systems
Low	1. Does not impact a large number of people **OR** large area of the city **AND** 3. Does not impact other critical assets/systems

Note: The size of the population and area impacted were estimated qualitatively based on background knowledge of the City.

Probability

- Heat
  - High: 4-day >90°F heatwave (2030 scenario)
  - Low: 5-day >90°F heatwave with 3 days >100°F (2070 scenario)
- Flooding
  - High: 10 year 24-hour storm (2030 and 2070)
  - Low: 100 year 24-hour storm (2030 and 2070)

Risk

		Probability	
		Low	High
Consequence	High	R3	R4
	Medium	R2	R3
	Low	R1	R2

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA)

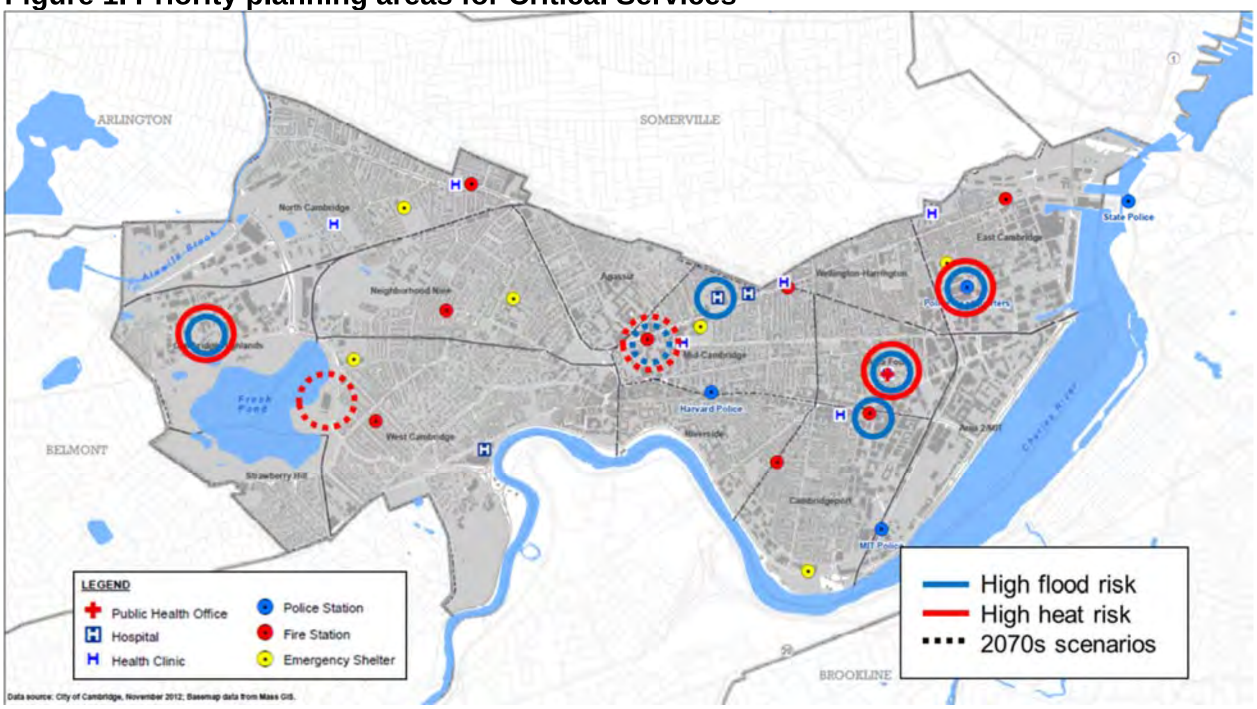
Technical Memorandum: Critical Services

Prepared by Kleinfelder, 2-23-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

The summary of the high-risk priority planning areas for Critical Services infrastructure is presented in Figure 1. Only assets with high risk scores are highlighted (R3 or R4). Those with solid circles around them were identified as high risks for heat (red) or inland flooding (blue) in the 2015-2044 (2030s) scenarios, while those surrounded by dashed circles were only identified as high risks in the 2055-2084 (2070s) scenarios. These priority planning areas should be addressed in the development of the City's Climate Change Preparedness Plan.

Figure 1. Priority planning areas for Critical Services



Of most concern are the following three assets, which had the highest risk scores (R4) in both Heat and Inland Flooding in the 2030s scenarios:

- Police Department headquarters
- Public Health Department office
- Professional Ambulance Services

Other high risks / high priorities for preparedness planning are as follows:

Inland Flooding – 2030s

- Youville Hospital (R3)
- Fire Company 2 (R3)
- Windsor St Health Center (R3)

<u>Heat and Inland Flooding – 2070s</u>

- Fire Department headquarters (R3)

<u>Heat – 2070s</u>

- Water Department building / City's Emergency Operations Center (R3)

B. Summary of Assessment Process and Methods

Selection of Assets

Critical Services infrastructure in Cambridge, including police stations, fire stations, emergency operations centers, emergency shelters, hospitals, health centers, and municipal offices were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. Assets were screened to ensure that the vulnerability assessment focused on the most important assets in the system. The final list of assets assessed in this study is the result of iterative review and revision by the project team and stakeholders.

Vulnerability and Risk Scoring

The methods and assumptions for scoring the vulnerability and risk of assets were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

<u>Vulnerability</u> of each asset was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.

- <u>Exposure</u> was assessed based on scenario maps developed for the project (see Attachment 1).
- <u>Sensitivity</u> of assets was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the asset to fail to function (see Attachment 2).
- <u>Adaptive capacity</u> was assessed based on whether assets had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure (see Attachment 2).

<u>Risk</u> is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.

- <u>Probability</u> was assessed based on whether assets were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- <u>Consequence</u> was assessed based on the scale of the service disruption caused by an asset's failure (entire city vs. neighborhood vs. locality) and the potential for their failure to cause cascading impacts on other assets within or across systems.

Specific protocols for Critical Services were developed to standardize assumptions for scoring assets' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge (see Attachment 2).

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed assets were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 3).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Critical Services were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC), and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The latest feedback from a workshop with City stakeholders on October 6, 2014, and a meeting with TAC members on December 11, 2014, as well as subsequent follow-up has been incorporated. Participants included the City's Fire Department, Public Health Department, Community Development Department, Department of Public Works, and Cambridge Health Alliance, among others.

Attachments 1-3 and the results reported in this memorandum reflect the latest understanding and assumptions.

Sections C & D below report the heat and inland flooding vulnerability and risk assessment results for Critical Services infrastructure.

Section E compiles the risk scores for only highly vulnerable assets.

C. Heat Vulnerability and Risk Assessment

Critical Services in Cambridge are vulnerable to heat and may pose a risk from failure during extreme heat events in the future (Table 1). Asset failures would likely be due to a combination of system-wide stress caused by increased demand for services, and asset-level exposure to extreme heat which could impact occupant health and safety as well as damage heat-sensitive equipment.

Highly Vulnerable Assets

Several Critical Services assets are highly vulnerable to heat under the 2030s scenario. Of these, the assets that pose the highest risk are the Police Department headquarters, Public Health Department office, and Professional Ambulance Services. These assets serve the entire city, providing system-wide and/or cross-system services. Therefore their consequences of failure would be high. These facilities are also highly vulnerable to flooding, as described in Section D.

The Fire Department headquarters and the Water Department building, which also serves as the City's Emergency Operations Center, have similarly high consequences of failure. However, they are less exposed to heat island effects and therefore only highly vulnerable under the 2070s scenario.

One public school, designated as an emergency shelter, was also identified as highly vulnerable: Graham & Parks in the 2070s. However, due to its limited potential to cause cascading impacts on other assets within or across systems, its consequence of failure (and therefore risk) was not as high as other assets.

Adaptive Capacity

Other Critical Services facilities, including fire stations, emergency shelters, hospitals, and healthcare centers, were identified as being highly exposed and sensitive to heat. However, they were not considered highly vulnerable due to their higher adaptive capacity. Some have technological and operational systems in place to counteract the external stress of extreme heat.

Key technologies include air conditioning and emergency generators. These assets may also have system-wide redundancy, such that if one facility is not able to operate, another facility can be used to substitute for some level of lost service.

The city's hospitals, for example, are fully air conditioned and have redundant power, fuel, phone, and life sustaining electronic systems. Their emergency generators are generally capable of supporting the following systems and equipment during an electrical power outage:

- Critical lifesaving systems (suction devices, gases, telemetry systems)
- Red outlets (cardiac monitors, ventilators, surgical equipment, blood & lab systems, etc.)
- Fire suppression systems, emergency lighting, doors
- Designated lights in the building, or HVAC systems

Vulnerability from Cascading Impacts

In general, heat will lead to surges in demand and increase system-wide stress on Critical Services. However, cascading impacts from failures in other systems are not likely a key factor in the vulnerability of Critical Services to heat.

In the vulnerability assessment of Cambridge's water system, it was determined that the city does not face a high risk of water supply failure due to heat (or flooding). Hospitals, which require water for certain functions, are required to maintain a five-day water supply (one gallon of water per person per day). Considering these factors, hospitals were not considered highly vulnerable to heat due to cascading impacts.

It was also determined that Cambridge's critical electrical infrastructure is not highly vulnerable to heat, due to high adaptive capacity. In addition, many (though not most) Critical Services facilities have emergency generators. However, it is worth reporting that at least four critical health centers that are highly exposed and sensitive to heat lack emergency generators. In the event of a large-scale electrical outage during an extreme heat event (a low likelihood scenario, based on energy system vulnerability and risk assessment results), those without emergency generators would not be able to power their air conditioning systems and could temporarily close or change hours of operations.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 1: Heat vulnerability and risk of the Critical Services system
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Type	Name	Heat - 2030		Heat - 2070	
		Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
Emergency Operations Center	Water Department	V1-V2		V3-V4	R3
Police Stations	Police Headquarters	V3-V4	R4	V3-V4	R3
	MIT Police Station	V1-V2		V1-V2	
	Harvard Police Station	V1-V2		V1-V2	
Fire Stations	Fire Headquarters	V1-V2		V3-V4	R3
	Fire Company 2	V1-V2		V1-V2	
	Fire Company 3	V0		V1-V2	
	Fire Company 4	V1-V2		V1-V2	
	Fire Company 5	V1-V2		V1-V2	
	Fire Company 6	V0		V1-V2	
	Fire Company 8	V0		V1-V2	
	Fire Company 9	V0		V0	
Emergency Shelters	Kennedy / Longfellow School	V3-V4	R3	V3-V4	R2
	Peabody School	V3-V4	R3	V3-V4	R2
	Tobin School	V1-V2		V3-V4	R2
	Graham & Parks School	V1-V2		V3-V4	R2
	Cambridge Rindge and Latin	V1-V2		V1-V2	
	Morse School	V1-V2		V3-V4	R2
Hospitals	Cambridge Hospital	V1-V2		V1-V2	
	Youville Hospital	V0		V1-V2	
	Mount Auburn Hospital	V1-V2		V1-V2	

Type	Name	Heat - 2030		Heat - 2070	
		Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
	Sancta Maria Nursing Facility	V0		V1-V2	
Health Centers	Cambridge Family Health	V1-V2		V1-V2	
	Cambridge Family Health North	V1-V2		V1-V2	
	North Cambridge Health Center	V0		V1-V2	
	Senior Health Center	V1-V2		V1-V2	
	Windsor Street Health Center	V1-V2		V1-V2	
	Teen Health Center at Cambridge Rindge and Latin	V1-V2		V1-V2	
	East Cambridge Health Center	V1-V2		V1-V2	
Ambulance Services	Professional Ambulance Services	V3-V4	R4	V3-V4	R3
Municipal Offices	Public Health Department	V3-V4	R4	V3-V4	R3

D. Inland Flooding Vulnerability and Risk Assessment

Critical service facilities in Cambridge are also vulnerable to flooding and may pose a risk from failure during future extreme rainfall events (Tables 2a and 2b). Asset failures would likely be due to direct exposure to localized flooding. Based on the results of this assessment, flooding could also impact lifeline systems such as energy, transportation, and telecommunications without which Critical Services facilities may not be able to properly function.

Highly Vulnerable Assets

Three Critical Services facilities are highly vulnerable to flooding in the 10-year 24 hour storm scenarios for the 2030s and 2070s: Police Department headquarters, Public Health Department office (building also houses the Windsor Street Health Center), and Professional Ambulance Services. These assets serve the entire city, providing system-wide and/or cross-system services. Therefore the consequences of their failure would be high.

The Fire Department headquarters, Fire Company 2, and Youville Hospital have similarly high consequences of failure. However, they are only highly vulnerable under 100-year 24 hour storm scenarios. Fire Department headquarters is only highly vulnerable in the 2070s scenario. The difference between the 2030s and 2070s scenarios is 1.5 inches of rainfall.

Public schools designated as emergency shelters were also identified as highly vulnerable in the 100-year 24 hour storm scenarios: Tobin in the 2030s; Kennedy/Longfellow and Peabody in the 2070s. However, due to their limited potential to cause cascading impacts on other assets within or across systems, their consequences of failure (and therefore risk) were not as high as other assets.

Adaptive Capacity

As informed by this assessment, the understanding is that Critical Services have largely not been designed or adapted to flooding. This factor contributed to the low adaptive capacity and high vulnerability of exposed assets.

Vulnerability from Cascading Impacts

Energy, transportation, and telecommunications infrastructure have been identified as being highly vulnerable and high risk from inland flooding. The functioning of Critical Services facilities, some of which have not been identified as being highly vulnerable or high risk, could be impacted by failure of any of the three systems listed above.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 2a: Critical Services vulnerability and risk from inland flooding by 2030s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Type	Name	Flooding – 2030s			
		10 yr 24-hr (5.6 in.)		100 year 24-hr (10.2 in.)	
		Vulnerability	Risk	Vulnerability	Risk
Emergency Operations Center	Water Department	V3		V3	
Police Stations	Police Headquarters	V3-V5	R4	V5	R3
	MIT Police Station	V1-V3		V1-V3	
	Harvard Police Station	V1		V1	
Fire Stations	Fire Headquarters	V2		V2	
	Fire Company 2	V1-V3		V4	R3
	Fire Company 3	V1		V1	
	Fire Company 4	V1		V1-V3	
	Fire Company 5	V1-V3		V1-V3	
	Fire Company 6	V1		V1-V3	
	Fire Company 8	V1-V3		V1-V3	
	Fire Company 9	V1		V1	
Emergency Shelters	Kennedy / Longfellow School	V1-V3		V1-V3	
	Peabody School	V1		V1-V3	
	Tobin School	V1-V3		V4	R2
	Graham & Parks School	V1		V1	
	Cambridge Rindge and Latin	V1		V1-V3	
	Morse School	V1-V3		V1-V3	
Hospitals	Cambridge Hospital	V1		V1-V3	
	Youville Hospital	V1		V4	R3
	Mount Auburn Hospital	V1		V1-V3	

Type	Name	Flooding – 2030s			
		10 yr 24-hr (5.6 in.)		100 year 24-hr (10.2 in.)	
		Vulnerability	Risk	Vulnerability	Risk
	Sancta Maria Nursing Facility	V1		V1	
Health Centers	Cambridge Family Health	V1		V1-V3	
	Cambridge Family Health North	V1		V1-V3	
	North Cambridge Health Center	V1		V1-V3	
	Senior Health Center	V1		V1-V3	
	Windsor Street Health Center	V4	R3	V4	R2
	Teen Health Center at Cambridge Rindge and Latin	V1		V1-V3	
	East Cambridge Health Center	V1		V1-V3	
Ambulance Services	Professional Ambulance Services	V5	R4	V5	R3
Municipal Offices	Public Health Department	V5	R4	V5	R3

Table 2b: Critical Services vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Type	Name	Flooding – 2070s			
		10 yr 24-hr (6.4 in.)		100 year 24-hr (11.7 in.)	
		Vulnerability	Risk	Vulnerability	Risk
Emergency Operations Center	Water Department	V3		V3	
Police Stations	Police Headquarters	V3-V5	R4	V5	R3
	MIT Police Station	V1-V3		V1-V3	
	Harvard Police Station	V1		V1	
Fire Stations	Fire Headquarters	V2		V3-V5	R3
	Fire Company 2	V1-V3		V4	R3
	Fire Company 3	V1		V1	
	Fire Company 4	V1		V1-V3	
	Fire Company 5	V1-V3		V1-V3	
	Fire Company 6	V1-V3		V1-V3	
	Fire Company 8	V1-V3		V1-V3	
	Fire Company 9	V1		V1	
Emergency Shelters	Kennedy / Longfellow School	V1-V2		V1-V2	
	Peabody School	V1-V2		V1-V2	
	Tobin School	V0		V1-V2	
	Graham & Parks School	V1-V2		V3-V4	R2
	Cambridge Rindge and Latin	V1-V2		V1-V2	
	Morse School	V0		V1-V2	
Hospitals	Cambridge Hospital	V1		V1-V3	
	Youville Hospital	V1		V4	R3
	Mount Auburn Hospital	V1		V1-V3	
	Sancta Maria Nursing Facility	V1		V1	

Type	Name	Flooding – 2070s			
		10 yr 24-hr (6.4 in.)		100 year 24-hr (11.7 in.)	
		Vulnerability	Risk	Vulnerability	Risk
Health Centers	Cambridge Family Health	V1-V3		V1-V3	
	Cambridge Family Health North	V1-V3		V1-V3	
	North Cambridge Health Center	V1-V3		V1-V3	
	Senior Health Center	V1		V1-V3	
	Windsor Street Health Center	V4	R3	V4	R2
	Teen Health Center at Cambridge Rindge and Latin	V1		V1-V3	
	East Cambridge Health Center	V1-V3		V1-V3	
Ambulance Services	Professional Ambulance Services	V3-V5	R4	V5	R3
Municipal Offices	Public Health Department	V5	R4	V5	R3

E. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 3a and 3b below. Assets with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 3a: Risk ranking summary for heat
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	Score R3 • Water Department (Emergency Operations Center) • Public Health Department • Professional Ambulance Services • Police Headquarters • Fire Headquarters	Score R4 • Public Health Department • Professional Ambulance Services • Police Headquarters
	Medium	Score R2 • Graham & Parks School	Score R3
	Low	Score R1	Score R2

Table 3b: Risk ranking summary for inland flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	Score R3 • Youville Hospital • Public Health Department • Professional Ambulance Services • Police Headquarters • Fire Company 2 • Fire Headquarters (2070)	Score R4 • Public Health Department • Police Headquarters • Professional Ambulance Services
	Medium	Score R2 • Windsor Street Health Center • Tobin School • Morse School (2070) • Kennedy / Longfellow School (2070)	Score R3 • Windsor Street Health Center
	Low	Score R1	Score R2

*(2070) indicates that an asset is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

Attachment 1 – Scoring Protocol for Critical Services V&R Assessment

Attachment 1- Critical Services: Vulnerability & Risk Assessment – Scoring Protocol

Sensitivity to Heat: Extent to which the asset's functionality will be affected by high temperatures it is exposed to in the scenario

Threshold	Score	Description		Direct Impact - based on level of demand, stress on systems, and occupants (°F)
S0	S0	Not affected	Equipment failures, occupant health impacts, increased demand for services unlikely	<90
S1-S2	S1	Minimally affected	Equipment failures, occupant health impacts, increased demand for services possible	90-100
	S2	Somewhat affected		
S3-S4	S3	Largely affected	Equipment failures, occupant health impacts, high demand for services likely	>100
	S4	Greatly affected		

Assumptions:

- General
  - The extent to which a critical service infrastructure is functionally impacted depends on equipment, operational, and human aspects.
- Equipment impact
  - Electrical transformers and transmission/distribution line connections will experience accelerated degradation under higher local heat conditions, raising the risk of equipment failure during the event and over time with cumulative exposure.
  - It is assumed that there will generally be increased demand for energy services especially electricity and chilled air/water during the scenario, putting stress on building systems and raising the risks of component failures and fires.
- Operational impact
  - Generally it is assumed that increased heat will result in increased demand for fire, rescue, law enforcement, and health related services. Surge increases in demand for services are assumed to negatively impact operational functioning.
- Human impact
  - Critical service buildings such as hospitals, health centers, shelters, and municipal buildings are high occupancy structures. Higher exposure to heat is assumed to negatively impact their occupancy functions.

Sensitivity to Flooding: Extent to which the asset's functionality will be affected by flooding it is exposed to in the scenario

Threshold	Score	Description	Direct Impact - based on location of critical equipment	Indirect Impact - based on dependencies	
			Inside Building - direct flood contact (ft)	Access - local roads (ft)	Energy*
S0	S0	Not affected	0	<0.5	If upstream energy system is V1-V3
S1-S3	S1	Minimally affected	0-1	0.5-1.0	If upstream energy system is V4-V5
	S2	Somewhat affected			
	S3	Largely affected			
S4	S4	Greatly affected	>1 (or above basement opening heights)	>1.0 (w/ no alternative routes	NA

Assumptions:

- Inside building
  - Assumed that equipment is raised 1 ft above the adjacent ground (building first floor 0.5 ft above ground, equipment raised 0.5 ft above first floor). Flooding >1 ft in direct contact with the building will lead to critical equipment failure.
  - If the building has a basement, it is assumed that critical equipment is located in the basement. If flooding exceeds the elevation of openings to the basement, if visually identified, it is assumed that the basement will flood and that critical equipment will be non-functional as a result.
- Access
  - Access must be maintained for full functionality. Access flooding impairs functionality when >0.5 ft. According to key stakeholders from Cambridge Fire Department, when access flooding >1 ft on all available routes in/out of a critical facility, the functionality of the asset is greatly affected (e.g., police/fire/ambulance cannot respond to an emergency).
- Energy
  - Electricity is needed for critical functions of police and fire stations, emergency shelters, hospitals, health centers, and municipal buildings. If power loss is expected, the facility will not fully function.

- Indirect energy impacts on critical services were not assessed, since NSTAR data regarding power distribution to critical services was confidential for public safety.
- Redundancy in terms of emergency generation will be accounted for in Adaptive Capacity.

Adaptive Capacity: Extent to which the asset will be able to accommodate or adjust to the impact

Score	Description	Criteria
AC2	High	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing the emergency services ARE available
AC1	Medium	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover OR 2. Alternative means for obtaining or providing the emergency services ARE available
AC0	Low	1. Physical/operational measures NOT in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing the emergency services are NOT available

Vulnerability

		Sensitivity: Low → High				
		S0	S1	S2	S3	S4
Adaptive Capacity: Low	AC0	V2	V3	V4	V5	V5
	AC1	V1	V1	V2	V3	V4

↓ High	AC2	V0	V0	V0	V1	V2

Consequence

	Criteria
High	1. Impacts a large number of people **OR** large area of the city **AND** 2. Impacts other critical assets/systems
Medium	1. Impacts a large number of people **OR** large area of the city **AND** 2. Does not impact other critical assets/systems
Low	1. Does not impact a large number of people **OR** large area of the city **AND** 3. Does not impact other critical assets/systems

Probability

- Heat
  - High: 4-day >90°F heatwave (2030 scenario)
  - Low: 5-day >90°F heatwave with 3 days >100°F (2070 scenario)
- Flooding
  - High: 10 year 24-hour storm (2030 and 2070)
  - Low: 100 year 24-hour storm (2030 and 2070)

Risk

		Probability	
		Low	High
Consequence	High	R3	R4
	Medium	R2	R3
	Low	R1	R2

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA)

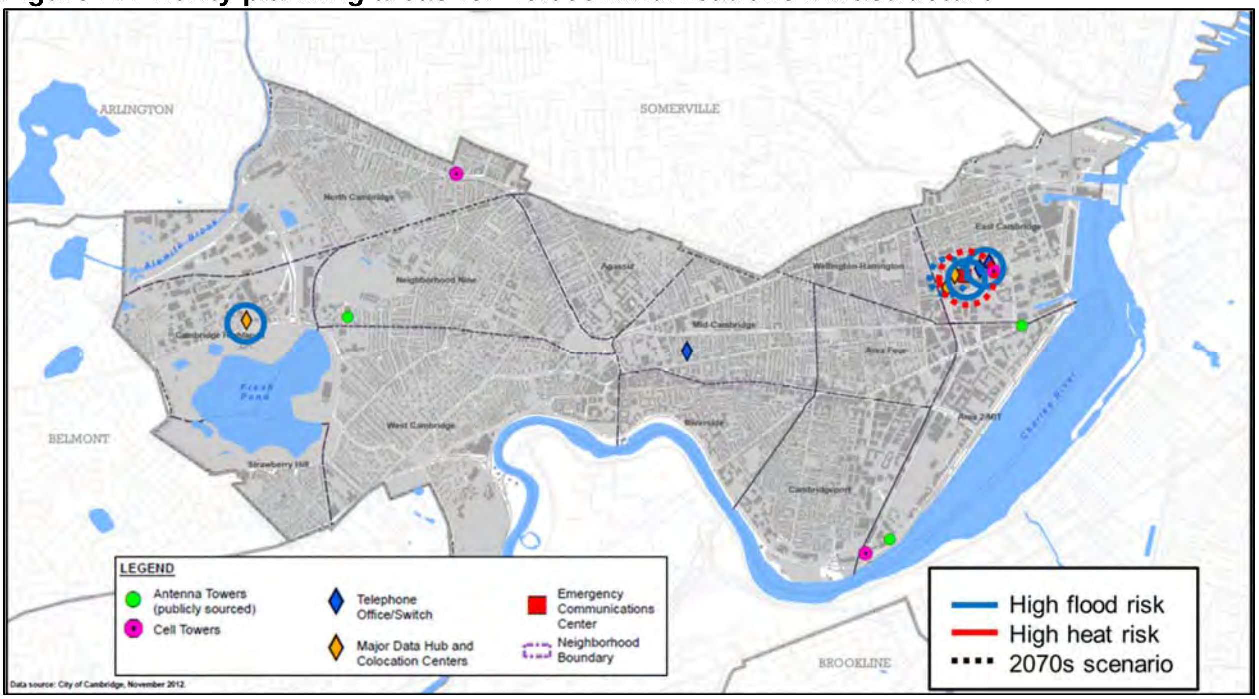
Technical Memorandum: Telecommunications Infrastructure

Prepared by Kleinfelder, 2-26-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

The summary of the high-risk priority planning areas for Telecommunications infrastructure is presented in Figure 1. Only assets with high risk scores are highlighted (R3 or R4). Those with solid circles around them were identified as high risks for heat (red) or inland flooding (blue) in the 2015-2044 (2030s) scenarios, while those surrounded by dashed circles were only identified as high risks in the 2055-2084 (2070s) scenarios. These priority planning areas should be addressed in the development of the City's Climate Change Preparedness Plan.

Figure 1. Priority planning areas for Telecommunications infrastructure



The **City's Emergency Communications Center**, located at the Cambridge Police Department headquarters, is the highest risk telecommunication asset **(R4)** in the Inland Flooding – 2030s scenario. It is also the only high risk asset **(R3)** in the Heat – 2070s scenario.

Other high risks / high priorities for preparedness planning are as follows:

Inland Flooding – 2030s

- BBN Technologies data hub (R3)
- AT&T telephone office/long-line switch (R3)

Inland Flooding – 2070s

- AT&T data hub/co-location center (CO-LOC) (R3)

Several of the high risk telecommunications assets are geographically concentrated in a small area of the East Cambridge neighborhood that is exposed to manhole flooding in the modeled scenarios.

Telecommunications infrastructure is more vulnerable and at risk from flooding than heat. This is mainly because of their higher adaptive capacity to mitigate or cope with the impacts of heat.

B. Summary of Assessment Process and Methods

Selection of Assets

Telecommunications infrastructure in Cambridge, including data centers, co-location centers (CO-LOCs), telephone offices and long line switches, antenna towers, cellular towers, and emergency communications centers were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. Assets were screened to ensure that the vulnerability assessment focused on the most important assets in the system. The final list of assets assessed in this study is the result of iterative review and revision by the project team and stakeholders.

Vulnerability and Risk Scoring

The methods and assumptions for scoring the vulnerability and risk of assets were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

Vulnerability of each asset was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.

- Exposure was assessed based on scenario maps developed for the project (see Attachment 1).
- Sensitivity of assets was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the asset to fail to function (see Attachment 2).
- Adaptive capacity was assessed based on whether assets had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure (see Attachment 2).

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.

- Probability was assessed based on whether assets were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- Consequence was assessed based on the scale of the service disruption caused by an asset's failure (entire city vs. neighborhood vs. locality) and the potential for their failure to cause cascading impacts on other assets within or across systems.

Specific protocols for Telecommunications infrastructure were developed to standardize assumptions for scoring assets' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge (see Attachment 2).

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed assets were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 3).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Telecommunications infrastructure were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC), and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The protocols and preliminary findings were presented at a workshop with City stakeholders on October 6, 2014 and a meeting with TAC members, including a Verizon representative, on December 11, 2014. However, stakeholders did not provide any feedback on the telecommunications information.

Attachments 1-3 and the results reported in this memorandum reflect the latest understanding and assumptions.

Sections C & D below report the heat and inland flooding vulnerability and risk assessment results for all assessed Telecommunications infrastructure.

Section E compiles the risk scores for only highly vulnerable assets.

C. Heat Vulnerability and Risk Assessment

The vulnerability of Telecommunications infrastructure in Cambridge to heat is limited to a small number of assets which may pose a risk from failure during extreme heat events in the future (Table 1). Asset failures would likely be due to asset-level exposure to extreme heat that could damage heat-sensitive equipment, such as electrical transformers.

Highly Vulnerable Assets

Three Telecommunications assets are highly vulnerable to heat in the 2070s scenario:

- The City's Emergency Communications Center
- AT&T data center/CO-LOC
- XO Communications data center/CO-LOC

However, they have relatively low sensitivity to heat and only moderate exposure to heat island effects. For these reasons, they are only highly vulnerable under the 2070s scenario when critical thresholds for damage to electrical equipment are predicted to be exceeded.

Of the three highly vulnerable assets, the two data centers/CO-LOCs pose less of a risk from failure (R2). This is because, in terms of consequences, their failure would only affect the specific facilities and customers they serve. It is assumed that they do not provide telecommunications service to critical infrastructure facilities.

In contrast, the Emergency Communications Center serves the entire city and provides critical system-wide and cross-system functions. Therefore it has a higher consequence and risk score (R3).

Adaptive Capacity

In the 2070s scenario, all but one (BBN Technologies data center/CO-LOC) of the critical telecommunications assets assessed were exposed to heat that would exceed their critical thresholds and potentially cause failure. However, most were not considered highly vulnerable due to their high adaptive capacity.

All the critical Telecommunications facilities were either known or assumed to have both air conditioning and emergency generators. Long-line switches and antenna towers were assumed to have a higher level of system-wide redundancy, with the assumption that telecommunications services could be accessing via multiple networks, including cellular.

Vulnerability from Cascading Impacts
Cascading impacts from failures in other systems are not likely a key factor in the vulnerability of Telecommunications infrastructure to heat.

Telecommunications infrastructure depends heavily on the electrical system for normal operations. However, it was determined that Cambridge's critical electrical infrastructure is not highly vulnerable to heat, due to high adaptive capacity. In addition, most Telecommunications facilities have emergency generators in the event of an unlikely outage during an extreme heat event.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 1: Telecommunications infrastructure vulnerability and risk from heat
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Heat - 2030		Heat - 2070	
Type	Name	Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
Data Hubs and Co-location Centers	AT&T	V1-V2		V3-V4	R2
	XO Communications	V1-V2		V3-V4	R2
	BBN Technology	V1-V2		V1-V2	
Telephone Office and Long Line Switches	Verizon	V1-V2		V1-V2	
	AT&T	V0		V1-V2	
	Verizon	V1-V2		V1-V2	

Antenna Towers	Concord Ave Antenna Tower	V0		V1-V2	
Emergency Communications Center	Emergency Communications Center (Police HQ)	V1-V2		V3-V4	R3

D. Inland Flooding Vulnerability and Risk Assessment

Telecommunications facilities in Cambridge are more vulnerable to flooding than heat in the near term and overall, and may pose a risk from failure during future extreme rainfall events (Tables 2a and 2b). Asset failures would likely be due to direct exposure to localized flooding. Based on the results of this assessment, flooding could also impact the City's electrical system, without which some Telecommunications facilities may not be able to properly function.

Highly Vulnerable Assets

A limited number of telecommunications facilities are vulnerable in the 10-year 24 hour storm scenarios, and significant majority are vulnerable in the 100-year 24 hour storms. In both sets of scenarios, telecommunications vulnerability and risk increases over time, from the 2030s to the 2070s. The highly vulnerable assets with the highest consequences of failure and risk are the Emergency Communications Center and AT&T's telephone office/long-line switch.

Highly vulnerable assets in the 2030s 10-year 24 hour storm scenario include two facilities that are mostly impacted by limited access due to street flooding: the City's Emergency Communications Center (located at Cambridge Police Department headquarters) and BBN Technology data hub/CO-LOC. Of these, the Emergency Communications Center has a high consequence and high risk, whereas the data hub/CO-LOC represents a moderate consequence and risk.

In the 2070s 10-year scenario, the BBN Technology facility is again impacted by access flooding. The Emergency Communications Center and AT&T data hub/CO-LOC are impacted by flooding of sufficient magnitude to enter the interiors of the buildings, but possibly not high enough to damage major building systems.

In the 2030s 100-year 24 hour storm scenario, almost all facilities are directly exposed to flooding. However, interior flooding is only expected to be high enough to damage critical building systems at three of them: Emergency Communications Center, AT&T telephone office/long-line switch, and AT&T data hub/CO-LOC. All three are highly vulnerable.

In the 2070s 100-year storm scenario, all critical telecommunications assets except the two Verizon telephone offices/long-line switches and the Concord Ave Antenna Tower are exposed to sufficient flooding as to cause failure.

Adaptive Capacity

A main reason that flood vulnerability and risk is more widespread throughout the system than heat is due to low adaptive capacity. As informed by this assessment, the understanding is that Telecommunications infrastructure have largely not been designed or adapted to flooding. This factor contributed to the low adaptive capacity and high vulnerability of exposed assets.

Long-line switches and antenna towers were assumed to have higher degrees of system-wide redundancy, with the assumption that telecommunications services could be accessing via multiple networks, including cellular.

Vulnerability from Cascading Impacts

Energy infrastructure has been identified as being highly vulnerable and high risk from inland flooding. The functioning of Telecommunications facilities, some of which have not been identified as being highly vulnerable or high risk, could be impacted by failure of the City's electrical systems. However, this vulnerability is mitigated by assumption that all critical Telecommunications facilities have emergency generators.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 2a: Telecommunications infrastructure vulnerability and risk from inland flooding by 2030s

(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Data Hubs and Co-location Centers	AT&T	V2		V5	R2
	XO Communications	V2		V3-V5	R2
	BBN Technology	V3-V5	R3	V3-V5	R2
Telephone Office and Long Line Switches	Verizon	V1-V3		V1-V3	
	AT&T	V1		V4	R3
	Verizon	V1-V3		V1-V3	
Antenna Towers	Concord Ave Antenna Tower	V1-V3		V1-V3	
Emergency Communications Center	Emergency Communications Center (Police HQ)	V3-V5	R4	V5	R3

Table 2b: Telecommunications infrastructure vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 year 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Data Hubs and Co-location Centers	AT&T	V3-V5	R3	V5	R2
	XO Communications	V2		V5	R2
	BBN Technology	V3-V5	R3	V5	R2
Telephone Office and Long Line Switches	Verizon	V1-V3		V1-V3	
	AT&T	V1		V4	R3
	Verizon	V1-V3		V1-V3	
Antenna Towers	Concord Ave Antenna Tower	V1-V3		V1-V3	
Emergency Communications Center	Emergency Communications Center (Police HQ)	V3-V5	R4	V5	R3

E. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 3a and 3b below. Assets with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

In Table 3a, the "High Probability" column indicates which assets are highly vulnerable and their corresponding risk scores under the 2030s heat scenario. The "Low Probability" column contains the same information but corresponds with the 2070s heat scenario.

In Table 3b – Risk ranking summary for inland flooding – the "High Probability" column indicates which assets are highly vulnerable and their corresponding risk scores under the 10-year 24 hour storm scenarios of the 2030s and 2070s. The "Low Probability" column contains the same information but corresponds with the 100-year 24 hour storm scenarios of the 2030s and 2070s. Assets with "(2070)" next to their names were assessed to be highly vulnerable in the 2070s scenario, but not the 2030s.

Assumptions are further documented in the protocol defined in Attachment 2 and the detailed spreadsheet in Attachment 3.

Table 3a: Risk ranking summary for heat
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	Score R3 • City Emergency Communications Center (125 Sixth Street)	Score R4
	Medium	Score R2 • XO Communications (89 Fulkerson Street) • AT&T Data Hub/CO-LOC3 (300 Bent Street)	Score R3
	Low	Score R1	Score R2

Table 3b: Risk ranking summary for inland flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	**Score R3** • City Emergency Communications Cente) • AT&T Telephone Office/Long Line Switch	**Score R4** • City Emergency Communications Cente)
	Medium	**Score R2** • XO Communications Data Hub/CO-LOC • AT&T Data Hub/CO-LOC • BBN Technology Data Hub/CO-LOC	**Score R3** • AT&T Data Hub/CO-LOC (2070) • BBN Technology Data Hub/CO-LOC
	Low	**Score R1**	**Score R2**

*(2070) indicates that an asset is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

Attachment 1 – Scoring Protocol for Telecommunications Infrastructure V&R Assessment

Attachment 1- Telecommunications: Vulnerability & Risk Assessment Scoring Protocol

Sensitivity to Heat: Extent to which the asset's functionality will be affected by high temperatures it is exposed to in the scenario

Threshold	Score	Description		Direct Impact - based on heat stress on system (°F)
S0	S0	Not affected	Equipment failures due to heat unlikely	<90
S1-S2	S1	Minimally affected	Equipment failures due to heat possible	90-110
	S2	Somewhat affected		
S3-S4	S3	Largely affected	Equipment failures due to heat likely	>110
	S4	Greatly affected		

Assumptions:

- Telecommunications assets are at risk of failing during heatwaves due to impacts on associated electrical and mechanical (mostly for cooling) systems. Without electricity or cooling, it is assumed that telecommunications systems will not function.
- Electrical transformers and distribution line connections will experience accelerated degradation under higher local heat conditions, raising the risk of component failure during the event and over time with cumulative exposure (according to City of Cambridge Electrical Department, during heatwave lasting longer than 3 days, vulnerability of electrical equipment to failure increases).
- Higher demand for cooling services and energy to cool higher temperature ambient air will put increased stress on mechanical and electrical equipment increasing the likelihood of component failures.

Sensitivity to Flooding: Extent to which the asset's functionality will be affected by flooding it is exposed to in the scenario

<table>
<tr><th rowspan="2">Threshold</th><th rowspan="2">Score</th><th rowspan="2">Description</th><th colspan="2">Direct Impact - based on location of critical equipment</th><th colspan="2">Indirect Impact - based on dependencies</th></tr>
<tr><th>Exterior (ft)</th><th>Inside Building - direct flood contact (ft)</th><th>Access - local roads (ft)</th><th>Energy</th></tr>
<tr><td>S0</td><td>S0</td><td>Not affected</td><td>0</td><td>0</td><td><0.5</td><td>If upstream energy system is V1-V3</td></tr>
<tr><td rowspan="3">S1-S3</td><td>S1</td><td>Minimally affected</td><td rowspan="3"><0.5</td><td rowspan="3">0-1</td><td rowspan="3">>0.5</td><td rowspan="3">If upstream energy system is V4-V5</td></tr>
<tr><td>S2</td><td>Somewhat affected</td></tr>
<tr><td>S3</td><td>Largely affected</td></tr>
<tr><td>S4</td><td>S4</td><td>Greatly affected</td><td>>0.5</td><td>>1</td><td>NA</td><td>NA</td></tr>
</table>

Assumptions:

- Exterior
  - Assumed that equipment is raised 0.5 ft above ground. Flooding >0.5 will lead to critical equipment failure.
- Inside building
  - Assumed that equipment is raised 1 ft above ground (building first floor 0.5 ft above ground, equipment raised 0.5 ft above first floor). Flooding >1 ft in direct contact with the building will lead to critical equipment failure.
- Access
  - Access must be maintained for full functionality. Access flooding impairs functionality when >0.5 ft. However access impacts alone are insufficient to "greatly affect" functionality.
- Energy
  - Electricity is needed for critical functions of data hubs and co-location centers, telephone offices and long line switches, and antenna towers. If power loss occurs, the facility will not fully function. Upstream energy impacts alone are insufficient to "greatly affect" the functionality. Redundancy in terms of emergency generation will be accounted for in Adaptive Capacity.

Adaptive Capacity: Extent to which the asset will be able to accommodate or adjust to the impact

Score	Description	Criteria
AC2	High	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing telecommunications services ARE available
AC1	Medium	1. Physical/operational measures ARE in place to prepare/mitigate and respond/recover OR 2. Alternative means for obtaining or providing telecommunications services ARE available
AC0	Low	1. Physical/operational measures NOT in place to prepare/mitigate and respond/recover AND 2. Alternative means for obtaining or providing telecommunications services are NOT available

Vulnerability

		Sensitivity: Low → High				
		S0	S1	S2	S3	S4
Adaptive Capacity: Low ↓ High	AC0	V2	V3	V4	V5	V5
	AC1	V1	V1	V2	V3	V4
	AC2	V0	V0	V0	V1	V2

Consequence

	Criteria
High	1. Impacts a large number of people **OR** large area of the city **AND** 2. Impacts other critical assets/systems
Medium	1. Impacts a large number of people **OR** large area of the city **AND** 2. Does not impact other critical assets/systems
Low	1. Does not impact a large number of people **OR** large area of the city **AND** 3. Does not impact other critical assets/systems

Probability

- Heat
  - High: 4-day >90°F heatwave (2030 scenario)
  - Low: 5-day >90°F heatwave with 3 days >100°F (2070 scenario)
- Flooding
  - High: 10 year 24-hour storm (2030 and 2070)
  - Low: 100 year 24-hour storm (2030 and 2070)

Risk

		Probability	
		Low	High
Consequence	High	R3	R4
	Medium	R2	R3
	Low	R1	R2

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA)

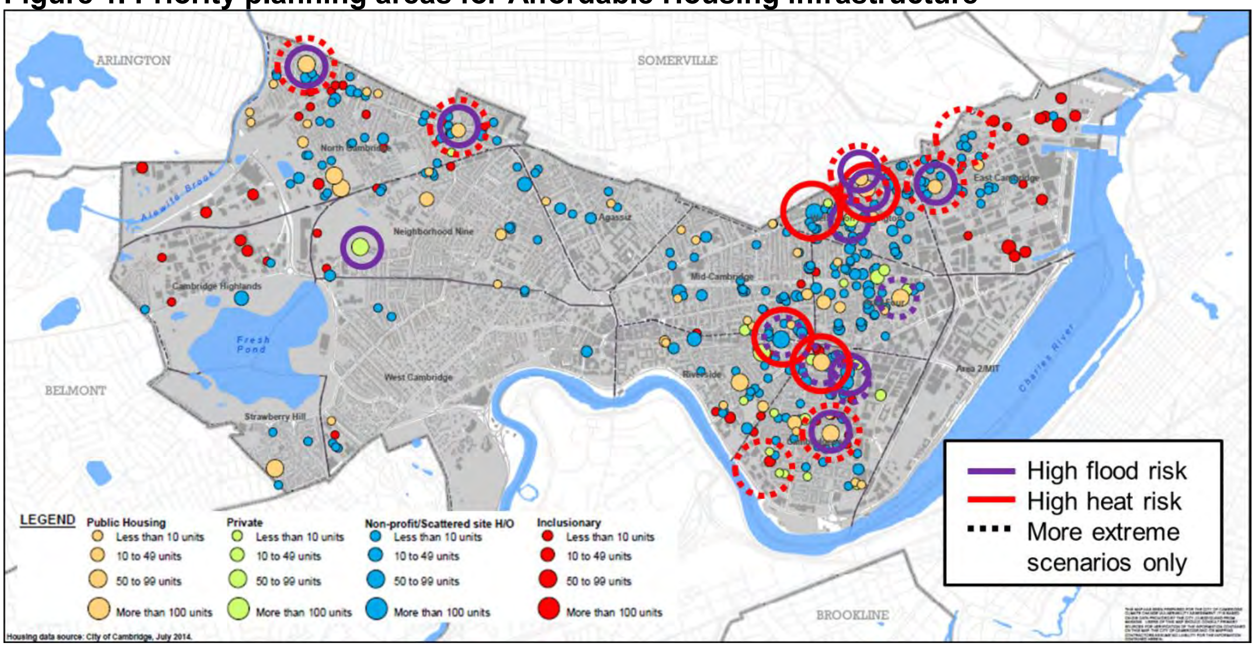
Technical Memorandum: Affordable Housing Infrastructure

Prepared by Kleinfelder, 11-03-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

The summary of the high-risk priority planning areas for Affordable Housing infrastructure is presented in Figure 1. Only facilities with high risk scores are highlighted (R3 or R4). Those with solid circles around them were identified as high risks for heat (red) or inland flooding (blue) in the 2015-2044 (2030s) scenarios, while those surrounded by dashed circles were only identified as high risks in the 2055-2084 (2070s) scenarios. These priority planning areas should be addressed in the development of the City's Climate Change Preparedness Plan.

Figure 1. Priority planning areas for Affordable Housing infrastructure



Affordable Housing infrastructure in Cambridge is at high risk from both inland flooding and heat. A significant factor in the broad vulnerability to heat and flooding is the limited adaptive capacity to relocate residents from facilities with a large number of units, in the event of a failure.

High risks / high priorities for preparedness planning are as follows:

<u>Inland Flooding – 2030s</u>

- Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units (R4)
- Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units (R4)
- Daniel F. Burns Apt (50 Churchill Ave), 198 units (R4)
- Harwell Homes (1 Citizens Place), 56 units (R3)
- Briston Arms (247 Garden St), 105 units (R3)

- Auburn Court I (80 Auburn Park), 77 units (R3)
- Truman Apts (25 Eighth St), 60 units (R3)
- Johnson Apts (150 Erie St), 180 units (R3)
- 2050 Mass Ave/ Leonard J. Russell Apts, 51 units (R3)

Heat – 2030s

- YMCA (820 Mass Ave), 128 units (R4)
- Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units (R4)
- Manning Apts (237 Franklin St), 199 units (R4)
- Inman Sq Apts (1203-1221 Cambridge St), 116 units (R3)

Inland Flooding – 2070s

- Truman Apts (25 Eighth St), 60 units (R4)
- Johnson Apts (150 Erie St), 180 units (R4)
- Washington Elms (131 Washington St), 175 units (R3)
- Auburn Court II (80 Brookline St), 60 units (R3)
- YMCA (820 Mass Ave), 128 units (R3)
- Manning Apts (237 Franklin St), 199 units (R3)

Heat – 2070s

- Truman Apts (25 Eighth St), 60 units (R3)
- Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units (R3)
- Miller's River Apts (15 Lambert St), 301 units (R3)
- Johnson Apts (150 Erie St), 180 units (R3)
- Daniel F. Burns Apt (50 Churchill Ave), 198 units (R3)
- 808 Memorial Dr (808-812 Memorial Dr), 300 units (R3)
- 2050 Mass Ave/ Leonard J. Russell Apts, 51 units (R3)

B. Summary of Assessment Process and Methods

Selection of Facilities

Affordable Housing infrastructure in Cambridge, including inclusionary, non-profit/scattered site, private, and public facilities, were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. Facilities were screened to ensure that the vulnerability assessment focused on the most important facilities in the system. For example, only Affordable Housing facilities with greater than 50 units were included. This subset encompassed six of the thirteen Affordable Housing facilities in the database designated as serving elderly or disabled populations, and 88% of the total units among those thirteen facilities. The final list of facilities assessed in this study is the result of iterative review and revision by the project team and stakeholders.

Vulnerability and Risk Scoring

The methods and assumptions for scoring the vulnerability and risk of facilities were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

Vulnerability of each facility was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.

- Exposure was assessed based on scenario maps developed for the project (see Attachment 1).
- Sensitivity of facilities was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the facility to fail to function (see Section C for heat & Section D for flooding).
- Adaptive capacity was assessed based on whether facilities had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure (see Section C for heat & Section D for flooding).

Risk is a function of the probability of the scenario occurring and the consequences of the facility failing as a result. Only facilities that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.

- Probability was assessed based on whether facilities were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- Consequence was assessed based on the scale of the service disruption caused by a facility's failure (all were assumed to affect a large number of people) and the potential for their failure to cause cascading impacts (i.e., Affordable Housing facilities that also housed daycare services or were designated as serving elderly or disabled populations).

Specific protocols for Affordable Housing infrastructure were developed to standardize assumptions for scoring facilities' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge (see Section C for heat & Section D for flooding).

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed facilities were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 2).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Affordable Housing infrastructure were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC) – which Cambridge Housing Authority is a member of, and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The latest feedback from a workshop with City stakeholders on October 20, 2014, a meeting with TAC members on December 11, 2014, as well as subsequent follow-up has been incorporated. Participants included the City's Department of Public Works, Community Development Department, and Cambridge Housing Authority.

Attachments 1 & 2 and the results reported in this memorandum reflect the latest understanding and assumptions.

Sections C & D below report the heat and inland flooding vulnerability and risk assessment results for Affordable Housing infrastructure.

Section E compiles the risk scores for only highly vulnerable facilities.

C. Heat Vulnerability and Risk Assessment

All Affordable Housing facilities were assumed to be highly sensitive to ambient air temperatures of 100°F or higher.

Their adaptive capacity was assessed to be moderate, due to the assumed availability of air conditioning, offset by a general lack of redundancy given the difficulty of relocating large number of residents in the event of building system failures. The assumption regarding redundancy is backed by recent experience relocating residents of an Affordable Housing facility with over 100 units after a pipe burst during a winter storm.

Affordable Housing facilities that also housed daycare services or were designated as serving elderly or disabled populations were assumed to have a higher consequence of failure than others.

The highest risk facilities for heat are documented in Section A of this memorandum, as well as in Table 3a. Table 1 includes the vulnerability scores for all Affordable Housing facilities assessed.

In the 2030s scenario, four Affordable Housing facilities were highly vulnerable to heat: YMCA (R4), Manning Apts (R4), Roosevelt Towers – Low-rise (R4), and Inman Square Apts (R3). These facilities were exposed to particularly high ambient temperatures (110°F or higher) in the 2070s scenario, due to the heat island effect.

In the 2070s scenario, all but one Affordable Housing facility (Neville Center at Fresh Pond) were highly vulnerable to heat. In addition to the four facilities that were highly vulnerable in the 2030s scenario, two other facilities were exposed to especially high ambient temperatures (110°F or higher) in 2070s scenario due to heat island effect: 285/303 Third St (R2), Jefferson Park – Federal (R2).

Assumptions are further documented in the detailed spreadsheet in Attachment 2.

Table 1: Affordable Housing infrastructure vulnerability and risk from heat
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Facilities		Heat - 2030		Heat - 2070	
		Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Inclusionary Affordable Housing	1 Leighton St/ Charles E. Smith, 52 units	V1-V2		V3-V4	R2

Critical Facilities		Heat - 2030		Heat - 2070	
Type	Name	Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
	285/303 Third St, 56 units	V1-V2		V3-V4	R2
Non-Profit/ Scattered Site H/O Affordable Housing	808 Memorial Dr (808-812 Memorial Dr), 300 units	V1-V2		V3-V4	R3
	402 Rindge Ave, 273 units	V1-V2		V3-V4	R2
	Neville Center at Fresh Pond (650 Concord Ave), 57 units	V1		V1-V2	
	Lancaster Apartments (8-10 Lancaster St), 65 units	V1-V2		V3-V4	R2
	18-20 Ware St, 56 units	V1-V2		V3-V4	R2
	Putnam Sq/2 Mt. Auburn, 94 units	V1-V2		V3-V4	R2
	YMCA (820 Mass Ave), 128 units	V3-V4	R4	V3-V4	R3
	YWCA SROs (136 Bishop Allen Dr), 103 units	not assessed		not assessed	
	Auburn Court I (80 Auburn Park), 77 units	V1-V2		V3-V4	R2
	Auburn Court II (80 Brookline St), 60 units	V1-V2		V3-V4	R2
	Inman Sq Apts (1203-1221 Cambridge St), 116 units	V3-V4	R3	V3-V4	R2
Private Affordable Housing	Briston Arms (247 Garden St), 105 units	V1-V2		V3-V4	R2
	Waldren Square Apts (104 Waldren Square Rd), 240 units	V1-V2		V3-V4	R2
	Cambridge Court/411 Franklin (411 Frankling St), 122 units	V1-V2		V3-V4	R2
	Close Building (243 Broadway), 61 units	V1-V2		V3-V4	R2
	Harwell Homes (1 Citizens Place), 56 units	V1-V2		V3-V4	R2
	Fresh Pond Apts (360-364 Rindge Ave), 504 units	V1-V2		V3-V4	R2

Critical Facilities		Heat - 2030		Heat - 2070	
Type	Name	Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
Public Affordable Housing	Miller's River Apts (15 Lambert St), 301 units	V1-V2		V3-V4	R3
	Newtowne Court (131 Washington St), 268 units	V1-V2		V3-V4	R2
	Corcoran Park (100 Thingvalla Ave), 153 units	V1-V2		V3-V4	R2
	Jefferson Park (Federal)(1 Jackson Pl), 175 units	V1-V2		V3-V4	R2
	Jefferson Park (State)(1 Jackson Pl), 109 units	V1-V2		V3-V4	R2
	Daniel F. Burns Apt (50 Churchill Ave), 198 units	V1-V2		V3-V4	R3
	Lincoln Way (39 Lincoln Way), 70 units	V1-V2		V3-V4	R2
	2050 Mass Ave/ Leonard J. Russell Apts, 51 units	V1-V2		V3-V4	R3
	Putnam Gardens (64 Magee St), 122 units	V1-V2		V3-V4	R2
	3 Woodrow Wilson Court, 69 units	V1-V2		V3-V4	R2
	Johnson Apts (150 Erie St), 180 units	V1-V2		V3-V4	R3
	Manning Apts (237 Franklin St), 199 units	V3-V4	R4	V3-V4	R3
	Kennedy Apts (55 Essex St), 69 units	V1-V2		V3-V4	R2
	Washington Elms (131 Washington St), 175 units	V1-V2		V3-V4	R2
	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units	V3-V4	R4	V3-V4	R3
	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units	V1-V2		V3-V4	R3
	Truman Apts (25 Eighth St), 60 units	V1-V2		V3-V4	R3

D. Inland Flooding Vulnerability and Risk Assessment

The sensitivity of Affordable Housing facilities was determined based on whether they were directly exposed to flooding (i.e. flooding in direct contact with the building) and building characteristics (doors and windows to basement or first floor). Details on assumptions for specific facilities are included in Attachment 2 (Scoring Spreadsheet).

Their adaptive capacity was assumed to be low, due to lack of floodproofing in their design and operations, as well as a general lack of redundancy given the difficulty of relocating a large number of residents in the event of failure. Due to their low adaptive capacity, all Affordable Housing facilities with direct exposure to flooding (i.e., flooding in contact with the building) were considered highly vulnerable, even if flooding was insufficient to result in interior flooding.

Affordable Housing facilities that also housed daycare services or were designated as serving elderly or disabled populations were assumed to have a higher consequence of failure than others.

The highest risk facilities for inland flooding are documented in Section A of this memorandum, as well as in Table 3b. Tables 2a and 2b include the vulnerability scores for all Affordable Housing facilities assessed.

10-year 24 hour storm, 2030s and 2070s
Six Affordable Housing facilities were highly vulnerable in the 10-year 24 hour storm scenario of the 2030s, and eleven were highly vulnerable in the 10-year scenario of the 2070s.

Facilities with the highest vulnerability (V5) in both the 2030s and 2070s 10-year scenarios were Auburn Court I, Daniel F. Burns Apt, and Putnam Gardens (2070 only). These facilities were exposed to sufficient flooding to result in interior flooding of their basements or first floors. Together they account for approximately 400 units.

100-year 24 hour storm, 2030s and 2070s
Eighteen (18) Affordable Housing facilities were highly vulnerable in the 100-year 24 hour storm scenario of the 2030s, and twenty two (22) were highly vulnerable in the 100-year scenario of the 2070s.

Facilities with the highest vulnerability (V5) in the 2030s 100-year scenario (i.e., those exposed to interior flooding) were Auburn Court I, Auburn Court II, Briston Arms, Cambridge Court/411 Franklin, Close Building, Newtown Court, Daniel F. Burns Apt, 2050 Mass Ave/Leonard J. Russell Apts, Putnam Gardens, Kennedy Apts, Washington Elms, and Truman Apts. Together, these facilities account for over 1,300 units.

In the 2070s 100-year scenario, two additional facilities were exposed to interior flooding (V5), Manning Apts and Waldren Square Apts, bringing the total number of units in highly vulnerable facilities up to just over 1,800.

Units at these facilities are not assumed to be equally vulnerable. Some of these facilities include multiple separate buildings, of which only a proportion are highly vulnerable. Unit-level assessments were not part of this assessment.

Assumptions are further documented in the detailed spreadsheet in Attachment 2.

Table 2a: Affordable Housing infrastructure vulnerability and risk from inland flooding by 2030s

(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Facilities		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Inclusionary Affordable Housing	1 Leighton St/ Charles E. Smith, 52 units	V2		V2	
	285/303 Third St, 56 units	V2		V3-V5	R2
Non-Profit/ Scattered Site H/O Affordable Housing	808 Memorial Dr (808-812 Memorial Dr), 300 units	V2		V2	
	402 Rindge Ave, 273 units	V2		V2	
	Neville Center at Fresh Pond (650 Concord Ave), 57 units	V2		V2	
	Lancaster Apartments (8-10 Lancaster St), 65 units	V2		V2	
	18-20 Ware St, 56 units	V2		V2	
	Putnam Sq/2 Mt. Auburn, 94 units	V2		V2	
	YMCA (820 Mass Ave), 128 units	V2		V2	
	YWCA SROs (136 Bishop Allen Dr), 103 units	not assessed		not assessed	
	Auburn Court I (80 Auburn Park), 77 units	V5	R3	V5	R2
	Auburn Court II (80 Brookline St), 60 units	V2		V5	R2
	Inman Sq Apts (1203-1221 Cambridge St), 116 units	V2		V2	
Private Affordable Housing	Briston Arms (247 Garden St), 105 units	V3-V5	R3	V5	R2
	Waldren Square Apts (104 Waldren Square Rd), 240 units	V2		V2	
	Cambridge Court/411 Franklin (411 Frankling St), 122 units	V2		V5	R2

Critical Facilities		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	Close Building (243 Broadway), 61 units	V2		V5	R2
	Harwell Homes (1 Citizens Place), 56 units	V3-V5	R3	V3-V5	R2
	Fresh Pond Apts (360-364 Rindge Ave), 504 units	V2		V2	
Public Affordable Housing	Miller's River Apts (15 Lambert St), 301 units	V2		V2	
	Newtowne Court (131 Washington St), 268 units	V2		V5	R2
	Corcoran Park (100 Thingvalla Ave), 153 units	V2		V2	
	Jefferson Park (Federal)(1 Jackson Pl), 175 units	V2		V2	
	Jefferson Park (State)(1 Jackson Pl), 109 units	V2		V2	
	Daniel F. Burns Apt (50 Churchill Ave), 198 units	V5	R4	V5	R3
	Lincoln Way (39 Lincoln Way), 70 units	V2		V3-V5	R2
	2050 Mass Ave/ Leonard J. Russell Apts, 51 units	V2		V5	R3
	Putnam Gardens (64 Magee St), 122 units	V2		V5	R2
	3 Woodrow Wilson Court, 69 units	V2		V2	
	Johnson Apts (150 Erie St), 180 units	V2		V3-V5	R3
	Manning Apts (237 Franklin St), 199 units	V2		V2	
	Kennedy Apts (55 Essex St), 69 units	V2		V5	R2
	Washington Elms (131 Washington St), 175 units	V2		V5	R2
	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units	V3-V5	R4	V3-V5	R3

Critical Facilities		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units	V3-V5	R4	V3-V5	R3
	Truman Apts (25 Eighth St), 60 units	V2		V5	R3

Table 2b: Affordable Housing Infrastructure vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Facilities		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Inclusionary Affordable Housing	1 Leighton St/ Charles E. Smith, 52 units	V2		V2	
	285/303 Third St, 56 units	V2		V3-V5	R2
Non-Profit/ Scattered Site H/O Affordable Housing	808 Memorial Dr (808-812 Memorial Dr), 300 units	V2		V2	
	402 Rindge Ave, 273 units	V2		V2	
	Neville Center at Fresh Pond (650 Concord Ave), 57 units	V2		V2	
	Lancaster Apartments (8-10 Lancaster St), 65 units	V2		V2	
	18-20 Ware St, 56 units	V2		V2	
	Putnam Sq/2 Mt. Auburn, 94 units	V2		V2	
	YMCA (820 Mass Ave), 128 units	V2		V3-V5	R3
	YWCA SROs (136 Bishop Allen Dr), 103 units	not assessed		not assessed	
	Auburn Court I (80 Auburn Park), 77 units	V5	R3	V5	R2
	Auburn Court II (80 Brookline St), 60 units	V3-V5	R3	V5	R2
	Inman Sq Apts (1203-1221 Cambridge St), 116 units	V2		V2	
Private Affordable Housing	Briston Arms (247 Garden St), 105 units	V3-V5	R3	V5	R2
	Waldren Square Apts (104 Waldren Square Rd), 240 units	V2		V5	R2

Critical Facilities		Flooding - 2070			
Type	Name	10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
		Vulnerability	Risk	Vulnerability	Risk
	Cambridge Court/411 Franklin (411 Franklin St), 122 units	V2		V5	R2
	Close Building (243 Broadway), 61 units	V2		V5	R2
	Harwell Homes (1 Citizens Place), 56 units	V3-V5	R3	V3-V5	R2
	Fresh Pond Apts (360-364 Rindge Ave), 504 units	V2		V2	
Public Affordable Housing	Miller's River Apts (15 Lambert St), 301 units	V2		V2	
	Newtowne Court (131 Washington St), 268 units	V2		V5	R2
	Corcoran Park (100 Thingvalla Ave), 153 units	V2		V2	
	Jefferson Park (Federal)(1 Jackson Pl), 175 units	V2		V2	
	Jefferson Park (State)(1 Jackson Pl), 109 units	V2		V2	
	Daniel F. Burns Apt (50 Churchill Ave), 198 units	V5	R4	V5	R3
	Lincoln Way (39 Lincoln Way), 70 units	V2		V3-V5	R2
	2050 Mass Ave/ Leonard J. Russell Apts, 51 units	V2		V5	R3
	Putnam Gardens (64 Magee St), 122 units	V2		V5	R2
	3 Woodrow Wilson Court, 69 units	V2		V3-V5	R2
	Johnson Apts (150 Erie St), 180 units	V3-V5	R4	V3-V5	R3
	Manning Apts (237 Franklin St), 199 units	V2		V5	R3
	Kennedy Apts (55 Essex St), 69 units	V2		V5	R2

Critical Facilities		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	Washington Elms (131 Washington St), 175 units	V3-V5	R3	V5	R2
	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units	V3-V5	R4	V3-V5	R3
	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units	V3-V5	R4	V3-V5	R3
	Truman Apts (25 Eighth St), 60 units	V3-V5	R4	V5	R3

E. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the facility failing as a result. Only facilities that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 3a and 3b below. Facilities with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

In Table 3a, the “High Probability” column indicates which facilities are highly vulnerable and their corresponding risk scores under the 2030s heat scenario. The “Low Probability” column contains the same information but corresponds with the 2070s heat scenario.

In Table 3b – Risk ranking summary for inland flooding – the “High Probability” column indicates which facilities are highly vulnerable and their corresponding risk scores under the 10-year 24 hour storm scenarios of the 2030s and 2070s. The “Low Probability” column contains the same information but corresponds with the 100-year 24 hour storm scenarios of the 2030s and 2070s. Facilities with “(2070)” next to their names were assessed to be highly vulnerable in the 2070s scenario, but not the 2030s.

Assumptions are further documented in the detailed spreadsheet in Attachment 2.

Table 3a: Risk ranking summary for heat
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	**Score R3** • YMCA (820 Mass Ave), 128 units • Truman Apts (25 Eighth St), 60 units • Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units • Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units • Miller's River Apts (15 Lambert St), 301 units • Manning Apts (237 Franklin St), 199 units • Johnson Apts (150 Erie St), 180 units • Daniel F. Burns Apt (50 Churchill Ave), 198 units • 808 Memorial Dr (808-812 Memorial Dr), 300 units • 2050 Mass Ave/ Leonard J. Russell Apts, 51 units	**Score R4** • YMCA (820 Mass Ave), 128 units • Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units • Manning Apts (237 Franklin St), 199 units
	Medium	**Score R2** • Washington Elms (131 Washington St), 175 units • Waldren Square Apts (104 Waldren Square Rd), 240 units • Putnam Sq/2 Mt. Auburn, 94 units • Putnam Gardens (64 Magee St), 122 units • Newtowne Court (131 Washington St), 268 units • Lincoln Way (39 Lincoln Way), 70 units • Lancaster Apartments (8-10 Lancaster St), 65 units • Kennedy Apts (55 Essex St), 69 units • Jefferson Park (State)(1 Jackson Pl), 109 units • Jefferson Park (Federal)(1 Jackson Pl), 175 units • Inman Sq Apts (1203-1221 Cambridge St), 116 units • Harwell Homes (1 Citizens Place), 56 units • Fresh Pond Apts (360-364 Rindge Ave), 504 units • Corcoran Park (100 Thingvalla Ave), 153 units • Close Building (243 Broadway), 61 units • Cambridge Court/411 Franklin (411 Frankling St), 122 units • Briston Arms (247 Garden St), 105 units • Auburn Court II (80 Brookline St), 60 units • Auburn Court I (80 Auburn Park), 77 units • 402 Rindge Ave, 273 units • 3 Woodrow Wilson Court, 69 units • 285/303 Third St, 56 units • 18-20 Ware St, 56 units • 1 Leighton St/ Charles E. Smith, 52 units	**Score R3** • Inman Sq Apts (1203-1221 Cambridge St), 116 units
	Low	**Score R1**	**Score R2**

Table 3b: Risk ranking summary for flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	Score R3 • Truman Apts (25 Eighth St), 60 units • Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units • Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units • Johnson Apts (150 Erie St), 180 units • Daniel F. Burns Apt (50 Churchill Ave), 198 units • 2050 Mass Ave/ Leonard J. Russell Apts, 51 units • YMCA (820 Mass Ave), 128 units (2070) • Manning Apts (237 Franklin St), 199 units (2070)	Score R4 • Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units • Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units • Daniel F. Burns Apt (50 Churchill Ave), 198 units • Truman Apts (25 Eighth St), 60 units (2070) • Johnson Apts (150 Erie St), 180 units (2070)
	Medium	Score R2 • Washington Elms (131 Washington St), 175 units • Putnam Gardens (64 Magee St), 122 units • Newtowne Court (131 Washington St), 268 units • Lincoln Way (39 Lincoln Way), 70 units • Kennedy Apts (55 Essex St), 69 units • Harwell Homes (1 Citizens Place), 56 units • Close Building (243 Broadway), 61 units • Cambridge Court/411 Franklin (411 Frankling St), 122 units • Briston Arms (247 Garden St), 105 units • Auburn Court II (80 Brookline St), 60 units • Auburn Court I (80 Auburn Park), 77 units • 285/303 Third St, 56 units • Waldren Square Apts (104 Waldren Square Rd), 240 units (2070) • 3 Woodrow Wilson Court, 69 units (2070)	Score R3 • Harwell Homes (1 Citizens Place), 56 units • Briston Arms (247 Garden St), 105 units • Auburn Court I (80 Auburn Park), 77 units • Washington Elms (131 Washington St), 175 units (2070) • Auburn Court II (80 Brookline St), 60 units (2070)
	Low	Score R1	Score R2

*(2070) indicates that a facility is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA)

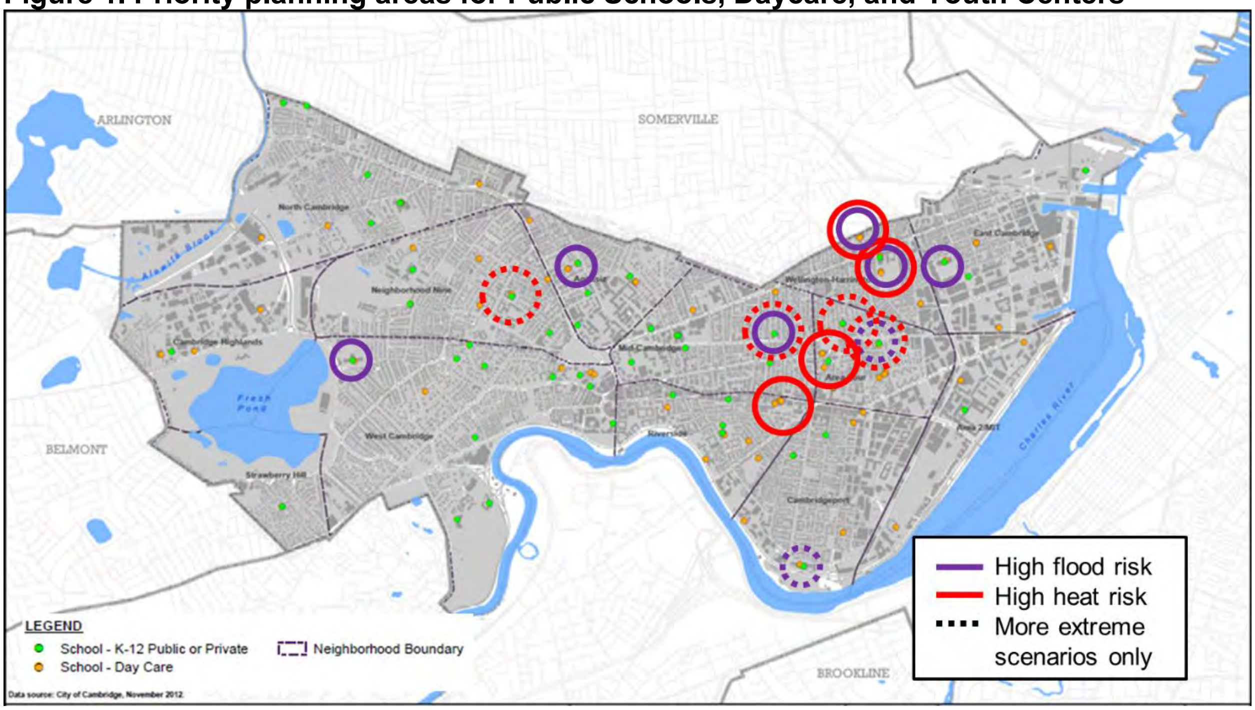
Technical Memorandum: Public Schools, Daycare, and Youth Centers

Prepared by Kleinfelder, 3-1-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

The summary of the high-risk priority planning areas for Public Schools, Daycare, and Youth Centers is presented in Figure 1. Only facilities with high risk scores are highlighted (R3 or R4). Those with solid circles around them were identified as high risks for heat (red) or inland flooding (blue) in the 2015-2044 (2030s) scenarios, while those surrounded by dashed circles were only identified as high risks in the 2055-2084 (2070s) scenarios. These priority planning areas should be addressed in the development of the City's Climate Change Preparedness Plan.

Figure 1. Priority planning areas for Public Schools, Daycare, and Youth Centers



Public Schools, Daycare, and Youth Centers in Cambridge are at high risk from both inland flooding and heat.

In the 2030s and 2070s 100-year 24 hour storm scenarios, flooding exceeds the critical thresholds for sensitivity at multiple Public Schools, indicating the potential for multiple closures. Because many public schools also serve as emergency shelters and Daycare, the consequences associated with these lower probability scenarios are high and their risks are worthy of attention.

The 2070s heat scenario also results in broad vulnerability among Public Schools. In addition to high exposure, lack of air conditioning is the major factor influencing which schools are vulnerable to heat. For Youth Centers and Daycare at Affordable Housing facilities, limited system-wide redundancy is a key factor.

High risks / high priorities for preparedness planning are as follows:

Inland Flooding – 2030s

- Daycare at Roosevelt Towers(14 Roosevelt Towers) (R3)
- Tobin School & Daycare (197 Vassal Lane) (R3)
- King Open School & Daycare (850 Cambridge St) (R3)
- Kennedy / Longfellow School & Daycare (158 Spring Street) (R3)
- CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway) (R3)
- Baldwin School & Daycare (28 Sacramento St) (R3)

Heat – 2030s

- King Open School & Daycare (850 Cambridge St) (R4)
- Daycare at YMCA (820 Mass Ave) (R3)
- Daycare at Roosevelt Towers (Low-Rise)(14 Roosevelt Towers) (R3)
- Area IV Youth Center & Daycare (243 Harvard St) (R3)

Inland Flooding – 2070s

- Morse School & Daycare (40 Granite St.) (R3)
- Fletcher/Maynard Academy & Daycare (225 Windsor St) (R3)

Heat – 2070s

- Graham & Parks School & Daycare (44 Linnaean St) (R3)
- Fletcher/Maynard Academy & Daycare (225 Windsor St) (R3)
- CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway) (R3)
- Cambridgeport School & Daycare (89 Elm St) (R3)

B. Summary of Assessment Process and Methods

Selection of Facilities

Public Schools, Daycare, and Youth Centers in Cambridge were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. The final list of facilities assessed in this study is the result of iterative review and revision by the project team and stakeholders.

All Public Schools and Youth Centers were selected for full assessment.

Daycare was a broad category and also included afterschool programs. Eighteen (18) of the fifty eight (58) daycare facilities included in the GIS database provided by the City of Cambridge were assessed as part of this study. This includes all of the daycare facilities noted as being “public” in the database. These Daycare facilities were included because they also served another critical function. For example, daycare facilities or programs were located at almost all Public Schools and several affordable housing facilities.

Twenty-one (21) private and charter schools were also included in the GIS database provided by the City of Cambridge. All private/charter schools were screened for flooding exposure in the 2070s 100-year 24 hour storm scenarios. The following nine private/charter schools were identified as having some direct exposure to flooding in this scenario. However, they were not further assessed to determine their extent of vulnerability. Private and charter schools were not screened or assessed for exposure or vulnerability to heat.

1. Buckingham Browne & Nichols School (80 Gerry's Landing Rd)
2. Cambridge Friends School (5 Cadbury Rd)
3. Cambridge Montessori School (also a Daycare facility)(161 Garden St)
4. International School of Boston (45 Matignon Rd)
5. Castle School (298 Harvard St)
6. Fayerweather Street School (765 Concord Ave)
7. Henry Buckner School (85 Bishop Allen Dr)
8. Community Charter School of Cambridge (Charter school)(245 Bent St)
9. Prospect Hill Academy Upper School (Charter School)(50 Essex St)

Vulnerability and Risk Scoring

The methods and assumptions for scoring the vulnerability and risk of facilities were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

<u>Vulnerability</u> of each facility was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.

- <u>Exposure</u> was assessed based on scenario maps developed for the project (see Attachment 1).
- <u>Sensitivity</u> of facilities was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the facility to fail to function (see Section C for heat & Section D for flooding).
- <u>Adaptive capacity</u> was assessed based on whether facilities had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure (see Section C for heat & Section D for flooding).

<u>Risk</u> is a function of the probability of the scenario occurring and the consequences of the facility failing as a result. Only facilities that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.

- <u>Probability</u> was assessed based on whether facilities were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- <u>Consequence</u> was assessed based on the scale of the service disruption caused by a facility's failure (entire city vs. neighborhood vs. locality) and the potential for their failure to cause cascading impacts (i.e., Public Schools, Daycare, and Youth Centers that were also affordable housing or emergency shelters).

Specific protocols for Public Schools, Daycare, and Youth Centers were developed to standardize assumptions for scoring facilities' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge (see Section C for heat & Section D for flooding).

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed facilities were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 2).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Public Schools, Daycare, and Youth Centers were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC), and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The latest feedback from a workshop with City stakeholders on October 20, 2014, a meeting with TAC members on December 11, 2014, as well as subsequent follow-up has been incorporated. Participants included the City's Department of Public Works, Community Development Department, and Human Services Department. In addition, Cambridge Public Schools Department provided information on the availability of emergency generators and air conditioning at public schools.

Attachments 1 & 2 and the results reported in this memorandum reflect the latest understanding and assumptions.

Sections C & D below report the heat and inland flooding vulnerability and risk assessment results for Public Schools, Daycare, and Youth Centers.

Section E compiles the risk scores for only highly vulnerable facilities.

C. Heat Vulnerability and Risk Assessment

All Public Schools, Daycare, and Youth Centers were assumed to be highly sensitive to ambient air temperatures of 100°F or higher.

The adaptive capacities of Public Schools (including those with onsite Daycare) were assessed as being moderate to high, depending on the known availability of air conditioning or assumed lack thereof. It was assumed that there is adequate system-wide redundancy so that public school students could temporarily relocate to facilities that are not highly vulnerable.

Youth Center and Affordable Housing Daycare facilities were assessed to have moderate adaptive capacity. They were assumed to have air conditioning, but very limited redundancy. This was due to the small number of Youth Centers, and the assumed challenges for low-income users of affordable housing Daycare facilities to arrange alternatives.

Public Schools, Daycare, and Youth Centers that had multiple important roles (i.e. were also affordable housing facilities, or emergency shelters) were assumed to have a higher consequence of failure than others.

The highest risk facilities for heat are documented in Section A of this memorandum, as well as in Table 3a. Table 1 includes the vulnerability scores for all Public Schools, Daycare, and Youth Centers assessed.

In the 2030s scenario, one Public School (King Open School & Daycare), two Daycares at Affordable Housing facilities (YMCA and Roosevelt Towers), and two Youth Centers (Gately Youth Center and Area IV Youth Center & Daycare) were highly vulnerable to heat (V3-V4).

In the 2070s scenario, all of the Public Schools, Daycares at Affordable Housing facilities, and Youth Centers were exposed to ambient air temperatures of 100°F or higher. However, only half of the Public Schools were highly vulnerable to heat due to assumed lack of air conditioning. All of the Daycares and all of the Youth Centers assessed in this study were highly vulnerable to heat in the 2070s scenario due to lack of redundancy.

Assumptions are further documented in the detailed spreadsheet in Attachment 2.

Table 1: Public Schools, Daycare, and Youth Centers vulnerability and risk from heat
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Heat - 2030		Heat - 2070	
Type	Name	Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
		Vulnerability	Risk	Vulnerability	Risk
Affordable Housing / Daycare	808 Memorial Dr (808-812 Memorial Dr)	V1-V2		V3-V4	R2
	YMCA (820 Mass Ave)	V3-V4	R3	V3-V4	R2
	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers)	V3-V4	R3	V3-V4	R2
	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers)	V1-V2		V3-V4	R2
Public Schools	Cambridgeport School & Daycare (89 Elm St)	V1-V2		V3-V4	R3
	Graham & Parks School & Daycare (44 Linnaean St)	V1-V2		V3-V4	R3
	Haggerty School & Daycare (110 Cushing St)	V0		V1-V2	
	Peabody School & Daycare (70 Rindge Ave)	V1-V2		V1-V2	
	Cambridge Rindge & Latin School / Rindge School of Technical Arts (459 Broadway)	V1-V2		V1-V2	
	Rindge & Latin Auto Shop (456 Broadway)	V1-V2		V3-V4	R1
	High School Extension Program & Daycare (15 Upton St)	V1-V2		V3-V4	R2
	Kennedy / Longfellow School & Daycare (158 Spring Street)	V1-V2		V1-V2	
	Tobin School & Daycare (197 Vassal Lane)	V0		V1-V2	
	Morse School & Daycare (40 Granite St.)	V0		V1-V2	
	Fletcher/Maynard Academy & Daycare (225 Windsor St)	V1-V2		V3-V4	R3

	King Open School & Daycare (850 Cambridge St)	V3-V4	R4	V3-V4	R3
	Martin Luther King, Jr School (100 Putnam Ave)	not assessed		not assessed	
	Baldwin School & Daycare (28 Sacramento St)	V0		V1-V2	
	CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway)	V1-V2		V3-V4	R3
	Amigos School (101 Kinnard St)	not assessed		not assessed	
Youth Centers	Gately Youth Center (70R Rindge Ave)	V3-V4	R2	V3-V4	R1
	Area IV Youth Center & Daycare (243 Harvard St)	V3-V4	R3	V3-V4	R2
	Frisoli Youth Center & Daycare (61 Willow St)	V1-V2		V3-V4	R2
	Moore Youth Center & Daycare (11 Gilmore St)	V1-V2		V3-V4	R2
	West Cambridge Youth Center (680 Huron Ave)	V1-V2		V3-V4	R1

D. Inland Flooding Vulnerability and Risk Assessment

The sensitivity of Public Schools, Daycare, and Youth Centers was determined based on whether they were directly exposed to flooding (i.e. flooding in direct contact with the building) as well as building characteristics (doors and windows to basement or first floor). Details on assumptions for specific facilities are included in Attachment 2 (Scoring Spreadsheet).

The adaptive capacities of Public Schools (including those with onsite Daycare) in relation to flooding were assessed to be moderate. They were assumed to lack floodproofing in their design and operations. However, they were assumed to have adequate system-wide redundancy so that public school students could temporarily relocate to facilities that are not highly vulnerable.

Youth Center and Affordable Housing Daycare facilities were assessed to have low adaptive capacity. They were assumed to lack floodproofing and have very limited redundancy. This was due to the small number of Youth Centers, and the assumed limited ability of low-income users of affordable housing Daycare facilities to arrange alternatives.

Public Schools, Daycare, and Youth Centers that had multiple important roles (i.e. were also affordable housing facilities, or emergency shelters) were assumed to have a higher consequence of failure than others.

The highest risk facilities for inland flooding are documented in Section A of this memorandum, as well as in Table 3b. Tables 2a and 2b include the vulnerability scores for all Public Schools, Daycare, and Youth Centers assessed.

10-year 24 hour storm, 2030s and 2070s
Daycare at Roosevelt Towers (Cambridge Head Start and Afterschool Classroom) was the only facility directly exposed to flooding in these scenarios. However the flooding was not sufficient in depth and extent to be expected to cause interior flooding. Still, because of its low adaptive capacity it was assessed to be highly vulnerable (V3-V5).

100-year 24 hour storm, 2030s and 2070s
Five Public Schools (V4) and one Youth Center (V5) were highly vulnerable to flooding (V4 or V5) in the 2030s and 2070s 100-year 24 hour storm scenarios. They include Kennedy/Longfellow School & Daycare, Tobin School & Daycare, King Open School & Daycare, Baldwin School & Daycare, and CRLS 9th Grade Campus/MLK Jr. Elementary School & Daycare, and Area IV Youth Center & Daycare.

One more Public School, Morse School & Daycare, was highly vulnerable to flooding (V5) in the 2070s 100-year 24 hour storm scenario.

Daycare at Roosevelt Towers (Cambridge Head Start and Afterschool Classroom) and Moore Youth Center and Daycare had minor exposure to flooding in the 2030s and 2070s 100-year 24 hour storm scenarios and low adaptive capacity, so were considered highly vulnerable (V3-V5).

In addition, Fletcher/Maynard Academy & Daycare, Frisoli Youth Center & Daycare, and Daycare at the YMCA had minor exposure to flooding in the 2070s 100-year scenario and low adaptive capacity so were considered highly vulnerable (V3-V5).

Assumptions are further documented in the detailed spreadsheet in Attachment 2.

Table 2a: Public Schools, Daycare, and Youth Centers vulnerability and risk from inland flooding by 2030s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Affordable Housing / Daycare	808 Memorial Dr (808-812 Memorial Dr)	V2		V2	
	YMCA (820 Mass Ave)	V2		V2	

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers)	V3-V5	R3	V3-V5	R2
	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers)	V3-V5	R3	V3-V5	R2
Public Schools	Cambridgeport School & Daycare (89 Elm St)	V1		V1	
	Graham & Parks School & Daycare (44 Linnaean St)	V1		V1	
	Haggerty School & Daycare (110 Cushing St)	V1		V1	
	Peabody School & Daycare (70 Rindge Ave)	V1		V1	
	Cambridge Rindge & Latin School / Rindge School of Technical Arts (459 Broadway)	V1		V1	
	Rindge & Latin Auto Shop (456 Broadway)	V1		V1	
	High School Extension Program & Daycare (15 Upton St)	V1		V1	
	Kennedy / Longfellow School & Daycare (158 Spring Street)	V1-V3		V4	R3
	Tobin School & Daycare (197 Vassal Lane)	V1		V4	R3
	Morse School & Daycare (40 Granite St.)	V1-V3		V1-V3	
	Fletcher/Maynard Academy & Daycare (225 Windsor St)	V1		V1-V3	
	King Open School & Daycare (850 Cambridge St)	V1		V4	R3

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
	Martin Luther King, Jr School (100 Putnam Ave)	not assessed		not assessed	
	Baldwin School & Daycare (28 Sacramento St)	V1		V4	R3
	CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway)	V1		V4	R3
	Amigos School (101 Kinnard St)	not assessed		not assessed	
Youth Centers	Gately Youth Center (70R Rindge Ave)	V2		V2	
	Area IV Youth Center & Daycare (243 Harvard St)	V2		V5	R2
	Frisoli Youth Center & Daycare (61 Willow St)	V2		V2	
	Moore Youth Center & Daycare (11 Gilmore St)	V2		V3-V5	R2
	West Cambridge Youth Center (680 Huron Ave)	V2		V2	
Health Centers	Teen Health Center at Cambridge Rindge and Latin	V1		V1-V3	

Table 2b: Public Schools, Daycare, and Youth Centers vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Affordable Housing / Daycare	808 Memorial Dr (808-812 Memorial Dr)	V2		V2	
	YMCA (820 Mass Ave)	V2		V3-V5	R2
	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers)	V3-V5	R3	V3-V5	R2
	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers)	V3-V5	R3	V3-V5	R2
Public Schools	Cambridgeport School & Daycare (89 Elm St)	V1		V2	
	Graham & Parks School & Daycare (44 Linnaean St)	V1		V2	
	Haggerty School & Daycare (110 Cushing St)	V1		V2	
	Peabody School & Daycare (70 Rindge Ave)	V1		V2	
	Cambridge Rindge & Latin School / Rindge School of Technical Arts (459 Broadway)	V1		V2	
	Rindge & Latin Auto Shop (456 Broadway)	V1		V2	
	High School Extension Program & Daycare (15 Upton St)	V1		V2	
	Kennedy / Longfellow School & Daycare (158 Spring Street)	V1-V3		V5	R3
	Tobin School & Daycare (197 Vassal Lane)	V1		V5	R3
	Morse School & Daycare (40 Granite St.)	V1-V3		V5	R3
	Fletcher/Maynard Academy & Daycare (225 Windsor St)	V1		V3-V5	R3
	King Open School & Daycare (850 Cambridge St)	V1-V3		V5	R3
	Martin Luther King, Jr School (100 Putnam Ave)	not assessed		not assessed	

	Baldwin School & Daycare (28 Sacramento St)	V1		V5	R3
	CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway)	V1		V5	R3
	Amigos School (101 Kinnard St)	not assessed		not assessed	
Youth Centers	Gately Youth Center (70R Rindge Ave)	V2		V2	
	Area IV Youth Center & Daycare (243 Harvard St)	V2		V5	R2
	Frisoli Youth Center & Daycare (61 Willow St)	V2		V3-V5	R2
	Moore Youth Center & Daycare (11 Gilmore St)	V2		V3-V5	R2
	West Cambridge Youth Center (680 Huron Ave)	V2		V2	
Health Centers	Teen Health Center at Cambridge Rindge and Latin	V1		V1-V3	

E. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the facility failing as a result. Only facilities that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 3a and 3b below. Facilities with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

In Table 3a, the “High Probability” column indicates which facilities are highly vulnerable and their corresponding risk scores under the 2030s heat scenario. The “Low Probability” column contains the same information but corresponds with the 2070s heat scenario.

In Table 3b – Risk ranking summary for inland flooding – the “High Probability” column indicates which facilities are highly vulnerable and their corresponding risk scores under the 10-year 24 hour storm scenarios of the 2030s and 2070s. The “Low Probability” column contains the same information but corresponds with the 100-year 24 hour storm scenarios of the 2030s and 2070s. Facilities with “(2070)” next to their names were assessed to be highly vulnerable in the 2070s scenario, but not the 2030s.

Assumptions are further documented in the detailed spreadsheet in Attachment 2.

Table 3a: Risk ranking summary for heat
(R4 – Highest Risk, R1 – Lowest Risk)

<table>
<tr><th colspan="2"></th><th colspan="2">Probability</th></tr>
<tr><th colspan="2"></th><th>Low</th><th>High</th></tr>
<tr><td rowspan="3">Consequence</td><td>High</td><td>Score R3
• King Open School & Daycare (850 Cambridge St)
• Graham & Parks School & Daycare (44 Linnaean St)
• Fletcher/Maynard Academy & Daycare (225 Windsor St)
• CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway)
• Cambridgeport School & Daycare (89 Elm St)</td><td>Score R4
• King Open School & Daycare (850 Cambridge St)</td></tr>
<tr><td>Medium</td><td>Score R2
• Daycare at YMCA (820 Mass Ave)
• Daycare at Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers)
• Daycare at Roosevelt Towers (Low-Rise)(14 Roosevelt Towers)
• Daycare at 808 Memorial Dr (808-812 Memorial Dr)
• Moore Youth Center & Daycare (11 Gilmore St)
• Frisoli Youth Center & Daycare (61 Willow St)
• Area IV Youth Center & Daycare (243 Harvard St)
• High School Extension Program (15 Upton St)</td><td>Score R3
• Daycare at YMCA (820 Mass Ave)
• Daycare at Roosevelt Towers (Low-Rise)(14 Roosevelt Towers)
• Area IV Youth Center & Daycare (243 Harvard St)</td></tr>
<tr><td>Low</td><td>Score R1
• West Cambridge Youth Center (680 Huron Ave)
• Rindge & Latin Auto Shop (456 Broadway)
• Gately Youth Center (70R Rindge Ave)</td><td>Score R2
• Gately Youth Center (70R Rindge Ave)</td></tr>
</table>

Table 3b: Risk ranking summary for flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	High	**Score R3** • Tobin School & Daycare (197 Vassal Lane) • King Open School & Daycare (850 Cambridge St) • Kennedy / Longfellow School & Daycare (158 Spring Street) • CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway) • Baldwin School & Daycare (28 Sacramento St) • Morse School & Daycare (40 Granite St.) (2070) • Fletcher/Maynard Academy & Daycare (225 Windsor St) (2070)	**Score R4**
Consequence	Medium	**Score R2** • Daycare at Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers) • Daycare at Roosevelt Towers (Low-Rise)(14 Roosevelt Towers) • Area IV Youth Center & Daycare (243 Harvard St) • Moore Youth Center & Daycare (11 Gilmore St) • Frisoli Youth Center & Daycare (61 Willow St) (2070) • Daycare at YMCA (820 Mass Ave) (2070)	**Score R3** • Daycare at Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers) • Daycare at Roosevelt Towers (Low-Rise)(14 Roosevelt Towers)
Consequence	Low	**Score R1**	**Score R2**

*(2070) indicates that a facility is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA)

Technical Memorandum: Pharmacy, Food Assistance, & Municipal Resources

Prepared by Kleinfelder, 2-26-2015

A. Summary of Key Findings and High-Risk Priority Planning Areas

Pharmacy

Pharmacies were only assessed with respect to vulnerability and risk from inland flooding. Pharmacies are not highly vulnerable or at risk from flooding in the 10-year 24 hour storm scenarios. Of the fourteen Pharmacies included in the GIS database provided by the City, only one, Walgreens Pharmacy 6767 (625 Mass Ave), was highly vulnerable to flooding (V4) and this was only in the 100-year 24 hour storm scenarios of the 2030s and 2070s. Due to the moderate consequences and lower probability of the scenarios, the risk for this facility is relatively low (R2).

The following Pharmacies were assessed as having some direct exposure to flooding, but **not enough to exceed critical thresholds** for failure:

<u>10-year 24 hour storm, 2070s</u>

- Inman Pharmacy (1414 Cambridge St) – also exposed in the 2070s 10-year 24 hour storm scenario

<u>100-year 24 hour storm, 2030s</u>

- Walgreens Pharmacy (822 Somerville Ave)
- CVS Pharmacy 717 (36 White St)

<u>100-year 24 hour storm, 2070s</u>

- Skenderian Pharmacy (1613 Cambridge St)
- CVS Pharmacy 1022 (215 Alewife Brook Pkwy)

Assumptions are further documented in the detailed spreadsheet in Attachment 2.

Table 1a: Pharmacy vulnerability and risk from inland flooding by 2030s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	**Name**	**Vulnerability**	**Risk**	**Vulnerability**	**Risk**
Pharmacy	Rite Aid Pharmacy 10159 (330 River St)	V1		V1	
	CVS Pharmacy 240 (1426 Massachusetts Ave)	V1		V1	
	CVS Pharmacy 1002 (624 Massachusetts Ave)	V1		V1	
	CVS Pharmacy 1262 (29 JFK St)	V1		V1	
	Rite Aid Pharmacy 10158 (1740 Massachusetts Ave)	V1		V1	
	Osco Pharmacy (699 Mount Auburn St)	V1		V1	
	CHA Cambridge Hospital Campus (1493 Cambridge St)	V1		V1	
	Colonial Drug, (49 Brattle St)	V1		V1	
	Inman Pharmacy (1414 Cambridge St)	V1		V1-V3	
	Skenderian Pharmacy (1613 Cambridge St)	V1		V1	
	Walgreens Pharmacy 6767 (625 Mass Ave)	V1		V4	R2
	Walgreens Pharmacy (822 Somerville Ave)	V1		V1-V3	
	CVS Pharmacy 717 (36 White St)	V1		V1-V3	
	CVS Pharmacy 1022 (215 Alewife Brook Pkwy)	V1		V1	

Table 1b: Pharmacy vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Pharmacy	Rite Aid Pharmacy 10159 (330 River St)	V1		V1	
	CVS Pharmacy 240 (1426 Massachusetts Ave)	V1		V1	
	CVS Pharmacy 1002 (624 Massachusetts Ave)	V1		V1	
	CVS Pharmacy 1262 (29 JFK St)	V1		V1	
	Rite Aid Pharmacy 10158 (1740 Massachusetts Ave)	V1		V1	
	Osco Pharmacy (699 Mount Auburn St)	V1		V1	
	CHA Cambridge Hospital Campus (1493 Cambridge St)	V1		V1	
	Colonial Drug, (49 Brattle St)	V1		V1-V3	
	Inman Pharmacy (1414 Cambridge St)	V1-V3		V1-V3	
	Skenderian Pharmacy (1613 Cambridge St)	V1		V1-V3	
	Walgreens Pharmacy 6767 (625 Mass Ave)	V1		V4	R2
	Walgreens Pharmacy (822 Somerville Ave)	V1		V1-V3	
	CVS Pharmacy 717 (36 White St)	V1		V1-V3	
	CVS Pharmacy 1022 (215 Alewife Brook Pkwy)	V1		V1-V3	

Table 1c: Pharmacy risk ranking summary for flooding
(R4 – Highest Risk, R1 – Lowest Risk

		Probability	
		Low	High
Consequence	High	Score R3	Score R4
	Medium	Score R2 • Walgreens Pharmacy 6767 (625 Mass Ave)	Score R3
	Low	Score R1	Score R2

Food Assistance
Food Assistance facilities were only assessed with respect to vulnerability and risk from inland flooding. Twenty one (21) facilities where Food Assistance programs were located were included in the GIS database provided by the City of Cambridge. All of these facilities were screened for inland flooding exposure in the 2070s 100-year 24 hour storm scenario (the most severe flooding scenario). Seven of the 21 Food Assistance facilities were identified as having some direct exposure to flooding in this scenario. These seven were fully assessed across all four flooding scenarios.

The results indicate that the following Food Assistance facilities are at high risk from inland flooding under the noted scenarios. Their risk scores (R) are included in parenthesis:

10-year 24 hour storm, 2030s and 2070s

- Margaret Fuller Neighborhood House (71 Cherry St) (R3)
- Salvation Army/Daily Lunch (402 Mass Ave) (R3)
- WIC Program Services (119 Windsor St) (R3)

Two Food Assistance facilities were highly vulnerable to flooding in the 100-year 24 hour storm, 2030s and 2070s, but did not have a high risk score: St. Paul AME Food Pantry (85 Bishop Allen Dr) (R2) and Project Uplift Thursday Night Dinner (874 Main St) (R1).

In addition, two other Food Assistance facilities were exposed to flooding, but not enough to exceed critical thresholds for failure: Western Ave Baptist Church (2030s 100-year scenario) and Cambridge Senior Center Meals Program (2070s 100-year scenario).

The Food Assistance facilities that did not have exposure to flooding in the scenarios included the following:

- East End House (105 Spring St)
- CEOC Food Pantry/Food For Free (11 Inman St)
- Project Manna Mass Ave Baptist Church (146 Hampshire St)
- Zinberg Clinic Pantry, Cambridge Hospital (1493 Cambridge St)
- Helping Hand Food Pantry (1991 Massachusetts Ave)
- Tuesday Meal Program (3 Church St)
- Faith Kitchen (311 Broadway)
- Loaves and Fishes Meal Program (35 Magazine St)
- St. James Church (362 Rindge Ave)
- Cambridgeport Baptist Church Food Pantry & Clothes Closet (459 Putnam Ave)
- Bread and Jams Self-Advocacy Center (50 Quincy)
- Summer Food Service Program (51 Inman St)
- Community Care/St. Peter's Episcopal Church (838 Massachusetts Ave)
- Harvard Square Thursday Night Meal Program (0 Garden St)

Assumptions are further documented in the detailed spreadsheet in Attachment 3.

Table 2a: Food Assistance vulnerability and risk from inland flooding by 2030
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2030			
		10 yr 24-hr (5.6 in.)		100 yr 24-hr (10.2 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Food Assistance	Cambridge Senior Center Meals Program (806 Mass Ave)	V1		V1	
	Margaret Fuller Neighborhood House (71 Cherry St)	V4	R3	V4	R2
	Salvation Army / Daily Lunch (402 Mass Ave)	V4	R3	V4	R2
	Western Avenue Baptist Church (299 Western Ave)	V1		V1-V3	
	WIC Program Services (119 Windsor St - Public Health Dept)	V4	R3	V4	R2
	St. Paul AME Food Pantry (85 Bishop Allen Dr)	V1		V4	R2
	Project Uplift Thursday Night Dinner (874 Main St)	V1		V4	R1

Table 2b: Food Assistance vulnerability and risk from inland flooding by 2070s
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Flooding - 2070			
		10 yr 24-hr (6.4 in.)		100 yr 24-hr (11.7 in.)	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Food/Nutrition	Cambridge Senior Center Meals Program (806 Mass Ave)	V1		V1-V3	
	Margaret Fuller Neighborhood House (71 Cherry St)	V4	R3	V4	R2
	Salvation Army / Daily Lunch (402 Mass Ave)	V4	R3	V4	R2
	Western Avenue Baptist Church (299 Western Ave)	V1		V1-V3	
	WIC Program Services (119 Windsor St - Public Health Dept)	V4	R3	V4	R2
	St. Paul AME Food Pantry (85 Bishop Allen Dr)	V1		V4	R2
	Project Uplift Thursday Night Dinner (874 Main St)	V1-V3		V4	R1

Table2c: Food Assistance risk ranking summary for flooding
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	Score R3	Score R4
	Medium	Score R2 • Margaret Fuller Neighborhood House (71 Cherry St) • Salvation Army/Daily Lunch (402 Mass Ave) • WIC Program Services (199 Windsor St) • St. Paul AME Food Pantry (85 Bishop Allen Dr)	Score R3 • Margaret Fuller Neighborhood House (71 Cherry St) • Salvation Army/Daily Lunch (402 Mass Ave) • WIC Program Services (199 Windsor St)
	Low	Score R1 • Project Uplift Thursday Night Dinner (874 Main St)	Score R2

*(2070) indicates that an asset is highly vulnerable in the 2070s scenarios, but not in the 2030s scenarios.

Municipal Resources

A limited number of Municipal buildings were assessed as part of the Social Environment analysis. These included City Hall, City Hall Annex, and the Human Services Department building (51 Inman St).

None of these buildings had any direct exposure to inland flooding in the 2030s or 2070s scenarios. Therefore they do not have a high vulnerability or pose a risk from inland flooding.

None of the Municipal buildings were exposed to ambient air temperatures above their critical thresholds (100°F) in the 2030s heat scenario, but all three were in the 2070s scenario. City Hall Annex in particular was exposed to high heat island effects with temperature >110°F. However, due to redundancy between the City Hall and City Hall Annex, and a lack of redundancy for the Human Services Department building, only the **Human Services Department building** was assessed to be highly vulnerable (V3-V4) and high risk **(R3)** from heat.

Assumptions are further documented in the detailed spreadsheet in Attachment 4.

Table 3: Municipal Resources vulnerability and risk from heat
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		Heat - 2030		Heat - 2070	
		Scenario: 4-day >90 F heatwave		Scenario: 5-day >90 F heatwave with 3 days > 100 F	
Type	Name	Vulnerability	Risk	Vulnerability	Risk
Municipal Resources	City Hall (795 Massachusetts Ave)	V0		V1-V2	
	City Hall Annex (344 Broadway)	V0		V1-V2	
	Human Services Department (51 Inman St)	V1-V2		V3-V4	R3

Table3c: Municipal risk ranking summary for heat
(R4 – Highest Risk, R1 – Lowest Risk

		Probability	
		Low	High
Consequence	High	Score R3 • Human Services Department (51 Inman St)	Score R4
	Medium	Score R2	Score R3
	Low	Score R1	Score R2

B. Summary of Assessment Process and Methods

Selection of Assets
Pharmacies, Food Assistance, and Municipal Resources facilities were identified based on review of GIS infrastructure databases and collection of information from stakeholders, including key experts. Assets were screened to ensure that the vulnerability assessment focused on the most important assets in the system. Specific screening applied to each type of assets (i.e., Pharmacy vs. Food Assistance vs. Municipal Resources) are described in the relevant sections of this memorandum. The final list of assets assessed in this study is the result of iterative review and revision by the project team and stakeholders.

Vulnerability and Risk Scoring
The methods and assumptions for scoring the vulnerability and risk of assets were developed around the ICLEI ADAPT framework. (http://www.icleiusa.org/tools/adapt)

Vulnerability of each asset was scored for based on whether it was exposed to heat or inland flooding, its degree of sensitivity to the impact, and its degree of adaptive capacity.

- Exposure was assessed based on scenario maps developed for the project (see Attachment 1).
- Sensitivity of assets was assessed under each scenario according to whether critical thresholds for exposure were exceeded that would cause the asset to fail to function.
- Adaptive capacity was assessed based on whether assets had technological or operational protections in place and system-wide redundancy to help mitigate or cope with the impacts of exposure.

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario were further assessed for risk.

- Probability was assessed based on whether assets were highly vulnerable under the less likely (more extreme) and more likely (less extreme) scenarios.
- Consequence was assessed based on the scale of the service disruption caused by an asset's failure (entire city vs. neighborhood vs. locality) and the potential for their failure to cause cascading impacts on other assets within or across systems.

Specific protocols for facilities were developed to standardize assumptions for scoring assets' sensitivity, adaptive capacity, probability and consequence of failure for the City of Cambridge.

Exposure, sensitivity, adaptive capacity, vulnerability, probability, consequence, and risk of assessed assets were documented in spreadsheets to allow for a transparent scoring process that can be reviewed and revised by stakeholders (see Attachment 2-4).

Integration of Stakeholder Feedback

Scenarios, protocols, and spreadsheets for Transit infrastructure were reviewed with the project Steering Committee (STC), Technical Advisory Committee (TAC), and other public and private stakeholders, and iteratively revised throughout the assessment to reflect the most up to date information. The latest feedback from a workshop with City stakeholders on October 20, 2014, a meeting with TAC members on December 11, 2014, as well as subsequent follow-up has been incorporated. Participants included the City's Department of Public Works, Community Development Department, Human Services Department, and Public Health Department.

C. Risk Assessment Compilation

Risk is a function of the probability of the scenario occurring and the consequences of the asset failing as a result. Only assets that were identified as being highly vulnerable (i.e., those that might fail) in a given scenario are included in the compiled risk assessment results in Table 1c, 2c, and 3c above. Assets with scores of R3 to R4 are most at risk for the City and have been reported as high priority planning areas for the City to address climate change.

In Table 1c and 2c in the sections above the "High Probability" column indicates which assets are highly vulnerable and their corresponding risk scores under the 10-year 24 hour storm scenarios of the 2030s and 2070s. The "Low Probability" column contains the same information but corresponds with the 100-year 24 hour storm scenarios of the 2030s and 2070s. Assets with "(2070)" next to their names were assessed to be highly vulnerable in the 2070s scenario, but not the 2030s.

In Table 3c, the "High Probability" column indicates which facilities are highly vulnerable and their corresponding risk scores under the 2030s heat scenario. The "Low Probability" column contains the same information but corresponds with the 2070s heat scenario.