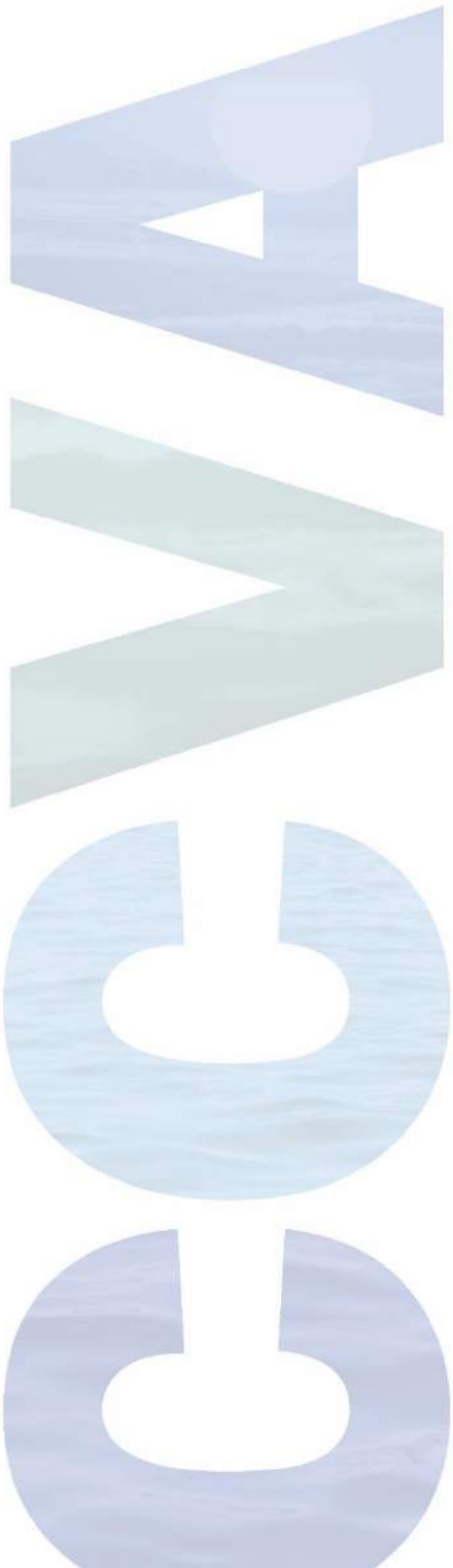
Sea Level Rise and Coastal Storm Surge Vulnerability Assessment



Climate Change Vulnerability Assessment

Part 2 – Sea Level Rise and Storm Surge

City of Cambridge, Massachusetts

April 2017

Disclaimer: The CCVA Part 2 Vulnerability Assessment is based on best available information for sea level rise and storm surge projections at the time the analysis was conducted. It is also informed by the CCVA Part 1 key findings as published on November 2015. Updates will be provided as new information is made available and key findings re-assessed accordingly.

Acknowledgments

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

Technical Reports

Critical Infrastructure and Community Resources, Kleinfelder, 2017

Vulnerable Populations, Kleinfelder, 2017

Executive Summary

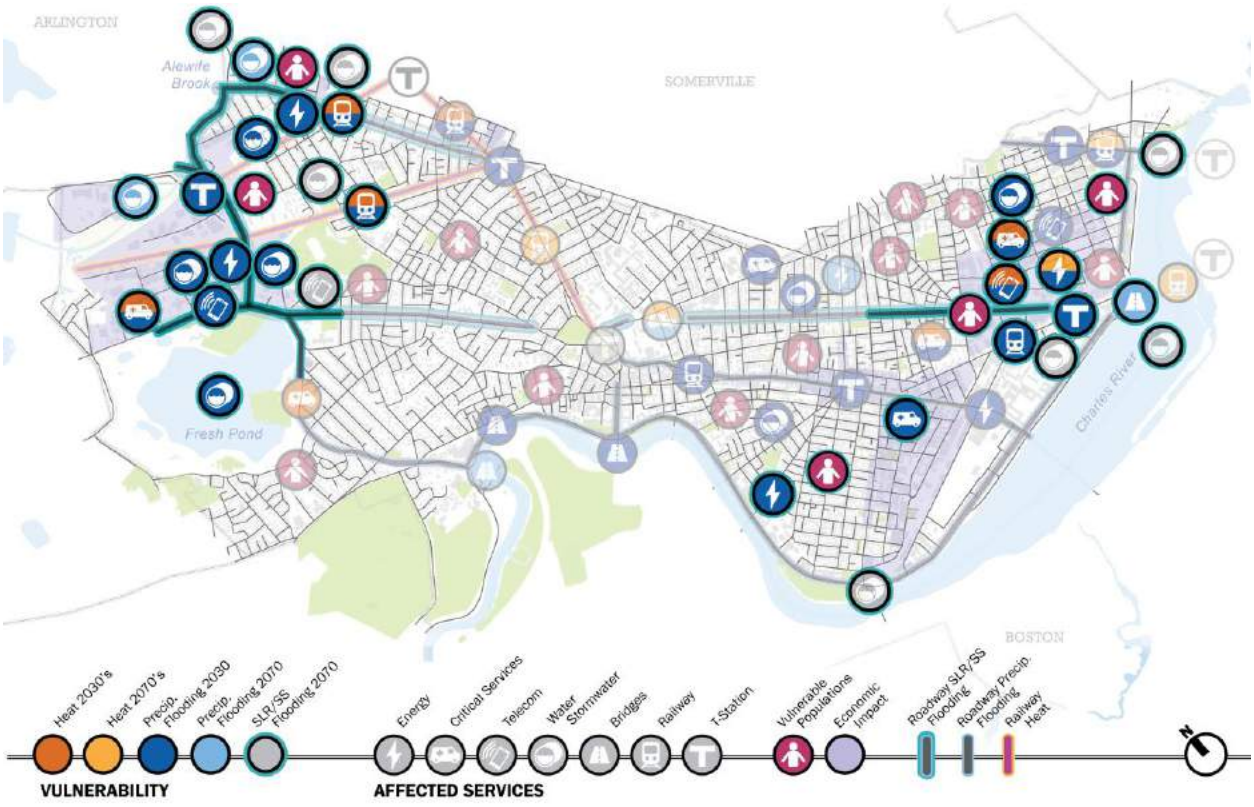
The Climate Change Vulnerability Assessment (CCVA) Part 1 identified Cambridge's future risks from extreme heat and precipitation-driven flooding. This Part 2 report assesses the potential impacts and risks from Sea Level Rise and Storm Surge (SLR/SS).

Those elements identified as the most at-risk in CCVA Part 1 and Part 2 will become the primary focus of the *Climate Change Preparedness and Resilience Plan*.

The key findings from the Vulnerability and Risk Assessments for Sea Level Rise and Storm Surge are as follows:

- Cambridge's coastal storm surge protections will likely hold until at least 2030. Cambridge will face significantly increased risks of flooding from sea level rise and coastal storm surges in the longer-term. The Amelia Earhart Dam on the Mystic River will fail before the Charles River Dam.
- The Alewife area will experience increased risk of SLR/SS flooding earlier than neighborhoods abutting the Charles River.
- Critical infrastructure systems – energy, roadways, public transit, telecommunications, critical service facilities, and water/wastewater systems – located in the Fresh Pond-Alewife area and in low-lying areas of the City linked to the Charles River are at increased risk from SLR/SS flooding after 2030.
- The Fresh Pond-Alewife area is an area of particular concern due to the high probability of SLR/SS flooding and high depth of flooding that could significantly impact socially vulnerable populations, critical infrastructure, and community resources.
- The stormwater and combined wastewater systems will likely be significantly impacted by SLR/SS flooding as there are additional areas that are likely to reach capacity and fail due to SLR/SS flooding compared to precipitation driven flooding alone.
- Climate change threatens regional systems that Cambridge depends on, such as energy distribution and transportation networks. A significant level of coordination and cooperation will be required among agencies, cities, the state, businesses, institutions, and residents to effectively prepare for the long-term effects of climate change.

- Socially vulnerable populations will likley be particularly burdened by potential public health and safety impacts, economic losses, and displacement caused by SLR/SS flooding in their communities.
- The most likely vulnerable populations to be affected by SLR/ SS flooding are located:
  - in the Fresh Pond-Alewife area exposed to flooding of the Mystic River/ Alewife Brook
  - in the low-lying areas of Riverside due to flood water backing up through stormwater pipes due to the higher tailwater elevations in the Charles River.



Map 1: Planning Priority Areas Map (Source: Kleinfelder, April 2017)

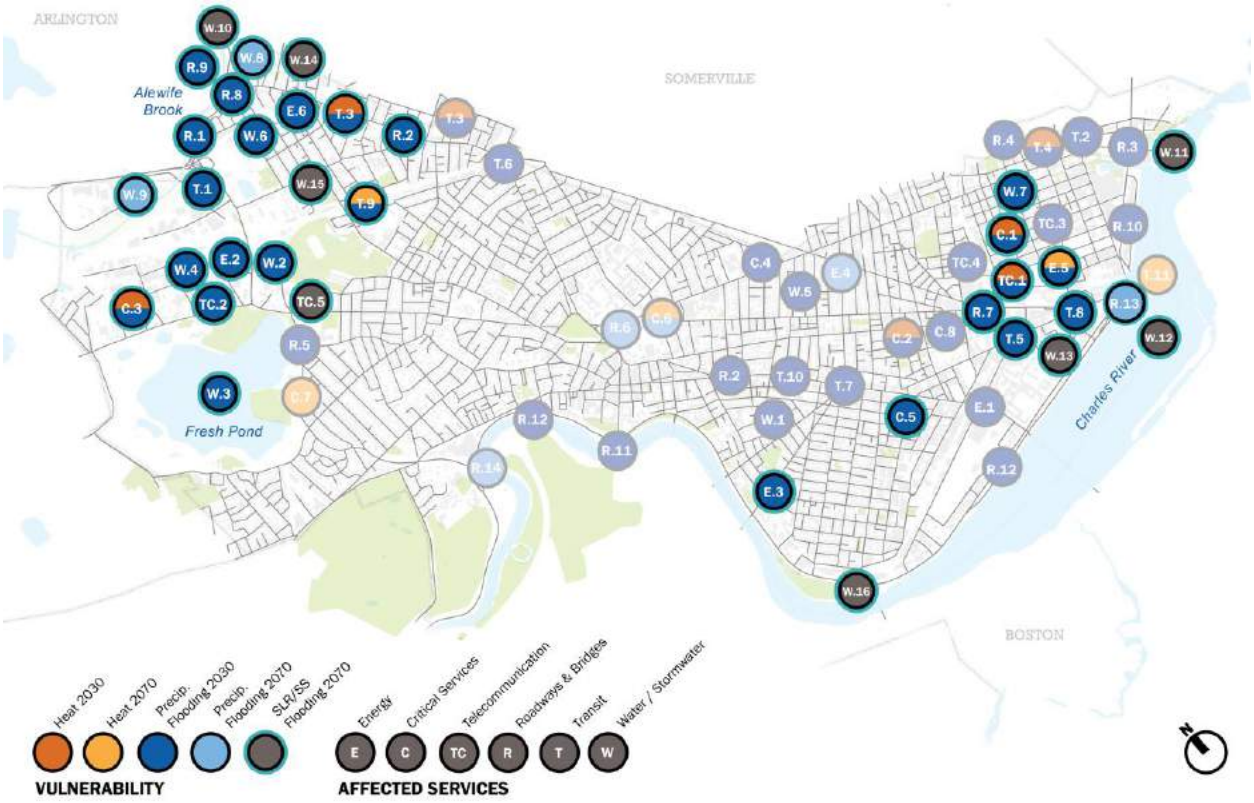
The Priority Planning Areas Map (Map 1) -- created as part of CCVA Part 1 --- has been updated to reflect the findings of the SLR/SS vulnerability assessment. The Affected Services and Vulnerable Populations at risk for SLR/SS flooding have been identified. The Planning Priority Areas represent the areas most at-risk with respect to climate change impacts within the boundaries of Cambridge by illustrating a concentration of disrupted services, populations and economic impacts. It represents a risk assessment that compares seemingly unrelated

resources, such as public health and the transportation system, and compares the risks within each (e.g., what is the greatest public health concern?) as well as between them (e.g., how does the risk of an overheated school rate against the risk of a flooded MBTA station?). Services and vulnerable populations impacted by SLR/SS flooding are mostly concentrated in the Fresh Pond-Alewife area and the Riverside and East Cambridge neighborhoods.

Flooding can cause physical damage to buildings and infrastructure, which could make areas inaccessible and create public safety hazards. Damages tend to increase with longer duration flooding, which could occur if the pumps at the Charles River Dam and Amelia Earhart Dam are not able to function properly during and after a storm. Salt water flooding from SLR/SS also has the potential to cause long-term impacts to vulnerable local and regional infrastructure, such as the MBTA Red Line, due to its corrosive effects. Contamination from salt water or hazardous pollutants could also cause damages to water resources, such the Fresh Pond Reservoir. The potential for salt water flooding from SLR/SS flooding in the Alewife area and in flooding propagated through the stormwater drainage system in the Port, East Cambridge, and Riverside neighborhoods has not yet been determined. Further analyses will be performed to assess this additional risk

The impacts of SLR/SS flooding transcend municipal boundaries. Cambridge and neighboring municipalities rely on regional systems outside of their direct control for energy distribution, transportation netowrks, and food services, among others. When regional infrastructure outside of Cambridge is impacted, Cambridge will likely feel the effects. Similarly, impacts to infrastructure in Cambridge can have ripple effects elsewhere in the region. Regional coordination among cities, agencies, and organizations on adaptation planning and implementation will be needed to address these systemic risks.

Most At-Risk Infrastructure



Map 2: Most At-Risk Infrastructure (Source: Kleinfelder, April 2017)

All infrastructure systems have assets impacted by SLR/SS, most of them being in the Alewife area and East Cambridge neighborhood. SLR/SS flooding occurs in Cambridge when the Amelia Earhart Dam on the Mystic River and the Charles River Dam are flanked and/or overtopped. Most infrastructure assets identified as being at risk for SLR/SS are also at risk for flooding caused by precipitation. However, there are some additional assets and areas in the drinking water, stormwater and combined sewer infrastructure systems that are at high-risk (risk scores of R3 and R4 as defined in Appendix 1) from SLR/SS flooding. SLR/SS flooding could present a significant challenge for the City in terms of both infrastructure and vulnerable populations, and will most likely have regional implications as well. Mitigating some of these flooding risks will require a coordinated approach for adaptation measures at both the Citywide and regional scales.

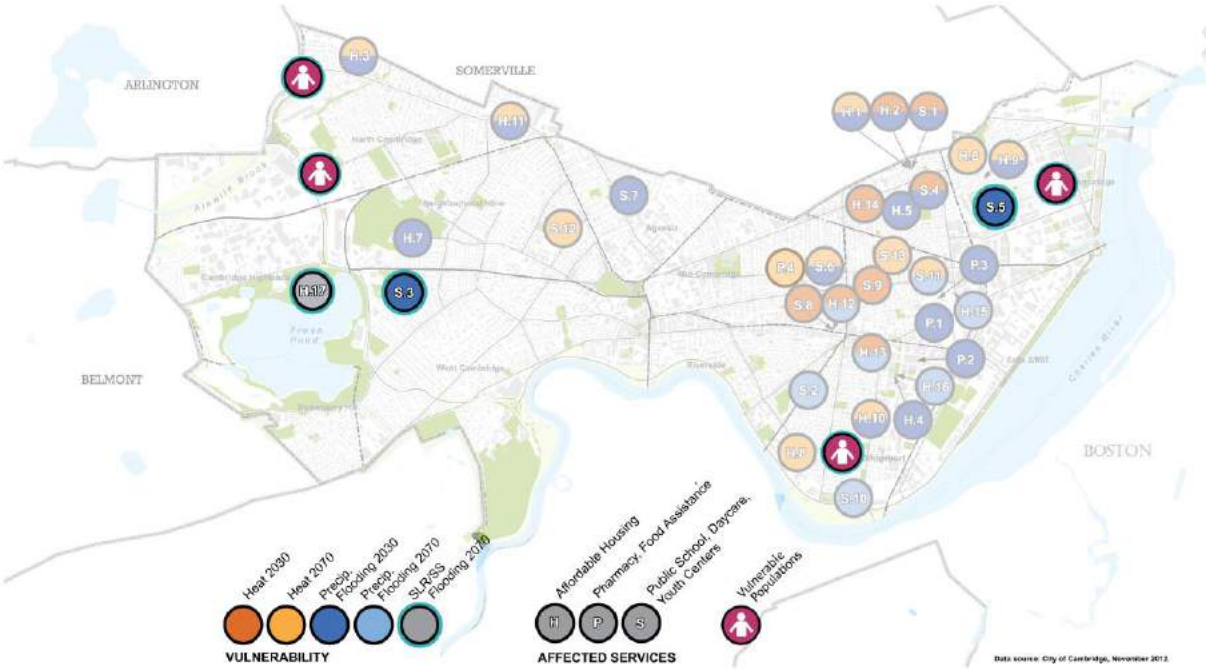
		Asset	Heat		Precip. Flood		SLR/ SS Flood
			2030	2070	2030	2070	2070
Energy	E.1	MIT Co-generation Plant					
	E.2	North Cambridge Substation					
	E.3	Putnam Substation					
	E.4	Prospect Substation					
	E.5	Third Street Regulator Station – natural gas					
	E.6	Brookford Street Take Station – natural 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)					
	TC.5	Concord Ave Antenna Tower					
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)					
	W.10	Alewife Brook					
	W.11	Charles River Dam					
	W.12	Charles River					
	W.13	Ames Wadsworth (Charles, Separated)					
	W.14	CAM 002/002A (Alewife Combined)					
	W.15	CAM 401 A/B (Alewife Combined)					
	W.16	Cottage Farm Pump Station					

Table 1a: Most At-Risk Infrastructure (Source: Kleinfelder, April 2017)

	Asset		Heat		Precip. Flood		SLR/ SS Flood
			2030	2070	2030	2070	2070
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	Harvard - Central Rail line (Red)					
	T.11	Kendall - Charles MGH Rail Line (Red)					

Table 1b: Most At-Risk Infrastructure (Source: Kleinfelder, April 2017)

Most at Risk Community Resources



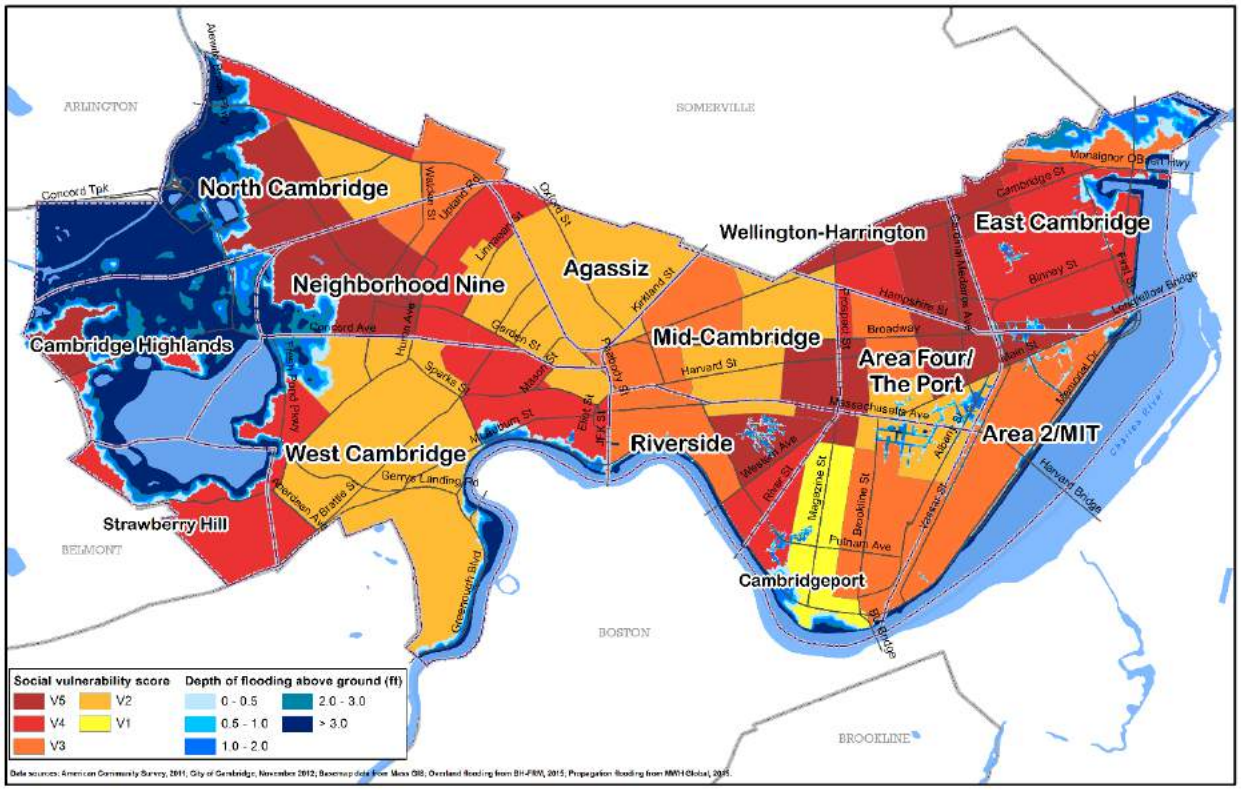
Map 2: Community Resources Priority Areas (Source: Kleinfelder, April 2017)

Only three key community resource facilities have a high risk of flooding impact from SLR/SS in 2070: the Neville Center (a nursing and rehabilitation facility) on Concord Avenue and the Tobin School and Daycare, both in the Alewife area, and the Kennedy/ Longfellow School in East Cambridge. The Tobin School and Daycare is the only one of these facilities with a high probability of being directly exposed to high depths of flooding. Neville Center faces a high risk of becoming temporarily inaccessible due to flooding on Concord Avenue. The Kennedy/Longfellow School could be exposed to flooding due to SLR/SS flood water being propagated through the stormwater drainage system, but only in low probability events.

		Asset	Heat		Precip. Flood		SLR/ SS Flood
			2030	2070	2030	2070	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					
	H.17	Neville Center (650 Concord Ave), 57 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)					

Table 2: Most At-Risk Community Resources (Source: Kleinfelder, April 2017)

Vulnerable Populations



Map 4. Social Vulnerability Scores and 1% Probability SLR/SS Flood Depths in 2070
(Source: Kleinfelder, April 2016)

As illustrated in Map 4, socially vulnerable populations in the Fresh Pond-Alewife area and the Riverside neighborhood may be disproportionately exposed to flooding from SLR/SS in 2070. The Fresh Pond-Alewife area is exposed to higher probability of SLR/SS flooding, primarily from overland flooding of the Alewife Brook as a result of flanking and overtopping of the Amelia Earhart Dam. Projected depths of flooding from SLR/SS in the Fresh Pond-Alewife area are higher and more extensive than for flooding from precipitation and could be more disruptive to vulnerable populations. Low-lying areas of the Riverside neighborhood could also experience SLR/SS flooding, but only in extreme scenarios (i.e., 1% annual probability) where flood water backs up through the City's drainage system due to higher tailwater elevations in the Charles River.

The failure of critical infrastructure systems and community resources caused by SLR/SS flooding are also likely to occur at a regional scale. Consequently, disruptions to key services, from transit to nutrition assistance, are likely to be more significant and take longer to recover

from. Longer recovery times would likely have greater consequences for populations in Cambridge that were already coping with higher levels of social vulnerability.

For additional details about the SLR/SS vulnerability and risk assessments, including methodologies used and results, please refer to the following reports attached to the Executive Summary:

- **Appendix 1 – Technical Memorandum: Critical Infrastructure and Community Resources**, Kleinfelder, 2017
- **Appendix 2 – Technical Memorandum: Vulnerable Populations**, Kleinfelder, 2017

Appendix 1

Critical Infrastructure and Community Resources

Climate Change Vulnerability Assessment

Part 2 – Sea Level Rise and Storm Surge

City of Cambridge, Massachusetts

April 2017

Disclaimer: The CCVA Part 2 Vulnerability Assessment is based on best available information for sea level rise and storm surge projections. It is also informed by the CCVA Part 1 key findings as published on November 2015. Updates will be provided as new information is made available and key findings re-assessed accordingly.

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT
PART 2 - SEA LEVEL RISE AND STORM SURGE

Technical Memorandum: Critical Infrastructure and Community Resources

Prepared by Kleinfelder, 04-18-2016, Updated 04-21-2017

This Technical Memorandum describes the vulnerabilities and risks facing critical infrastructure and community resources in Cambridge due to Sea Level Rise and Storm Surge (SLR/SS). In each section, the sources of highest risk are identified per system, including asset-level risks and potentials for cascading failures and regional disruptions. These key findings will inform priority planning areas to be addressed in Cambridge' Preparedness & Resiliency Plan.

In addition to key findings, this memo describes the methodologies used to develop SLR/SS vulnerability and risk scores for each asset assessed. The scoring protocols used in the Climate Change Vulnerability Assessment (CCVA) Part 1 to assess the impacts of precipitation-driven flooding were used again for the purposes of assessing SLR/SS impacts, with the exception that the probability of flooding was assessed and scored differently (as described below). The scoring protocols from Part 1 were reviewed with key stakeholders and are documented in the Vulnerability and Risk Assessment Technical Report attachments. To avoid repetition, they are not attached to this memo.

This Technical Memorandum is organized as follows:

A. Methodology
B. Key Findings and High Risk Priority Planning Areas for Critical Infrastructure
C. Key Findings and High Risk Priority Planning Areas for Community Resources

A. Methodology

The vulnerability and risk scoring framework used in the CCVA is an adapted version of the ICLEI ADAPT tool (http://www.icleiusa.org/tools/adapt). The main concepts underlying that framework include vulnerability (as a function of exposure, sensitivity, and adaptive capacity) and risk (as a function of probability and consequence).

To ensure that the data and methods used were transparent, and the results were reproducible, all vulnerability and risk scoring data, notes, assumptions, and results were documented in spreadsheets organized by system and submitted along with this report.

Selection of Assets

All critical assets that were assessed for vulnerability and risk in CCVA Part 1 were assessed for flooding from SLR/SS in Part 2. Details on the selection process of critical assets and community resources, including stakeholder engagement, are described in CCVA Part 1 Technical Report: Vulnerability and Risk Assessment: Ranking Reports Critical Assets and Resources[1].

Vulnerability Assessment

The SLR/SS modeling results from the Boston Harbor - Flood Risk Model (BH-FRM) indicate that that the probability of SLR/SS flooding reaching Cambridge by 2030 is very low (less than 0.1%). Based on this, the vulnerability and risk assessment for SLR/SS flooding has only been conducted for the 2070 scenario.

Exposure is the extent to which an asset is directly influenced by a climate change impact, in this case SLR/SS flooding. Flood exposure was assessed based on the 2070 1% annual probability SLR/SS scenario. Overland flooding was modeled using the BH-FRM. In addition, flooding from storm surge propagating or "backing up" through the City's drainage and combined sewer pipes was modeled using the ICM-2D model (assuming no rainfall). The overland and propagated flood modeling results were merged into one combined flooding scenario map, which was then used to assess the exposure of each critical asset. The maximum depth of flooding in direct contact with each asset under this scenario was determined using GIS. The assets that were only exposed to flooding from propagation through the City's piped infrastructure were marked with an asterisk in the assessment spreadsheets for later reference.

Sensitivity is the extent to which an asset's functionality is impacted by flooding in a given scenario. The method used to assess sensitivity recognizes that functionality can be affected by both direct impacts (e.g., critical equipment damage) and indirect impacts (e.g., loss of transportation access). Sensitivity scores (S), ranging from S0 (not affected) to S4 (greatly affected), were assigned to each asset based on a comparison of their exposure (e.g., depth of flooding) to critical thresholds for their functional degradation or failure. Standardized critical thresholds for flooding were developed as part of CCVA Part 1 for different systems (e.g., telecommunications, transportation, energy) and asset types (e.g., rail lines, subway stations, bus routes), reflecting the different depths at which their functions would be impacted by flooding.

[1] The report is available online at http://www.cambridgema.gov/climateprep

Adaptive capacity is the extent to which an asset is be able to accommodate or adjust to an impact. Adaptive capacity was assessed based on whether assets had technological or operational protections and/or system-level redundancies in place to strengthen resilience to impacts. Adaptive capacity scores (AC), ranging from AC0 (no protection – no redundancy in place) to AC2 (high ability to accommodate the flooding impact – high redundancy), were assigned to each asset based on the results of the scoring conducted in CCVA Part 1 for precipitation-driven flooding. A narrative describing the adaptive capacity characteristics of each system was included in the CCVA Part 1 Vulnerability and Risk Assessment Technical Report and is not repeated in this memo.

Vulnerability of each asset was assessed and scored based on its sensitivity and adaptive capacity to SLR/SS flooding. Vulnerability scores (V) were assigned to assets using the vulnerability scoring matrix below (Figure 1). These scores were documented in the respective spreadsheets for the assets/systems. Assets that were assessed to be highly vulnerable (vulnerability scores of V4 or V5) were further assessed for risk based on probability and consequence of SLR/SS flooding.

Figure 1. Vulnerability Scoring Matrix

		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**

Risk Assessment

Probability of SLR/SS flooding in 2070 was assessed to determine whether assets were highly vulnerable under high probability scenarios (more frequent, less extreme) or only in low probability scenarios (less frequent, more extreme). The flooding probabilities were derived from the BH-FRM. A 'High' probability score was assigned to assets with a 10% or greater probability of flooding, while those with less than 10% probability were assigned a 'Low' Probability Score. These threshold probability levels for "High" and "Low" scores were adopted to align with the "High" and "Low" probability scenarios used to assess risks from precipitation-driven flooding and extreme heat in CCVA Part 1.

To determine the probability of SLR/SS flooding for each highly vulnerable asset, Probability of Exceedance (PE) tables for 2070 were extracted from the model results of BH-FRM. The PE tables report both the water surface elevation (in feet-NAVD88), as well as water depth above ground (in feet) at a specific location for different annual probabilities ranging from 0.1% to 100% (See Figure 2 for an example of a PE table). In this example of a substation with medium adaptive capacity (AC1), the substation's critical threshold of >0.5 feet of flood depth (S4) for exterior equipment is first exceeded at the 30% probability level. It is therefore assigned a 'High' Probability Score, as it is greater than 10%.

Figure 2. Probability of Exceedance (PE) Table for North Cambridge Substation

Exceedance Probability (%)	Water Surface Elevation (feet NAVD88)	Water Depth (feet)
0.1	11.7	3.6
0.2	11.6	3.5
0.5	11.3	3.2
1	10.8	2.7
2	10.7	2.6
5	10.5	2.4
10	10.1	2
20	10	1.9
25	9.9	1.8
30	9.8	1.7
50	dry	dry
100	dry	dry

In determining the probability of flooding for highly vulnerable assets (scores V4 or V5), the first probability level at which the depth of flooding equals or exceeds the critical threshold of flood depth for that asset was identified from the PE table. Depending on the probability level, a score of 'High' (≥ 10%) or 'Low' (< 10%) was documented in the probability score column of the spreadsheet. The actual percent probability of exceedance was also documented in the spreadsheet in the notes column.

For critical assets that were only impacted by SLR/SS flooding propagated through piped infrastructure (not direct overland flooding) in the 2070 1% annual probability SLR/SS scenario, PE tables were not available. There were only 10 such assets of the 48 highly vulnerable assets under this scenario. Since these assets were determined to be highly vulnerable from propagated flooding for the 2070 1% annual probability SLR/SS scenario, they were assigned a 'Low' (< 10%) probability score. ***These assets are marked with an asterisk in this report, as well in the assessment spreadsheets.***

Consequence was assessed based on the scale of the assumed service disruption that would likely be caused by an asset's failure (in terms of the number of people or area of the City impacted), as well as the potential for such failure to cause cascading impacts on other assets within or across systems. The consequence scores, shown in Figure 3, range from "Low" (would not impact large area/population – would not have cascading impacts to other assets/systems) to "High" (would impact large area/population – would have cascading impacts to other assets/systems). Consequence scores assigned to assets were documented in the spreadsheet, and the criteria underlying their scores were recorded under the assumptions column. The assumptions for different systems were vetted with key stakeholders as part of CCVA Part 1.

Figure 3. Consequence Scoring Protocol

	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

Risk for each asset was assessed and scored based on their probability of flooding and the consequences of their degradation or failure as a result. Only assets that were identified as being highly vulnerable (V4 or V5) in the 2070 1% annual probability SLR/SS scenario were assessed for risk. Risk Scores were assigned to assets using the risk scoring matrix shown below (Figure 4). Risk scores were then documented in the assessment spreadsheets. Assets that had risk scores of R3 or R4 were considered high risk assets, and therefore, would be potential priorities to be addressed in Cambridge's Preparedness and Resiliency Plan.

Figure 4. Risk Scoring Matrix

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

B. Key Findings and High Risk Priority Planning Areas for Critical Infrastructure

Six critical infrastructure systems were studied in CCVA Part 1, and the same six systems were assessed for their vulnerability and risk to flooding from SLR and SS:

B-1 Energy
B-2 Critical Services
B-3 Telecommunication
B-4 Roadways and Bridges
B-5 Transit
B-6 Water/Stormwater

B-1 Energy

Summary of Key Findings
The critical energy assets listed in Figure 5 are all highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk.

Figure 5. Energy System Risk Ranking for SLR/SS in 2070
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3** • *Putnam Substation	**Score R4** • North Cambridge Substation • Brookford Street Take Station • Third Street Regulator Station
	Medium	**Score R2** • *MIT Co-generation Plant	**Score R3**
	Low	**Score R1**	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

North Cambridge Substation (R4), **Brookford Street Take Station (R4)**, and **Third Street Regulator Station (R4)** represent the highest risk to Cambridge. Most of the electricity and natural gas used in Cambridge is supplied by regional energy systems outside the City's boundaries. Those supplies transfer into the City at specific locations and then are distributed to energy users throughout the City. North Cambridge Substation is the most important asset in the City's electrical system, acting as the primary gateway for accessing power from the

regional electricity grid. Similarly, Brookford Street Take Station is the City's primary gateway for accessing natural gas from pipelines that supply the region. Both of these assets are located within the large floodplain in the Alewife area potentially affected by SLR/SS. They are highly vulnerable in 2070, with a 30% annual probability of flooding to depths greater than 1.0 ft.

The Third Street Regulator Station, which further distributes natural gas to an economically important area of the City – Kendall Square – as well as specific critical customers (e.g., Veolia-Kendall Cogeneration Station), is also a high risk to the City. While the regulator station is not directly exposed to SLR/SS flooding, it lacks redundancy due to its total reliance on natural gas supplied from the Brookford Street Take Station. With a 30% annual probability that Brookford Street Take Station will be flooded in 2070, there is a correspondingly high probability that Third Street Regulator Station will be unable to function as a result.

The Putnam Substation and MIT Co-generation Plant are highly vulnerable only in the low probability, 2070 1% annual probability SLR/SS scenario due to propagation of SLR/SS flooding through the piped infrastructure. They therefore represent a lower risk than the three noted in bold above. Nonetheless, **Putnam Substation (R3)** still is a high risk asset due to its high consequence of failure which would impact electrical services for large areas of the City as well as specific critical customers. Failure of the MIT Co-generation Plant (R2), however, would only have a medium consequence because it would not cause cascading impacts on other critical systems in the City. It therefore poses only a moderate risk.

None of the other critical energy infrastructure assessed in this study were directly exposed to flooding under the 1% annual probability SLR/SS scenario in 2070.

Other Vulnerabilities

Potential corrosion from salinity in floodwaters caused by SLR/SS can impact energy infrastructure long after flooding has receded, especially if the duration of the flooding is long. This is the case both for electrical equipment at utility facilities, such as substations and transmission lines, and end-use facilities that are exposed to flooding. The recovery process may require extensive cleaning to remediate salinity exposure and impact longer-term maintenance budgets due to impact of salinity on accelerating degradation and shortening the lifetime of infrastructure. Further study is required to determine the potential impacts of salinity from SLR/SS flooding in Cambridge, as fresh and salt water mixing in the Charles and Alewife Brook basins have not been modeled under the 2070 SLR/SS scenario.

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 consist of cast iron distribution mains that may be susceptible to flooding, and district regulator stations. Eversource 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 level 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.

Vulnerability from Cascading Impacts / Regional Issues

As was seen in other recent disruptive events, utilities would likely shut down the electrical and natural gas system temporarily in advance of a major coastal flooding event, halting economic activities along with most non-emergency public services. After the event, it could take days or

even longer to fully restore services. Segments less impacted by the event could potentially be brought back into service before the entire system is restored.

The energy system could also be indirectly impacted by failures in other systems due to flooding. Flooding could impact key systems such as roadways and telecommunication, without which some energy infrastructure and operations may not be able to properly function.

Flooding impacts to regional energy system infrastructure outside of Cambridge could also have cascading impacts in the City. The metro region's limited power generation capacity is centered on several coastal sites, including the Mystic Generating Station, and the region's liquid fuel supplies are overwhelmingly imported and stored in marine terminals situated along Boston Harbor. These sites have yet to be publicly assessed in terms of their climate change vulnerability, but if these infrastructure were impacted, Cambridge would likely feel the ripple effects in its energy system.

Figure 6. Energy – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Power Plants (>10MW)	Veolia-Kendall Cogeneration Station	V1	
	*MIT Co-generation Plant	V5	R2
Bulk Transformer/ Substations	North Cambridge	V4	R4
	*Putnam	V4	R3
	East Cambridge	V1-V3	
	Prospect	V1-V3	
Natural Gas City Gate Stations	Brookford Street Take Station (N. Cambridge)	V5	R4
Natural Gas Distribution Regulator Stations	Third Street Intermediate/Low-Pressure Regulator Station	V3-V5	R4
Steam Plants	Harvard Blackstone Plant	V1-V3	

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

B-2 Critical Services

Summary of Key Findings
The critical services facilities listed in Figure 7 are all highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk.

Figure 7. Critical Services Risk Ranking for SLR/SS in 2070
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3** • *Cambridge Police Department Headquarters • *Fire Company 2	**Score R4** • Tobin School Emergency Shelter • Professional Ambulance Services
	Medium	**Score R2**	**Score R3**
	Low	**Score R1**	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

The highly vulnerable assets that pose the highest risk are **Tobin School Emergency Shelter (R4)** and the **Professional Ambulance Services (R4)** facility. In 2070, these critical services in the Alewife floodplain have a 30% annual probability of flooding to depths of 2.0 ft. or greater due to SLR/SS.

In contrast, ***Cambridge Police Department Headquarters (R3)** and ***Fire Company 2 (R3)** are located in more inland areas that in the 2070 1% annual probability SLR/SS scenario are only affected by propagation of floodwaters through the City's stormwater and combined sewer infrastructure.

None of the other critical services infrastructure assessed in CCVA Part 1 were directly exposed to flooding under the 2070 1% annual probability SLR/SS scenario.

Vulnerability from Cascading Impacts / Regional Issues
Energy, transportation, and telecommunication infrastructure have been identified as being highly vulnerable and high risk from SLR/SS flooding. Failure of these systems could impact the functioning of critical services facilities, including those not exposed to flooding. Energy is needed to run the buildings, transportation is needed for employees and service users to access the facilities, and telecommunication is needed to coordinate emergency response activities.

Figure 8. Critical Services – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Emergency Operations Center	Water Department	V2	
Police Stations	*Cambridge Police Dept. Headquarters	V3-V5	R3
	MIT Police Station	V1-V3	
	Harvard Police Station	V1	
Fire Stations	Fire Headquarters	V2	
	*Fire Company 2	V4	R3
	Fire Company 3	V1	
	Fire Company 4	V1	
	Fire Company 5	V1	
	Fire Company 6	V1	
	Fire Company 8	V1	
	Fire Company 9	V1	
Emergency Shelters	Kennedy / Longfellow School	V1-V3	
	Peabody School	V1	
	Tobin School	V4	R4
	Graham & Parks School	V1	
	Cambridge Rindge and Latin	V1	
	Morse School	V1	
Hospitals	Cambridge Hospital	V1	
	Youville Hospital	V1	
	Mount Auburn Hospital	V1-V3	
	Sancta Maria Nursing Facility	V1-V3	
Health Centers	Cambridge Family Health	V1	
	Cambridge Family Health North	V1	
	North Cambridge Health Center	V1-V3	
	Senior Health Center	V1-V3	
	Windsor Street Health Center	V1	
	Teen Health Center at Cambridge Rindge and Latin	V1	
	East Cambridge Health Center	V1	
Ambulance Services	Professional Ambulance Services	V5	R4

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Municipal Offices	Public Health Department	V2	

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

B-3 Telecommunication

Summary of Key Findings

The telecommunication assets listed in Figure 9 are all highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk.

Figure 9. Telecommunication Risk Ranking for SLR/SS in 2070
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	High
Consequence	High	**Score R3** • *Emergency Communications Center at Cambridge Police Department Headquarters	**Score R4**
	Medium	**Score R2**	**Score R3** • BBN Technology Data Hub/Co-location Center • Concord Ave Antenna Tower
	Low	**Score R1**	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

The assets listed in Figure 9 all have high risk scores. However, the profiles of their risks differ.

While **BBN Technology Data Hub/Co-location Center (R3)** and **Concord Ave Antenna Tower (R3)** are located in the Alewife floodplain and have a high annual probability of flooding from SLR/SS in 2070 (30% and 10% respectively), their failure would have more moderate consequences.

In contrast, flooding of the ***Emergency Communications Center at Cambridge Police Department Headquarters (R3)** would result in very high consequences, but the probability of flooding is lower, with flooding in the 2070 1% annual probability SLR/SS scenario only occurring due to propagation through the piped infrastructure.

None of the other critical telecommunications infrastructure assessed in this study were directly exposed to flooding under the 2070 1% annual probability SLR/SS scenario.

Other Vulnerabilities

Telecommunication infrastructure that is exposed to flooding from SLR/SS, with its higher salinity content, may be subject to longer-term degradation and higher risk of failure from corrosion. The recovery process may therefore require extensive cleaning to remediate salinity exposure and impact longer-term maintenance budgets. This is a potential issue for data centers, switching stations, and cabling at the sites of telecommunications service providers, both underground and at end-user facilities exposed to flooding. Further study is required to determine the potential impacts of salinity from SLR/SS flooding in Cambridge, as fresh and salt water mixing in the Charles and Alewife Brook basins have not been modeled under the 2070 SLR/SS scenario.

Vulnerability from Cascading Impacts / Regional Issues

Telecommunications services are vulnerable to indirect impacts caused by major coastal flooding events. A potential temporary indirect impact, in the period before and after a major coastal flood, is an overwhelming of the cellular network due to high call volumes and data use. This is a common occurrence for all types of disasters. People use their cellphones to communicate with family members inside and outside of the affected area, and more than ever, they use them to search the internet and use social media for finding and sharing situational information. This spike in cellular use in a specific geography can overwhelm the capacity of local cellular towers, resulting in temporary inaccessibility of cellular services, right when people need it. Telecommunications companies working with emergency management agencies have piloted response plans for managing such failures, including by delivering mobile cellular towers to affected areas. More than ever, people of all demographics are using cellular phones as their primary means of telecommunication. Vulnerable populations, particularly those with low-incomes, may lack alternative telecommunications options if cellular services fail. Traditional communication modes, including distributing multi-lingual information word-of-mouth or in print through community and faith-based organizations, becomes critical for communicating with these groups and others.

Telecommunications infrastructure is highly dependent on the regional electrical system as well as local transmission and distribution infrastructure to function. Fiber-optic networks, for example, require electricity both at service provider facilities and at end-user locations in order to function. Power loss, especially for extended periods of time, can therefore cause telecommunications systems to fail. Some redundancies are in place, but they are limited in their efficacy over an extended period of time.

Without power from the grid, smaller telecommunications facilities such as cellular towers can be run continuously on emergency generator power. However, in the scenario of a major coastal flood, liquid fuel supply chains may be disrupted limiting the amount of time the generators can run before they run out of fuel.

For larger telecommunications facilities, such as data centers and telecommunications company offices, emergency generator capacity is generally insufficient to provide full power, let alone continuous operation. Large power storage units are generally in place to prevent sudden equipment power-downs and protect stored data, with enough capacity to give operators time to shut down equipment correctly (but not enough time to continue operating as normal).

Figure 10. Telecommunication – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Data Hubs and Co-location Centers	AT&T	V2	
	XO Communications	V2	
	BBN Technology	V5	R3
Telephone Office and Long Line Switches	Verizon	V1	
	AT&T	V1	
	Verizon	V1	
Antenna Towers	Concord Ave Antenna Tower	V4	R3
Emergency Communications Center	*Emergency Communications Center at Cambridge Police Headquarters	V3-V5	R3

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

B-4 Roadways and Bridges

Summary of Key Findings

The critical roadway and bridge assets listed in Figure 11 are all highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk. No major bridges were exposed to flooding in the 2070 1% annual probability SLR/SS scenario.

Figure 11. Roadways and Bridges Risk Ranking for SLR/SS in 2070
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3** • *Broadway	**Score R4** • Alewife Brook Parkway • Concord Turnpike / Route 2 • Massachusetts Avenue / Route 16 • Intersection of Alewife Brook Parkway with Route 2 and Route 16
	Medium	**Score R2**	**Score R3** • MBTA Alewife Station Garage
	Low	**Score R1** • First Street Municipal Garage • *Broadway Bicycle Route	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

The assets that pose the greatest risk in this scenario are those located in the Alewife Brook floodplain, as they have high probabilities (≥ 10%) of flooding. These include **Alewife Brook Parkway (R4)**, **Concord Turnpike / Route 2 (R4)**, **Massachusetts Avenue / Route 16 (R4)**, and the key **Intersection of Alewife Brook Parkway with Route 2 and Route 16 (R4)**.

MBTA Alewife Station Garage (R3) is also in this area, and has a high probability of flooding, but the consequences of flooding are not considered to be as high as for a major roadway, and it is therefore not considered as high a risk (though still high).

In addition, ***Broadway (R3)** is a high-risk roadway, with the entire stretch of Broadway within the Kendall Square area flooded with depths ranging between 2 and 3 feet. Areas that have a high probability of overland flooding were mapped, but Broadway was not affected by overland flooding. The source of SLR/SS flooding on Broadway is due to propagation of floodwaters through piped infrastructure. As propagated flooding was only modeled for the 2070 1% annual probability SLR/SS scenario, it was assumed that this area has a low probability of flooding. This assumption can be tested in the future with additional modeling.

While the SLR/SS scenario map suggests that Fresh Pond Parkway, Monsignor O'Brien Highway (at Charles River Dam Bridge), and Memorial Drive are likely to be flooded in the 2070 1% annual probability SLR/SS scenario, further examination of the more detailed modeling results indicates that they are not directly exposed. The appearance of flooding in these areas is an artifact of interpolation between nodes in the model, which in some areas are further apart and therefore provide lower resolution and visualization accuracy.

None of the other critical roadway and bridge infrastructure assessed in this study were directly exposed to flooding under the 1% annual probability SLR/SS scenario in 2070.

Other Vulnerabilities

SLR/SS flooding in the Alewife area could have significant transportation-related impacts beyond the temporary impact of roads being impassable due to standing water. Those include public safety hazards, debris, and contamination in roadways.

The leading cause of flood-related deaths in the United States is vehicular drowning. Too often, people attempt to drive through standing water that is too deep and are trapped in their vehicles. The presence of roadway-adjacent water bodies, such as Alewife Brook and Fresh Pond, as well as depressed areas, like the swales along the Fitchburg Commuter Rail Line, raise the risks of vehicles being flooded to dangerous depths if vehicles are swept from flooded roadways. This risk applies to minor roadways that were not specifically assessed as part of this study.

Overland flooding from storm surge also generates large amounts of debris which are often deposited on roadways where they remain until roads are cleared. Along with debris, hazardous materials and soil contaminants can be suspended during a flood and be deposited on roadways. Local government agencies, particularly public works departments, tend to play a key role in debris management after major floods. Collection, storage, segregation, and disposal of debris, including hazardous materials, is often a costly for local governments and challenging in terms of the regulatory process.

Vulnerability from Cascading Impacts / Regional Issues

Roadways, bridges, and parking facilities in Cambridge can be indirectly impacted by SLR/SS flooding, including through impacts to transportation assets outside of the City and through cascading failures caused by other infrastructure systems.

The functioning of the roadway system in Cambridge relies heavily on the major regional transportation assets outside of the City boundaries. Of central importance to the entire metro region, including Cambridge, is the Central Artery Tunnel system located in Boston. This system provides the principle means of access to areas north, south, and west of Boston via I-90, I-93, Route 1A, Route 28, and Storrow Drive, among others. These routes are important truck routes used for transporting essential goods and materials to communities throughout the region. Massachusetts Department of Transportation (MassDOT) completed a climate change vulnerability assessment of the Central Artery Tunnel system and is in the process of performing a state-wide vulnerability assessment of all of its assets. The Central Artery study used the same SLR/SS scenarios as are being used for Cambridge's assessment. In that study, MassDOT found that in the 2070 1% annual probability SLR/SS scenario, the Central Artery would be highly vulnerable to flooding. The Central Artery being shut down pre-emptively to prevent flood damages or post-flood to repair damages would have cascading impacts on the economies of the region. The state-wide assessment results will provide further insight into potential impacts in Cambridge from other vulnerabilities in the regional system.

Transportation infrastructure is also dependent on other critical systems such as energy and telecommunications, without which some roadway infrastructure (e.g., traffic signals, lighting, ITS, pump stations) will not function. This in turn can lead to public safety hazards, increased congestion, and longer travel times. Critical services, such as law enforcement and emergency medical services, may be impacted by the same flooding event as the roadways are, limiting their ability to provide redundancy for lost telecommunications and energy services before, during, or after a flood (e.g., traffic management).

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.

Figure 12. Roadways and Bridges – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Major Roads (ADT >30,000)	Fresh Pond Parkway / Route 60	V2	
	Monsignor O'Brien Highway / McGrath Highway / Route 28	V2	
	Alewife Brook Parkway	V5	R4
	Concord Turnpike / Route 2	V5	R4
	Memorial Drive	V2	
	*Broadway	V5	R3
	Massachusetts Avenue / Route 16	V5	R4
	Charlestown Avenue	V2	
	Land Boulevard	V2	
Key Intersections	BU Rotary/Reid overpass	V2	
	Alewife Brook Parkway at Route 2 and Route 16	V5	R4
	Monsignor O'Brien Highway at Charlestown Ave/Land Boulevard	V2	
Bridges and Underpasses	Charles River Dam Bridge / Lechmere Viaduct (Rt. 28 and MBTA Green Line)	V1	
	Longfellow Bridge (Rt. 3 and MBTA Red Line)	V1	
	Harvard Bridge (Rt. 3 and MBTA Red Line)	V1	
	Boston University Bridge (Rt. 2)	V1	
	River Street Bridge	V1	
	Western Ave. Bridge	V1	
	Lars Anderson Memorial Bridge (N. Harvard St./JFK St and MBTA #66 Bus Route)	V1	
	Eliot Bridge (Rt. 2 to Fresh Pond Parkway)	V1	
	Cambridge Street underpass	V1	
	Memorial Drive underpasses	V1	
Parking Facilities	MBTA Alewife Station Garage	V5	R3
	*First Street Municipal Garage	V4	R1
	Green Street Garage	V1	
Key Bicycle Routes and Intersections	*Broadway Bicycle Route	V4	R1
	Hampshire St Bicycle Route to Porter Sq.	V1	

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

B-5 Transit

Summary of Key Findings
The critical transit assets listed in Figure 13 are all highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk.

Figure 13. Transit Risk Ranking for SLR/SS in 2070
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3** • *Kendall Station (Red Line) • *Central-Kendal Rail Line (Red Line)	**Score R4** • Alewife Station (Red Line) • Fitchburg Commuter Rail Line • Alewife-Davis-Porter Rail Line (Red Line)
	Medium	**Score R2** • *MBTA #66 Bus Route • *MBTA #1 Bus Route	**Score R3**
	Low	**Score R1**	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

Several assets that are critical to the functioning of the MBTA Red Line, Cambridge's most important transit system, were determined to be high risks under the 2070 SLR/SS flooding scenarios. **Alewife Station (R4)** and the **Alewife-Davis-Porter Rail Line (R4)** segment have a high probability of being exposed to overland flooding from the Alewife Brook. Meanwhile, **Kendall Station (R3)** and the **Central-Kendall Rail Line (R3)** segment could experience flooding propagated through piped infrastructure in the 2070 1% annual probability SLR/SS scenario. The potential impacts to this more inland segment of the Red Line are less certain, however, due to limited information on the location of ground-level openings (e.g., vent grates) through which surface flooding could enter the subway tunnels. Because flooding is present at Kendall Station entrances and along the Central-Kendall route, it was assumed that these assets would be impacted.

In addition, **Fitchburg Commuter Rail Line (R4)** between Belmont Station and Porter Station poses a high risk. This line segment passes through the Alewife Brook floodplain which has a high probability of flooding due to SLR/SS in 2070.

The two major bus routes assessed in this study, MBTA #66 Bus Route (R2) and MBTA #1 Bus Route (R2), were determined to be a moderate risk because in the 2070 1% annual probability SLR/SS scenario they were only exposed to flooding through the propagation of floodwaters

through the City's piped infrastructure and because the consequences of the routes being partially flooded would be moderate.

None of the other critical transit infrastructure assessed in CCVA Part 1 were directly exposed to flooding under the 2070 1% annual probability SLR/SS scenario.

Other Vulnerabilities

Direct impacts of corrosion due to higher levels of salinity in floodwaters caused by SLR/SS also represent a potential longer-term risk to the rail transit system that is greater than for inland flooding caused by precipitation. The recovery process may require extensive cleaning to remediate salinity exposure and impact longer-term maintenance budgets due to impact of salinity on accelerating degradation and shortening the lifetime of infrastructure. This is a potential issue for rail tracks, train cars, signaling and switching equipment, electrical systems, cabling, station HVAC equipment, and subway tunnels. Further study is required to determine the potential impacts of salinity from SLR/SS flooding in Cambridge, as fresh and salt water mixing in the Charles and Alewife Brook basins have not been modeled under the 2070 SLR/SS scenario.

Vulnerability from Cascading Impacts / Regional Issues

As was seen in other recent disruptive events, the MBTA would likely shut down the transit system temporarily in advance of a major coastal flooding event, bringing economic activities to a standstill. After the event, it could take days or even longer to fully restore services. Segments less impacted by the event could be brought back into service before the entire system is restored, as was done in New York and New Jersey post-Hurricane Sandy.

The transit system could also be impacted by failures in other systems due to flooding. Flooding could impact key systems such as power distribution, roadways, and telecommunications, without which most transit infrastructure and operations would 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 other stations, lines, and routes, or to MBTA's supportive electrical infrastructure or train and bus storage and maintenance facilities. The MBTA has not yet completed a system-wide climate change vulnerability assessment, but once it has, the system-level risks for Cambridge will become more apparent.

Figure 14. Transit – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Subway Stations	Alewife Station (Red Line)	V5	R4
	Porter Square Subway Station and Commuter Rail (Red Line, Fitchburg Line)	V1	
	Harvard Square Station (Red Line)	V1	
	Central Square Station (Red Line)	V1	
	*Kendall Station (Red Line)	V4	R3
	Lechmere Station (Green Line)	V1	
Rail Lines (Subway and Commuter)	Fitchburg Commuter Rail Line	V5	R4
	Alewife-Davis-Porter (Red)	V5	R4
	Porter - Harvard (Red)	V1	
	Harvard - Central (Red)	V1	
	*Central - Kendall (Red)	V5	R3
	Lechmere-Science Park (Green)	V1	
Bus	Harvard Square hub	V1	
	Central Square hub	V1	
	*MBTA #66 Bus Route	V4	R2
	*MBTA #1 Bus Route	V4	R2

*Indicates that an asset is highly vulnerable in the 1% flood due to flood propagation through pipes, not overland.

B-6 Water/Stormwater

The water system in Cambridge is classified into two broad categories: (1) natural systems that includes surface water bodies and wetlands, and (2) infrastructure systems that are further comprised of three broad sub-categories: (a) dams, (b) drinking water supply, treatment and distribution system, and (c) stormwater and combined wastewater conveyance system..

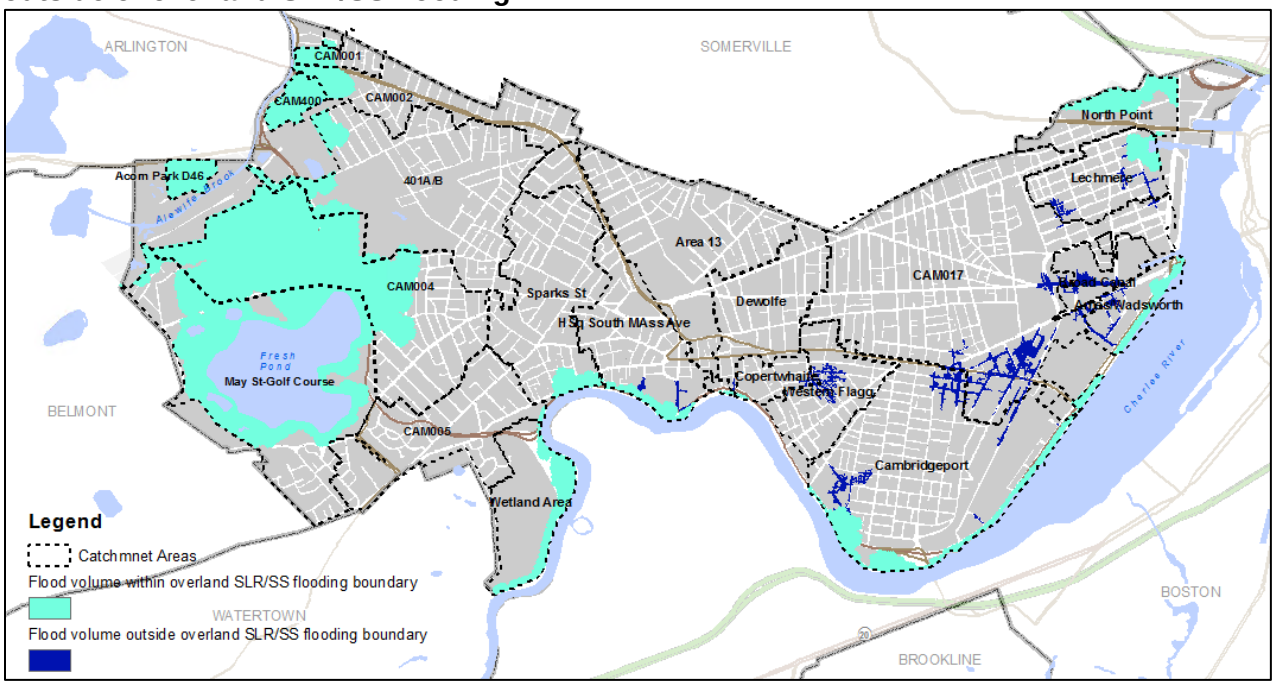
The vulnerability assessment of natural systems, including the Charles River and Alewife Brook was based on considering the maximum depth of flooding along these water bodies, as well as in areas adjacent to them as reported from BH-FRM.

The vulnerability assessment of infrastructure systems was carried out using two different methods. For assets with individual point locations, such as dams, pump stations and the Walter J. Sullivan Water Purification Facility, the vulnerability assessment was conducted using the methodology described in Section A of this report, by considering the maximum depth of flooding exposure at these assets under the 2070 1% annual probability SLR/SS scenario and their respective sensitivity and adaptive capacity.

For stormwater and combined wastewater collection systems, the vulnerability assessment was based on the performance of the associated major catchment/conveyance system areas in the City (shown in Figure 15) under the 2070 1% annual probability SLR/SS flooding scenario. Performance was measured based on the maximum flood volume per catchment area for each stormwater and combined sewer catchment area. This approach was determined to be more appropriate than basing the assessment on the depth of flooding at individual point locations (e.g., outfalls).

Maximum flood volume (reported in million gallons MG) for each catchment area was calculated separately for SLR/SS overland flooding and SLR/SS propagated flooding through piped infrastructure. The maximum flood volume in the SLR/SS overland flooding zones for each catchment area was determined using the BH-FRM depth of flooding for the 2070 1% annual probability SLR/SS scenario and the respective reporting area for each catchment. The volume of flooding for each catchment area due to SLR/SS propagated flooding through piped infrastructure was determined from ICM-2D model results for the 2070 1% annual probability SLR/SS scenario. The volume due to SLR/SS propagated flooding in each catchment area was separated into two categories: 1) volume contained within the boundaries of the SLR/SS overland flooding zone (shown in green in Figure 15), and 2) volume contained outside the boundaries of the SLR/SS overland flooding zone (shown in blue in Figure 15).

Figure 15. Catchment areas used for ranking the City's stormwater and combined wastewater collection system and boundaries used to report flood volume within and outside of overland SLR/SS flooding



The total flood volume for each catchment area was calculated by summing the volumes from SLR/SS overland flooding (Category 1) and SLR/SS propagated flooding contained outside of the SLR/SS overland flooding zone (Category 2). The flood volume within water bodies, such as the Fresh Pond was excluded. The volumes from SLR/SS propagated flooding contained inside the overland flooding zone were excluded in calculating the total flood volume for each catchment area, since the volume from SLR/SS overland flooding was always significantly higher (approximately one to two orders of magnitude higher). Total flood volumes (reported in million gallons) were then normalized by size of the catchment area to give a standardized unit ranking by area (calculated in acre-feet/acre). In addition, the range of actual flood depths for each catchment was also reported using the maximum and minimum depth within each catchment. The relative flood volumes from SLR/SS overland flooding and propagated flooding through piped infrastructure, and these flood volumes normalized by catchment area, as well as the maximum and minimum flood depths are reported in Figure 16. These normalized flood volumes were used to relatively rank the catchment areas with their associated collections systems, and therefore determine the catchment areas in the City that may have a high-risk of flooding

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Figure 16. Relative Flood Volumes from 2070 1% Annual Probability of Overland Flooding (from BH-FRM) and from Flooding Propagated through Piped Infrastructure (from ICM-2D)

Catchment Area Name	Receiving Water Body	Catchment Area (excluding water bodies) (acres)	Flood Volume (Million Gallons MG)			Average Flood Volume per unit catchment area (acre-ft/acre) (min-max ft)
			Overland SLR/SS Flooding Using BH-FRM	Propagated SLR/SS Flooding through Piped Infrastructure Using ICM-2D	Total Flood Volume	
Separated Stormwater Conveyance System						
D46 (Alewife)	Alewife	18	13.35	0.00	13.35	2.2 (4.6 – 11.4)
CAM 400 (Alewife)	Alewife	23	12.00	0.00	12.00	1.6 (1.1-13.2)
May Street Golf Course (Alewife)	Alewife	261	47.10	0.38	47.48	0.6 (0.01-11.0)
CAM 004 (Alewife)	Alewife	378	79.11	0.97	80.08	0.7 (0.01-13.1)
Ames Wadsworth (Charles)	Charles	51	13.04	0.56	13.59	0.8 (0.01-17.6)
Wetland Area (Charles)	Charles	113	18.59	0.00	18.59	0.5 (0.01-15.8)
Lechmere (Charles)	Charles	102	4.96	1.83	6.79	0.2 (0.01-13.2)
Cambridgeport (Charles)	Charles	415	32.18	5.37	37.56	0.3 (0.01-17.6
North Point (Charles)	Charles	80	9.47	0.00	9.47	0.4 (0.01-3.3)
Harvard Square (Charles)	Charles	186	5.10	0.86	5.96	0.1 (0.01-11.8)
Sparks Street (Charles)	Charles	221	5.22	0.58	5.80	0.1 (0.01-11.8)
Western Flagg (Charles)	Charles	103	0.00	1.04	1.04	0.001 (Max 2.6)
Coperthaite (Charles)	Charles	36	0.15	0.20	0.34	0.03 (0.01- 5.4)
Area 13 (Charles)	Charles	261	0.20	0.00	0.20	0.002 (Max 5.5)
Dewolfe (Charles)	Charles	135	0.02	0.02	0.04	0.001 (Max 4.9)

Catchment Area Name	Receiving Water Body	Catchment Area (excluding water bodies) (acres)	Flood Volume (Million Gallons MG)			Average Flood Volume per unit catchment area (acre-ft/acre) (min-max ft)
			Overland SLR/SS Flooding Using BH-FRM	Propagated SLR/SS Flooding through Piped Infrastructure Using ICM-2D	Total Flood Volume	
Combined Wastewater Conveyance System						
CAM 001 (Alewife)	Alewife	9	3.00	0.00	3.00	0.4 (0.01-11.1)
CAM 002 (+ CAM 002a for manhole flooding) (Alewife)	Alewife	129	3.62	0.00	3.62	0.1 (0.01-13.3)
CAM 401 A/B (Alewife)	Alewife	349	5.77	0.01	5.78	0.05 (0.01-12.6)
CAM 017 (Charles)	Charles	624	1.86	6.35	8.21	0.04 (0.01-15.3)
CAM 005 (Charles)	Charles	188	0.26	0.00	0.26	0.004 (Max 14.5)

Summary of Key Findings

The critical water/stormwater natural systems and infrastructure listed in Figure 17 are all highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). Systems and assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only those with scores of R4 and R3 are considered high risk. Additional details about the high risk assets in Figure 17 are provided below.

Figure 17. Water/Stormwater Infrastructure Assets and Areas Risk Ranking for SLR/SS in 2070

(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3** • Charles River • Charles River Dam • **Lechmere (Charles – separate stormwater catchment) • **Ames/Wadsworth (Charles – separate stormwater catchment)	**Score R4** • Alewife Brook • +Amelia Earhart Dam • Fresh Pond Reservoir • **CAM 004 (Alewife – separate stormwater catchment)
	Medium	**Score R2** • Prison Point Pump Station • Sparks St (Charles) • **Harvard Square (Charles) • North Point (Charles) • **Cambridgeport (Charles – separate stormwater catchment)	**Score R3** • New Street Stormwater Pump Station • +Cottage Farm Pump Station • CAM 400 (Alewife – separate stormwater catchment) • D46 (Alewife -separated stormwater catchment) • CAM 001 (Alewife – combined sewer catchment) • CAM 002/002A (Alewife – combined sewer catchment) • **CAM 401 A/B (Alewife – combined sewer catchment) •
	Low	**Score R1** • Wetland Area (Charles – separated sewer catchment)	**Score R2** • **May St Golf Course (Alewife - separated sewer catchment)

All unmarked catchment areas and assets in Figure 17 are highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to coastal overland flooding only.

**Indicates that a catchment area is highly vulnerable in the 2070 1% annual probability SLR/SS scenario and is affected by both coastal overland flooding and flood propagation through piped infrastructure.

+Indicates that the asset is located outside of Cambridge.

The **Alewife Brook (R4)** and majority of the areas adjacent to the Alewife Brook have a 10-20% annual flooding probability (5-10 year return period water surface elevations) in 2070 (as shown

in Appendix 1, Map 2). In Cambridge specifically, the Upper Ponds adjacent to Alewife Brook are flooded significantly from coastal overland flooding, with most of the area experiencing a 10-20% inundation probability. Flood depths along the Mystic River and Alewife Brook generally are between 1-10 feet, with the upper Ponds within Cambridge having several areas of 10 foot depths.

Based on the BH-FRM results, the +**Amelia Earhart Dam (R4)** is flanked on the west side of the dam near the Assembly Row area, as well as a larger flood pathway initiated in Chelsea and Everett. The Amelia Earhart Dam is flanked and overtopped before the Charles River Dam by approximately 15-20 years. The Amelia Earhart Dam is flanked as soon as 2030-2035 in a 0.2% annual probability SLR/SS flooding scenario (500 year return period) and by 2045-2050 in a 1% annual probability SLR/SS flooding scenario (100 year return period). The Amelia Earhart Dam is overtopped by 2040 in a 0.2% annual probability SLR/SS flooding scenario and by 2055-2060 in a 1% annual probability SLR/SS flooding scenario. When this dam is overtopped, there is no redundancy available for the Mystic River/Alewife Brook basin in terms of flood protection.

The **Fresh Pond Reservoir (R4)** serves as the terminal reservoir for the City's drinking water supply and is flooded under the 2070 1% annual probability SLR/SS scenario. In the 2070 1% annual probability SLR/SS scenario, there is a greater than 10% probability that an SLR/SS overland flood pathway will open up between Alewife Brook and the Fresh Pond Reservoir. The maximum operating elevation of 5.35 feet NAVD88 (17 feet City of Cambridge Base) is exceeded. However, the City has some redundancy in being able to use MWRA connections to provide drinking water supply to the City for a certain period of time.

The **CAM 400 (R4)** and ****CAM 004 (R4)** areas are separated stormwater catchments in the Alewife area that are expected to experience significant flooding by 2070, on the order of 1.6 acre-feet/acre and 0.7 acre-feet/acre, respectively, with some localized low-lying spots that could experience maximum flood depth greater than 10 feet. These catchments have critical roadway, transit, energy, and critical services infrastructure which could experience significant flooding by 2070.

The **Charles River (R3)** has different annual probabilities of SLR/SS flooding in 2070, depending on which part of the River one examines. In the area between the new and old Charles River dams in the North Point area of Cambridge, the annual probability of SLR/SS flooding in 2070 is 2-5% (50-20 year return period). Between the banks of the River, upstream of the Charles River Dam, annual probabilities of SLR/SS flooding in 2070 range from 0.2-1% (100-500 year return period). Along the north bank of the Charles River, in Cambridge, annual probabilities of SLR/SS flooding are approximately 0.5% (200-year return period). However, flood depths associated with the 0.1% annual probability SLR/SS scenario are generally less than 3 feet along the north bank, with the exception of the Longfellow Park area, which could experience flood depths of up to 10 feet.

Based on the BH-FRM results, the **Charles River Dam (R3)** is flanked directly south of the dam, as well as via a significant SLR/SS overland flood pathway that initiates from the Mystic River and advances through Somerville and the Sullivan Square area. The Charles River Dam is flanked as soon as 2045 in a 0.2% annual probability SLR/SS flooding scenario (500 year return period) and by 2055-2060 in a 1% annual probability SLR/SS flooding scenario (100 year return period). The Charles River Dam is overtopped by 2050 in a 0.2% annual probability SLR/SS flooding scenario and by 2065 in a 1% annual probability SLR/SS flooding. When the

Dam is overtopped, there is no redundancy available for the lower Charles River basin in terms of flood protection.

The **New Street Pump Station (R3)** has a high probability of being exposed to SLR/SS overland flooding from the Alewife Brook in 2070. This stormwater pump station has 3 pumps and is designed to convey flow generated by a present day 10-year storm[2]. If the New Street Pump Station fails to function, it will not be able to protect critical roadways, such as Route 2.

The +**Cottage Farm Pump Station (R3)** is not in Cambridge, but it serves combined sewer systems in the City. It is expected to experience significant SLR/SS flooding in 2070, which could result in its functional failure. This could impact the functioning of combined sewered areas in Cambridgeport that are served by the Cottage Farm Pump Station.

The **CAM 001 (R3), CAM 002/002A (R3)** and **CAM 401 A/B (R3)** areas are combined sewer catchments in the Alewife area that are expected to experience significant flooding by 2070, on the order of 0.4 acre-feet/acre, 0.1 acre-feet/acre and 0.1 acre-feet/acre, respectively in the 2070 1% annual probability SLR/SS scenario. Some localized low-lying spots, particularly in the vicinity of the Alewife Brook, could experience maximum flood depth greater than 10 feet. Increased flooding in and from these combined catchments can cause public health and water quality impacts.

The **Lechmere (R3)** and **Ames/Wadsworth (R3)** areas are separated stormwater catchments in the Charles River basin that are expected to experience significant flooding by 2070, on the order of 0.2 acre-feet/acre and 0.8 acre-feet/acre, respectively, in the 2070 1% annual probability SLR/SS scenario. Some localized low-lying spots, particularly in the vicinity of the Charles River, could experience maximum flood depth greater than 10 feet. These catchments have critical infrastructure that could be impacted under this scenario, including the Kennedy-Longfellow School and the MBTA Kendall Station.

Other Vulnerabilities

The possible impact of salinity from SLR/SS flooding and the extent to which saltwater can move upstream in the Alewife Brook area, including into the Fresh Pond Reservoir, are serious concerns. If saltwater intrusions does extend to the Fresh Pond Reservoir it could cause a significant impact to the City's drinking water system. Also, certain above-ground components of the City's water/stormwater infrastructure, including valves, hydrants, manhole covers, and pump stations, are likely to be impacted by corrosion due to SLR/SS flooding exposure, especially if such flooding occurs for longer duration. SLR/SS floodwaters have higher salinity levels than precipitation floodwaters and, therefore, pose a greater risk to infrastructure in terms of corrosion. Corrosion causes accelerated degradation of materials and makes equipment more likely to fail. The recovery process from SLR/SS flooding may therefore require extensive cleaning to remediate salinity exposure. It also may require higher longer-term maintenance budgets as well as the capital costs of early replacement of infrastructure. In addition, saline floodwaters may adversely affect the natural wetlands habitat and ecology in the Alewife area, especially if such flooding occurs for longer duration. Further study is required to determine the potential impacts of salinity from SLR/SS flooding in Cambridge, as fresh and salt water mixing in the Charles and Alewife Brook basins have not been modeled under the 2070 SLR/SS scenario.

[2] The present 10-year 24-hour storm is defined as the rainfall depth that has a 10% annual chance of exceeding in any given year and is equal to 4.9 inches of rain over a period of 24 hours.

Vulnerability from Cascading Impacts / Regional Issues

The impacts of SLR/SS flooding on the City's water/stormwater infrastructure, as well as MWRA-owned infrastructure in the City, would have cascading impacts on the City's and the region's other infrastructure systems. Roadway, transit, energy, and all other critical systems and community resources in the City depend on the functioning of stormwater systems and dams to provide flood protection. The entire City depends on drinking water systems and sewer systems to carry on normal social and economic activities. Impacts to water/stormwater infrastructure will have significant economic, environmental and public health impacts that would also impact the functioning of infrastructure systems in adjacent communities.

The City's water/stormwater systems, both infrastructure and natural systems, could also be impacted by failures in other systems within and outside the City due to SLR/SS flooding. SLR/SS flooding could impact key systems such as electrical substations, roadways, transit and telecommunications, which in turn would impact infrastructure assets, such as pump stations not having power or access roads being flooded. In addition, flooding of regional transportation infrastructure may lead to personnel not being able to get to operations sites, such as at the dams and pump stations, which would then not be able to properly function.

The detailed vulnerability and risk scores for the critical water/stormwater infrastructure assets and natural systems in the City are listed in Figure 17.

Figure 17. Water/Stormwater – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets/Areas		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Surface Water Bodies	Charles River	V5	R3
	Alewife Brook	V5	R4
Dams	Charles River Dam	V5	R3
	+Amelia Earhart Dam	V5	R4
Drinking Water System	Fresh Pond Reservoir	V4	R4
	Walter J. Sullivan Water Purification Facility	V1	
Stormwater Pump Stations	New Street Pump Station	V5	R3
	Cambridge Street Underpass Pump Station	V2	
Combined Sewer Pump Stations	Prison Point	V3-V5	R2
	+Cottage Farm	V5	R3
Separated Stormwater Catchment Areas	CAM 400 (Alewife)	V5	R3
	D46 (Alewife)	V5	R3
	**CAM 004 (Alewife)	V5	R4
	**May Street Golf Course (Alewife)	V5	R2
	Sparks Street (Charles)	V4	R2
	**Harvard Square (Charles)	V4	R2
	Area 13 (Charles)	V3	
	**Coperthaite (Charles)	V3	
	**Dewolfe (Charles)	V3	
	*Western Flagg (Charles)	V3	
	**Cambridgeport (Charles)	V5	R2
	North Point (Charles)	V5	R2
	**Lechmere (Charles)	V5	R3
	**Ames Wadsworth (Charles)	V5	R3
	Wetland Area (Charles)	V5	R1
Combined Sewer Catchment Areas	CAM 001 (Alewife)	V5	R3
	CAM 002 (plus CAM 002a for manhole flooding) (Alewife)	V4	R3
	**CAM 401 A/B (Alewife)	V4	R3
	CAM 005 (Charles)	V3	
	**CAM 017 (Charles)	V3	

*Indicates that an asset is only affected by flood propagation through piped infrastructure in the 2070 1% annual probability SLR/SS scenario.
**Indicates that a catchment area is highly vulnerable in the 2070 1% annual probability SLR/SS scenario and is affected by both coastal overland flooding and flood propagation through piped infrastructure.
+Indicates that the asset is located outside of Cambridge.

C. Key Findings and High Risk Priority Planning Areas for Community Resources

In the CCVA Part 1, the City examined the extent to which community resources are at risk of harm from climate stressors as a proxy for measuring harm to social support systems. The same resources were assessed for their vulnerability and risk from SLR/SS flooding.

C-1 Affordable Housing

C-2 Public Schools, Daycare, and Youth Centers

C-3 Pharmacies

C-4 Food Assistance

C-5 Municipal Resources

C-1 Affordable Housing

Summary of Key Findings
The affordable housing facilities listed in Figure 18 are all highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk.

Figure 18. Affordable Housing Risk Ranking for SLR/SS in 2070
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3**	**Score R4**
	Medium	**Score R2** • *Auburn Court I (80 Auburn Park), 77 units • *Auburn Court II (80 Brookline St), 60 units • Briston Arms (247 Garden St), 105 units • *Cambridge Court (411 Franklin St), 122 units • 402 Rindge Ave, 273 units • Fresh Pond Apts (360-364 Rindge Ave), 504 units	**Score R3** • Neville Center at Fresh Pond (650 Concord Ave), 57 units
	Low	**Score R1**	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

The highest risk affordable housing facility is **Neville Center at Fresh Pond (650 Concord Ave) (R3)**. The main vulnerability of this facility, or rather its residents, is that they will be completely inaccessible during, and possibly after, a SLR/SS flood due to overland flooding from Alewife Brook. The 2070 1% annual probability SLR/SS scenario will inundate all roadways leading to and from the facility with depths of greater than 2 ft. in all directions. The building itself has no direct exposure to flooding in the 2070 1% annual probability SLR/SS scenario.

Other affordable housing facilities in Cambridge actually have higher vulnerability scores. Buildings at *Auburn Court I (80 Auburn Park), Briston Arms (247 Garden St), *Cambridge Court (411 Franklin St), 402 Rindge Ave, and Fresh Pond Apartments (360-364 Rindge Ave) could all be directly exposed to flood depths of up to 2 or 3 ft. However, due to the relatively low probabilities of such conditions occurring (less than 10%), their risk scores were lower.

None of the other affordable housing facilities included in CCVA Part 1 were exposed to flooding in the 2070 1% annual probability SLR/SS flood. This study only included buildings in Cambridge with 50 or more units of affordable housing.

Other Vulnerabilities

Direct exposure of affordable housing facilities to high depths of flooding will result in a variety of different damages and costs. Elevated levels of salinity in SLR/SS flood waters can cause structural elements as well as mechanical and electrical system components to corrode. Further study is required to determine the potential impacts of salinity from SLR/SS flooding in Cambridge, as fresh and salt water mixing in the Charles and Alewife Brook basins have not been modeled under the 2070 SLR/SS scenario. In addition, remediation or replacement of indoor finishes will be required to prevent indoor mold growth and dampness, which can cause longer term respiratory health problems for building occupants. Temporary closures of specific units or entire facilities would result in displacement of residents. These are particularly concerning impacts due to the prevalence of socially vulnerable residents, many of whom may be at greater physical, financial, or emotional risk.

Vulnerability from Cascading Impacts / Regional Issues

Critical energy and transportation infrastructure have been identified as being highly vulnerable and at high risk from SLR/SS flooding. The functioning of affordable housing buildings, including those that are not directly exposed to flooding, could be impacted by failure of any of these systems. Energy is needed to run the facilities, and transportation systems are needed for residents and employees to access the facilities.

Figure 19. Affordable Housing – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Inclusionary Affordable Housing	1 Leighton St/ Charles E. Smith, 52 units	V2	
	285/303 Third St, 56 units	V2	
Non-Profit/ Scattered Site H/O Affordable Housing	808 Memorial Dr (808-812 Memorial Dr), 300 units	V2	
	402 Rindge Ave, 273 units	V5	R2
	Neville Center at Fresh Pond (650 Concord Ave), 57 units	V3-V5	R3
	Lancaster Apartments (8-10 Lancaster St), 65 units	V2	
	18-20 Ware St, 56 units	V2	
	Putnam Sq./2 Mt. Auburn, 94 units	V2	
	YMCA (820 Mass Ave), 128 units	V2	
	*Auburn Court I (80 Auburn Park), 77 units	V5	R2
	*Auburn Court II (80 Brookline St), 60 units	V3-V5	R2
	Inman Sq. Apts (1203-1221 Cambridge St), 116 units	V2	

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Private Affordable Housing	Briston Arms (247 Garden St), 105 units	V5	R2
	Waldren Square Apts (104 Waldren Square Rd), 240 units	V2	
	*Cambridge Court (411 Franklin St), 122 units	V5	R2
	Close Building (243 Broadway), 61 units	V2	
	Harwell Homes (1 Citizens Place), 56 units	V2	
	Fresh Pond Apts (360-364 Rindge Ave), 504 units	V5	R2
Public Affordable Housing	Miller's River Apts (15 Lambert St), 301 units	V2	
	Newtowne Court (131 Washington St), 268 units	V2	
	Corcoran Park (100 Thingvalla Ave), 153 units	V2	
	Jefferson Park (Federal)(1 Jackson Pl), 175 units	V2	
	Jefferson Park (State)(1 Jackson Pl), 109 units	V2	
	Daniel F. Burns Apt (50 Churchill Ave), 198 units	V2	
	Lincoln Way (39 Lincoln Way), 70 units	V2	
	2050 Mass Ave/ Leonard J. Russell Apts, 51 units	V2	
	Putnam Gardens (64 Magee St), 122 units	V2	
	3 Woodrow Wilson Court, 69 units	V2	
	Johnson Apts (150 Erie St), 180 units	V2	
	Manning Apts (237 Franklin St), 199 units	V2	
	Kennedy Apts (55 Essex St), 69 units	V2	
	Washington Elms (131 Washington St), 175 units	V2	
	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers), 124 units	V2	
	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers), 75 units	V2	
	Truman Apts (25 Eighth St), 60 units	V2	

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

C-2 Public Schools, Daycare, and Youth Centers

Summary of Key Findings

The public school and daycare facilities listed in Figure 20 are all highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). No youth centers were highly vulnerable to flooding under this scenario. Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk.

Figure 20. Public Schools, Daycare, and Youth Centers Risk Ranking for SLR/SS in 2070 (R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3** • *Kennedy / Longfellow School & Daycare (158 Spring Street)	**Score R4** • Tobin School & Daycare (197 Vassal Lane)
	Medium	**Score R2**	**Score R3**
	Low	**Score R1**	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

Tobin School & Daycare (R4) is the highest risk asset, not only among schools, daycare facilities, and youth centers, but also among all Community Resources in Cambridge that were assessed as part of CCVA Part 1. The 2070 1% annual probability SLR/SS scenario is projected to bring over 5 ft. of flooding in direct contact with the school building and flood all of the access roads surrounding the school. Even in less extreme SLR/SS floods, of up to a 30% probability, flood depths could reach almost 3 ft. The source of flooding in these scenarios is overland flooding from the Alewife Brook.

***Kennedy / Longfellow School & Daycare (R3)** is another high risk asset, though a lower risk than the Tobin School & Daycare. In the 2070 1% annual probability SLR/SS scenario, the school is only exposed to flooding from propagation through piped infrastructure. This lower probability of flooding contributes to its lower risk score. The flooding in this scenario is also not projected to come directly into contact with the school building at depths high enough to cause significant damage. While some key roadways surrounding the school would be impassable due to high flood depths, alternative access routes would still be available.

No other schools or daycare facilities included in CCVA Part 1 were exposed to flooding in the 2070 1% annual probability SLR/SS scenario.

Other Vulnerabilities

Direct exposure of the Tobin School & Daycare to high depths of flooding will result in a variety of different damages and costs. Direct impacts of corrosion to school buildings from elevated levels of salinity in SLR/SS flood waters can cause more long term damage costs both in terms of degradation and salinity remediation. For school buildings, salinity could damage structural elements as well as mechanical and electrical system components that are exposed to flooding. Further study is required to determine the potential impacts of salinity from SLR/SS flooding in Cambridge, as fresh and salt water mixing in the Charles and Alewife Brook basins have not been modeled under the 2070 SLR/SS scenario. In addition, remediation or replacement of indoor finishes will be required to prevent indoor mold growth and dampness, which can cause longer term respiratory health problems for building occupants, including children. Temporary closure of the school will result in additional child care, transportation, or lost-wage costs for households with children who attend, particularly those with low incomes or other social vulnerabilities.

Vulnerability from Cascading Impacts / Regional Issues

Typically, schools would be closed in advance of a major hurricane or nor'easter that might produce the projected storm surge. However, the Tobin School & Daycare and Kennedy / Longfellow School & Daycare also serve as area emergency shelters and therefore may be occupied during the event. This creates the risk that occupants may actually be physically endangered by the buildings' exposure to flooding during an event.

Critical energy and transportation infrastructure that have been identified as being highly vulnerable and high risk from SLR/SS flooding could impact the functioning of schools, daycare facilities, and youth centers. Energy is needed to run buildings, and transportation systems are needed for employees and children to access the facilities post-storm.

Figure 21. Public Schools, Daycare, and Youth Centers – Vulnerability and Risk Scores for SLR/SS in 2070

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

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Affordable Housing / Daycare	808 Memorial Dr (808-812 Memorial Dr)	V2	
	YMCA (820 Mass Ave)	V2	
	Roosevelt Towers (Low-Rise)(14 Roosevelt Towers)	V2	
	Roosevelt Towers (Mid-Rise)(14 Roosevelt Towers)	V2	
Public Schools	Cambridgeport School & Daycare (89 Elm St)	V2	
	Graham & Parks School & Daycare (44 Linnaean St)	V2	
	Haggerty School & Daycare (110 Cushing St)	V2	

	Peabody School & Daycare (70 Rindge Ave)	V2	
	Cambridge Rindge & Latin School / Rindge School of Technical Arts (459 Broadway)	V2	
	Rindge & Latin Auto Shop (456 Broadway)	V2	
	High School Extension Program & Daycare (15 Upton St)	V2	
	*Kennedy / Longfellow School & Daycare (158 Spring Street)	V3-V5	R3
	Tobin School & Daycare (197 Vassal Lane)	V5	R4
	Morse School & Daycare (40 Granite St.)	V2	
	Fletcher/Maynard Academy & Daycare (225 Windsor St)	V2	
	King Open School & Daycare (850 Cambridge St)	V2	
	Martin Luther King, Jr School (100 Putnam Ave)	not assessed	
	Baldwin School & Daycare (28 Sacramento St)	V2	
	CRLS 9th Grade Campus / Martin Luther King Jr Elementary School & Daycare (359 Broadway)	V2	
	Amigos School (101 Kinnard St)	not assessed	
Youth Centers	Gately Youth Center (70R Rindge Ave)	V2	
	Area IV Youth Center & Daycare (243 Harvard St)	V2	
	Frisoli Youth Center & Daycare (61 Willow St)	V2	
	Moore Youth Center & Daycare (11 Gilmore St)	V2	
	West Cambridge Youth Center (680 Huron Ave)	V2	
Health Centers	Teen Health Center at Cambridge Rindge and Latin	V2	

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

C-3 Pharmacies

Summary of Key Findings
The pharmacy listed in Figure 22 is highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4 or V5). Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk.

Figure 22. Pharmacy Risk Ranking for SLR/SS in 2070
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3**	**Score R4**
	Medium	**Score R2** • CVS Pharmacy 1022 (215 Alewife Brook Pkwy)	**Score R3**
	Low	**Score R1**	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

CVS Pharmacy 1022 (215 Alewife Brook Pkwy) (R2) is at moderate risk from SLR/SS flooding in 2070. In the 2070 1% annual probability SLR/SS scenario, the pharmacy could be directly exposed to significant depths of flooding (greater than 3 feet), making it highly vulnerable (V4). However, flood depths in higher probability scenarios (10% or greater) are below the threshold assumed to cause serious damage.

No other pharmacies studied in CCVA Part 1 are directly exposed to flooding in the 2070 1% SLR/SS flooding scenario.

Vulnerability from Cascading Impacts / Regional Issues
Critical energy and transportation infrastructure have been identified as being highly vulnerable and at high risk from SLR/SS flooding. The functioning of pharmacies in Cambridge, most of which are not exposed to flooding, could be impacted by failure of any of these systems. Energy and telecommunication systems are needed to run the pharmacies and process transactions, and transportation systems are needed for supplies, employees, and customers to access the pharmacies.

Figure 23. Pharmacy – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Pharmacy	Rite Aid Pharmacy 10159 (330 River St)	V1-V3	
	CVS Pharmacy 240 (1426 Massachusetts Ave)	V1	
	CVS Pharmacy 1002 (624 Massachusetts Ave)	V1	
	CVS Pharmacy 1262 (29 JFK St)	V1	
	Rite Aid Pharmacy 10158 (1740 Massachusetts Ave)	V1	
	Osco Pharmacy (699 Mount Auburn St)	V1	
	CHA Cambridge Hospital Campus (1493 Cambridge St)	V1	
	Colonial Drug, (49 Brattle St)	V1	
	Inman Pharmacy (1414 Cambridge St)	V1	
	Skenderian Pharmacy (1613 Cambridge St)	V1	
	Walgreens Pharmacy 6767 (625 Mass Ave)	V1	
	Walgreens Pharmacy (822 Somerville Ave)	V1	
	CVS Pharmacy 717 (36 White St)	V1	
	CVS Pharmacy 1022 (215 Alewife Brook Pkwy)	V4	R2

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

C-4 Food Assistance

Summary of Key Findings
The food assistance provider listed in Figure 24 is highly vulnerable in the 2070 1% annual probability SLR/SS scenario (V4). Assets with risk scores of R4 are the highest risk, followed by those with R3 scores. Only R4 and R3 assets are considered high risk.

Figure 24. Food Assistance Risk Ranking for SLR/SS in 2070
(R4 – Highest Risk, R1 – Lowest Risk)

		Probability	
		Low	**High**
Consequence	**High**	**Score R3**	**Score R4**
	Medium	**Score R2** • *Salvation Army / Daily Lunch (402 Mass Ave)	**Score R3**
	Low	**Score R1**	**Score R2**

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

*Salvation Army / Daily Lunch at 402 Massachusetts Ave is the only food assistance provider in Cambridge that is highly vulnerable (V4) in the 2070 1% annual probability SLR/SS scenario. It is considered a moderate risk (R2) due to the relatively limited number of people and area of the city that would be impacted, and because it is only at risk in the 2070 1% annual probability SLR/SS scenario due to propagation through piped infrastructure emanating from the Charles River.

Vulnerability from Cascading Impacts / Regional Issues
Critical energy and transportation infrastructure have been identified as being highly vulnerable and at high risk from SLR/SS flooding. The functioning of food assistance facilities, most of which are not highly vulnerable or at high risk from SLR/SS flooding, could be impacted by failure of any of the these systems. Energy is needed to run these facilities, and transportation is needed for supplies, service providers, and service users to access the facilities.

Regional food system vulnerabilities and risks have not been assessed as part of the CCVA. However, key assets in Chelsea, Boston, and transportation system assets (particularly truck routes) have been identified as being within potential flood zones. Disruptions of these assets, coinciding with higher demand due to a disaster, could lead to shortages or extended wait times for replenishment of food supplies at food assistance providers.

Figure 25. Food Assistance – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Food Assistance	Cambridge Senior Center Meals Program (806 Massachusetts Ave)	V1	
	Margaret Fuller Neighborhood House (71 Cherry St)	V1	
	*Salvation Army / Daily Lunch (402 Massachusetts Ave)	V4	R2
	Western Avenue Baptist Church (299 Western Ave)	V1	
	WIC Program Services (119 Windsor St - Public Health Dept.)	V1	
	St. Paul AME Food Pantry (85 Bishop Allen Dr)	V1	
	*Project Uplift Thursday Night Dinner (874 Main St)	V1-V3	

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

C-5 Municipal Resources

Summary of Key Findings
None of the key municipal resource buildings assessed as part of the CCVA Part 1 are highly vulnerable (V4 or V5) in the 2070 1% annual probability SLR/SS scenario (Figure 26). Assets were therefore not assigned risk scores.

Vulnerability from Cascading Impacts / Regional Issues
Energy, transportation, and telecommunication infrastructure have been identified as being highly vulnerable and at high risk from SLR/SS flooding. The functioning of municipal resource facilities could be impacted by failure of any of the three systems listed above. Energy is needed to run the buildings, transportation is needed for employees and service users to access the facilities, and telecommunication is needed to coordinate emergency response activities.

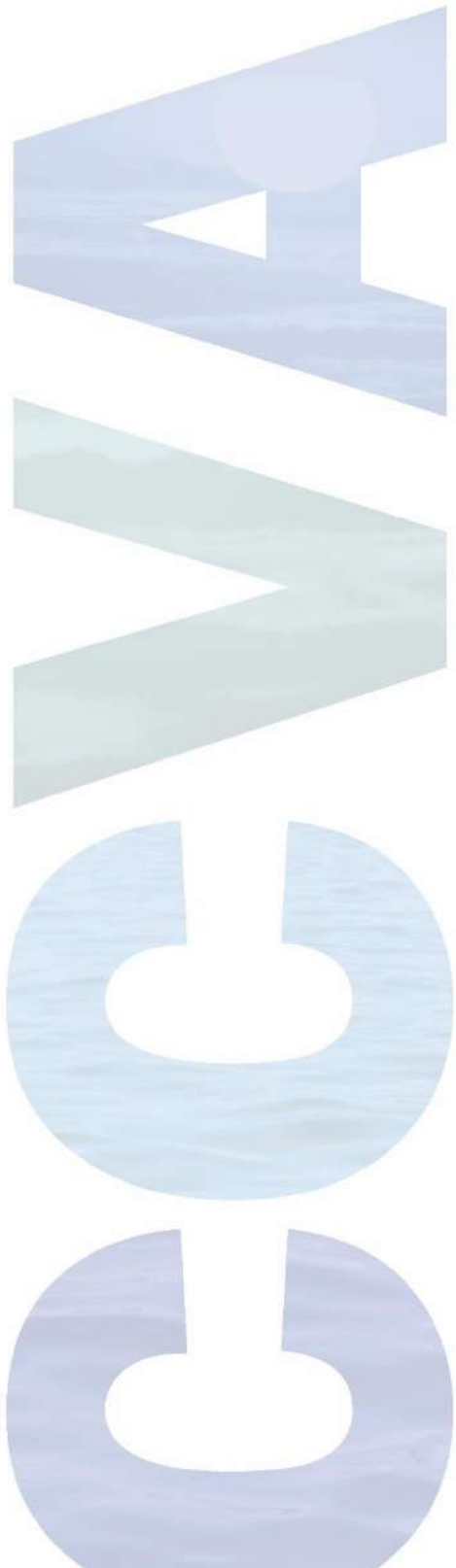
Figure 26. Municipal Resources – Vulnerability and Risk Scores for SLR/SS in 2070
(V5 – Most Vulnerable, V0 – Least Vulnerable; R4 – Highest Risk, R1 – Lowest Risk)

Critical Assets		SLR/SS Flooding - 2070	
		1% Annual Probability	
Type	Name	Vulnerability	Risk
Municipal Resources	City Hall (795 Massachusetts Ave)	V1	
	City Hall Annex (344 Broadway)	V1	
	Human Services Department (51 Inman St)	V2	

*Indicates that an asset is highly vulnerable in the 2070 1% annual probability SLR/SS scenario due to flood propagation through pipes, not overland.

Appendix 2

Vulnerable Populations



Climate Change Vulnerability Assessment

Part 2 – Sea Level Rise and Storm Surge

City of Cambridge, Massachusetts

April 2017

Disclaimer: The CCVA Part 2 Vulnerability Assessment is based on best available information for sea level rise and storm surge projections at the time the analysis was conducted. It is also informed by the CCVA Part 1 key findings as published on November 2015. Updates will be provided as new information is made available and key findings re-assessed accordingly.

CITY OF CAMBRIDGE CLIMATE CHANGE VULNERABILITY ASSESSMENT
PART 2 – SEA LEVEL RISE AND STORM SURGE

Technical Memorandum: Vulnerable Populations

Prepared by Kleinfelder, 04-15-2016

Context and Overview

This Memorandum describes socially vulnerable areas in Cambridge and their potential exposure and impacts from Sea Level Rise and Storm Surge (SLR/SS) flooding.

The Cambridge Climate Change Vulnerability Assessment (CCVA) Part 1 included a social vulnerability analysis which identified these areas and summarized their potential impacts from extreme precipitation and extreme heat. The social vulnerability analysis used readily available US Census data to construct sensitivity and adaptive capacity indices for extreme heat and extreme precipitation (flooding) and scored the social vulnerability of each census tract in Cambridge. A summary of the analysis is provided below. The CCVA Part 1 Vulnerable Population Ranking Memorandum describes the methodology, applications, limitations, and findings of that analysis in detail.

This memorandum will focus on reporting the results of the SLR/SS analysis in the context of relevant CCVA Part 1 findings.

Social Vulnerability Analysis

The social vulnerability analysis provided 'sensitivity' and 'adaptive capacity' scorings by which to rank the census tracts of Cambridge, using select indicators based on vulnerability literature. The use of geographic boundaries and US Census data offered one perspective on those individual and systemic vulnerabilities that can be understood with mapping tools.

The analysis provided a limited but valuable geospatial evaluation of community risk. It was not intended to provide a comprehensive picture of the strengths and vulnerabilities of the City's residents and workers individually, or of the capacity of its existing service networks and community or faith-based groups, to meet the most pressing needs of the community during a weather-related crisis. No single assessment can quantify all the important aspects contributing to the social dimensions of vulnerability. For example, information on disabilities and chronic illness, which make people more sensitive to climate stresses, is not collected by the Census or the City and therefore was not included in the assessment. However, the approach taken offers a clarifying picture of the service-based vulnerabilities Cambridge faces, by neighborhood and census tract, which can help further understanding of how the community will fare during extreme weather events.

Social indicators of sensitivity and adaptive capacity were uniquely derived from Cambridge-specific demographic indicators, shown in Figure 1. The sensitivity indicators are positively correlated with sensitivity (e.g., higher poverty corresponds to higher sensitivity), while the adaptive capacity indicators are negatively correlated with adaptive capacity (e.g., higher poverty corresponds to lower adaptive capacity).

Sensitivity	Adaptive Capacity
Poverty (as a proxy for health) *% below poverty line*	Poverty *% below poverty line*
Elderly *% above 65 years*	Limited Educational Attainment *% without high school diploma or equivalent*
Children *% below 5 years*	Language Isolation *% with limited English proficiency*
	Elderly Living Alone *% single person households, above 65 years*

Figure 1. Social Indicators of Sensitivity and Adaptive Capacity
(Source: Kleinfelder, May 2015)

Census tracts were ranked and assigned scores, based on the quartile they fell within for each indicator. Composite scores for each census tract were then created by summing across indicators and normalizing to 100. Sensitivity scores (S) and adaptive capacity scores (AC) of 0 - 3 were then assigned to each census tract based on quartiles of the normalized composite scores they fell within. Finally, vulnerability scores (V) were assigned to tracts using the social vulnerability scoring matrix below (Figure 2).

		Sensitivity: *Low → High*			
		S0	**S1**	**S2**	**S3**
Adaptive Capacity: *Low* ↓ *High*	**AC0**	**V3**	**V4**	**V5**	**V5**
	AC1	**V2**	**V3**	**V4**	**V4**
	AC2	**V1**	**V2**	**V3**	**V4**
	AC3	**V1**	**V1**	**V2**	**V3**

Figure 2. Social Vulnerability Scoring Matrix

(Source: Kleinfelder adapted from ICLEI)

Figure 3 shows the scoring results mapped to census tract areas using geographic information systems (GIS). Census tracts with the highest social vulnerability scores are identified by the V5 scores (dark red).

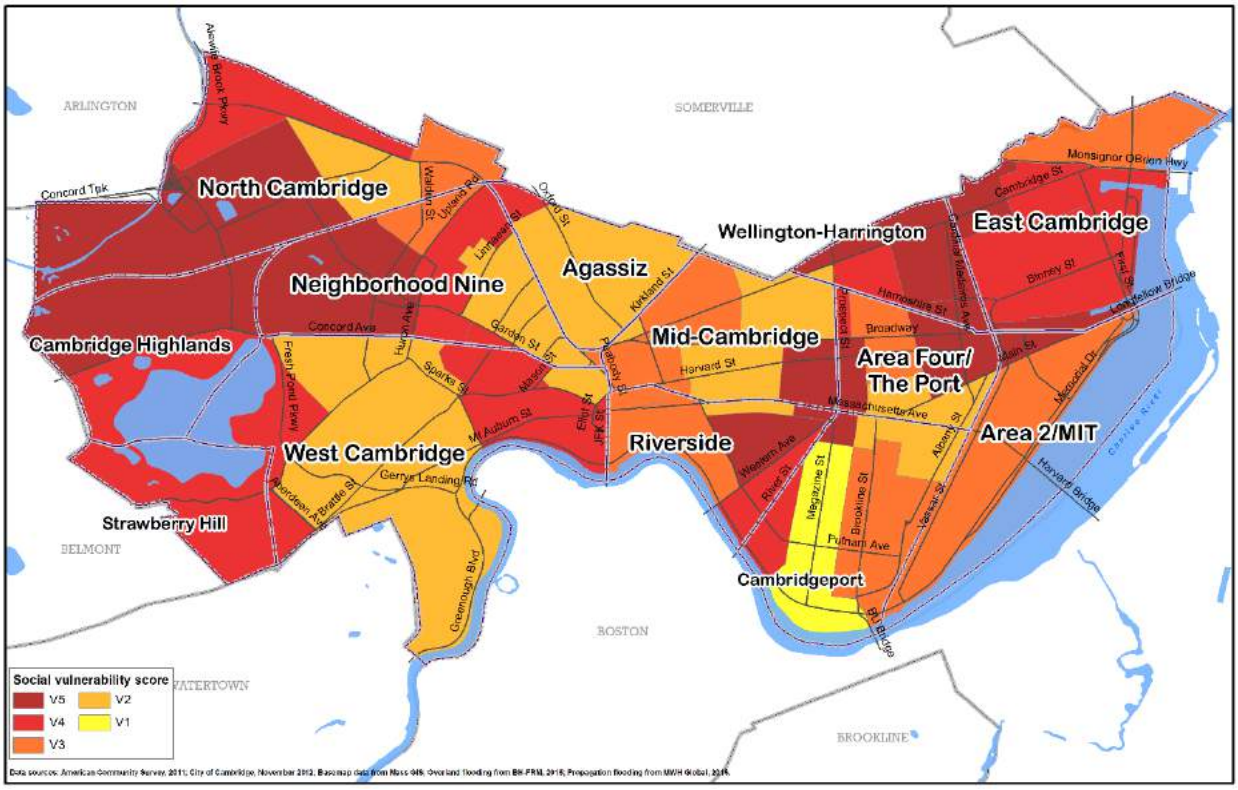


Figure 3. Census Tract Social Vulnerability Scores (Source: Kleinfelder, May 2015)

Three distinct clusters of socially vulnerable populations are evident by examining the map:

- The intersection of the Portland St/Cardinal Medeiros Ave and Cambridge St corridors
- Central Square and a large portion of the Riverside neighborhood, and
- The Fresh Pond/Alewife area, quadrisected by Alewife Brook Parkway and the Fitchburg Commuter Rail line.

A commonality between most vulnerable areas is the higher prevalence of poverty among residents. In addition, all but one of these census tracts fell in the top quartile city-wide for the percentage of adults without a high school diploma or equivalent. All but two fell in the top quartile for percent with limited English proficiency. They differed more in terms of their ranking for percentage of population made up of vulnerable age groups (e.g., under 5, over 65), though in general V5 tracts fell in the upper half of tracts city-wide for these indicators as well. The highest percentages of elderly and elderly living along, city-wide, was in a V5 tract in the Cambridge St corridor (East Cambridge), while the highest city-wide percentage of children under 5 years was in a Fresh Pond/Alewife tract (North Cambridge). The convergence of these

demographic indicators in certain areas explain why they ranked the highest overall in terms of social vulnerability.

Exposure of Vulnerable Populations to SLR/SS Flooding

The SLR/ SS modeling shows no impact for Cambridge in 2030 consequently, only the 2070 scenario has been used. Based on the 2070 flood scenario modeled for this project, much of Cambridge including areas with high social vulnerability scores (V5) in Central Square and Portland St/Cardinal Medeiros Ave and Cambridge St corridors are likely to be spared from SLR/SS flooding in 2070. SLR/SS flooding will likely be concentrated in areas of Cambridge at risk from overland flooding and "back up" or propagation flooding through the City's storm and sewer pipes.

Figure 4 shows the 1% annual probability SLR/SS flood depths (2070), including overland and propagation flooding, overlaid on the census tract social vulnerability map. SLR/SS flooding in socially vulnerable areas could seriously exacerbate identified social vulnerabilities. The most impacted neighborhoods are in the Fresh Pond-Alewife area. The flooded areas in the assessed census tracts contain many residential buildings including affordable housing units, places of employment, a critical transit hub, known hazardous material sites, and a nursing home that could become temporarily isolated due to roadway flooding.

Overland flooding to the east and south of Fresh Pond in the Strawberry Hill neighborhood is mostly confined to open spaces, including Fresh Pond Golf Course, so the direct impact on vulnerable populations would appear to be limited. The depths of flooding in North Cambridge and Cambridge Highlands are very high – greater than 3 ft. High depths of flooding in populated areas are a serious safety hazard that could potentially lead to injuries or even deaths.

There are also residential areas with lower social vulnerability scores that would be exposed to significant depths of flooding, namely the V4 tract in North Cambridge and V2 tract in the northwest corner of West Cambridge. The flood-exposed area in West Cambridge also contains the Tobin School – a public school and emergency shelter that, according to Assessor's data, has a basement. Disruption of the Tobin School's operations could result in additional child care costs or lost wages for time taken off of work by parents to care for their children. Transporting children to alternative schooling sites, if the school remained closed for an extended period of time, could result in additional transportation costs or lost wages. These costs would be most difficult to bare for low-income households.

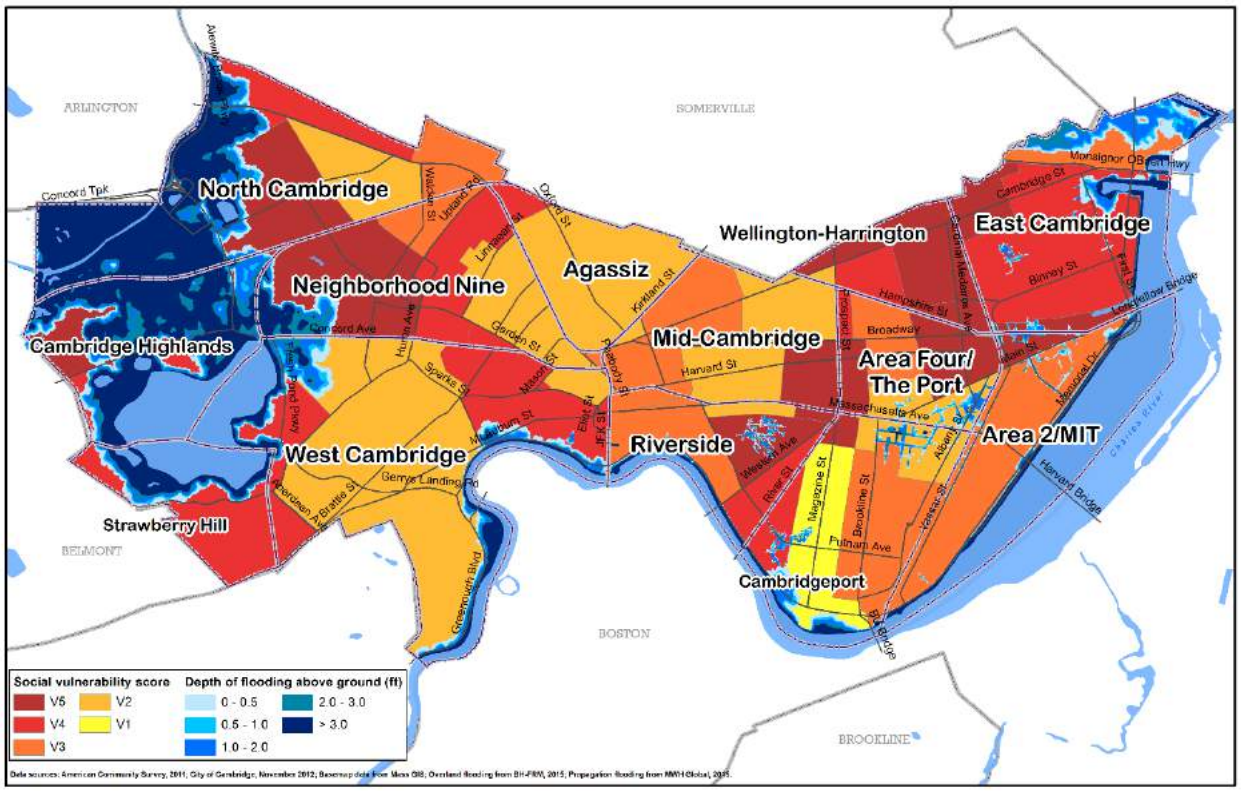


Figure 4. Social Vulnerability Scores and 1% Probability SLR/SS Flood Depths in 2070
(Source: Kleinfelder, March 2016)

Some sections of the Riverside neighborhood with the highest social vulnerability score (V5) are exposed to SLR/SS flooding in the 2070 scenario. Although the extent and depth of flooding is not as severe as in the Fresh Pond-Alewife area, some socially vulnerable populations in the Riverside neighborhood might be particularly burdened by the public health impacts, damage costs, and displacement caused by exposure to SLR/SS flooding.

Overland flooding and propagation flooding through the City's storm and sewer pipes could occur under the 1% annual probability SLR/SS flood in isolated pockets of East Cambridge, but not at the high depths projected for western parts of the City. A residential area of East Cambridge that is of potential concern due to flooding is around the intersection of Sixth Street and Rogers Street, near the Kennedy-Longfellow School. Flood depths under this scenario reach up to 2 ft. First Street, from the Lechmere Canal to Binney Street, is also potentially exposed to flooding.

Overland flooding along the Charles River is likely to be contained within open space under the 1% scenario.

Key Findings

- Socially vulnerable populations in the Fresh Pond-Alewife area and the Riverside neighborhood may be disproportionately exposed to flooding from SLR/SS in 2070.
- The Fresh Pond-Alewife area is particularly in danger from being exposed to frequent, extensive, and deep levels of overland SLR/SS flooding from the Alewife Brook.
- The Riverside neighborhood could also face severe SLR/SS flooding conditions, but only in rare and extreme scenarios (i.e., 1% probability) where water backs up through the drainage system from the Charles River.
- Socially vulnerable populations may be particularly burdened by potential public health and safety impacts, economic losses, and displacement caused by SLR/SS flooding in their communities.

Next Steps

The next step will be an integrated approach to minimize risk and increase resiliency to support the most vulnerable populations. The overlaying of the SLR/SS flooding maps on top of hazardous materials (Figure 5) and buildings with basements (Figures 6-8) highlights areas of risk to be further studied and addressed in the Preparedness Plan. Proximity to community-based organizations and services has also been mapped (Figure 9) as an element to be further considered and emphasized in developing resilient neighborhoods. The preliminary findings reported below are to inform the discussion with stakeholders and neighborhoods to develop a resilient Cambridge.

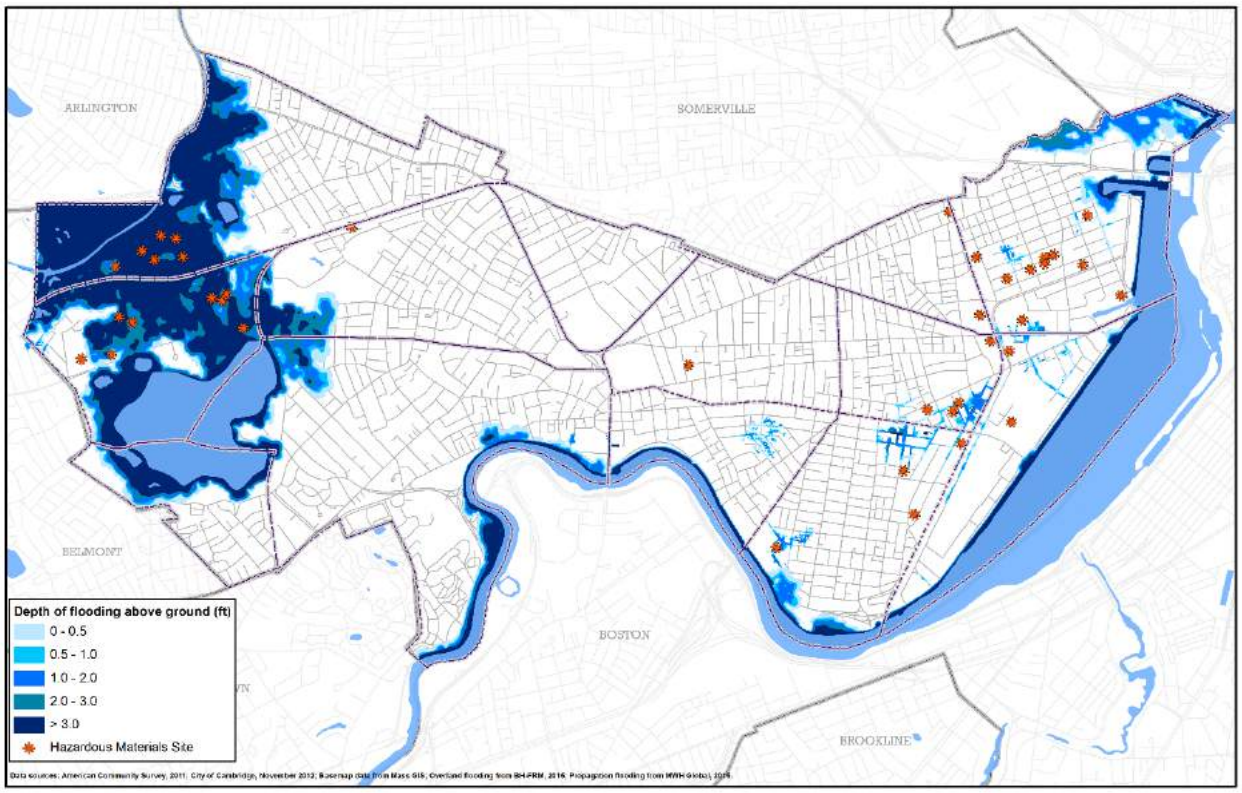


Figure 5. Hazardous Materials Sites and 1% Probability SLR/SS Flood Depths in 2070
(Source: Kleinfelder, March 2016 based on City of Cambridge, 2012 data)

Hazardous Material Sites: Figure 5 locates known hazardous materials sites throughout the City as provided by the City of Cambridge. Information on the location of these sites is shared with the local emergency planning commission and Cambridge Fire Department. Flood depths for the 1% probability SLR/SS scenario in 2070 are overlaid. There are many hazardous material sites in the Fresh Pond–Alewife area, which is an area with a high risk of severe flooding and also has highly vulnerable populations.

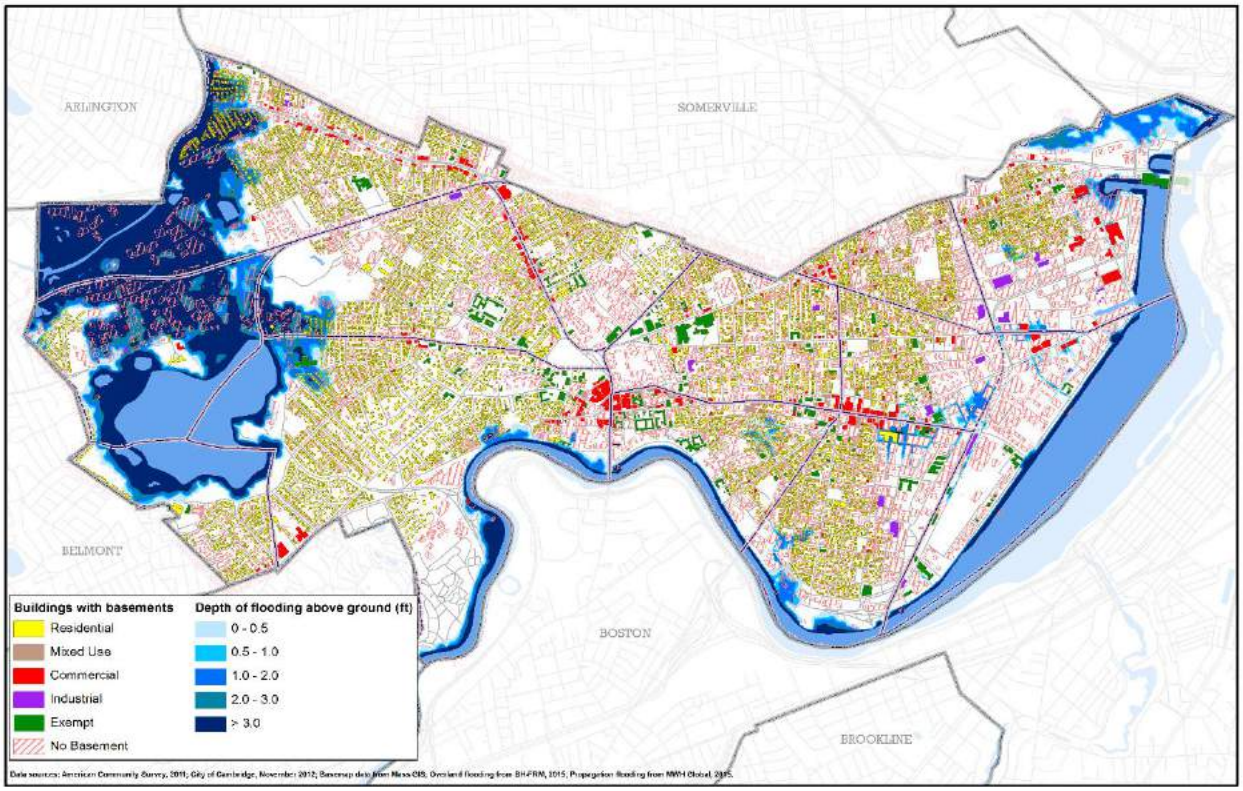


Figure 6. Buildings with Basements and 1% Probability SLR/SS Flood Depths in 2070
(Source: Kleinfelder, March 2016 based on City of Cambridge 2013 Assessors data)
Disclaimer: Based on assessors' data on basement which may not be complete.

Buildings with Basements: Figure 6 shows buildings with basements in Cambridge, according to the City Assessor's database. The Assessor's database identifies if buildings have a basement, but it does not document whether these are 'finished' or converted basements used as living space. Building types in Figure 6 have been color-coded according to the permitted zoning land use.

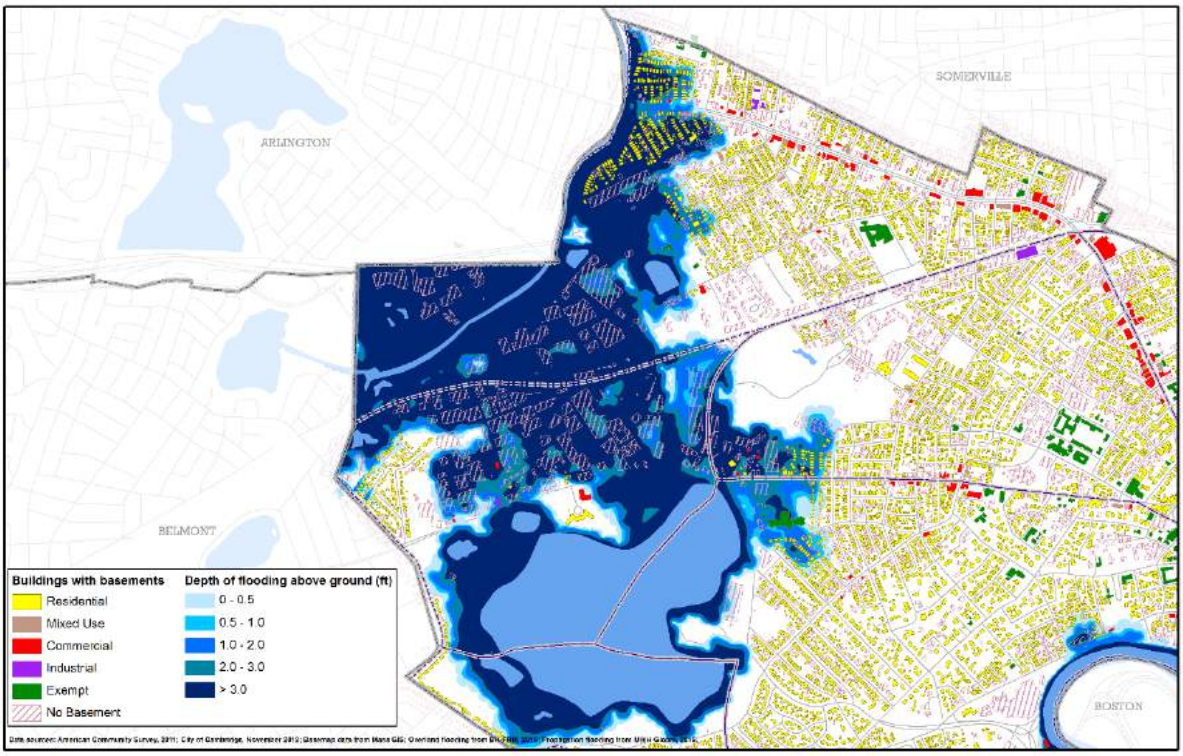


Figure 7. Fresh Pond-Alewife – Buildings with Basements and 1% Probability SLR/SS Flood Depths in 2070 (Source: Kleinfelder, March 2016 based on City of Cambridge 2013 Assessors data)
Disclaimer: Based on assessors' data on basement which may not be complete.

The projected higher depths of flooding in the Fresh Pond-Alewife area also increase the likelihood of structural damage to buildings and water entry into basements which can result in indoor dampness and mold growth. As shown in Figure 7, residential and non-residential buildings with basements are present in the area projected to be impacted by flooding. Basements often contain building mechanical and electrical systems as well as major appliances, any of which would likely be damaged by flooding. Also, as discussed in the CCVA Part 1 Public Health Assessment, indoor dampness and mold have long been known to cause adverse respiratory effects, including symptoms of cough and wheeze among persons of all ages. In addition to public health impacts and the economic burdens of paying for building remediation, repair, and replacement, damage to housing stock could result in displacement of people, including owners, renters and, affordable housing residents, many of whom are already socially vulnerable.

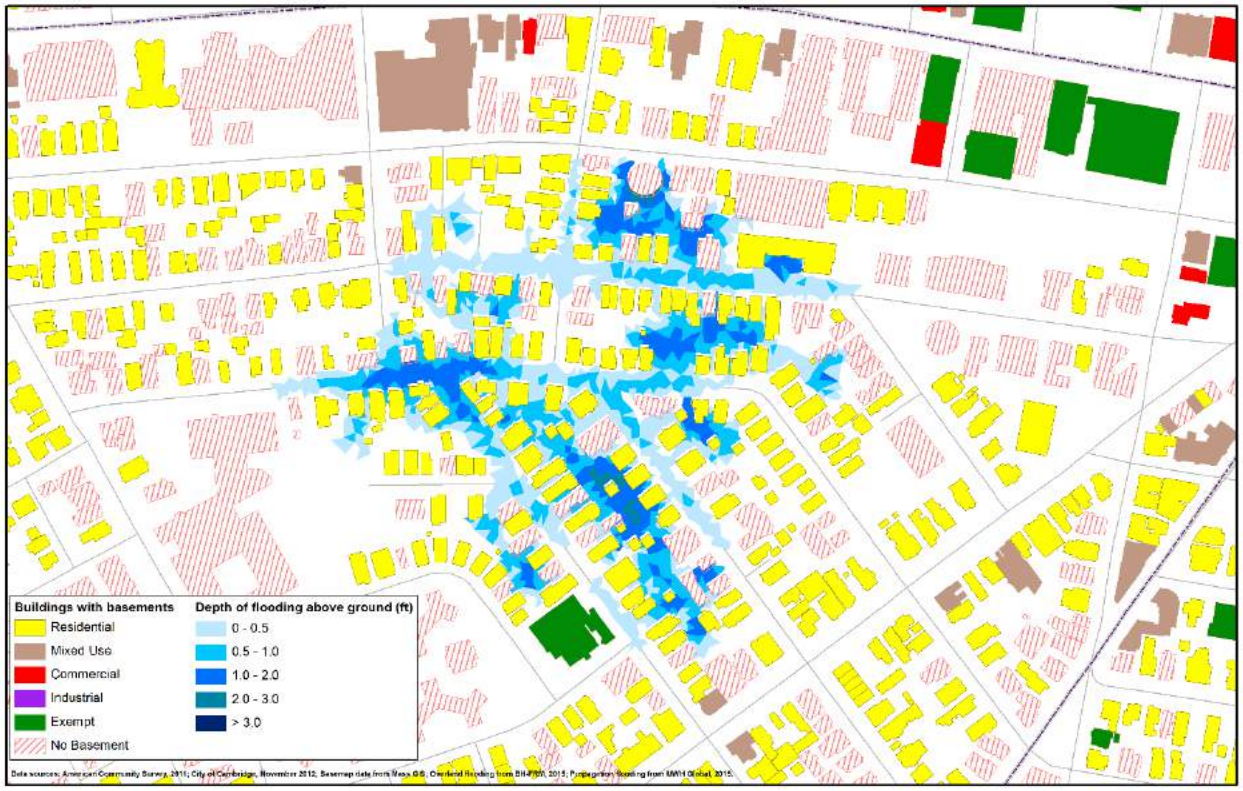


Figure 8. Riverside - Buildings with Basements and 1% Probability SLR/SS Flood Depths in 2070 (Source: Kleinfelder, March 2016 based on City of Cambridge 2013 Assessors data)
Disclaimer: Based on assessors' data on basement which may not be complete.

The Riverside area impacted is almost entirely residential (Figure 8). More than 100 buildings may be in direct contact with flood water, and even more may have flooding in the street, and approximately two thirds of them have basements.

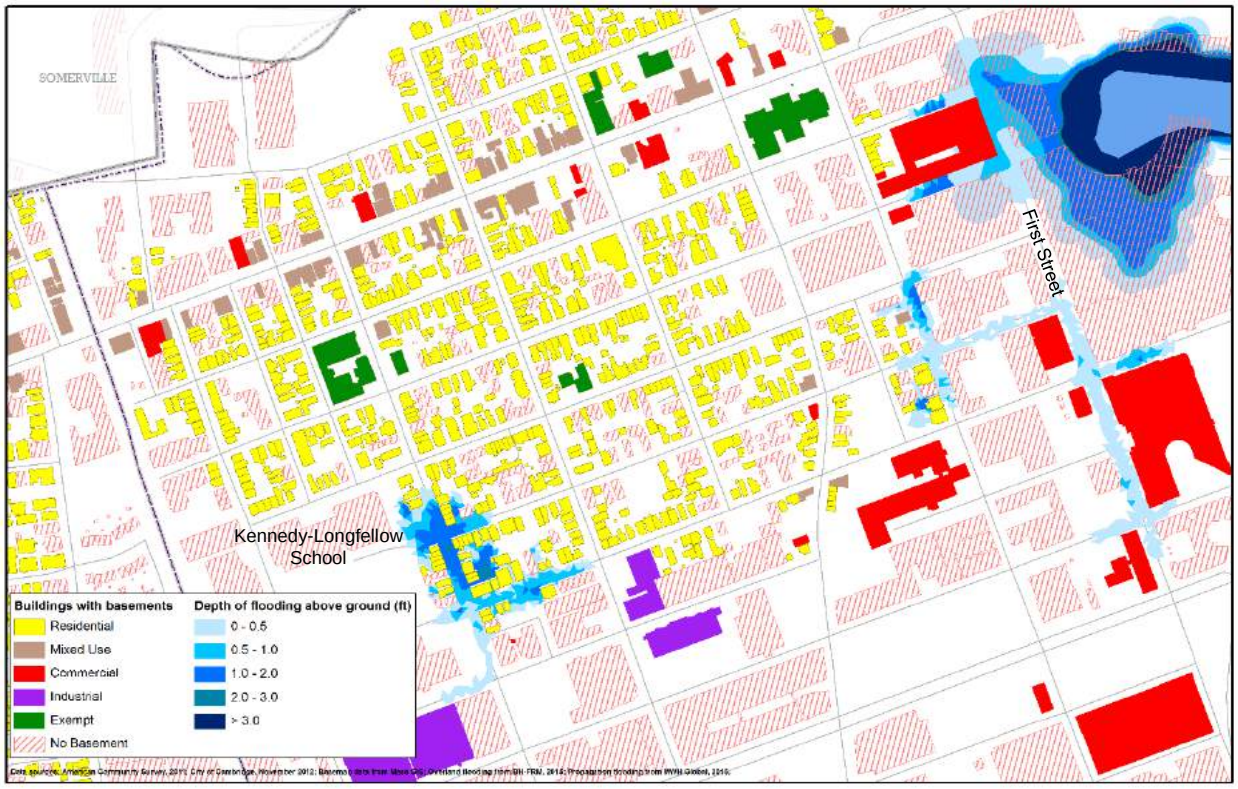


Figure 9. East Cambridge - Buildings with Basements and 1% Probability SLR/SS Flood Depths in 2070 (Source: Kleinfelder, March 2016 based on City of Cambridge 2013 Assessors data)
Disclaimer: Based on assessors' data on basement which may not be complete.

The residential area of East Cambridge, around the intersection of Sixth St and Rogers St, near the Kennedy-Longfellow School, also shows depth of flooding up to 2 ft. (Figure 9). Most houses in direct contact with floodwaters do have basements. However, the area does have various community groups and support services nearby that are not impacted (Figure 10).

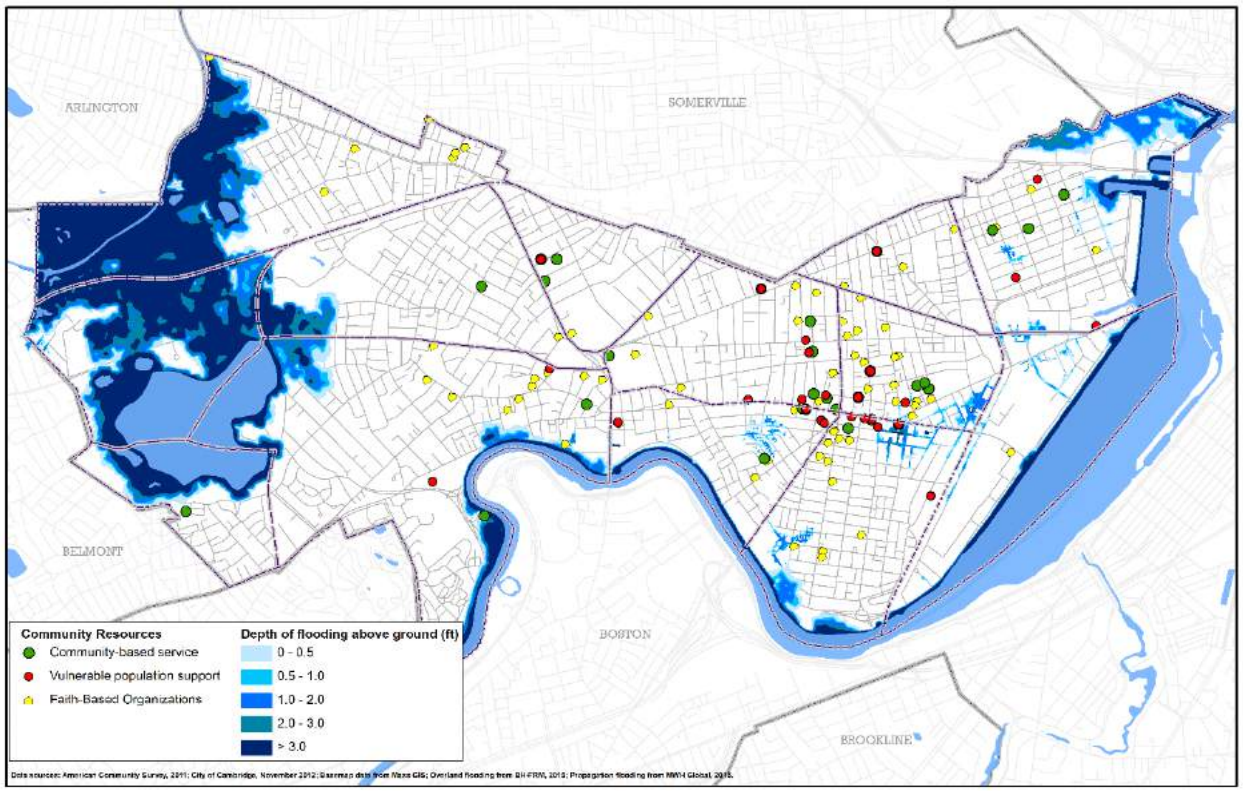


Figure 10. Community Resources and 1% Probability SLR/SS Flood Depths in 2070
(Source: Kleinfelder, March 2016 based on City of Cambridge, 2012 data)

Community Resources: Figure 10 shows the locations of a variety of community resources, as provided by the City of Cambridge. Cambridge is home to a diverse array of faith-based organizations, community-based services, and vulnerable population support providers. These organizations typically form a critical supportive network for residents and families in times of disaster and recovery, as they provide opportunities to connect with other families in the same religious, linguistic, and cultural community, or other people that are facing similar challenges. Figure 10 shows that, while there are quite a few faith-based organizations in North Cambridge (all but one are outside of the flood impacted area), there is a lack of secular community-based organizations and support services for vulnerable populations in the area. Without easy access to these organizations and services, vulnerable populations may have limited places to turn to in the immediate aftermath of a major flood or during the longer road to recovery.

Riverside and nearby Central Square have a much more robust cluster of faith-based and community-based organizations as well as numerous providers of vulnerable population support services. Most, if not all of these resources are outside of the SLR/SS flood-impacted area. This may provide a stronger safety net in the aftermath of a major flood and as the community works to recover. The presence of so many vulnerable population service providers, in combination with the high indicators of social vulnerability, suggests that the community already has a high

background level of need. A peak in demand after a major flood could temporarily overwhelm their ability to provide such services, without outside assistance.

Environmental Justice: While exploring the potential environmental justice implications in the City of Cambridge is not within the scope of this study, our initial findings from the social vulnerability ranking methodology can help to inform future research. A range of socioeconomic and demographic characteristics have been incorporated as proxies for considering the adaptive capacity and sensitivity of Cambridge communities. These characteristics dovetail with research conducted in other contexts exploring the possible connections between social vulnerability, climate hazard exposure, and post-disaster recovery experiences.

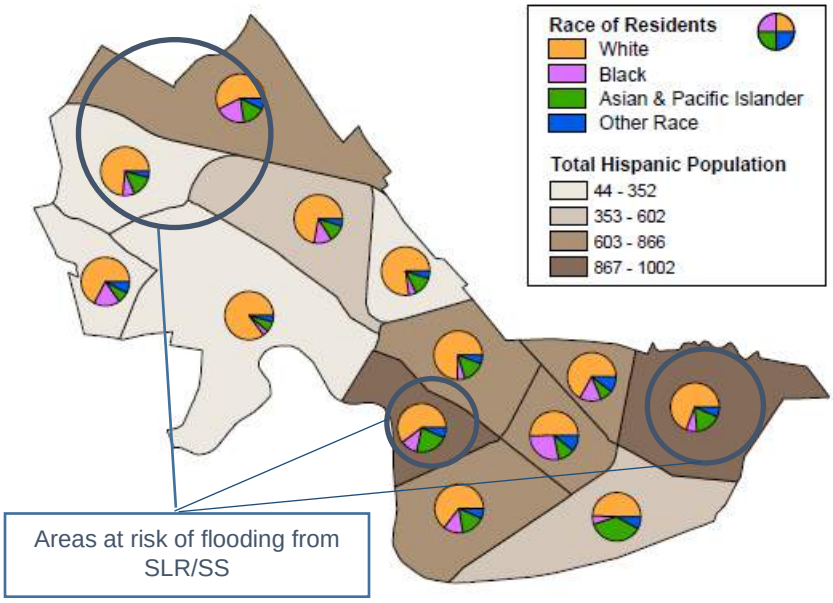


Figure 11. 2010 Race and Hispanic Population (Source: 2010 Decennial census)

As a preliminary qualitative analysis in comparing data reported by the City, it would appear that socially vulnerable areas in North Cambridge, Riverside, and East Cambridge neighborhoods that were identified as being at risk from SLR/SS flooding also have relatively large racial and ethnic minority populations (Figure 11).