Economic Vulnerability Assessment

Climate Change Vulnerability Assessment

City of Cambridge, Massachusetts

November 2015

ERRATA

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The Economic Vulnerability Assessment was performed in February 2015. The flooding maps have been revised since with changes in projection for the Riverside area for depth and extent of flooding in the Western Avenue and Flagg Street catchment areas. The forecasted flooding for the 10- and 100-year precipitation scenarios is less severe than initially projected. Consequently, the projected economic impact for structural damages for residential buildings that are within the revised area are overestimated in this report. This is not impacting projected losses in economic activity.

CATALYSIS ADAPTATION PARTNERS, LLC

Economic Vulnerability Assessment: A three-part approach to estimate the economic impact to the City of Cambridge from high rainfall events expected with climate change

Abstract

In support of Kleinfelder's larger efforts to address climate preparedness planning goals of the City of Cambridge, this document presents 1) Estimates of the value of one-time structural damage to building values from flooding, using extent and depth of inundation for four future precipitation scenarios (10- and 100-year events in year 2030, and 10- and 100-year events in year 2070); 2) Estimates of one-time, direct and indirect losses in economic activity due to flooding from these 10- and 100-year events in 2030 and 2070; and 3) Estimates of one-time economic activity losses from one day of interrupted economic activity for the entire city of Cambridge, for any disaster event with a city-wide geographic impact, such as a heat induced city-wide power failure. All estimates were based on impacts to the present day level of economic activity, and present day taxable assessed value of the City's building stock.

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1 EXECUTIVE SUMMARY

Catalysis Adaptation Partners LLC (CAP) was subcontracted to Kleinfelder (KLF) to provide the City of Cambridge with an economic vulnerability assessment from the impact of four future high precipitation scenarios, as part of the Cambridge Climate Change Vulnerability Assessment. This document presents:

1. Estimates of the value of one-time structural damage to building values from flooding, using extent and depth of inundation for four future precipitation scenarios (10- and 100-year events in year 2030, and 10- and 100-year events in year 2070);
2. Estimates of one-time, direct and indirect losses in economic activity due to flooding from these 10- and 100-year events in 2030 and 2070; and
3. Estimates of one-time economic activity losses from one day of interrupted economic activity for the entire city of Cambridge, for any disaster event with a city-wide geographic impact, such as a heat induced city-wide power failure.

All estimates were based on impacts to the present day level of economic activity, and present day taxable assessed value of the City's building stock.

Approach 1 estimated structural damage to buildings from the four scenarios. Modeling results revealed over $61 Million in damages for a 100-year event in 2030 and over $232 Million (less than 1% of total assessed value of city buildings) for a 100-year event in 2070, for all building types. When broken out by building use type, more than half of those damages in the 2030 event are comprised of residential building damages, while more than half of the damages in the 2070 event are comprised of non-residential buildings. Those non-residential buildings noted as "exempt", "commercial" and "laboratory" made up the majority of those damages in 2070 (88%). "Exempt" properties are non-profits, religious, and educational institutions, not subject to property taxes. The "laboratory" category was created by the city as part of this project, and is not a usual assessor's category.

Estimates of structural damage also were broken out by various geographies: districts, zip codes, and census tracts. When damage was analyzed by commercial district, the North Mass Ave. district had the most damage for the 100-year event in 2030, while the Kendall Square district had the most for the 100-year event in 2070. When damage was analyzed by development district, the Concord Alewife district had the highest amount of building damage for the 100-year event in both 2030 and 2070. Zip Codes 02140 and 02138 had the largest amount of flooding damage for both the 100-year event in 2030 and 2070. Not surprisingly, census tracts (354300, 354900 and 355000) located within those zip codes also fared worse than the other census tracts for the 100-year event in 2030, however the 100-year event in 2070 also included highly damaged buildings in census tracts located on the lower Charles River (352400, 353101 and 353102).

Approach 2 estimated one-time, direct and indirect losses in economic activity due to flooding from these same four high precipitation event scenarios. The impact of the temporary loss of employment was estimated using the IMPLAN model, which incorporates analysis of employment, wages and income, population, and output. One hundred thirty six properties were impacted by more than 6 inches of water from a 100-year event in 2030, affecting between 5,530 and 8,555 employees. For every day these properties are out of service, the City of Cambridge modeling indicates a loss of between $3.4 and $4.6 Million in the total output of the Cambridge economy (as measured by the city's

Gross Regional Product). Economic impacts can be further exacerbated when employees are laid off, resulting in loss of business from those workers who are no longer able to help support the local economy. Such losses include an additional 3,231 employees (indirectly) impacted[1].

This same economic analysis found there were 11 scientific research and development properties flooded by more than 6 inches from a 100-year event in 2030. This would affect between 3,702 and 3,712 employees and for every day these laboratories are not in service the City loses between $1.3 and $2.2 Million in Gross Regional Product. An additional 1,785 employees would be affected from indirect and induced impacts from this same flooding event. Additionally, the Scientific Research and Development Industry has an overall multiplier of 1.48; meaning the total effects on the Cambridge economy are 48% higher than the direct effects alone.

Approach 3 estimated one time economic activity losses from a one day disaster event with a city wide geographic impact, such as a heat induced widespread power failure. Such a one-day interruption of the Cambridge economy would affect about 128,000 jobs city-wide and result in the loss of $42.96 Million in output. These losses would continue as long as the disruption continued. While a vast majority of these losses can be made up once power is restored, an unknown proportion of losses would be permanent.

The estimation of potential economic effects from climate change is obviously subject to considerable uncertainty, particularly given the inability of current data systems to provide more precise estimates. Roughly $16.1 million could be lost in output per day, and as much as one quarter of the $15 billion in annual Gross Regional Product could be impacted by increased precipitation or extended heat waves for periods of a few days to many months. The effects would most probably spread well beyond Cambridge into the Massachusetts and New England economies. The size of the possible impacts makes clear the need to think more systematically and energetically about adaptation strategies.

[1] Job losses are caused by a combination of layoffs, temporary jobs that are not continued, and jobs that could be expected to be created under normal circumstances not being created because of the scenario examined.

2 BACKGROUND

In support of Kleinfelder's larger efforts to address climate preparedness planning goals of the City of Cambridge, Catalysis Adaptation Partners, LLC (CAP) was subcontracted by Kleinfelder to conduct an economic impact evaluation of several plausible climate future scenarios. Outlined below are: 1) Estimations of the value of one-time structural damage to building values from flooding, using extent and depth of inundation for four future precipitation scenarios (10- and 100-year events in year 2030, and 10- and 100-year events in year 2070); 2) Estimates of one-time, direct and indirect losses in economic activity due to flooding from the 10- and 100-year events in 2030 and 2070; and 3) Estimates of one-time direct and indirect economic activity losses from one day of interrupted economic activity for the entire city of Cambridge, for any disaster event with a city-wide geographic impact, such as a heat induced city-wide power failure. All estimates were based on impacts to the present day level of economic activity, and present day taxable assessed value of the City's building stock. Methods, results, caveats, and interpretation of results are provided in this report.

3 ESTIMATE OF ONE-TIME FLOODING STRUCTURAL DAMAGE TO BUILDINGS

Kleinfelder prepared four precipitation scenarios for the City of Cambridge for future 24-hour 10- and 100-year rainfall events made worse by climate change, for years 2030 and 2070. CAP evaluated the dollar value of one-time structural damage to building values from the flooding predicted in these scenarios. Flooding predictions, reported as flood depths above ground, were from two different flooding models: 1) stormwater system backups (obtained from a TIN polygon file); and 2) riverine flooding from the Charles River and Alewife Brook. A file of building footprints was provided by KLF and the City with property tax assessed values assigned to each individual footprint. A single mean value of flooding depth at the perimeter of each building footprint was derived for each of the four rainfall scenarios from the combined flooding data described above. A depth damage function per building type from the US Army Corps of Engineers was assigned to each footprint according to City-defined use codes to determine the predicted structural damage to each building per foot of predicted flooded depth. Total structural damage was then calculated by various use-types and geographies. This approach assumes no adaptive actions were undertaken by 2030 or 2070, and was modeled on present-day patterns of building locations and building values from the City's GIS data.

3.1 METHODS

<u>Assignment of Building Values to Building Footprints</u>

CAP used a file of the City of Cambridge building footprints joined with the City tax assessment data for building values from the year 2014. The building footprint file obtained from the city by Kleinfelder did not contain building values or other assessment data for each footprint, as value data is collected by the City for parcels, not buildings. In order to estimate structural building damage at each building footprint, a building value for each separate footprint needed to be assigned. When more than one building footprint fell within a single parcel, the total assessed value of buildings from the assessing record for the parcel was divided and a portion of the building value allocated to each footprint. In the absence of any data on the value of individual footprints, the method used was to divide the total building value for the parcel by the number of buildings located within it, and assign the equal fraction of building value to each individual footprint. Therefore multiple buildings on a parcel were each given an equal share of the total parcel building value, regardless of actual size or value differences between the multiple buildings.

Not all of the building footprints affected by flooding in the scenarios could be matched with building values from the 2014 database. Out of 5069 total footprints affected by the high 2070 rainfall scenario (by any mean depth greater than zero), 369 footprints had no assigned values, as the parcel's building value was blank in the city database. In order to achieve a higher match rate, the newest 2015 assessment database from the City was utilized, and out of the 369 unmatched footprints from the 2014 dataset, an additional 276 values were assigned, leaving only 93 footprints with no value, or less than 2 percent of the footprints affected by the flooding scenarios. Values assigned to the 276 footprints from the 2015 dataset were reduced by 11% to reflect that, on average, 2015 building values were 11% higher than 2014 building values (per consultation with the City assessing department). This was done to assure a consistent level of assessment. A detailed methodology of the GIS building value assignment process may be found in the metadata section of the appendix (6.1) and a spreadsheet of the 93 missing footprints in appendix (6.2). Overall, these limitations led to a more conservative estimate of building damages.

Assignment of Mean Flooding Depths at the Perimeter of Each Building Footprint

Flooding depths were obtained from two different data sources for each of the four future rainfall scenarios. Predicted depths from stormwater system flooding were provided in a TIN polygon format from ICM-2D model runs, and Alewife Brook and Charles River flooding were provided in a raster grid format. The flooding depths within five feet of the perimeter of each building footprint were averaged, and one mean flooding depth value was applied to each footprint. Footprints affected by the stormwater flooding were assigned mean depths from the polygon file, and footprints affected by the riverine flooding were assigned mean depths from the raster file. In cases where a building footprint was affected by flooding both the polygon stormwater flooding file and the raster surface water flooding file, the deeper of the two values was assigned. A detailed methodology of the GIS mean depth assignment process may be found in the metadata section of the appendix (6.1).

Assignment of Depth Damage Functions

An Army Corps of Engineers depth-damage function (DDF) was applied to estimate lost building value from flooding according to the mean depth of the flood waters around the building footprint as assigned from the four precipitation scenarios. For each building in the building footprint polygon file, CAP utilized the available coding provided to assign one of three depth-damage functions from the Army Corps of Engineers, as shown below. Assignments of more kinds of DDFs were not feasible given the condition of the construction type and use-type coding in the 2014 database provided.

Tables for building structural damage were utilized (not including the value of building contents), for freshwater flooding, as shown below:

Non-Residential Depth-Damage Function		
Masonry Bearing Walls		
Feet	Decimal Damage	Percent Damage
0	0.000	0.0%
0.5	0.000	0.0%
1	0.005	0.5%
2	0.131	13.1%
3	0.167	16.7%
4	0.193	19.3%
5	0.211	21.1%
6	0.234	23.4%
7	0.275	27.5%
8	0.280	28.0%
9	0.300	30.0%
10	0.316	31.6%

Residential Depth-Damage Function		
More Than One Story, On Foundation with Basement		
Feet	Decimal Damage	Percent Damage
0	0.000	0.0%
0.5	0.017	1.7%
1	0.025	2.5%
2	0.205	20.5%
3	0.256	25.6%
4	0.271	27.1%
5	0.297	29.7%
6	0.315	31.5%
7	0.383	38.3%
8	0.405	40.5%
9	0.413	41.3%
10	0.418	41.8%

Residential Depth-Damage Function		
More Than One Story, On Slab, no Basement		
Feet	Decimal Damage	Percent Damage
0	0.000	0.0%
0.5	0.000	0.0%
1	0.000	0.0%
2	0.181	18.1%
3	0.231	23.1%
4	0.238	23.8%
5	0.268	26.8%
6	0.290	29.0%
7	0.368	36.8%
8	0.394	39.4%
9	0.400	40.0%
10	0.403	40.3%

Table 1. Depth-damage functions. Source: Depth-Damage Relationships for Structures, Contents, and Vehicles and Content to Structure Value Ratios in Support of the Donaldsonville to the Gulf, Louisiana, Feasibility Study, USACOE, Contract No. DACW29-00-D-0001, March 7, 2006, Tables 1 and 3.
See http://www.mvn.usace.army.mil/Portals/56/docs/PD/Donaldsv-Gulf.pdf for a copy of the complete report.

Limitations of Depth Damage Functions

Catalysis performed a literature search on DDFs available from the US Army Corps of Engineers and other governments, and in our opinion the 2006 work done by the USACOE in the Louisiana Gulf region is the best available at this time for use in Cambridge. Prior to its availability we used Depth-Damage Functions from USACE from the 1990's from the Midwest and Appalachian areas, which was their next, most recent work. The army has historically done its statistics on midwestern and southern locations with large repetitive losses (as opposed to New England cities).

CAP utilized the depth damage functions that did not include building contents, given that we had no such information from City databases. The USACOE creates separate Depth-Damage Function tables for saltwater and freshwater flooding, and for Cambridge, we selected the freshwater static flooding values. DDFs for saltwater/coastal environments run considerably higher.

Note that the zero point in Army Corps DDF tables is set to the base floor elevation, not at the point where the finished grade meets the building. Catalysis needed to make a blanket assumption about the average BFE in Cambridge as 2 feet above grade, in the absence of any City database on such a detail.

The exact components of the structural damage captured in the various depth damage functions shown in Table 1 are found in the report starting on pdf page 19. For example, the depth-damage function for non-residential construction with masonry bearing walls from pdf page included 13 structural component damage estimates, as well as permitting, mold remediation, and emergency services costs, that all were aggregated to create the depth damage function values.

As the 2014 assessor's database had no consistent field for structure type (only exterior wall type). Given the fields avaialbe only three differentt ddfs were assigns, using assumptions of the predominant construction patterns.

3.2 Results

3.2.1 Damage by Building Type

The total estimated real estate damage for the City of Cambridge in 2070 from a 24-hour 100-year event was over $232 Million (Table 2). Non-Residential buildings accounted for most of the damage for this scenario, however residential building damage accounted for more damage under the other three precipitation scenarios (2030 10-year, 2030 100-year and 2070 10-year). Figures 1-3 show flooding damages for all buildings, residential buildings and non-residential buildings respectively.

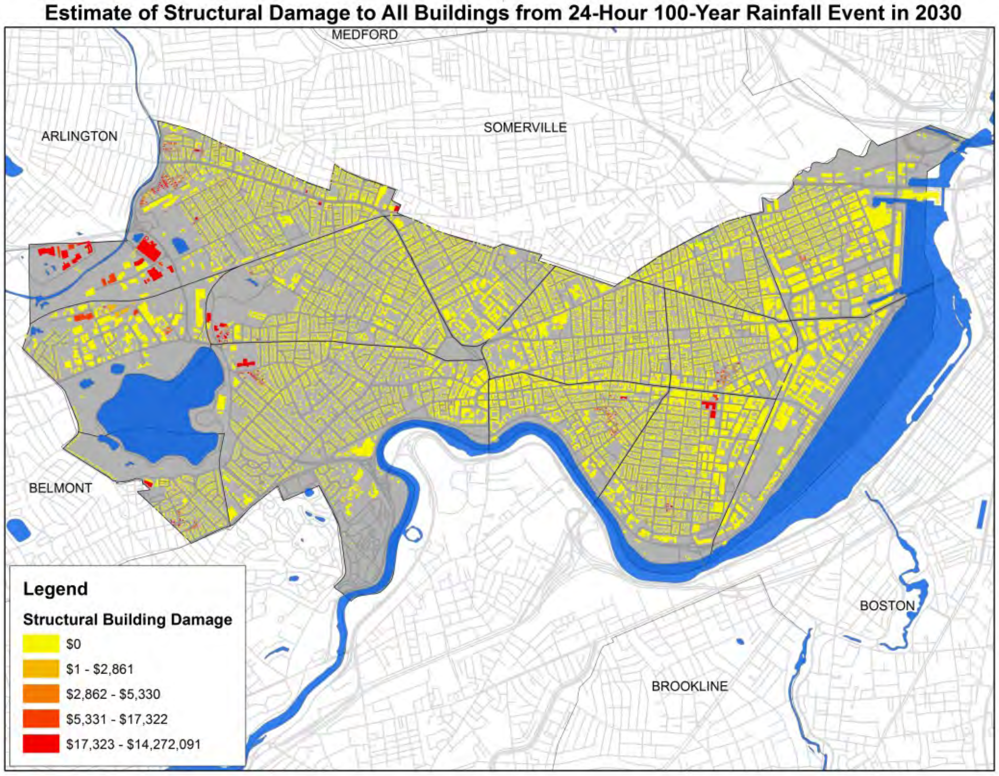
Of the nearly $137 Million in damages to non-residential buildings from a 100-year event in 2070, those listed as "Exempt" under the dataset's "Use Category" were damaged more than any other category of non-residential buildings. However, buildings listed as "Commercial" and "Laboratory" did have relatively high damages compared to the other building use categories, with damages exceeding $43 Million and $30 Million respectively for this same event in 2070. There were over $28 Million in damages to buildings that did not have a designated use category.

There were 1,350 building footprints that were flooded with less than 6 inches of water in the 100-year event in 2030, and 2,965 building footprints that were flooded with less than 6 inches of water in the 100-year event in 2070. The depth-damage function analysis used in this study only tallies damage to buildings flooded by 6 inches or more of water. For this reason, those footprints subjected to less than 6 inches of flooding were excluded from this analysis. The lack of information on building damages where flooding is less than 6 inches is another factor that makes damage estimates conservative. A map of those footprints and a spreadsheet breaking down the footprint flooding by two-inch increments are included in the appendix (6.3) of this report. Shapefiles for those footprints will also be included in the report package. Additional maps for scenarios not featured below (10-yr 2030 and 10-yr 2070) as well as all scenarios featured below can be found in full page layouts in the appendix (6.4). Map legends divide the structural damage estimates into color category ranges, based on division of the damage into quantiles (five parts).

Building Type	2030 10-yr	2030 100-yr	2070 10-yr	2070 100-yr
Residential	$ 8,606,602	$ 33,557,802	$ 10,913,628	$ 66,924,057
Non-Residential	$ 337,466	$ 22,007,236	$ 1,081,133	$ 136,918,605
Commercial	$ 169,224	$ 11,344,611	$ 305,680	$ 43,699,518
Exempt	$ 15,662	$ 2,326,722	$ 4,015	$ 44,952,945
Industrial	$ 1,071	$ 358,239	$ 9,267	$ 12,500,675
Laboratory	$ 148,887	$ 5,112,561	$ 736,467	$ 30,795,891
Mixed Use	$ 2,622	$ 2,865,103	$ 25,704	$ 4,969,576
Unlisted	$ -	$ 6,041,674	$ 2,754,198	$ 28,288,304
TOTAL	$ 8,944,068	$ 61,606,712	$ 14,748,959	$ 232,130,966

Table 2. Estimated structural damage to buildings from a 10- and 100-year rainfall event (24-hour) in 2030 and 2070.

Estimate of Structural Damage to All Buildings from 24-Hour 100-Year Rainfall Event in 2030



Estimate of Structural Damage to All Buildings from 24-Hour 100-Year Rainfall Event in 2070

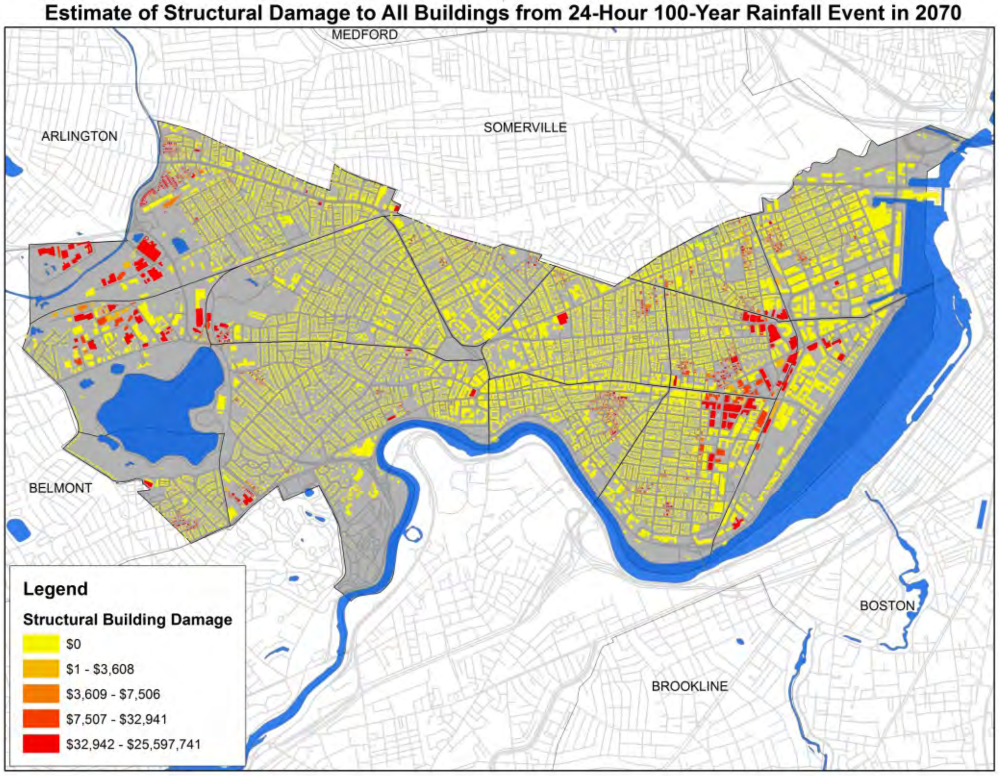
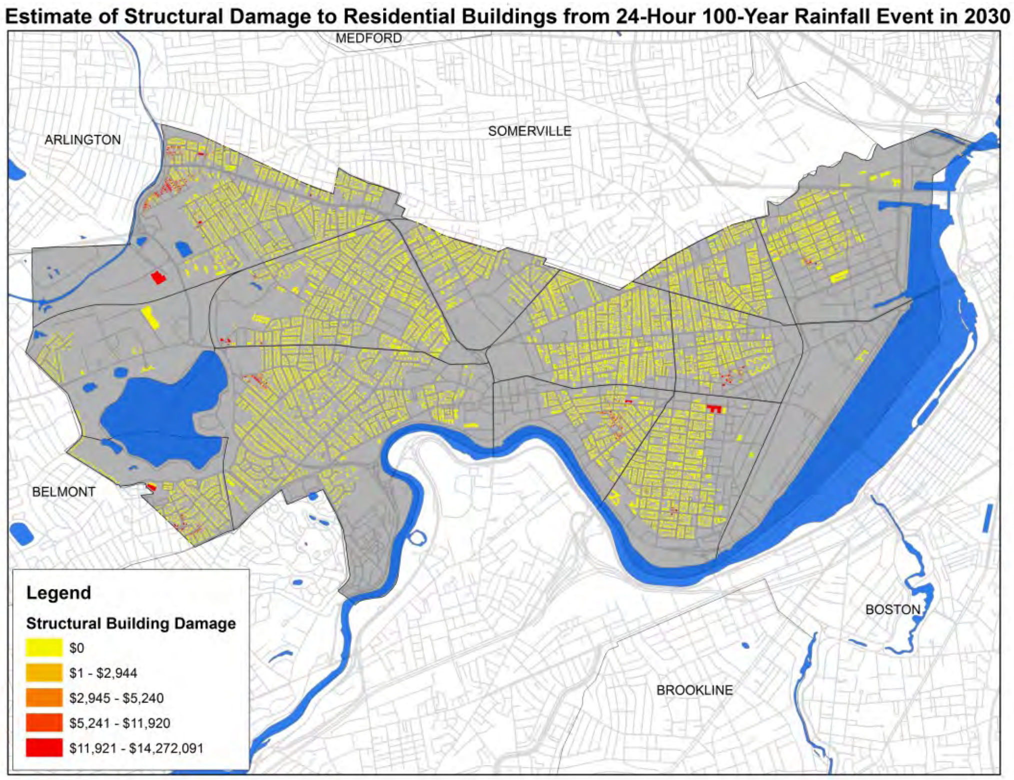


Figure 1. Estimated structural damage to <u>all</u> buildings in 2030 and 2070 from a 24-hour 100-year rainfall event



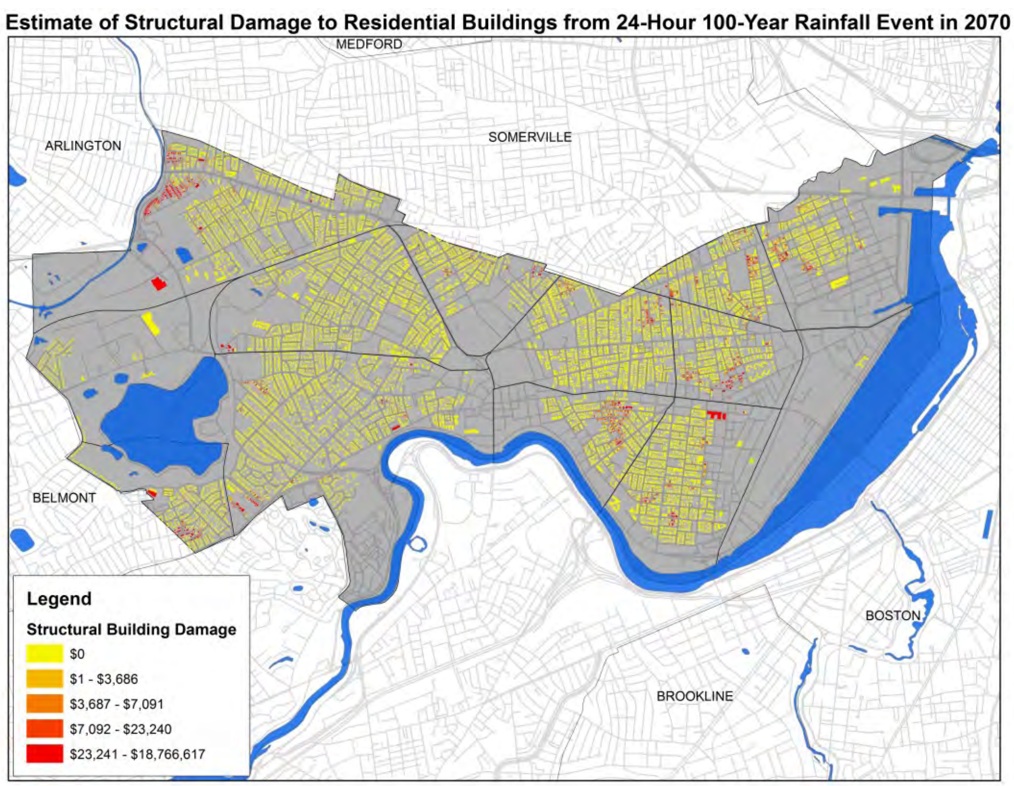
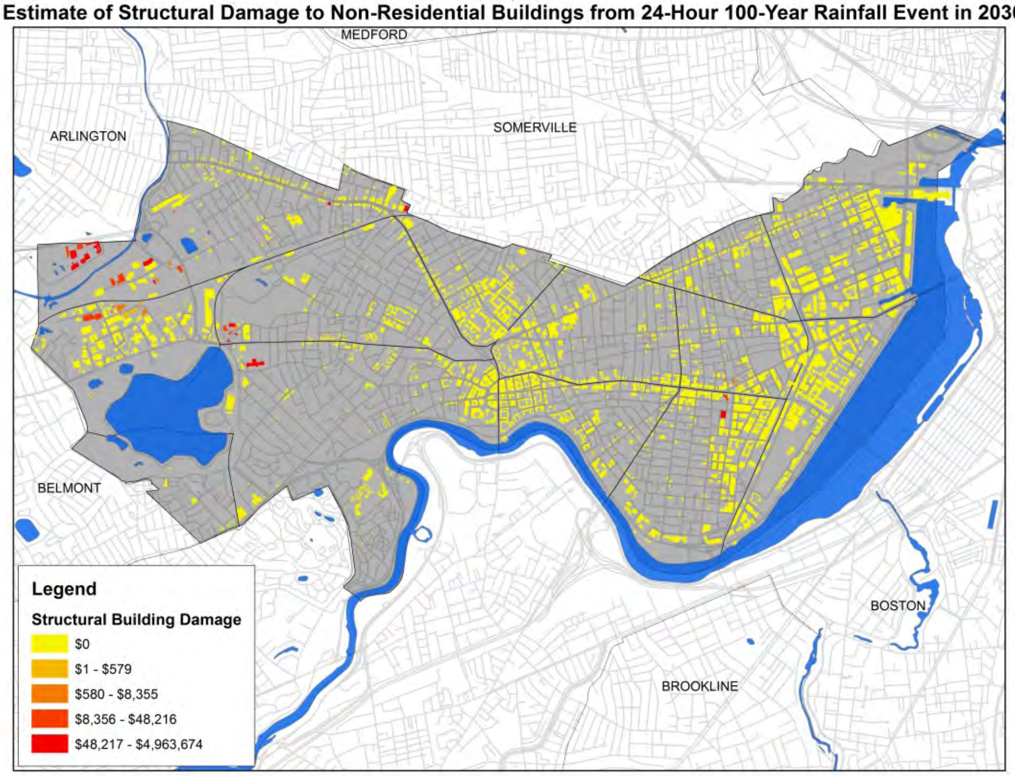
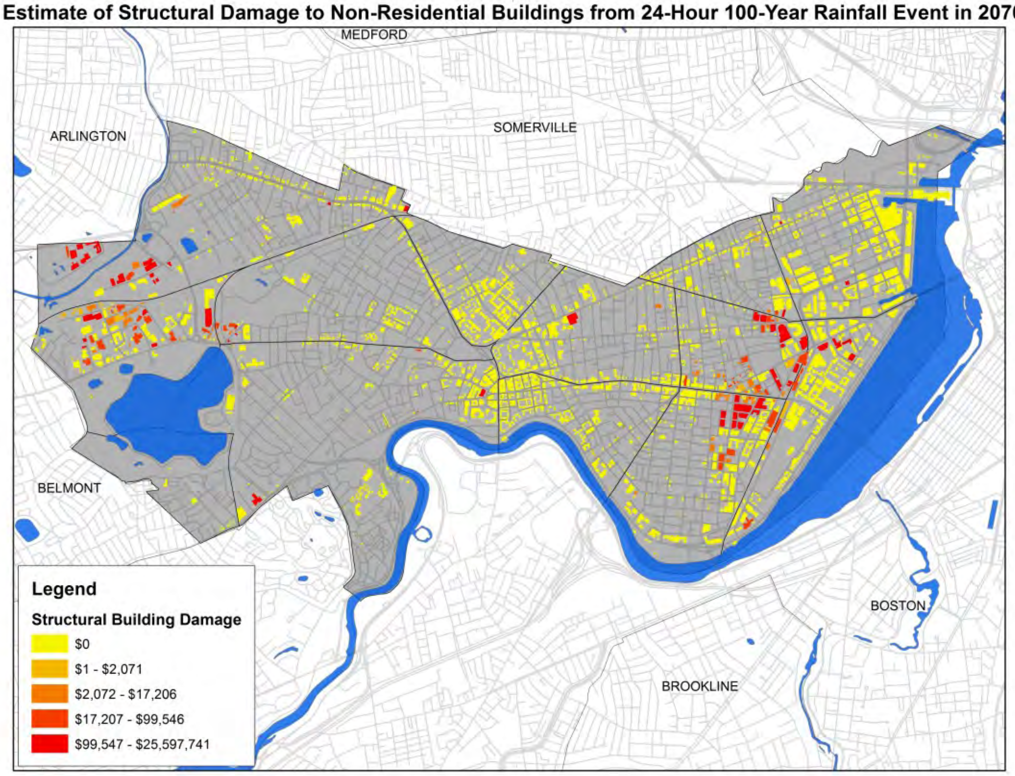


Figure 2. Estimated structural damage to residential bldgs. in 2030 & 2070 from a 24-hour 100-year rainfall event.

Estimate of Structural Damage to Non-Residential Buildings from 24-Hour 100-Year Rainfall Event in 2030



Estimate of Structural Damage to Non-Residential Buildings from 24-Hour 100-Year Rainfall Event in 2070

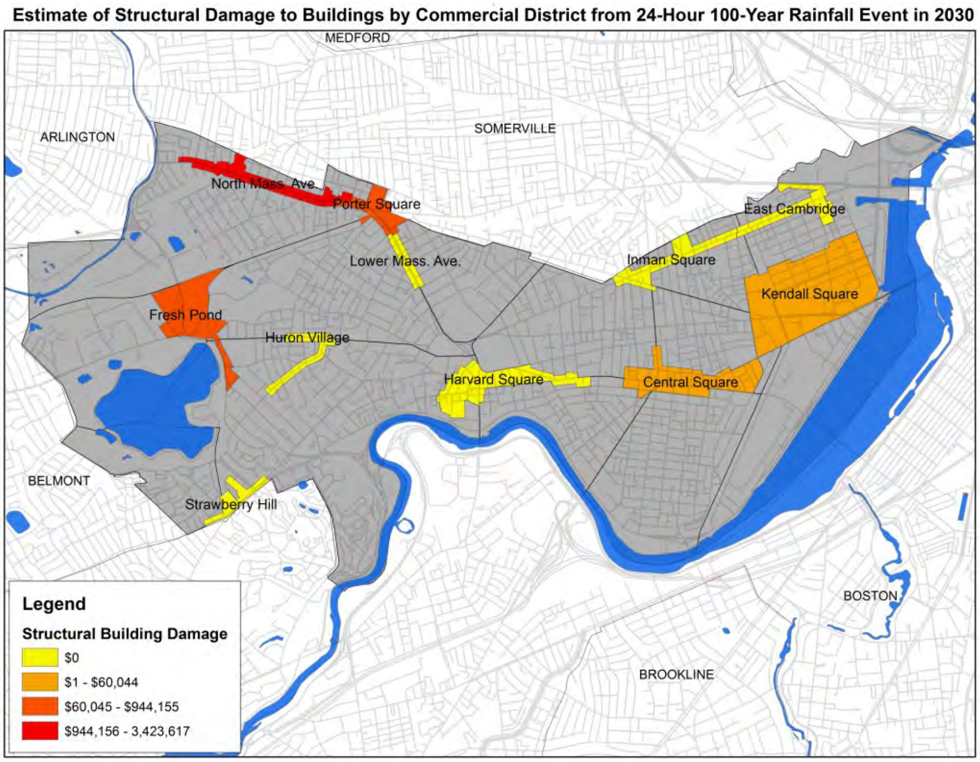


3.2.2 Figure 3. Estimated structural damage to non-residential buildings in 2030 and 2070 from a 24-hour 100-year rainfall event.Damage by Commercial and Development Districts

When the estimated building damages were analyzed by commercial district, Central Square, Fresh Pond and Kendall Square were the only districts that had damage from the 2030 10-year and 2070 10-year events (Table 4). Central Square had the highest estimated damage to buildings from the 2030 10-year event. The North Mass Ave. commercial district had the highest estimated damage for the 100-year event in 2030 (Fig. 5). Of all the commercial districts, Kendall Square had the highest estimated damages for both the 10-year and 100-year events in 2070. Huron Village/Observation Hill was the only commercial district to not have any estimated damages in any of the four rainfall scenarios.

Commercial District	2030 10-yr	2030 100-yr	2070 10-yr	2070 100-yr
Porter Square	$ -	$ 466,517	$ -	$ 466,517
Lower Mass. Ave.	$ -	$ -	$ -	$ 62,140
Huron Village/ Observation Hill	$ -	$ -	$ -	$ -
Strawberry Hill	$ -	$ -	$ -	$ 1,847,309
Harvard Square	$ -	$ -	$ -	$ 4,303,239
Central Square	$ 60,044	$ 60,044	$ 338,726	$ 3,857,962
North Mass. Ave.	$ -	$ 3,423,617	$ -	$ 3,193,673
East Cambridge	$ -	$ -	$ -	$ 2,306,649
Inman Square	$ -	$ -	$ -	$ 113,471
Fresh Pond	$ 32,566	$ 944,155	$ 154,775	$ 2,604,015
Kendall Square	$ 1,635	$ 1,635	$ 1,334,026	$ 5,162,919

Table 4. Estimated structural damage to buildings by commercial district in 2030 and 2070 from a 10- and 100-year rainfall event (24-hour).



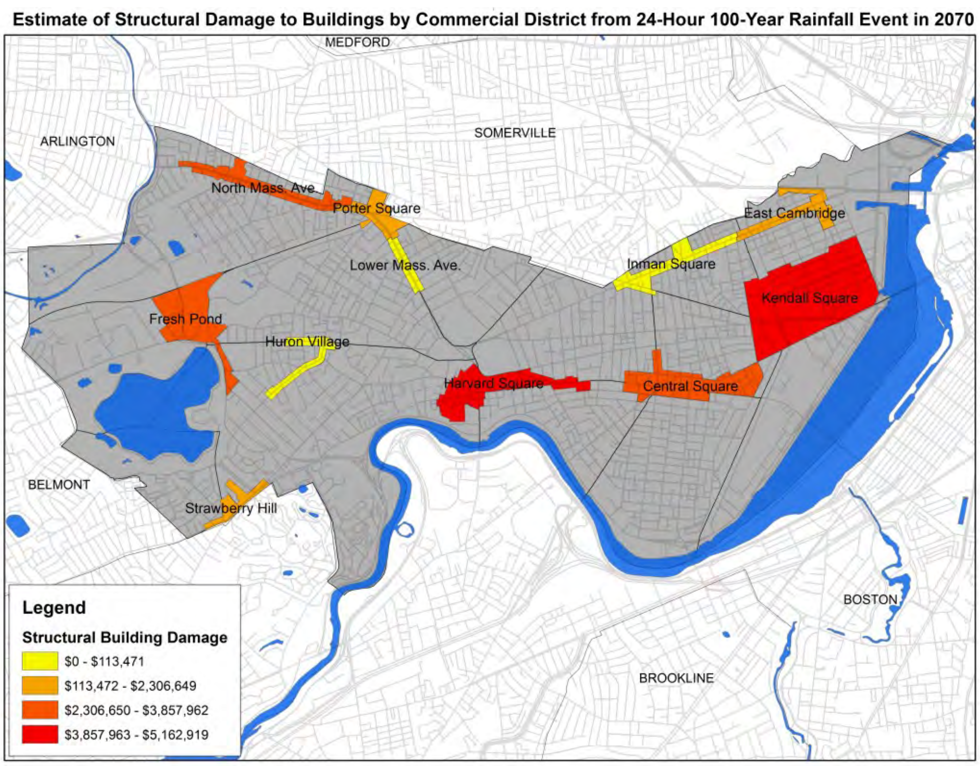


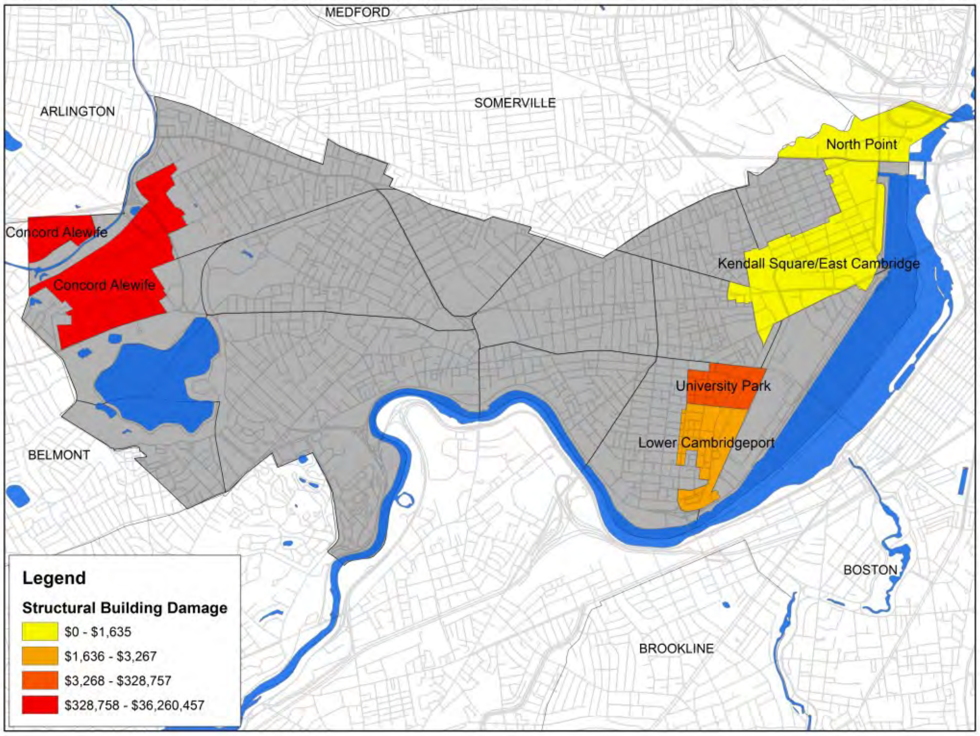
Figure 5. Estimated structural damage to buildings by commercial district from a 24-hour 100-year rainfall event in 2030 and 2070.

When the estimated building damages were analyzed by development district, North Port was the only district that did not have any damages to its buildings in all four rainfall events (Table 5). University Park had the highest estimated damages to buildings for the 10-year event in 2030. Concord Alewife had the highest estimated damages in both the 100-year event in 2030 and the 100-year event in 2070 (Fig. 6). Kendall Square/East Cambridge had the highest estimated damages for the 10-year event in 2070.

Development District	2030 10-yr	2030 100-yr	2070 10-yr	2070 100-yr
Concord Alewife	$ 128,548	$ 36,260,457	$ 249,152	$ 76,143,142
North Point	$ -	$ -	$ -	$ -
Kendall Square/East Cambridge	$ 1,635	$ 1,635	$ 1,334,026	$ 8,592,436
University Park	$ 328,757	$ 328,757	$ 916,337	$ 34,094,359
Lower Cambridgeport	$ 3,267	$ 3,267	$ -	$ 222,840

Table 5. Estimate structural damage to buildings by development district for the 10-year and 100-year rainfall events (24-hour) in 2030 and 2070.

Estimate of Structural Damage to Buildings by Development District from 24-Hour 100-Year Rainfall Event in 2030



Estimate of Structural Damage to Buildings by Development District from 24-Hour 100-Year Rainfall Event in 2070

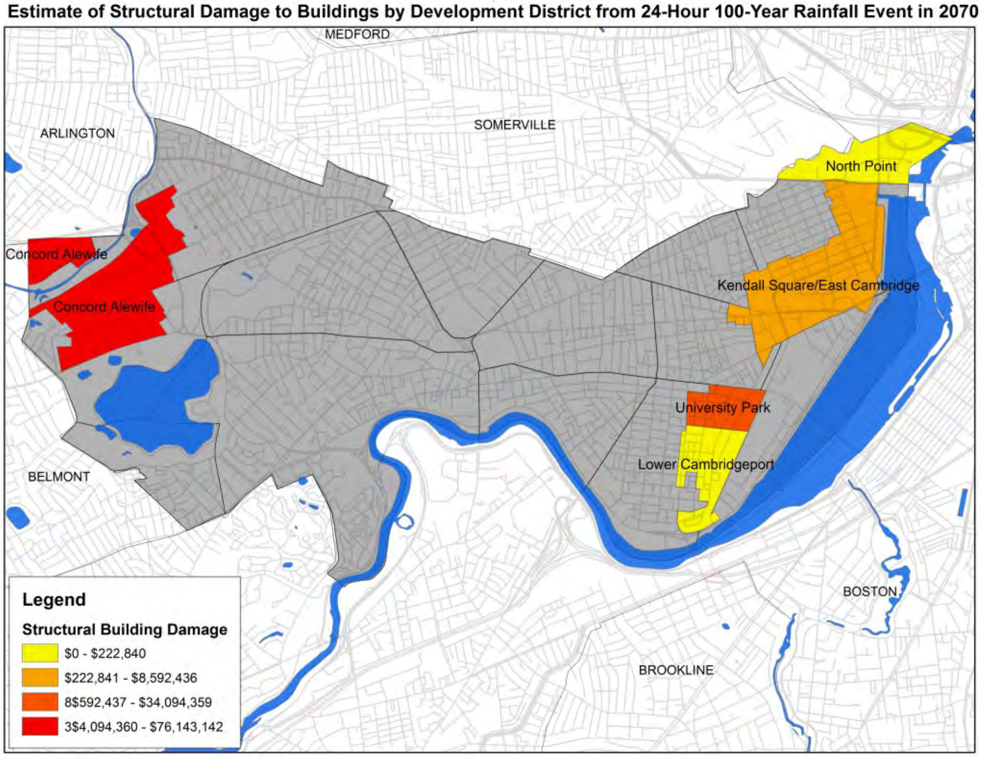


Figure 6. Estimated structural damage to buildings by development district from a 100-year rainfall event (24-hour) in 2030 and 2070.

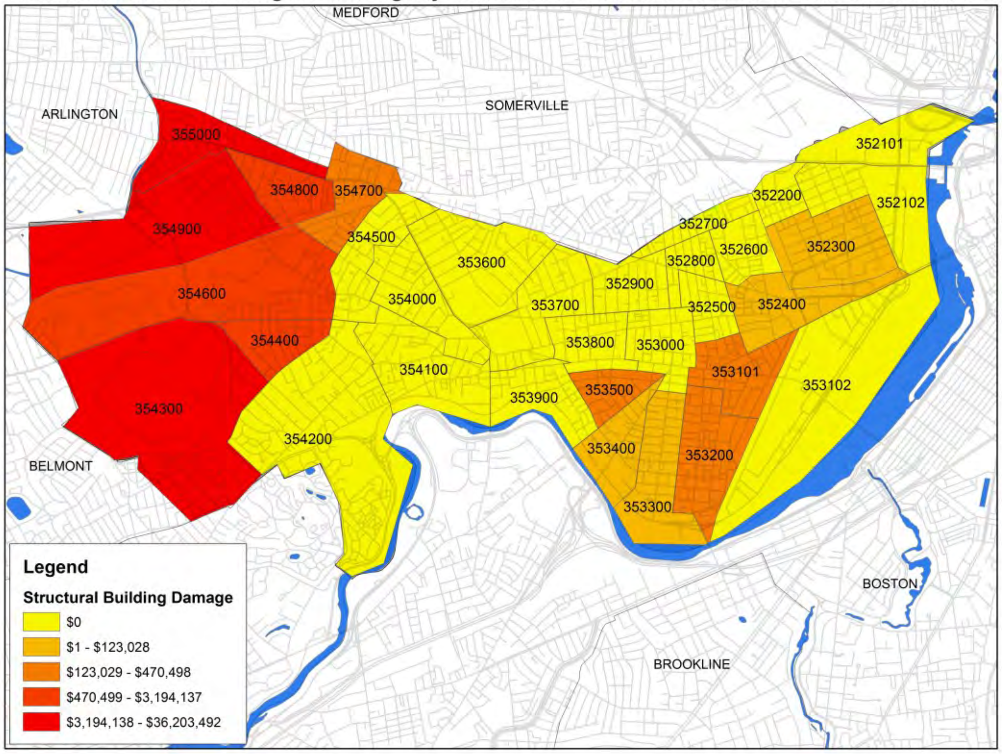
3.2.3 Damage by Census Tract

When analyzed at the census tract scale, 352101, 353800 and 352400 were the only tracts that had no estimated damage to buildings in all rainfall event scenarios (Table 6). 354300 had the highest estimated damages in both the 10-year event in 2030 and the 10-year event in 2070. 354900 had the highest estimated damage in both the 100-year event in 2030 and the 100-year event in 2070 (Fig. 7).

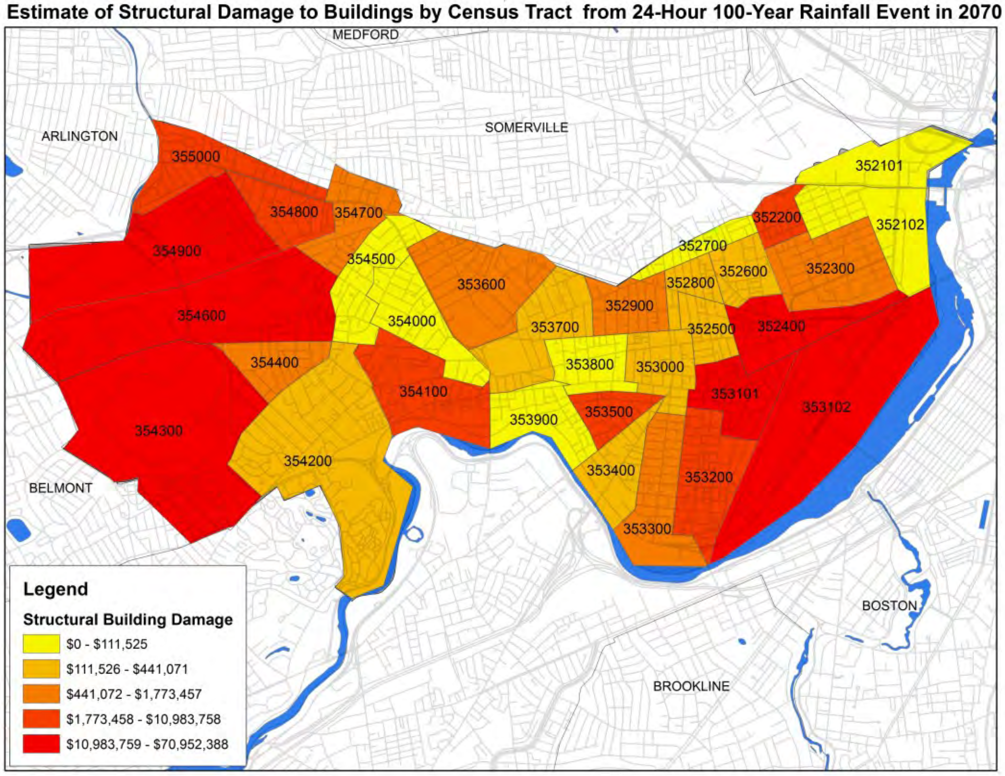
Census Tract	2030 10-yr	2030 100-yr	2070 10-yr	2070 100-yr
352700	$ -	$ -	$ 630	$ 111,525
354400	$ 37,925	$ 3,010,595	$ 122,012	$ 659,649
352300	$ 123,028	$ 123,028	$ 363,748	$ 1,276,817
353300	$ 79,985	$ 79,985	$ 162,969	$ 1,773,457
354300	$ 6,122,837	$ 9,373,183	$ 7,182,265	$ 14,323,335
354800	$ -	$ 2,876,403	$ -	$ 2,500,956
352101	$ -	$ -	$ -	$ -
352600	$ -	$ -	$ 10,767	$ 441,071
353400	$ 6,358	$ 6,358	$ 9,984	$ 118,437
352800	$ -	$ -	$ -	$ 145,175
353200	$ 155,298	$ 155,298	$ 153,511	$ 5,470,932
353800	$ -	$ -	$ -	$ -
352200	$ -	$ -	$ -	$ 2,505,163
354000	$ -	$ -	$ -	$ -
352400	$ 5,647	$ 5,647	$ 2,668,442	$ 13,487,243
352900	$ -	$ -	$ -	$ 730,412
353600	$ -	$ -	$ -	$ 495,365
353000	$ -	$ -	$ -	$ 346,894
353101	$ 410,232	$ 410,232	$ 1,298,978	$ 60,473,737
353500	$ 450,047	$ 450,047	$ 514,410	$ 2,870,667
353700	$ -	$ -	$ -	$ 284,544
354200	$ -	$ -	$ 13,456	$ 194,340
352500	$ -	$ -	$ 1,612	$ 131,743
354500	$ -	$ -	$ -	$ 94,032
355000	$ 1,379,886	$ 5,247,809	$ 1,789,943	$ 10,983,758
352102	$ -	$ -	$ -	$ 26,558
353900	$ -	$ -	$ -	$ 29,879
354900	$ 138,519	$ 36,203,492	$ 291,836	$ 70,952,388
354700	$ -	$ 470,498	$ -	$ 475,574
354600	$ 34,306	$ 3,194,137	$ 164,396	$ 11,042,457
354100	$ -	$ -	$ -	$ 9,679,398
353102	$ -	$ -	$ -	$ 20,505,460

Table 6. Estimated structural damage to buildings by census tract for the 10- and 100-year rainfall events (24-hour) in 2030 and 2070.

Estimate of Structural Damage to Buildings by Census Tract from 24-Hour 100-Year Rainfall Event in 2030



Estimate of Structural Damage to Buildings by Census Tract from 24-Hour 100-Year Rainfall Event in 2070



4 FIGURE 7. ESTIMATED STRUCTURAL DAMAGE TO BLDGS. BY CENSUS TRACT FOR 100-YR. RAINFALL EVENTS (24-HOUR) IN 2030 & 2070.ESTIMATED ONE-TIME, DIRECT AND INDIRECT ECONOMIC LOSSES FROM EXTREME RAINFALL EVENT SCENARIOS

In this section we develop an estimate of the economic impacts of the climate change effects on the city. The focus is on developing estimates of changes in employment and output, measured as value added or gross regional product. There are four parts to this section:

- Data sources
- Overview of the Cambridge Economy
- Impacts of Flooding Scenarios
- Impacts of Electric Supply Disruptions

4.1 DATA SOURCES AND ANALYTIC APPROACH

This analysis is based on two sources. Economic data for Cambridge is taken from IMPLAN®, a widely used economic data and modeling system that was originally developed for the U.S. Forest Service but is now used for economic impact analysis in a wide variety of applications[2]. The other data source is the 2014 City of Cambridge property tax Assessors database modified to reflect the estimated effects of climate change as discussed above.

IMPLAN permits analysis at both the county and zip code level; this permits analysis of Cambridge as a single economy within Middlesex County and to examine the five separate zip codes that are used in the city. IMPLAN data includes estimates of employment (measured as annual average employment), employee compensation, and Gross Regional Product (GRP). Gross Regional Product is a regional analog to the Gross Domestic Product-State developed by the Bureau of Economic Analysis and represents the value of the output of any regional economy (city, county, metropolitan area, state). It is a value added measure, meaning it is the value of output after subtracting the costs of intermediate inputs.[3]

Measurement of economic activity, whether as employment or Gross Regional Product, at very small geographic levels like counties, cities, and zip codes, raises significant issues of confidentiality in the collection and distribution of data. In general, government data series such as employment cannot be made available if the employment of any one establishment[4] could be revealed. This presents a particularly difficult problem for analysis of this type, which is based on highly site-specific determinations of impacts.

The ideal approach to estimating the economic impacts of climate change events is to identify the specific buildings affected by a flooding event, the extent of potential damage, and then, based on the amount of employment and the value of output of all organizations conducting operations in the building, to estimate the effects on employment and output. This would require information on the organizations located in each building, including their employment levels and their industry. Such data

[2] www.implan.com

[3] http://www.bea.gov/regional/docs/product/

[4] An establishment is a single place of employment

does exist in the Quarterly Census of Employment & Wages (QCEW), a data series collected in each state using standards set by the U.S. Bureau of Labor Statistics. Because each state is in charge of data collection, state departments of labor determine the rules for access to the establishment level original data. In Massachusetts, the Executive Office of Labor and Workforce Development manages the Quarterly Census of Employment & Wages data and allows access to the QCEW establishment level data only for purposes of managing the unemployment benefits system. Thus this analysis cannot use the establishment level employment data, which would allow for the most detailed and exact matches between estimated flooding effects and economic impacts.

Because location-specific data cannot be used for this analysis, available economic data for the smallest geographic area must be used. This is generally the zip code, of which Cambridge has five. The most complete estimates of economic activity at the zip code level are made for the IMPLAN economic model. These estimates are derived from both data sources such as the Census and from imputation (statistically derived estimates) of employment, Gross Regional Product, and other measures when the data is suppressed to preserve confidentiality.

Building specific impacts from flooding are available from the Assessors database as discussed above. To link the building-specific data on possible impacts with the economic values associated with larger geography of the zip code area, a proportional shares model is used. Each property estimated to be affected by 6 inches or more of flooding in the climate change scenarios was matched to its zip code. Then the share of that property of the zip code on three different measures is calculated. The measures are:

- The number of damaged properties as a share of all properties in the zip code of a given type
- The 2014 valuation of the damaged properties as a share of the total 2014 valuation of a given type in the zip code
- The adjusted area of the damaged properties as a share of the total adjusted area of the zip code for properties of a given type

Adjusted area is an approximation of the total physical area of the property. It is calculated as the area of the property's GIS record multiplied by the number of stories in the property record. This gives an estimate of physical size. These shares were then used to estimate the employment and Gross Regional Product impacts using the data from IMPLAN for each zip code. (Note that gross floor area was not available as a field in the assessor's database.)

There are two principal types of properties used in the analysis based on the Assessors building type classifications:

- All properties coded "industrial" in the Assessors database were considered to be in manufacturing industries and the shares of damaged properties were calculated as a proportion of manufacturing industries in the zip code

- All properties coded "commercial", "exempt" or "mixed use" were considered to be "commercial" and the shares of damaged properties were calculated as a share of all non-manufacturing industries in each zip code

4.2 Scientific Research and Development Facilities at Risk

In addition to the analysis of commercial and industrial properties, the City requested a special analysis of the scientific research and development facilities at risk from flooding. For this purpose a specific list of "laboratories" was provided by the City, including private and public, and for profit and non-profit entities, and this list was used to identify potentially damaged buildings. The economic effects of these potentially damaged facilities related to scientific research and development were then estimated using the same "share of zip code" methods described above, with the economic activity (employment and Gross Regional Product) measured as the Scientific Research & Development industry in the IMPLAN data.

This approach of deriving estimates using three different approaches yields a range of estimates that bounds a plausible "ballpark estimate" of likely economic effects, resulting in low, high, and middle estimates. The approach reflects the level of uncertainty that exists in the data sets used, and permits comparison between the scenarios developed for analysis. In the absence of location-specific data on economic activity or more detailed information on the economic role of properties in the assessor's database, this approach represents a reasonable, though somewhat imprecise, approach to the estimation of economic impacts sufficient to identify the order of magnitude of economic effects.

4.3 The Cambridge Economy

In 2012, Cambridge was the location of an estimated 129,030 jobs.[5] The Gross Regional Product was $15.796 billion. This was 11.9% of Middlesex County employment and 7.6% of Middlesex County GRP. Cambridge comprises 0.7% of Middlesex County's land area.

The ten largest industries by employment and by Gross Regional Product (and their share of the top ten industries) are shown in Figure 8 and Figure 9. The top ten industries employ 72,300 people, or 56% of Cambridge employment. The top ten industries by Gross Regional Product make up $14.53 billion, which is 92% of total GRP.

[5] Jobs include both full and part time jobs. The measure is not equal to "people employed" as one person can have more than one job.

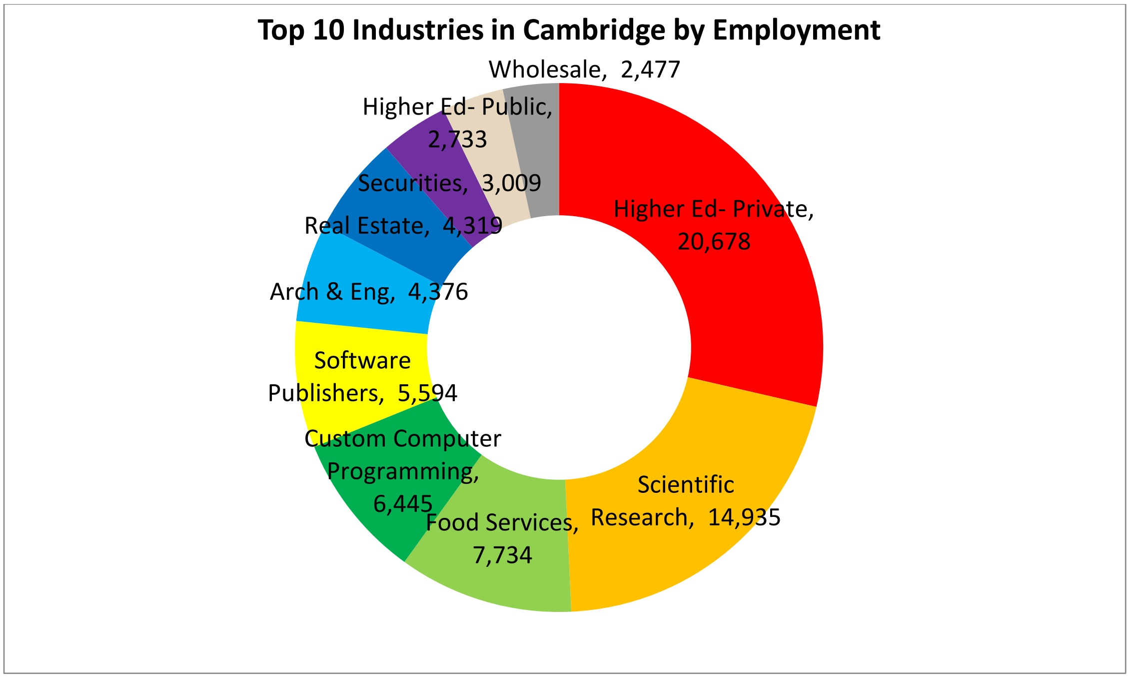


Figure 8. Pie chart of top ten industries in Cambridge, MA by employment (from IMPLAN).

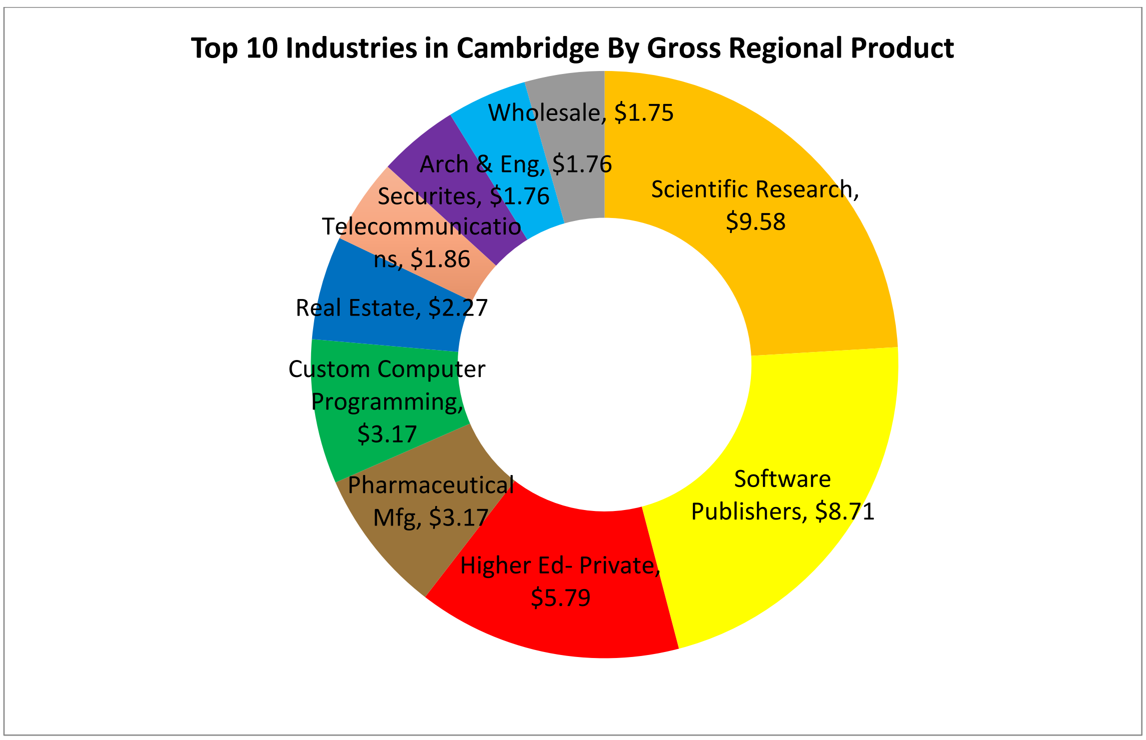


Figure 9. Pie chart of top ten industries in Cambridge, MA by Gross Regional Product (GRP), a value added measure. GRP is the value of a good or service's final sales price that is added within a region such as Cambridge. It includes employee compensation, profits, and certain taxes, but not the costs of raw materials inputs.[6]

[6] A more complete description of the methodology is can be found in Bureau of Economic Analysis, *Gross Domestic Product by State Estimation Methodology* Washington: 2006.

There are five zip codes in Cambridge (Figure 10). Table 8 shows the employment, Gross Regional Product, and population estimates for 2012 for each of the zip code areas and for Cambridge. Figure 11 shows the proportion of the Cambridge economy in each zip code as measured by employment, Gross Regional Product, and population.

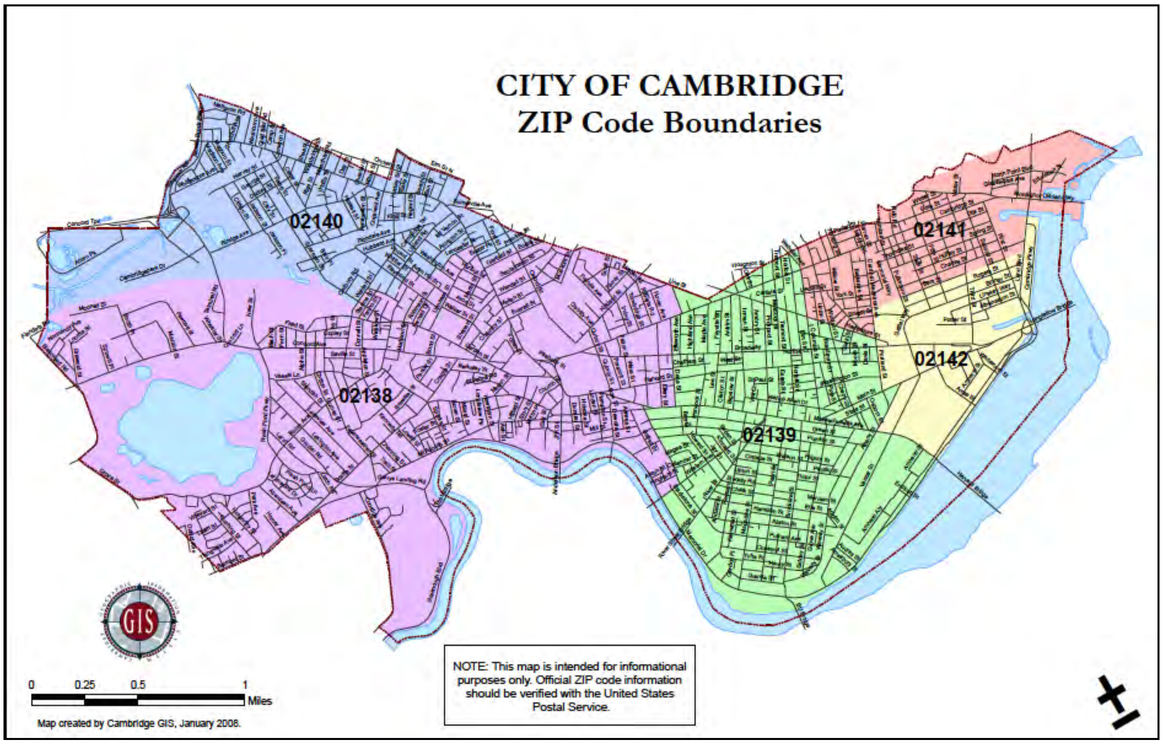


Figure 10. An image of zip code boundaries in Cambridge, MA.

	Employment	GRP	Population
Cambridge	129,030	$15.797	106,632
02138	43,940	$3.890	36,766
02139	39,022	$4.329	36,802
02140	12,548	$2.049	17,826
02141	9,968	$1.103	12,058
02142	23,552	$4.426	3,180
Middlesex	1,083,362	$128.733	1,537,215

Table 8. Employment, Gross Regional Product and Population by zip code in Cambridge, MA.

The Cambridge economy is centered in the zip codes that lie along the Charles River, with the upper Charles, Harvard University area (02138), and the lower Charles MIT area (02139 and 02142) areas together comprising 83% of the employment and 80% of the GRP in Cambridge. Of the zip codes bordered by the Charles, 02138 and 02139 also have significant populations, although in all three there are more employees than residents. In 02142, the employment to resident ratio exceeds 7:1. The "inland" zip codes of 02140 and 02141 have employee to resident ratios of 0.7 and 0.8 respectively, making these primarily residential areas (see Table 9).

	Employment/Population	Employees/Square Mile	Population/Square Mile
02138	1.20	14,647	12,255
02139	1.06	19,511	18,401
02140	0.70	12,548	17,826
02141	0.83	9,968	12,058
02142	7.41	23,552	3,180
Cambridge	1.21	21,505	17,772
Middlesex County	0.70	1,315	1,866

Table 9. Employment by population, and employees and population by square mile ratios.

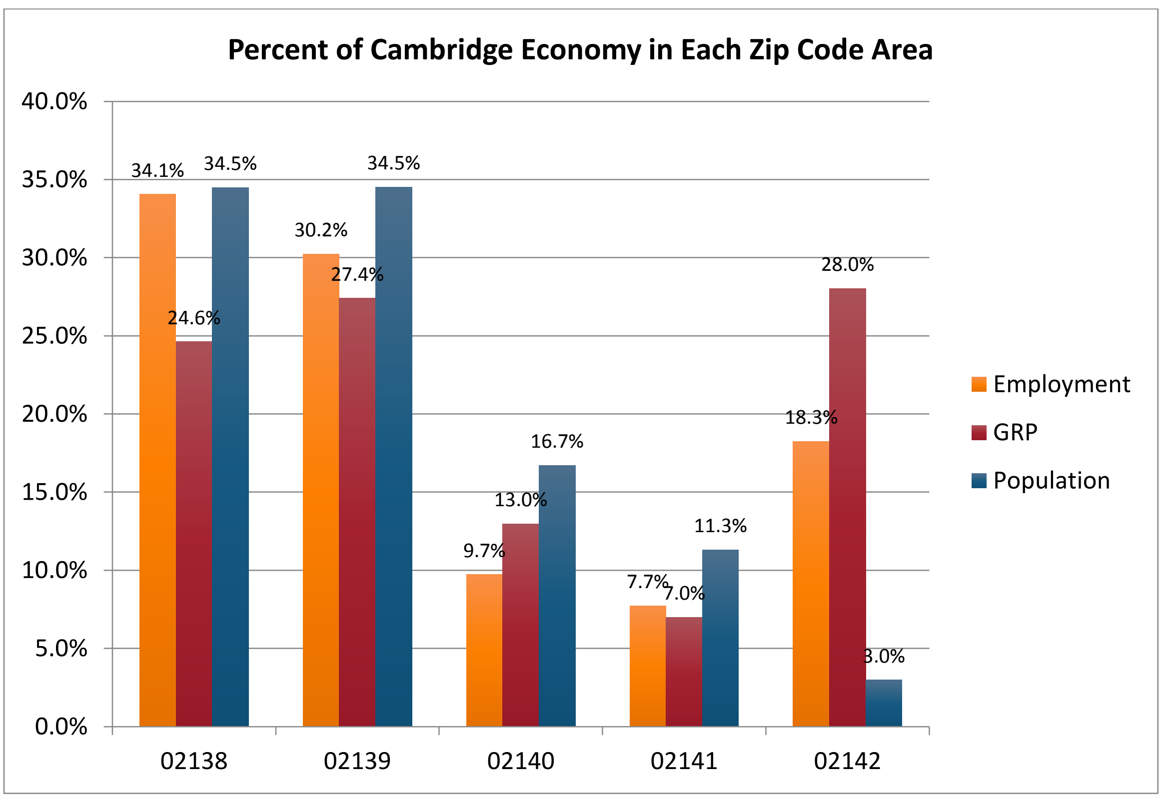


Figure 11. Bar graph of Cambridge economy by zip code.

Table 10 shows the top five industries by employment in each of the zip codes, and Table 11 shows the top five by Gross Regional Product. Private higher education is the largest employer in Cambridge, but it is in the top 5 in only two zip codes, 02138 and 02139, consistent with Harvard and MIT. Scientific Research is the second largest employer and the largest in terms of Gross Regional Product and it is found in the top five by both employment and GRP in all five zip codes. Software and custom computer programming are also major industries in Cambridge, with particular concentration of these industries in 02142 in the lower Charles.

Retail and consumer service industries like restaurants, which are frequently major employers in urban settings, are among the top 5 industries by employment in four of the five zip codes, at least with respect to restaurants (food service). Only in 02142 are restaurants absent from top five. But only in the inland zip codes are any retail industries in the top five. In addition, scientific research and development is a top five industry by employment in every Cambridge zip code.

In sum, the data clearly supports the general image of Cambridge as dominated by higher education, science, and technology. These industries are particularly located in the areas near the Charles River, making the investigation of the potential effects of climate change in terms of flooding a matter of considerable interest. It is to that investigation we now turn.

	Industry	Employment
02138	Private junior colleges, colleges, universities, and professional schools	14,375
	Food services and drinking places	3,228
	Scientific research and development services	1,693
	Internet publishing and broadcasting	1,633
	Real estate establishments	1,459
02139	Scientific research and development services	9,780
	Private junior colleges, colleges, universities, and professional schools	5,809
	Architectural, engineering, and related services	2,726
	Food services and drinking places	2,438
	Real estate establishments	1,474
02140	Scientific research and development services	1,573
	Custom computer programming services	1,017
	Food services and drinking places	830
	Computer systems design services	783
	Software publishers	677
02141	Management, scientific, and technical consulting services	833
	Food services and drinking places	769
	Retail Stores - Clothing and clothing accessories	601
	Scientific research and development services	437
	Retail Stores - General merchandise	435
02142	Software publishers	4,465
	Custom computer programming services	3,827
	Wholesale trade businesses	1,727
	Securities, commodity contracts, investments, and related activities	1,707
	Scientific research and development services	1,452

Table 10. Top Five Industries by Employment for Cambridge Zip Codes

	Description	Total Value Added ($ Millions)
02138	Private junior colleges, colleges, universities, and professional schools	$942.71
	Semiconductor and related device manufacturing	$265.75
	Scientific research and development services	$259.01
	Real estate establishments	$239.30
	Internet publishing and broadcasting	$204.65
02139	Scientific research and development services	$1,495.83
	Private junior colleges, colleges, universities, and professional schools	$380.96
	Architectural, engineering, and related services	$281.24
	Real estate establishments	$241.81
	Custom computer programming services	$126.04
02140	Pharmaceutical preparation manufacturing	$514.57
	Software publishers	$257.24
	Scientific research and development services	$240.63
	Custom computer programming services	$134.71
	All other miscellaneous professional, scientific, and technical services	$117.08
02141	Management, scientific, and technical consulting services	$89.07
	Software publishers	$77.27
	All other miscellaneous professional, scientific, and technical services	$69.24
	Scientific research and development services	$66.78
	Securities, commodity contracts, investments, and related activities	$54.47
02142	Software publishers	$1,697.35
	Custom computer programming services	$506.67
	Wholesale trade businesses	$326.82
	Scientific research and development services	$222.14
	Management of companies and enterprises	$210.62

Table 11. Top Five Industries by Gross Regional Product for Cambridge Zip Codes

4.4 Estimated City-wide Impacts of Climate Change-related Precipitation Events on the Cambridge Economy

4.4.1 Economic Impact Estimates for Four Climate Change Scenarios

Table 12 presents the summary of economic impact estimates for the City of Cambridge for each of the four climate change scenarios. The top part of the table shows the number of properties estimated to be affected by six inches or more of flooding: the total property tax assessed value that is at risk from flooding, and the proportion of the properties, valuation, and adjusted area of the impacted properties. The proportion data are based on the totals of impacted properties within the city as a whole. Actual calculations of economic impacts are based on the proportions of properties, valuation, and area within each land use category (commercial and industrial) within each zip code. These proportions are shown in the detailed table of impacts by land use category and zip code at the end of this section.

	Number of Properties >6" flood	**Assessed Value At Risk ($M)**	**Share of Valuation in Zip Code**	**Share of Properties in Zip Code**	**Share of Adjusted Area in Zip Code**	
2030 10-yr Event	48	$698	0.4%	1.8%	2.2%	
2030 100-yr Event	136	$2,366	0.8%	5.1%	5.3%	
2070 10-yr Event	90	$2,214	0.7%	3.4%	4.1%	
2070 100-yr Event	513	$18,841	6.0%	19.1%	25.7%	
	Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
2030 10-yr Event	1,181	2,190	3,478	$619,665	$1,023,428	$1,576,170
2030 100-yr Event	5,530	5,231	8,555	$3,360,266	$3,062,499	$4,627,345
2070 10-yr Event	2,357	4,357	6,695	$1,195,801	$2,280,311	$3,022,964
2070 100-yr Event	17,040	22,020	30,346	$10,170,349	$12,083,596	$16,078,138

Table 12. Estimated Economic Impacts in City of Cambridge

The bottom half of Table 12 shows the estimated employment impacts and the estimated impacts on Gross Regional Product. The Gross Regional Product estimates are shown on a daily basis[7]. The assumption is that flooding will affect a building for some period of time from the date of the initial impact to the time when repairs and reconstruction on the building are complete. This period will vary considerably from property to property and cannot be reasonably forecast, so the Gross Regional Product impacts are estimated on a daily basis and can be interpreted to mean "every day that impacted properties are out of service because of flooding damage, the Cambridge economy will be at risk to lose the estimated amount." In the actual event, these estimates will overstate the Gross Regional Product and employment effects when buildings are brought back into service faster than assumed for the analysis, and understate the effects when buildings are brought back into service slower than assumed.

With those caveats, however, the magnitude of the impacts from climate change related flooding from a low of nearly 1200 employees affected to a high of over 30,000 employees depending on the scenario and estimating procedure. The 100-year events in both 2030 and 2070 show significant differences from the 10-year events in those same years, with the 2070 100-year event scenario showing the most significant impacts. At the highest impact estimate (based on shares of adjusted area) of 30,000 jobs nearly one quarter of the 2012 level of employment would be affected. At $16.1 million in lost output per day, this estimate would indicate a loss of more than 27% of the daily Gross Regional Product in the Cambridge economy.

Differences in economic impacts between the events are also significant. In 2030, the 100-year event's impacts average three times those of the 10-year event across the estimating procedures, while the 2070 estimates average five times those of the 10-year event estimates. The 2070 impact estimates are twice those of the 2030 10-year event estimates, while the 2070 100-year event estimates average three times those of the 2030 100-year event estimates.

In each scenario, impact estimates based on adjusted area are the largest in both employment and Gross Regional Product impacts while impacts based on the number of properties affected are the lowest. Since the adjusted area calculation is the closest approximation to the size of a property, it may be closer to the likely impacts, but the best interpretation is probably that actual impacts will lie somewhere between the lower estimates based on properties and the higher estimates based on area, with a bias towards the higher estimates.

4.4.2 Indirect and Induced Effects Together Make Up the Multiplier Effect on the Cambridge Economy

Economic impacts identified in Table 12 represent potentially significant effects on the Cambridge economy, but it is only a part of the potential effects. If large numbers of employees are laid off, suppliers of goods and services to affected organizations will also be affected with a loss of business. Incomes spent in the local economy by residents and workers will no longer be available to support other jobs and output in Cambridge. These two additional effects, the first called the "indirect" effects and the latter called the "induced" effects, make up the "multiplier" effect. IMPLAN is designed to estimate these additional effects.

To estimate multiplier effects the normal process is to identify the industries directly affected by the change to be examined, but this presents a difficulty in the current study where we do not know the specific industries affected or the extent of the direct effects. To conduct the multiplier analysis,

[7] Based on 260 work days in the calendar year.

therefore, it was assumed that all industries in Cambridge would be affected in proportion to their size by employment. The implicit assumption is that all industries in Massachusetts have an equal chance of being affected within a random distribution of impacts. In order to keep the multiplier analysis simple, the analysis was done with the highest estimates of direct impacts from each of the scenarios.

Table 13 shows the estimates of multiplier effects based on employment for the four scenarios. IMPLAN is a fixed model; the economic interactions represented in the model do not change with the size of the impacts. Therefore the estimates in Table 13 represent consistent multipliers across the scenarios. The “indirect” multiplier estimated by IMPLAN for Cambridge is 1.22 (indirect effects are 22% of direct effects). The IMPLAN-estimated “induced” effects multiplier is 1.15. Combined the multiplier effect is 1.37.

	2030 10-yr	**2030 100-yr**	**2070 10-yr**	**2070 100-yr**
Direct	-3,478	-8,555	-6,695	-30,346
Indirect	-776	-1,910	-1,495	-6,775
Induced	-537	-1,321	-1,034	-4,686
Total	-4,791	-11,786	-9,223	-41,807

Table 13. Employment multiplier effects in Cambridge

Total economic impacts, which include both the direct and multiplier effects, altered the results considerably. Using the upper range of impact estimates for each scenario, total effects range from nearly 4% of the Cambridge economy for the 2030 10-year event to over one third of the Cambridge economy for the 100-year event in 2070.

4.4.3 Multiplier Effects on the Scientific Research and Development Industry, Specifically

As noted above, the scientific research and development industry is the largest industry in Cambridge by output. Data was provided to identify those 117 properties in Cambridge that are key laboratory facilities within this industry and a separate analysis of this group was conducted. This analysis, conducted in the same manner used for all properties in Cambridge, resulted in the estimates for Cambridge shown in Table 14.

	Number of Properties >6" flood	Assessed Value At Risk ($M)	Share of Valuation in Zip Code	Share of Properties in Zip Code	Share of Adjusted Area in Zip Code	
2030 10-yr Event	4	$392.58	17.5%	8.9%	17.4%	
2030 100-yr Event	11	$518.48	21.9%	22.0%	25.8%	
2070 10-yr Event	13	$1,225.67	10.3%	12.7%	6.4%	
2070 100-yr Event	52	$4,334.07	35.2%	44.4%	31.4%	
	Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**GRP Impact per day Based on Share of Value**	**GRP Impact per day Based on Share of Properties**	**GRP Impact per day Based on Share of Adjusted Area**
2030 10-yr Event	2,126	1,017	1,995	$1,250,534	$598,195	$1,173,900
2030 100-yr Event	3,702	2,737	3,712	$2,177,870	$1,610,277	$2,183,471
2070 10-yr Event	3,213	2,557	3,467	$1,890,435	$1,504,206	$2,039,651
2070 100-yr Event	8,523	7,777	9,252	$5,014,167	$4,574,782	$5,443,020

Table 14. Impacts of Flooding Effects on Scientific Research and Development Industry in Cambridge

With 2012 employment of 15,000 and a daily contribution to Gross Regional Product of $8.8 million, the estimated employment impacts range from 7% of the Scientific Research and Development industry for a 10-year event in the 2030 to over 62% of the industry employment for a 100-year event in the 2070. Table 15 shows the multiplier effects of these changes using employment as the measure. The Scientific Research and Development industry has an overall multiplier of 1.48, meaning the total effects on the Cambridge economy are 48% higher than the direct effects alone. This is due to the links between the Scientific Research and Development industry and other industries in Cambridge, such as higher education, and also the relatively high incomes of those employed in this industry.

	2030 10-yr	2030 100-yr	2070 10-yr	2070 100-yr
Direct	-2,126	-3,712	-3,467	-9,252
Indirect	-503	-878	-820	-2,188
Induced	-519	-907	-847	-2,261
Total (1.48 X Direct)	-3,148	-5,497	-5,134	-13,701

Table 15. Multiplier effects of negative impacts on the Scientific Research & Development Industry. The multiplier effects for this industry were 1.48.

5 ESTIMATED ONE-TIME ECONOMIC ACTIVITY LOSSES FROM ONE DAY OF INTERRUPTED ECONOMIC ACTIVITY

One of the consequences of climate change is likely to be a steady and significant increase in average temperatures. This will increase the demand for electric power for air conditioning and cooling in the summer months. Since 1997, all of the highest demand days in New England during both weekdays and weekends have occurred in June, July and August (Table 16) and the peak demand for electricity is becoming a larger and larger stress on the system as the ratio of peak demand to average demand has been steadily rising in New England (Figure 12).

PEAK DEMAND DAYS (taken from all demand days)		WEEKEND DEMAND DAYS (taken from weekend demand days)	
Date	**Demand (MW)**	**Date**	**Demand (MW)**
July 19, 2013	27,379	July 20, 2013	24,668
July 18, 2013	26,884	July 14, 2013	22,397
July 22, 2011	27,707	July 7, 2013	23,353
July 6, 2010	27,100	July 23, 2011	23,185
August 3, 2006	27,118	August 25, 2007	22,523
August 2, 2006	28,130	July 29, 2006	22,507
August 1, 2006	27,467	August 14, 2005	22,688
July 19, 2006	26,736	August 13, 2005	24,065
July 18, 2006	27,329	June 26, 2005	22,393
July 27, 2005	26,885	July 6, 2003	23,326

Table 16. Peak Demand Days in New England since 1997[8].

ISO New England, the independent systems operator for the New England electric power grid, already must routinely request reductions in electric use during the hottest days of the summer, partly from larger customers who agree in advance to curtail their electric use when requested and partly by issuing public calls for voluntary conservation. New England relies on oil and coal for 20% of its summer

[8] Source: ISO New England http://www.iso-ne.com/about/what-we-do/key-stats/electricity-use

peak generation, but over 80% of this capacity will be 40 years old or older by the end of this decade and will most likely to be retired.[9] With peak demand expected to continue to grow at 1.3% per year, the stresses on the electrical system are likely to increase significantly.

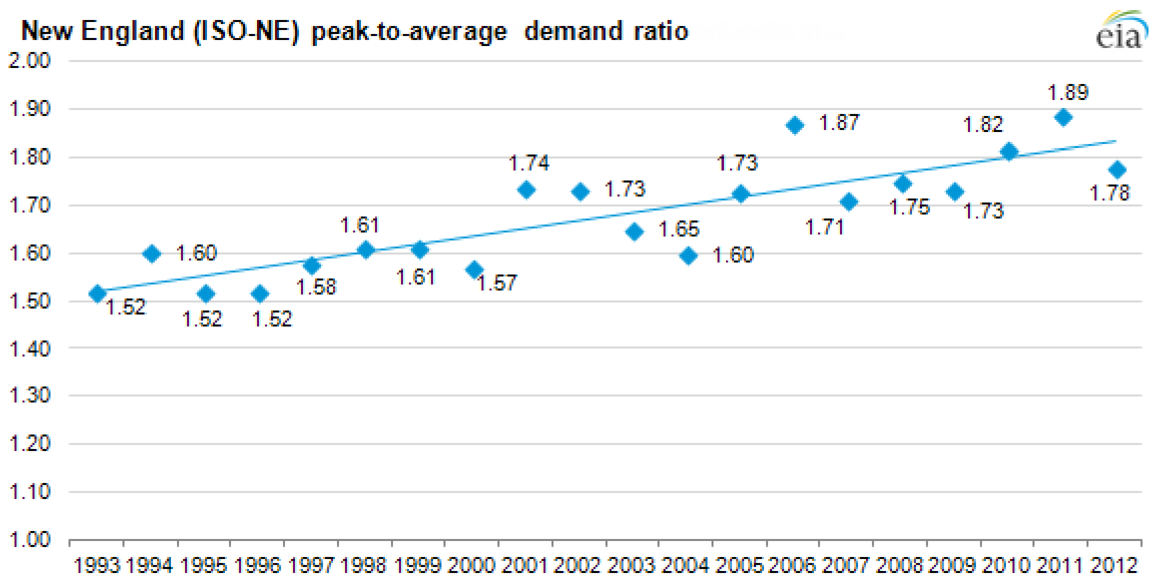


Figure 12. Ratio of Peak to Avergage Demand[10].

Over time, of course, an increase in generating capacity and conservation efforts by customers coupled with improvements in the transmission systems will mean that major breakdowns in the electric system are somewhat unlikely. But they have occurred in the past; the most recent major blackout in the northeastern U.S. was in 2003. It is reasonable to inquire what the consequences of a major electric systems failure caused by increasing summer demand that created increasing vulnerabilities in the system would mean in terms of economic consequences. To explore this question a simple assumption of a single day's loss of economic activity can be used.

As noted above, in 2012 there were 129,030 jobs in Cambridge. This is an annual average figure. Cambridge has very little seasonality in its economy, as shown in Figure 13 which shows each month's employment in the city as a percent of annual average employment.[11,12]

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[9] ISO New England *2014 Regional Energy Outlook* Holyoke, MA: ISO New England.

[10] Source: Energy Information Administration http://www.eia.gov/todayinenergy/detail.cfm?id=15051

[11] Source: Massachusetts Executive Office of Education and Workforce Development.

[12] There is also a slight increase in employment in November and December consistent with the Christmas shopping season. There is a slight drop in employment in the summer months relative to the annual average, driven primarily by the summer schedule of higher education institutions in the city.

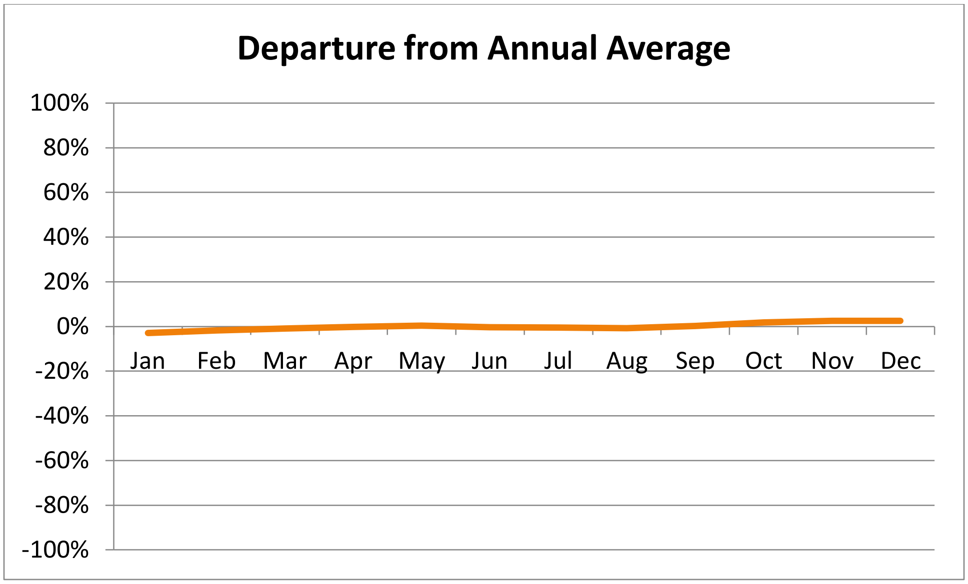

Figure 13. Monthly Employment in Cambridge as Percent of Annual Average Employment

Table 17 shows estimated employment and daily Gross Regional Product for the Cambridge economy divided between Higher Education (where the figures are 5% below annual averages) and all other industries. This indicates that a one-day interruption of the Cambridge economy in the summer would affect about 128,000 jobs and result in the loss of $42.96 million in output.[13] These losses would continue as long as the electric disruption would continue. The vast majority of these losses would be made up once power was restored but some unknown proportion of losses would be permanent. For example, tourists to the City whose visits were interrupted by the power outage may not return after leaving.

Geography	**Employment**	**Gross Regional Product (MM)**
Higher Education	19,545	$5.47
All Other	108,352	$37.49
Cambridge	127,897	$42.96

Table 17. Daily Economic Activity in Cambridge

[13] We make no assumption about local backup power provision that could mitigate some of this loss by maintaining operations even if the grid were to shut down. Such backup exists in a number of organizations, but the number is unknown.

5.1 Conclusion

The estimation of potential economic effects from climate change is obviously subject to considerable uncertainty, particularly given the inability of current data systems to provide more precise estimates. But the approximations generated here do clearly show that there are very large negative employment and economic value effects possible from reasonable climate change scenarios. As much as one quarter of the $15 billion Cambridge economy could be put out of commission for periods of a few days to many months. The effects would most probably spread well beyond Cambridge into the Massachusetts and New England economies. The size of the possible impacts makes clear the need to think more systematically and energetically about adaptation strategies.

6 APPENDIX

6.1 MEMORANDUM DATED AUGUST 22, 2014, REVISED JANUARY 19, 2015 – ECONOMIC VULNERABILITY ASSESSMENT, APPROACH AND METHODOLOGY

DATE: August 22, 2014, Revised January 19, 2015

TO: John Bolduc, City of Cambridge; Lise Hemmerle, City of Cambridge; Cliff Cooke, City of Cambridge.

FROM: Dr. Sam Merrill, J.T. Lockman AICP, and Dr. Charlie Colgan, Catalysis Adaptation Partners (CAP)

CC: STC members

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SUBJECT: Economic Vulnerability Assessment – Approach and Methodology

KLEINFELDER NO.: 2010259.01-A

The Economic Risk & Vulnerability Assessment will be performed as a three part approach to estimate the economic impact to Cambridge expected with climate change:

(1) Estimate the value of one-time structural damage to building values from flooding, using extent and depth of inundation for four future extreme precipitation scenarios: High (100-year storm) and Low (10-year storm) in year 2030, and High (100-year storm) and Low (10-year storm) in 2070;
(2) Estimate one-time, direct and indirect losses in economic activity due to such flooding for the same four future extreme precipitation scenarios; and
(3) Estimate one-time, direct and indirect economic activity losses from one day of interrupted economic activity for the entire City of Cambridge, for any disaster event with a city-wide geographic impact, such as a heat induced city-wide power failure.

All estimates will be based on impacts to the present day level of economic activity, and present day taxable assessed value of the City's building stock.

Approach 1: Estimating Flooding Damage to Real Estate

This approach assumes no adaptive actions by 2030 or 2070 and will be modeled on present-day patterns of building values from the City's GIS data. CAP will use the most-recently developed City's building footprint GIS polygon shapefile, joined with the City's assessor's data for building values. KLF and the City of Cambridge will provided the joined building footprint shapefile.

It should be noted that the City's building footprint shapefile does not contain a field for building value of each footprint. A total building value for each parcel in Cambridge exists only in a parcel shapefile, with the value of all buildings on each parcel aggregated in the case of multiple-building parcels.

Parcel information with total building value used will be from 2014, and building values will be linked to each of the building footprints by KLF and Cambridge. Where there are many buildings on one parcel, the total building value for the parcel will be divided by the number of buildings on the parcel, and the fraction of building value will be attributed to each individual footprint. By the end of this process, each individual building footprint will be assigned one value for modeling purposes.

For each building in the building footprint polygon file, KLF, in conjunction with the City, also will assign an attribute for each building's use type. CAP will develop a unique depth damage function to assess damage by depth of floodwaters, for different building use categories, with as much detail as data quality permits.

This building footprint shapefile, with attributes for each individual footprint polygon for value and use type, will be provided to CAP prior to the beginning of Approach 1. This shapefile will allow analyzing damage to the assessed value of buildings associated with flooding extents and depths identified in the four scenarios from rainfall modeling efforts: High Scenario for the 100-yr, 24 hr storm in 2030 and 2070; and the Low Scenario for the 10-yr, 24 hr storm in 2030 and 2070.

The GIS depiction of the spatial extent of flooding from these four rainfall scenarios will be provided as output of ICM-2D model runs in the form of GIS files, with a TIN polygon file for stormwater flood depths, and a raster file for riverine flood depths in the Alewife Brook and Charles River areas.

Expected deliverables from this task will include a full no-action assessment of building value losses for the four one-time flooding scenarios (without calculation of cumulative expected damages). Findings will be reported: by building use type, by commercial and development districts, by zip code, and by census tract.

<u>Detail on Assignment of Building Value for Parcels with Multiple Buildings– *Note: This section added January 2015*</u>

The following method for allocating building value from the parcel total, to individual building footprints, was utilized by KLF and the City of Cambridge. The method was summarized in an email from Karin Hagan to CAP on December 11, 2014:

Method overview:

- Used the Subtotal tool in Excel to Count the number of records/buildings for each map lot.
- Pulled the map-lot-countID and count information into a new sheet, sorted by map-lot-countID.
- Pulled the map lot and building value per parcel information into that same new sheet, sorted by map lot.

- Map lot and map-lot-countID didn't sort the same, so manually rearranged the map-lot-countID and count data to the same order as the map lot and building value per parcel data. (Catalyst to QA/QC first to confirm no mistake)
- Simplified the columns to just map lot, building count, and building value per parcel.
- Divided building value per parcel by the building count to determine the building value per building.
- Verified that map lot is text format and that building count and value data are number format so they should join to the GIS file easily.

Corrections / update of different sources for data:

- 2013 assessors data used for:
  - Building height
  - Building Air conditioning
  - Heat source
  - Structure type
  - Basement
  - Building use as reported in UseCategor attribute column (to be discarded)
- 2014 assessors used for:
  - o buildings' values (to be confirmed by Catalyst. If correct, the protocol will have to be revised)
  - o PARCELTota attribute column
  - o PARCELBLDG attribute column
  - o PARCELLAND attribute column
  - o Building use as reported in Type_1 attribute column (column to use to match 2014 assessed value)

- ***Catalyst to update September 2014 protocol to reflect:***
  - *o develop a proxy/ multiplier for correction of 2014 real estate data to adjust to recently published 2015 data. The protocol should be revised to document how this is being achieved*
  - *o update in data sources for 2013 and 2014 assessors data.*

Specification for attached file:

- the file has a map lot for each building.
- Catalyst should use the "ml" attribute column. The other map lot columns came from later joins and aren't as complete as "ml" and have been removed. Protocol for linking data:

  "Please use the sheet called "Final" in the attached excel file. This sheet contains the columns ml (MapLot ID), number of buildings in each parcel, assessed value for all buildings on the parcel, and the assessed value of each building in that parcel. This Excel sheet needs to be joined to the original building footprint file we had provided earlier which has the ml identified for each building. Please use the one-to-many join function (on the ml attribute column) in GIS to join this "Final" excel sheet with the original buildings GIS file."

It should be noted that on December 26, 2014, KLF instructed CAP to utilize the UseCategor attribute column and to not use the Type_1 attribute column, when breaking out data by building use type in the analysis. KLF determined that "UseCategor" was a more accurate dataset.

CAP worked with the data to fill in hundreds of missing building values in the footprint shapefile during late December 2014. Missing building values from the 2014 City assessing database were replaced by 2015 database building values, reduced by 11%, as per instructions of Andrew Johnson at the City of Cambridge. The number of building footprints without any assigned value was reduced to 93. A map and listing of these building footprints without any assigned value are found in a later appendix.

Building Footprints with Mean Depths of Flooding less than 6 inches– *Note: This section added January 2015*:

Our scope documents from August 2014 indicate that US Army Corps of Engineers Depth Damage Functions would be employed for determining the percent damage to buildings, for each foot of floodwater at their bases. The precipitation and riverine flooding layers provided to Catalysis show depths as low as hundredths of an inch. However the Army Corp Depth Damage Functions start at 6 inches, with the next level at 1 foot, and then go up in 1 foot increments starting at one foot. Using Corps Depth Damage Functions, we have no way to evaluate damage from depths less than 6 inches. Therefore we exclude those buildings with mean flood depths of less than 6 inches from our damage assessment.

This situation arises as the precipitation outputs are at a resolution far finer than the depth damage functions that have been developed by the government for these sorts of studies. The six inch threshold is used ubiquitously in flood vulnerability assessments, and we believe it is a good standard to use in this study. We are not aware of any depth damage functions available now that have been developed at a resolution of less than 6 inches, but if one were to be created by structural engineers, it could be employed in future work.

Metadata on Assignment of Flood Depths at Each Building Footprint Perimeter – *Note: This section added January 2015*

The following metadata was prepared by Peter Slovinsky of CAP:

Summary

These shapefiles represent those building footprints in Cambridge, MA that may be impacted by future riverine and/or precipitation flooding under a 10 year ("low" scenario) or 100 year ("high" scenario) recurrence interval event after climate change in the year 2030 or 2070, respectively. This was developed as part of a Climate Change Vulnerability Assessment (CCVA) for Kleinfelder (KLF) and the the City by Catalysis Adaptation Partners, LLC (CAP). This metadata is applicable to all the datasets referenced, including: Low_2030_All_Buildings_Impacted High_2030_All_Buildings_Impacted Low_2070_All_Buildings_Impacted High_2070_All_Buildings_Impacted

Description
KLF provided CAP with the following datasets for this analysis:

- precipitation shapefile from TIN output of ICM-2D model for Alewife Brook and Charles River areas of Cambridge. The dataset was developed with building footprints in place, thus has no inundation depth values within building footprints;
- riverine flooding raster (1 m cell size) from ADCIRC modeling for the Alewife Brook area. The dataset was developed over a bare earth DEM, thus has inundation depths within builidng fooptrints
- shapefile of building footprints with tax assessor database of parcel and building values from the City in 2014.
- Table of "mulitple buildings" where the assessed value (which was assigned to all multiple buildings on a parcel) was divided by the number of buildings on the parcel. This included attributes of ml, BldgCount,AllBldgVal, and PerBldgVal
- polygon shapefile defining the "commercial district" within Cambridge
- point shapefile defining the "laboratories" within Cambridge

- All data is in NAD_1983_StatePlane_Massachusetts_Mainland_FIPS_2001_Feet projection.

CAP Data Analysis Process Steps (conducted for each climate change scenario for 2030 (low and high) and 2070 (low and high))

- The "multiple building" value table was joined with the tax assessor database shapefile using "ml" as the join attribute and a new file (Assessor_Data_Joined.shp) created
- CAP spatially reviewed this file and found that it was systematically shifted 2 m to the southwest when compared with the precipitation dataset. This was evident by "holes" left in the precipitation dataset where building footprints should have existed. The tax assessor shapefile was therefore shifted to fit within the precipitation dataset.
- The point shapefile was used to extract those building footprint polygons which were labs. This was exported as Labs_Poly.shp.
- The precipitation datasets for Alewife Brook and Charles River areas were QA/QC'd and found to have null values and topology. Repair geometry tool was used on the datasets then they were merged into one City-wide dataset. These contain an attribute "DEPTH2D" which is the inundation depth.
- The building footprint shapefile was buffered by 5 feet on all sides. Original methodology was to use a 20 foot buffer around all buildings, but this was determined by CAP to not be the best method for working with the entire inundation dataset. In order to maintain integrity of each dataset while still using a consistent method between the two datasets, CAP slightly revised the methodology by reducing the buffering of building footprints to 5 feet, instead of 20. There are several reasons for this. First, because a raster was used for riverine flooding and this was developed using a bare-earth model, flooding depths exist within and adjacent to buildings. Using a building footprint expanded by 20 feet (which is used to calculate a mean value) captures flooding data well outside of the building footprint. At the same time, in locations where building footprints are immediately adjacent to one-another (e.g., city blocks), it also results in mean depth values being influenced by those adjoining building footprints. These factors introduce faulty data into the calculation of the mean depth values for riverine flooding at buildings. Thus, reducing the buffer to 5 feet minimizes influence of data far away from footprints, and neighboring footprints. However, using a buffer is still needed for the analysis and calculation of mean depths associated with precipitation data, which was developed with buildings in place and therefore has no data within a footprint. Using the reduced 5 foot buffer distance also more accurately captured precipitation data directly adjacent to buildings (instead of in the middle of streets). Thus, changing the methodology to use a 5 ft buffer instead of a 20 ft buffer allows for a consistent method to be used for both riverine and precipitation datasets, and increases the accuracy of mean depth values calculated from both datasets.
- Building footprints within 5 feet of precipitation flooding were selected and exported as a new dataset.
- Precipitation shapefile was clipped by the buffered building footprint file and unioned. A dissolve was then performed (keeping attributes of OBJECTID, Type, BldgID, ml, PARCELBLDG, AssValue, BldgCount, AllBldgVal, PerBldgVal), and statistics calculated using DEPTH2D attribute and the MEAN statistic. This output the selected attributes and calculated a mean inundation depth for each unique builidng footprint.
- The resulting shapefile (buffered building footprints with attributes and assigned DEPTH2D) was clipped with the original exported building footprints (not buffered) so that the depth values could be assigned. Attribute MEAN_DEPTH2D was added and equal to DEPTH2D and extraneous attributed removed.
- For riverine raster analysis, Spatial Analyst's zonal statistics was used to calculate a MEAN inundation depth using the 5 foot buffered building footprint file as a mask. However, this is a floating point raster. Thus, the raster was converted to an integer type using MapAlgebra INT(inraster*100), This results in an integer raster with values multiplied by 100 to maintain decimal spaces.

- This output raster was converted to a polygon, and in the attribute table, a new field MEAN_DEPTH2D was added and gridcode divided by 100 to return the decimal to appropriate location.
- This was clipped to the builidng footprints from the Assessor_Data_Joined.shp.
- A one-to-one spatial join was conducted between the output precipitation shapefile and the riverine flooding shapefile with only the selected attributes being output (Objectid, Type, BldgID, ml, PARCELBLDG, AssValue, BldgCount,AllBldgVal, PerBldgVal, and MEAN_DEPTH2D.
- Building footprints from impacted precipitation flooding data that are overlain by any riverine flooding building footprint data was erased as riverine data accounts for precipitaiton.
- Resulting shapefiles of building footprints impacted by precipitation and building footprints impacted by riverine flooding were then merged. This was completed for each scenario requested.

Additional Notes:
It was noted that some buildings have NO PARCELVALUE, PARCELBUILDING VALUE, PARCELTOTAL, OR values computed by KLF using multiple buildings (AllBldgVal and PerBVldgVal). For these locations, another column NoBldgVal was created (1=No value exists, 0=values exist).

To determine whether or not footprints are in the COMMERCIAL DISTRICT, a Select by Location was used and INTERSECT (if the footprint intersected commercial district), a Field COMMDIST was added (1=in the district, 0 = not in the district). The same was done for LABS.

There are also many building footprints assigned as TYPE “OUT CITY”, which likely means it is outside the city boundaries. These footprints have NULL PerBldgVal and can’t be used for the analysis and should be removed from further analysis.
Credits

Catalysis Adaptation Partners, LLC created these datasets using data provided by Kleinfelder and the City of Cambridge. Credit should be provided to those parties when referencing these data.
Use limitations

This data is provided for **general planning purposes** only for use by Catalysis Adaptation Partners, LLC, Kleinfelder, and the City of Cambridge. All potential end users should understand the limitations and assumptions in using this data before doing so and understand that future scenarios in actuality may be quite different than those presented herein.

Approach 2: Estimating Impacts of Interrupted Economic Activity from Flooding

Economic impact will be estimated/ assessed for one-time direct and indirect losses from interrupted economic activity in Cambridge, particularly lost employment and wages, for four rainfall scenarios (High and Low 2030, and High and Low 2070) as follows:

- CAP will use the same geographic extent and depths for the four rainfall event scenarios in Approach 1, to estimate the lost economic output from flooded areas of the City. Building footprints flooded by less than 6 inches of water in each scenario, will be excluded from the analysis. We will match the inundation analysis geography with property records using data from the City of Cambridge to locate employers who will be affected.
- Exact data on employment by specific building will not be available. Estimating

employment impacts will be done at the area level, where the areas are defined by the availability of data. A number of different data sources will be used each of which has different levels of industrial and geographic detail. We will construct estimates of employment by industry for the smallest areas for which industry-level employment data is available, taking into account both data availability and input from the City on preferred definitions. The data will include Cambridge property tax records, ESRI's business analytics, federal and state data sources such as the publicly available Quarterly Census of Employment and Wages, Zip Code Business patterns from Census, and the imputed estimates of employment in the IMPLAN zip code-based model.

- Employment impacts by area (for example, zip codes) will be estimated by taking the number, size (sq ft), and type (commercial, industrial, life sciences, etc.) of buildings estimated to be impacted by flooding as a proportion of the total number of buildings by size and type in the area. For example, if 10% of the sq ft of commercial buildings in 02142 are estimated to be damaged sufficient to cause at least one day of operations disruption then we will estimate 10% of commercial employment in 02142 to have been affected. We will use Zip Code Business Patterns reported employment (which includes data suppressions for confidentiality) and the IMPLAN imputations of suppressed data for the zip code area to estimate employment for the zip code area. We will use ESRI Business Analyst as an additional test of estimation validity. For sectors such as life sciences where more site-specific data may be available from Cambridge property tax records or other sources, we will use this specific data. In presenting the results, we will discuss factors affecting the accuracy and validity of the estimates and when possible provide a range of estimates reflecting the sources of uncertainty in the employment data.

Estimates will reflect the 2013 Cambridge economy affected by potential flooding events specified at the future points of the scenarios. The Team will use 2013 as a base year, but in some cases, different data sources may not be available for 2013 and other years may need to be substituted. The analysis of the economic effects will be limited to the direct and indirect damages from flooding using estimates of employment at-risk and the indirect impacts on Cambridge and the regional economy using the Zip-Code based IMPLAN model. The geography for breakdown of the analysis will be performed as indicated below, e.g. for the City as a whole and/or commercial districts, not to compromise confidentiality of business outputs. The proposed sub-geography for breaking up the analysis will be finalized in consultation with the City of Cambridge.

The economic impact analysis within the scope of the project will not include changes in economic activity associated with repair and reconstruction of damaged properties nor estimate any relocation of employment locations as a result of flooding events.

Expected deliverables from Approach 2 will include a shapefile of the City divided into sub-geographic areas with such breakouts of the estimated primary and secondary impacts of the lost economic output from business interruption for the four scenarios for High and Low 2030 and 2070. GIS output will be accompanied by a tabular and narrative depiction of these primary and secondary impacts, for the two rainfall event scenarios specified.

Findings will be reported:

- For the City has a whole

- For specific industries: e.g. Life Sciences
- Per commercial and development districts

Approach 3: Estimating Impacts of Each Day of Interrupted Economic Activity on Entire City

CAP will estimate the primary and secondary economic impacts of a disaster event that would interrupt the economic output of interrupted employment and lost wages for the entire geography of Cambridge for one day. An average weekday will be assumed. The same base data in Approach 2 will be used, and this model will assume that the entire economy of Cambridge would stop for a day, rather than just a geographically limited subset affected by flooding. This will be useful in later analyses that are looking a city-wide heat-induced 24-hour electrical power outage, or other disruptive climate change induced event.

CAP recommends estimating a one day rather than a multiple day interruption of economic activity, as has been discussed. The modeled flooding outputs of ICM-2D are for a 100-yr, 24 hour rain event (one day). We have no information on how long the water will stay or last past 24 hours for these one day modeled storm events, if at all. We would agree that interrupted activity is not linear with time, but given the uncertainties and lack of information, it may be too speculative to define a non-linear relationship. What we can do is estimate the economic impact from a 24 hour disruption on a typical work day, and then discuss how that disruption would play out depending on assumptions about length of time shut down and length of time to repair.

Final Report

Findings from analyses outlined in this memo will be compiled in a report, on the Economic of Climate Change for Cambridge for inundations caused by extreme precipitation. The report will cover:

(1) Estimates of the value of one-time flooding damage to building structural values using precipitation flooding geography for four future high rainfall event scenarios: High and Low in 2030, and High and Low in 2070;
(2) Estimates of the one-time, primary and secondary losses from interrupted economic activity for these same scenarios; and
(3) Estimates of the one-time, primary and secondary losses from one day of interrupted economic activity for the entire jurisdiction of the City of Cambridge, for any disaster event with a city-wide geographic impact, such as a heat induced city-wide power failure.

The report will present findings of economic impacts at a coarse level of geographic detail, and with generalized categories of uses and building types as described in the above scope, that will assure protection of confidential data for any single employer.

Working assumptions

- This approach assumes no adaptive actions and will be modeled to the exception of changes in population as provided by the City of Cambridge and referenced in the Scenario Development Draft Report. The team will not model the growth or changes, beyond present-day, in the types of economic activity in the vulnerable locations identified by the high rainfall event scenario layers to the exception of population projections as described above.

- Massachusetts law prohibits the distribution of business data that is available for similar economic studies conducted in other coastal localities in the US. Geographic extent of the precipitation flooding scenarios from will therefore probably be more accurate and at a higher resolution than the locations business activity data that is publicly available through ESRI Business Analyst or other tools or data sets as described in Approach 2.
- Interruption of Economic Activity will be assumed to occur at depths greater than 6 inches.

6.2 Estimate of One-Time Flooding Structural Damage to Buildings, by Zip Code and Construction Type

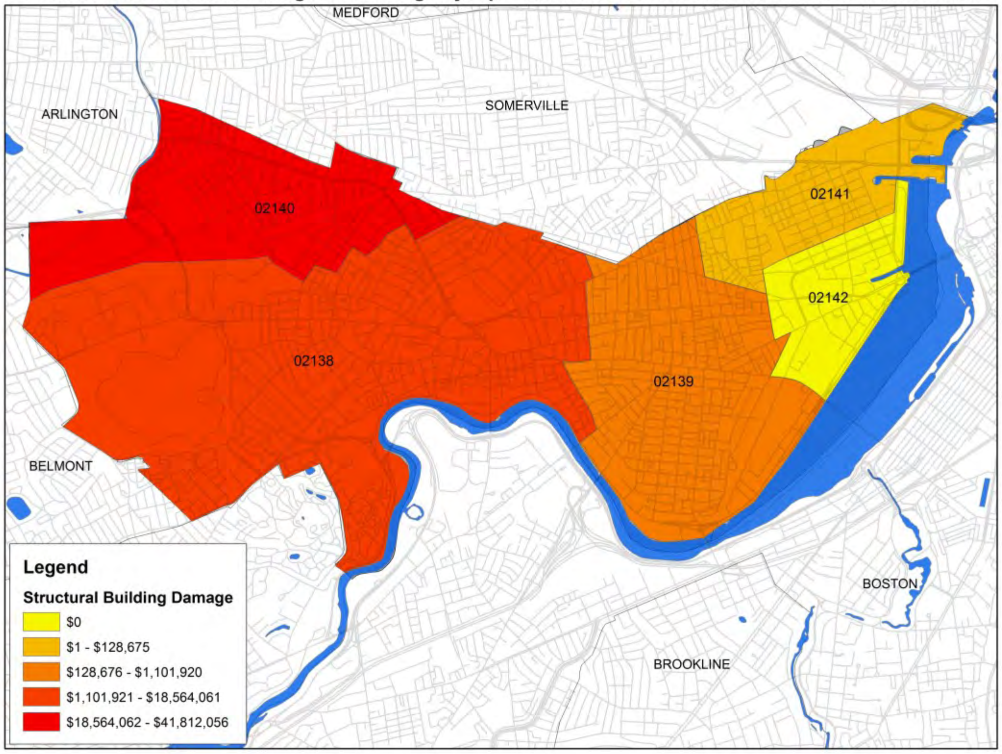
6.2.1 Damage by Zip Code

When the estimated building damages were analyzed at the zip code level, 02138 had the greatest estimated damage for the 2030 10-year and 2070 10-year events (Table 3 and Fig. 4). Zip code 02140 had the greatest estimated damage for the 2030 100-year event and 2070 100-year events. Zip code 02142 had no estimated damages for both events in 2030, and zip code 02141 had the least estimated damages for both events in 2070.

Zip Code	2030 10-yr	2030 100-yr	2070 10-yr	2070 100-yr
02138	$ 6,195,068	$ 18,564,061	$ 7,482,129	$ 56,931,562
02139	$ 1,101,920	$ 1,101,920	$ 2,141,464	$ 52,332,936
02140	$ 1,518,405	$ 41,812,056	$ 2,081,779	$ 64,784,113
02141	$ 128,675	$ 128,675	$ 388,849	$ 4,091,014
02142	$ -	$ -	$ 2,654,738	$ 53,991,341

Table 3. Estimated structural damage to buildings by zip code in 2030 and 2070 from a 10- and 100-year rainfall (24-hour) event.

Estimate of Structural Damage to Buildings by Zip Code from 24-Hour 100-Year Rainfall Event in 2030



Estimate of Structural Damage to Buildings by Zip Code from 24-Hour 100-Year Rainfall Event in 2070

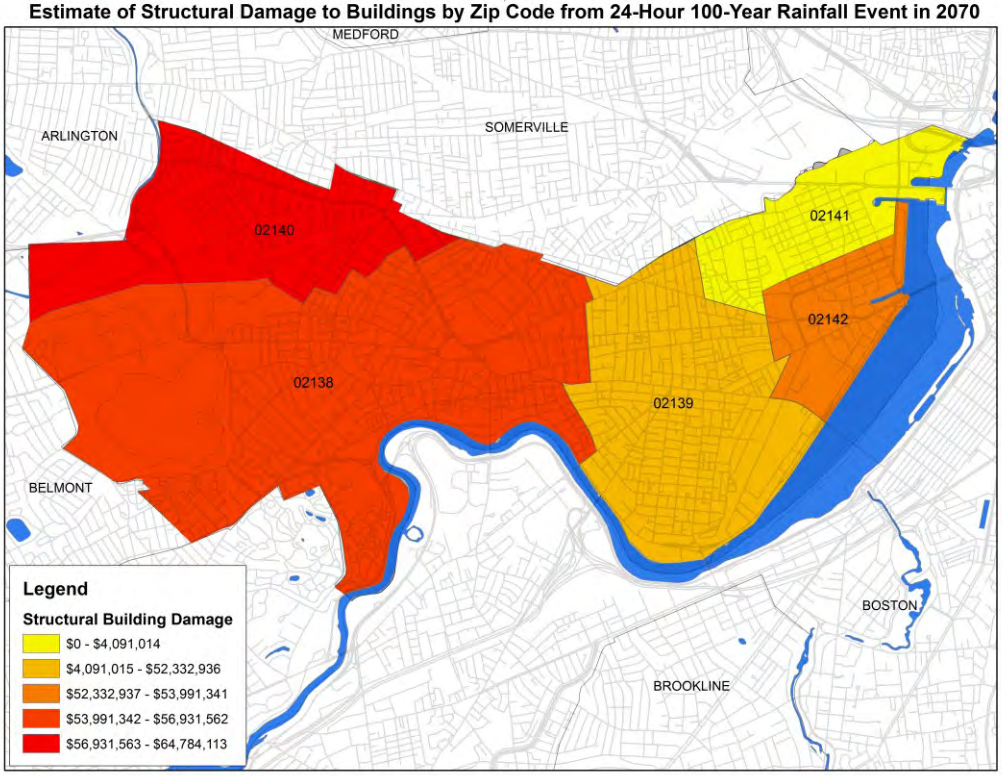


Figure 4. Estimated structural damage to bldgs. by zip code from 24-hour 100-year rainfall event in 2030 & 2070.

Damage by Construction Type

Kleinfelder requested that CAP estimate structural damage to buildings from flooding, according to type of construction. Assessing data on construction type was limited. However, CAP did analyze the percentage of one-story, combustible building stock built prior to 1964, for each flooding scenario. Buildings of this size, type, and age sustained the highest percent of structural damage per foot of floodwater, according to damage reports from the City of New York after Superstorm Sandy.[1]

For the purpose of identifying similar vulnerable buildings, Table 7 shows the amount of damages for buildings in Cambridge that fit these criteria, as well their percent of total damages. However, damage to such buildings in Cambridge represented less than 0.25% of all building damages for the scenario of the 100-year event in 2070. As Cambridge appears to have relatively few combustible, older residential buildings, this does not appear to be a problem or issue.

Building Damage	**2030 10-yr**		**2030 100-yr**		**2070 10-yr**		**2070 100-yr**	
All Buildings	$ 8,944,068		$ 61,606,712		$ 14,748,959		$ 232,130,966	
Vulnerable Buildings	$ 908	0.01%	$ 10,367	0.02%	$ 8,515	0.06%	$ 545,606	0.24%

Table 7. Structural damage to all buildings and to buildings that are combustible, only one story tall and built before 1964 (called vulnerable here). Percentages that follow damage amounts correspond to percent total damage for that scenario.

6.3 ESTIMATED IMPACTS OF CLIMATE CHANGE-RELATED PRECIPITATION EVENTS ON THE CAMBRIDGE ECONOMY, BY ZIP CODE

Tables 16 through 19 present data similar to Table 14 for each of the climate change scenarios by zip code.

The distribution of impacts across the city does vary with the scenario examined. In terms of properties affected, the 10-year events in 2030 and 2070 affect a larger number of properties in the middle zip code bordering the Charles River (02139), but the upper Charles River zip, 02138, exceeds properties affected in 02139 in the 100-year events. At the same time, the economic impacts in 02139 exceed those in 02138 based on shares of value or adjusted area in the four scenarios.

Zip code 02142, the furthest downstream on the Charles, has generally smaller estimated economic impacts than those up river (02139 and 02138), based on adjusted area and value shares for the 2030 events and the 10-year event in 2070, but grow to significant levels of between 2,300 and 5,000 employees and between $1.7 and $3.7 million per day in lost Gross Regional Product for the 100-year event in 2070.

The inland zip codes (02140 and 02141) generally have smaller impacts than the Charles River zip codes, but there are impacts in these zip codes in each of the events (although there are impacts in 02140 only for the 100-year event in 2030). In fact, impacts in 02140 are similar in size to the Charles River zip codes based on value and adjusted area in both of the High scenarios. The analysis indicates that significant economic impacts of climate change-related flooding are likely to occur throughout Cambridge.

		Number of Properties >6" flood	Assessed Value At Risk ($M)	Share of Valuation in Zip Code	Share of Properties in Zip Code	Share of Adjusted Area in Zip Code	
2030 10-yr Event	02138	20	$152.646	0.08%	1.95%	1.86%	
	02139	22	$499.21	3.51%	3.11%	7.46%	
	02140	1	$40.48	1.17%	0.34%	1.55%	
	02141	2	$1.84	0.04%	0.61%	0.11%	
	02142	3	$3.41	0.40%	0.91%	0.50%	
	Total	48	$697.59	0.36%	1.79%	2.22%	
		Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
	02138	100	616	683	$91,438	$289,259	$295,850
	02139	825	1,181	2,435	$380,342	$510,441	$1,074,480
	02140	158	44	199	$77,955	$21,612	$98,441
	02141	4	70	12	1,646	$28,759	$4,809
	02142	94	279	148	$68,284	$202,117	$107,399
	Total	1,181	2,190	3,478	$619,665	$1,052,187	$1,580,978

Table 16

		Number of Properties >6" flood	**Assessed Value At Risk ($M)**	**Share of Valuation in Zip Code**	**Share of Properties in Zip Code**	**Share of Adjusted Area in Zip Code**	
2030 100-yr Event	02138	70	$279.90	0.15%	6.83%	5.17%	
	02139	22	$499.21	3.51%	3.11%	7.46%	
	02140	41	$1,160.15	33.63%	13.95%	34.71%	
	02141	0	$0.00	0.04%	0.61%	0.11%	
	02142	3	$426.99	0.40%	0.91%	0.50%	
	Total	136	$2,366.24	0.76%	5.14%	5.32%	
		Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
	02138	327	2,072	1,588	$347,672	$1,011,482	$861,283
	02139	825	1,181	2,435	$380,342	$510,441	$1,074,480
	02140	4,284	1,698	4,383	$2,563,968	$1,338,459	$2,584,184
	02141	0	0	0	$0	$0	$0
	02142	94	279	148	$68,284	$202,117	$107,399
	Total	5,530	5,231	8,555	$3,360,266	$3,062,499	$4,627,345

Table 17

		Number of Properties >6" flood	Assessed Value At Risk ($M)	Share of Valuation in Zip Code	Share of Properties in Zip Code	Share of Adjusted Area in Zip Code	
2070 10-yr Event	02138	25	$191.31	0.10%	2.44%	2.33%	
	02139	40	$898.75	6.31%	5.66%	13.91%	
	02140	3	$54.28	1.57%	1.02%	5.05%	
	02141	10	$10.31	0.22%	3.03%	0.47%	
	02142	12	$1,059.71	1.00%	3.65%	1.00%	
	Total	90	$2,214.35	0.71%	3.35%	4.05%	
		Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
	02138	134	711	879	$126,129	$360,927	$366,067
	02139	1,756	2,075	4,826	$786,289	$911,080	$2,104,199
	02140	212	131	648	$104,527	$64,835	$319,885
	02141	21	322	47	$9,387	$135,002	$19,948
	02142	234	1,117	294	$169,469	$808,468	$212,866
	Total	2,357	4,357	6,695	$1,195,801	$2,280,311	$3,022,964

Table 18

		Number of Properties	Assessed Value At Risk	Share of Valuation in	Share of Properties in	Share of Adjusted Area	

		>6" flood	($M)	Zip Code	Zip Code	in Zip Code	
2070 100-yr Event	02138	163	$1,696.74	0.92%	15.90%	16.04%	
	02139	154	$4,594.36	32.27%	21.78%	44.06%	
	02140	53	$1,439.69	41.73%	18.03%	42.03%	
	02141	68	$690.10	14.64%	20.61%	17.17%	
	02142	75	$10,419.98	9.83%	22.80%	22.03%	
	Total	513	$18,840.86	6.04%	19.11%	25.70%	
		Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
	02138	1,024	5,337	5,607	$910,752	$2,360,922	$2,584,354
	02139	7,290	7,423	14,162	$3,387,732	$3,375,158	$6,267,771
	02140	5,046	2,175	5,191	$3,547,334	$1,823,991	$3,767,056
	02141	1,336	2,019	1,591	$634,555	$863,507	$722,083
	02142	2,345	5,066	3,796	$1,689,976	$3,660,019	$2,736,874
	Total	17,040	22,020	30,346	$10,170,349	$12,083,596	$16,078,138

Table 19

Tables 20-23 show the distribution of impacts for the Scientific Research and Development industry by zip code. Impacts occur in 02138 and 02139 occur in all four scenarios, with additional impacts in 02140 for the 100-year event in 2030 and in all five zip codes for the 100-year event in 2070. Impacts in this industry general exceed 1,000 employees directly affected in all of the scenarios and $1.0 million per day in lost output in all scenarios except for the 10-year event in 2030.

		Number of Properties >6" flood	Assessed Value At Risk ($M)	Share of Valuation in Zip Code	Share of Properties in Zip Code	Share of Adjusted Area in Zip Code	
2030 10-yr Event	02138	1	$41.32	28.7%	9.1%	16.5%	
	02139	3	$351.26	16.8%	8.8%	17.6%	
	Total	4	$392.58	17.5%	8.9%	17.4%	
		Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
	02138	486	154	279	$286,161	$90,562	$163,990
	02139	1,639	863	1,717	$964,373	$507,633	$1,009,910
	Total	2,126	1,017	1,995	$1,250,534	$598,195	$1,173,900

Table 20

		Number of Properties >6" flood	Assessed Value At Risk ($M)	Share of Valuation in Zip Code	Share of Properties in Zip Code	Share of Adjusted Area in Zip Code	
2030 100-yr Event	02138	4	$60.48	42.0%	36.4%	36.5%	
	02139	3	$351.26	16.8%	8.8%	17.6%	
	02140	4	$106.74	85.9%	80.0%	87.6%	
	Total	11	$518.48	21.9%	22.0%	25.8%	
		Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
	02138	712	616	617	$418,834	$362,248	$363,226
	02139	1,639	863	1,717	$964,373	$507,633	$1,009,910
	02140	1,351	1,259	1,377	$794,662	$740,396	$810,334
	Total	3,702	2,737	3,712	$2,177,870	$1,610,277	$2,183,471

Table 21

		Number of Properties >6" flood	Assessed Value At Risk ($M)	Share of Valuation in Zip Code	Share of Properties in Zip Code	Share of Adjusted Area in Zip Code	
2070 10-yr Event	02138	1	$41.32	28.7%	9.1%	16.5%	
	02139	8	$564.26	26.9%	23.5%	32.5%	
	02142	4	$620.09	6.5%	7.0%	0.8%	
	Total	13	$1,225.67	10.3%	12.7%	6.4%	
		Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
	02138	486	154	279	286,161	90,562	163,990
	02139	2,633	2,301	3,176	1,549,158	1,353,688	1,868,501
	02142	94	102	12	55,116	59,956	7,160
	Total	3,213	2,557	3,467	$1,890,435	$1,504,206	$2,039,651

Table 22

		Number of Properties >6" flood	Assessed Value At Risk ($M)	Share of Valuation in Zip Code	Share of Properties in Zip Code	Share of Adjusted Area in Zip Code	
2070 100-yr Event	02138	8	$105.32	73.2%	72.7%	70.2%	
	02139	16	$1,115.95	53.3%	47.1%	62.4%	
	02140	4	$106.74	85.9%	80.0%	87.6%	
	02141	4	$226.28	69.8%	40.0%	66.5%	
	02142	20	$2,779.78	28.9%	35.1%	20.0%	
	Total	52	$4,334.07	35.2%	44.4%	31.4%	
		Employment Impact Based on Share of Value	**Employment Impact Based on Share of Properties**	**Employment Impact Based on Share of Adjusted Area**	**Gross Regional Product Impact per day Based on Share of Value**	**Gross Regional Product Impact per day Based on Share of Properties**	**Gross Regional Product Impact per day Based on Share of Adjusted Area**
	02138	1,240	1,232	1,188	$729,330	$724,495	$698,914
	02139	5,208	4,602	6,106	$3,063,803	$2,707,376	$3,591,859
	02140	1,351	1,259	1,377	$794,662	$740,396	$810,334
	02141	305	175	290	$179,293	$102,735	$170,889
	02142	420	510	291	$247,078	$299,779	$171,024
	Total	8,523	7,777	9,252	$5,014,167	$4,574,782	$5,443,020

Table 23

6.4 FOOTPRINTS (93) WITH NO BUILDING VALUE AND LACKING ATTRIBUTES TO MATCH WITH 2015 ASSESSOR'S TABLE

TYPE	BldgID	ml
BLDG	48-1	267.4-296
BLDG	130-6	261-124
BLDG	112-4	152-53
BLDG	44-15	265D-55
BLDG	369-2	35-101
BLDG	38-2	269-127
BLDG	9-6	267.2-261
OUTBLDG	14-24	189-103
OUTBLDG	14-19	188-146
OUTBLDG	14-16	188-147
OUTBLDG	14-13	188-148
RUINS	69-24	267E-291
BLDG	322-19	221-52
BLDG	703-4	54-25
OUTBLDG	390-6	36-246
OUTBLDG	361-11	36-39
OUTBLDG	568-6	42-7
BLDG	703-5	54-26
BLDG	669-2	70-26
BLDG	473-10	108-89
BLDG	96-3	266-31
BLDG	130-1	261-124
BLDG		261-65
BLDG		267E-291
BLDG	44-19	265D-37
BLDG	44-18	265D-37
BLDG	44-17	265D-37
BLDG	44-16	265D-37
BLDG	9-24	267.2-261
BLDG	9-22	267.2-261
BLDG		267.2-261
BLDG		267.2-261
BLDG		267.2-261
BLDG	721-6	0
BLDG	112-7	---
OUTBLDG		---

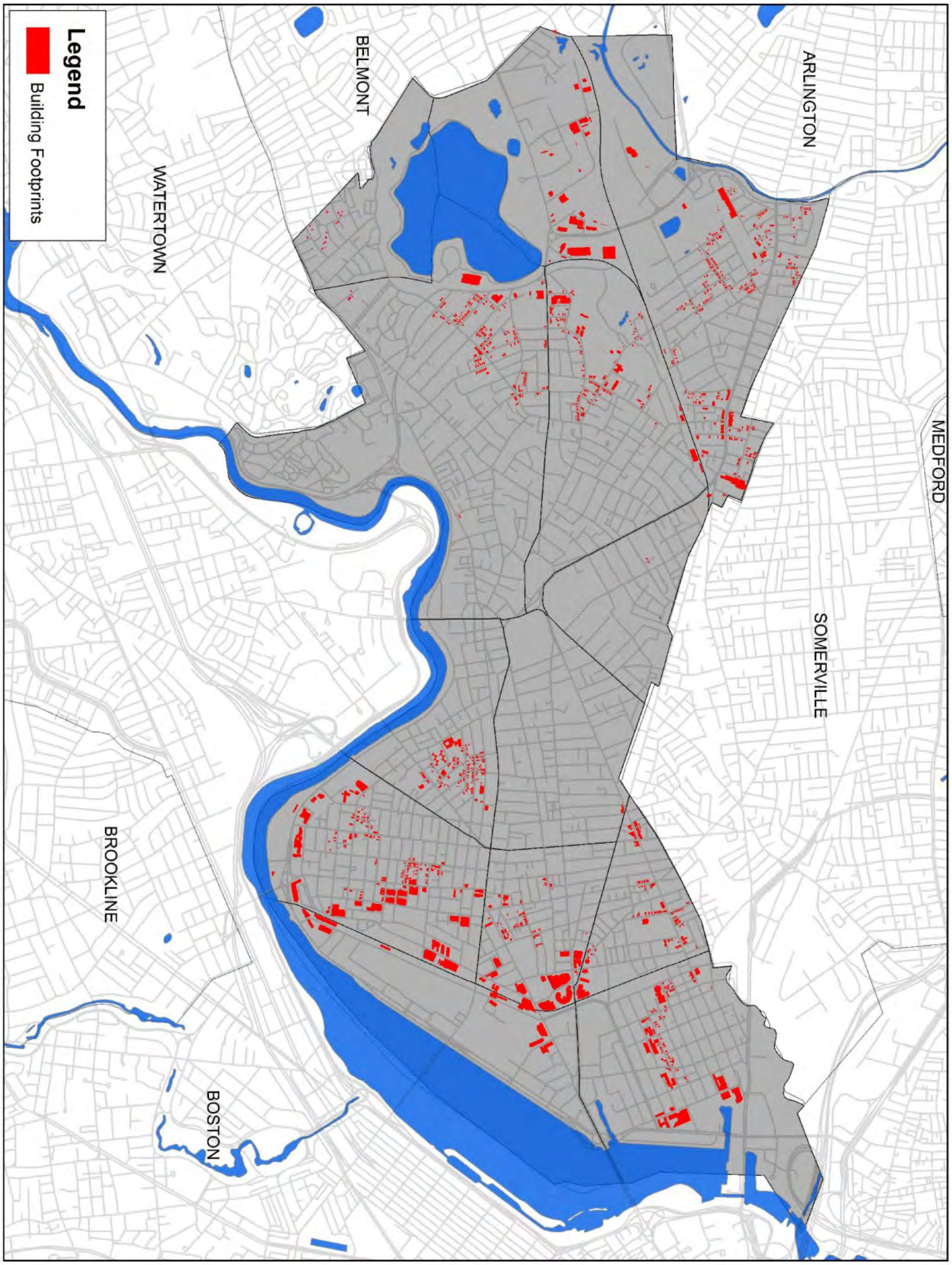
OUTBLDG		267.4-296
OUTBLDG		267.4-296
OUTBLDG		261-124
OUTBLDG		261-124
OUTBLDG		200-93
OUTBLDG		200-93
OUTBLDG		265D-37
OUTBLDG		265D-37
OUTBLDG		265D-37
OUTBLDG		268C-36
OUTBLDG	48-13	265D-37
OUTBLDG		265D-37
OUTBLDG		267.2-261
OUTBLDG		267.2-261
OUTBLDG	9-17	267.2-261
OUTBLDG	9-15	267.2-261
OUTBLDG		267.2-261
OUTBLDG		269-135
RUINS		265D-37
OUTBLDG		156-106
BLDG	322-15	221-52
BLDG	9-19	267.2-261
BLDG	9-16	267.2-261
BLDG		267.2-261
BLDG		267.2-261
OUTBLDG		248-79
OUTBLDG		248-79
OUTBLDG		267.2-262
OUTBLDG	9-8	267.2-262
OUTBLDG		40-239
OUTBLDG	412-27	37-109
BLDG		66-82
BLDG		66-82
OVHD-WALKWAY	667-8	53-70
OUTBLDG		53-64
OUTBLDG		48-20
RUINS	674-4	48-20
OUTBLDG		62-40
OVHD-WALKWAY	699-3	55-22
OUTBLDG		53-60
OUTBLDG		53-70
OUTBLDG		53-70

OUTBLDG		147-58
BLDG		267E-292
BLDG	560-16	130-121
BLDG	385-44	85-63
BLDG	381-18	85-92
BLDG	559-8	16-30
BLDG	559-8	16-30
OUTBLDG		---
OUTBLDG		---
OVHD-WALKWAY	35-2	ROAD
OVHD-WALKWAY	417-4	ROAD
OVHD-WALKWAY	417-4	ROAD
OVHD-WALKWAY	557-15	ROAD
OVHD-WALKWAY	557-15	ROAD
OVHD-WALKWAY	699-7	ROAD

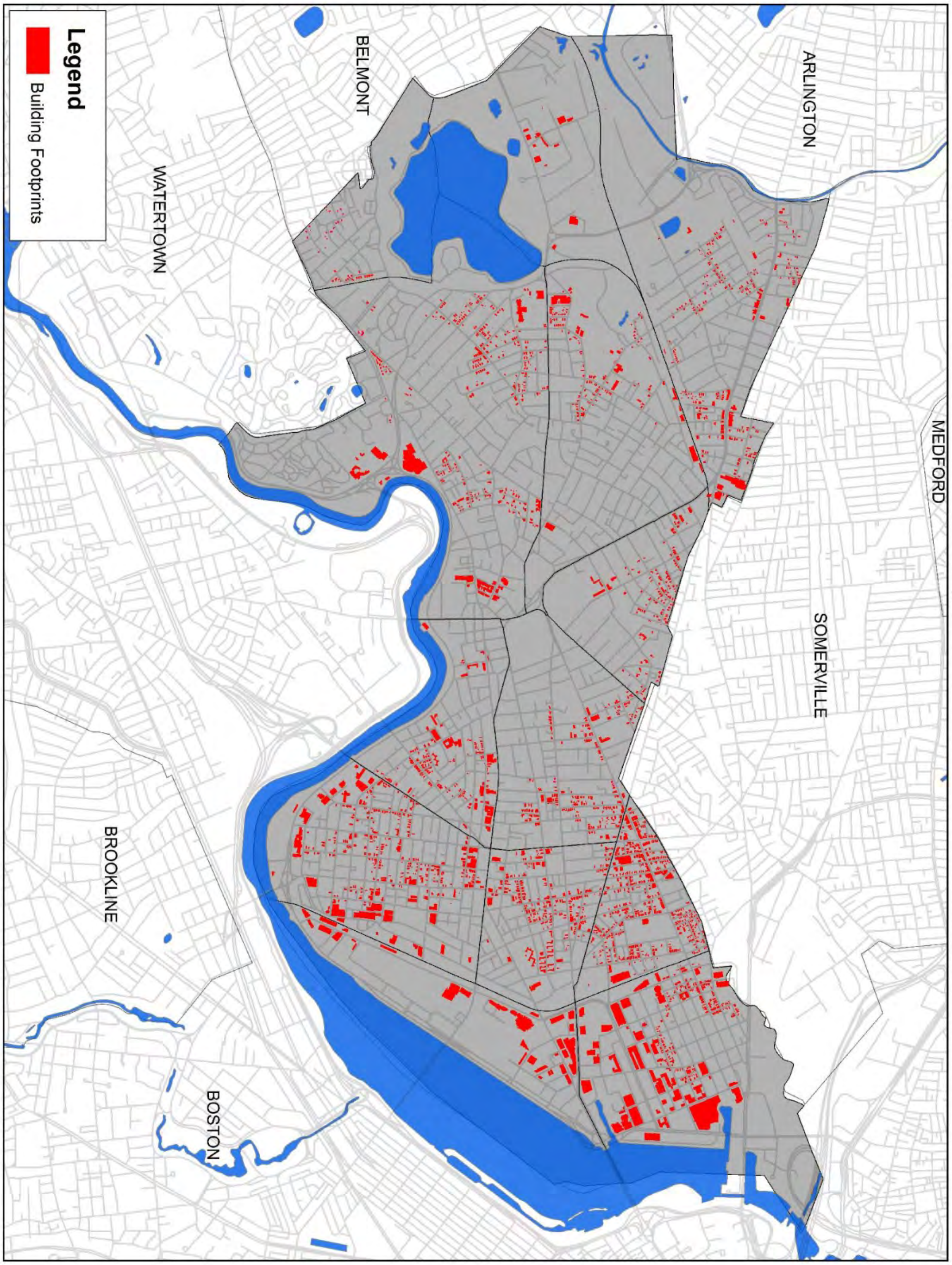
6.5 Buildings with Less than 6 Inches of Flooding

Number of Footprints with Less than 6" of Flooding by Flood Depth		
Flooding depths (In.)	**2030 100-yr**	**2070 100-yr**
0.0001 – 1.9999	829	1667
2.0000 – 3.9999	314	745
4.0000 – 5.9999	207	553
TOTAL	1350	2965

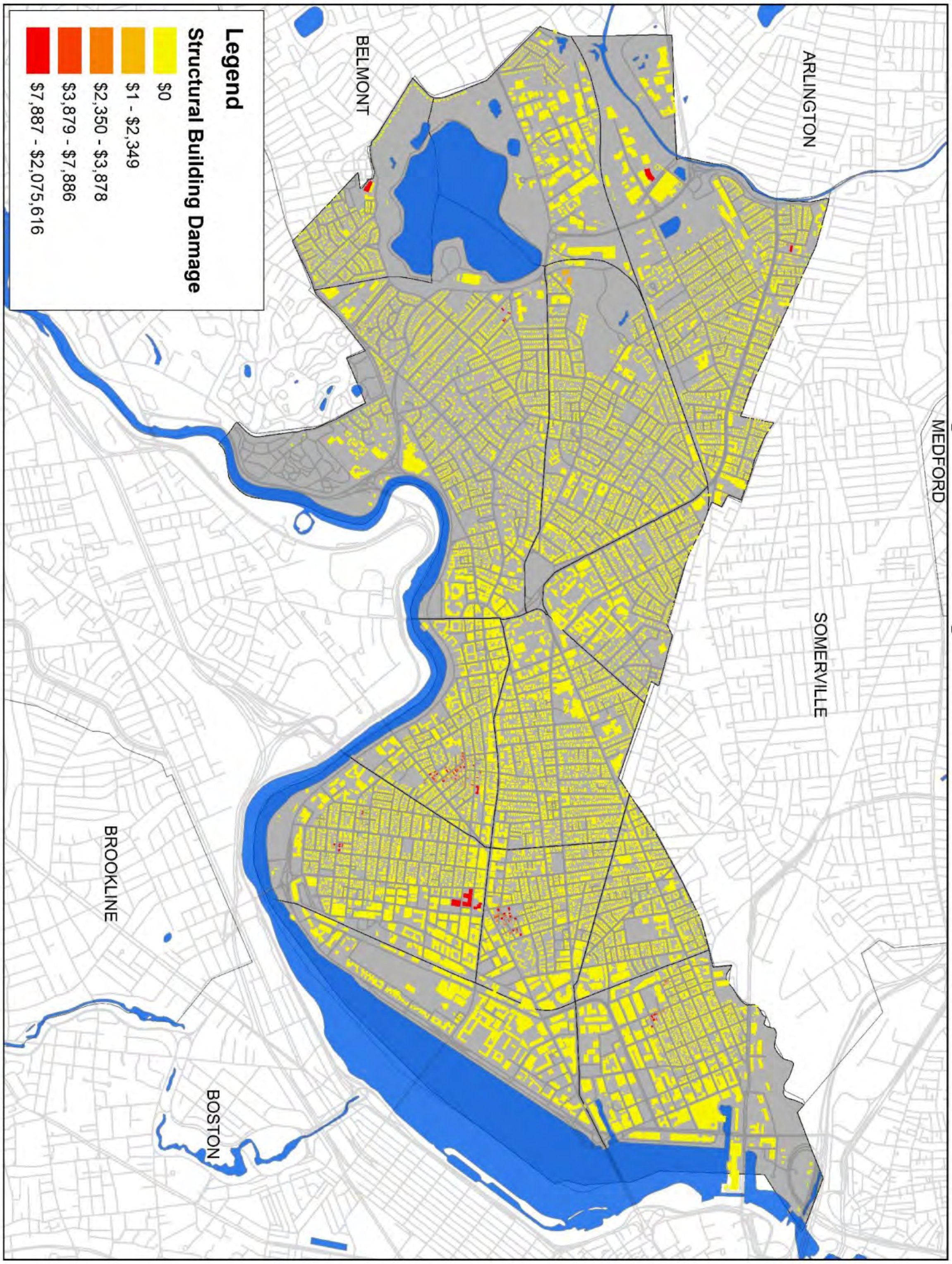
See maps of locations of these building on the following pages.

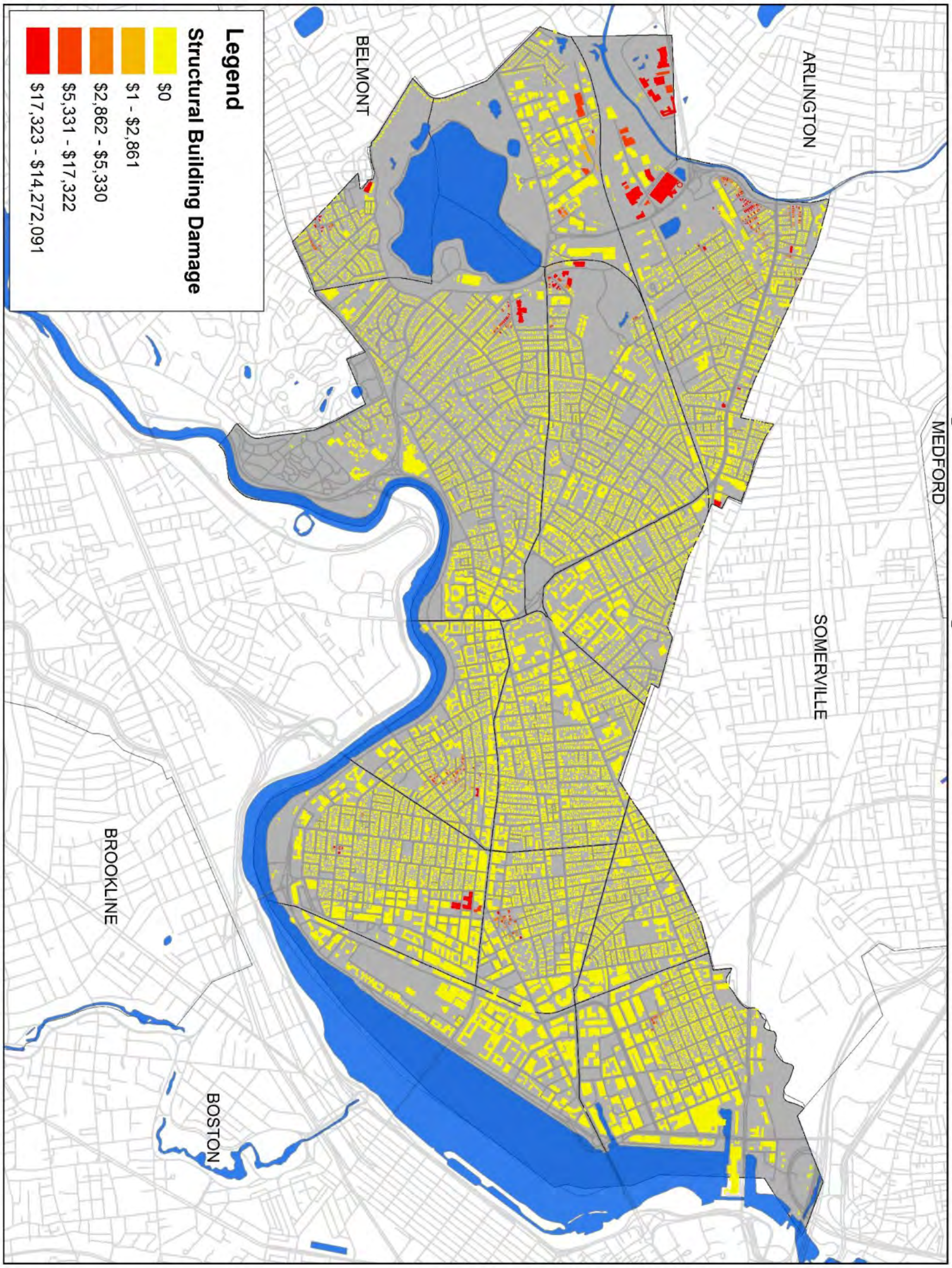

Buildings with Less than 6" of Flooding from 24-Hour 100-Year Rainfall Event in 2030
Legend
Building Footprints
BELMONT
ARLINGTON
WATERTOWN
MEDFORD
SOMERVILLE
BROOKLINE
BOSTON

Buildings with Less than 6" of Flooding from 24-Hour 100-Year Rainfall Event in 2070



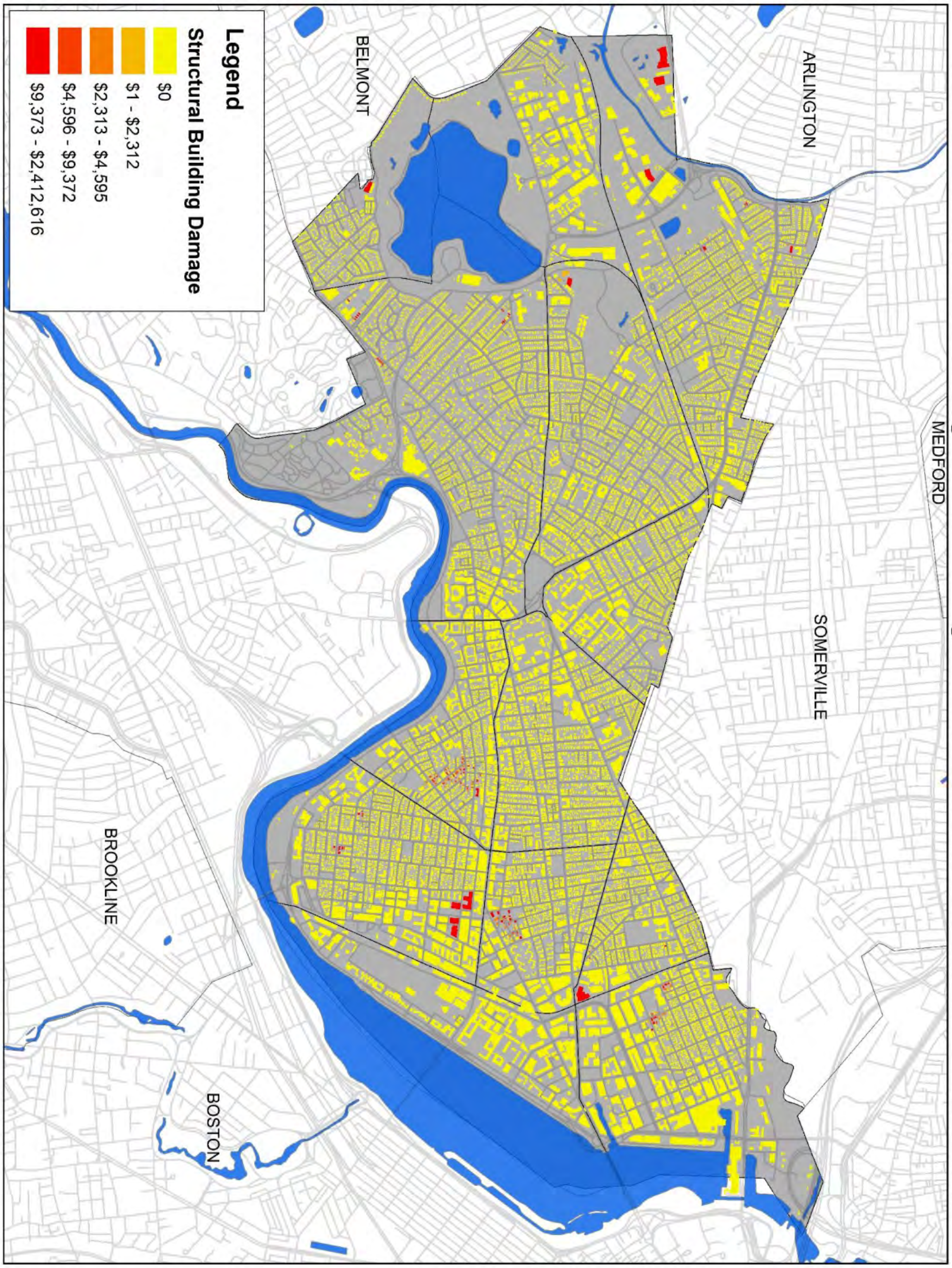
6.6 MAPS OF BUILDING DAMAGE FOR 10-YEAR AND 100-YEAR RAINFALL EVENTS IN 2030 AND 2070



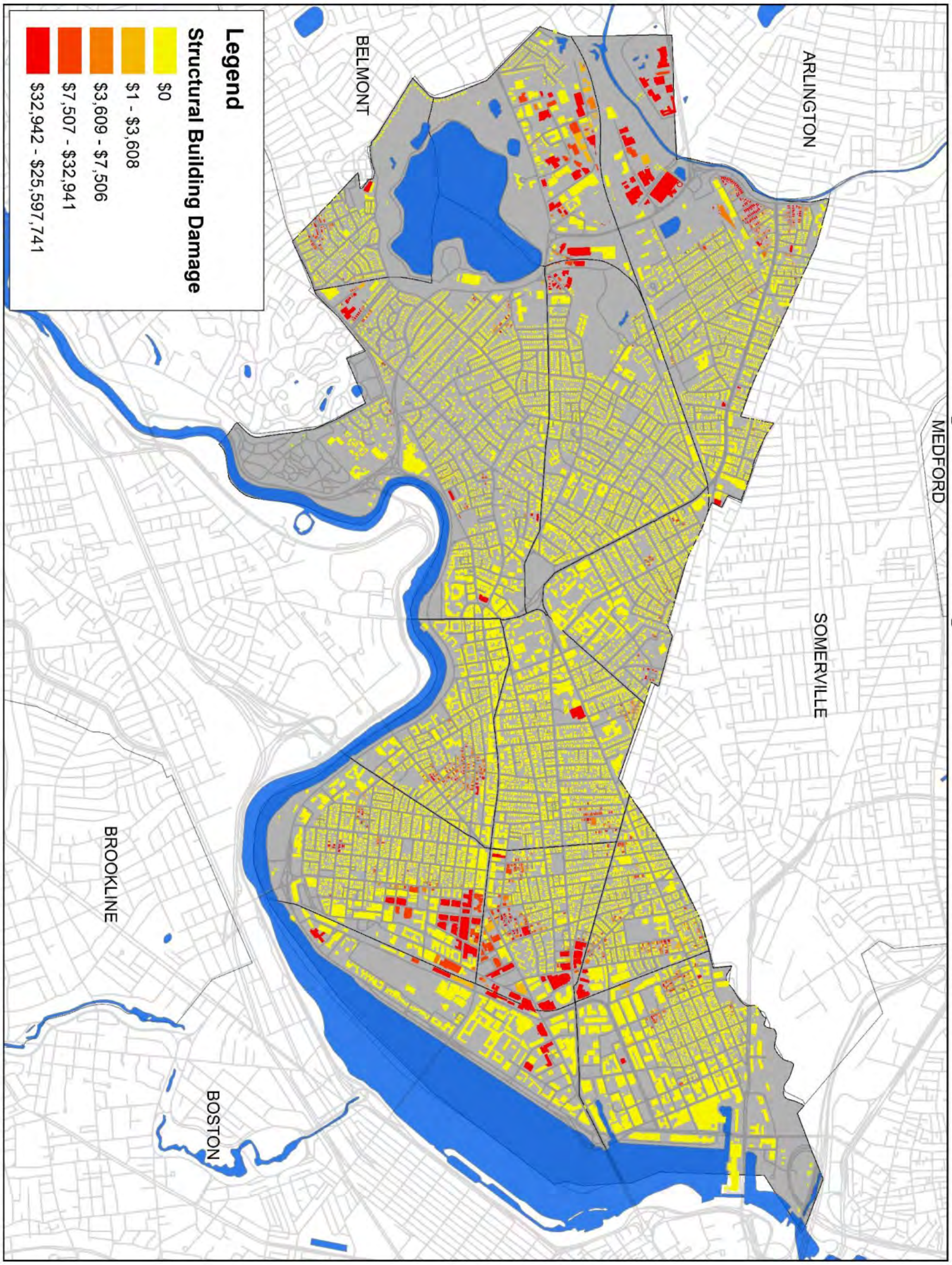


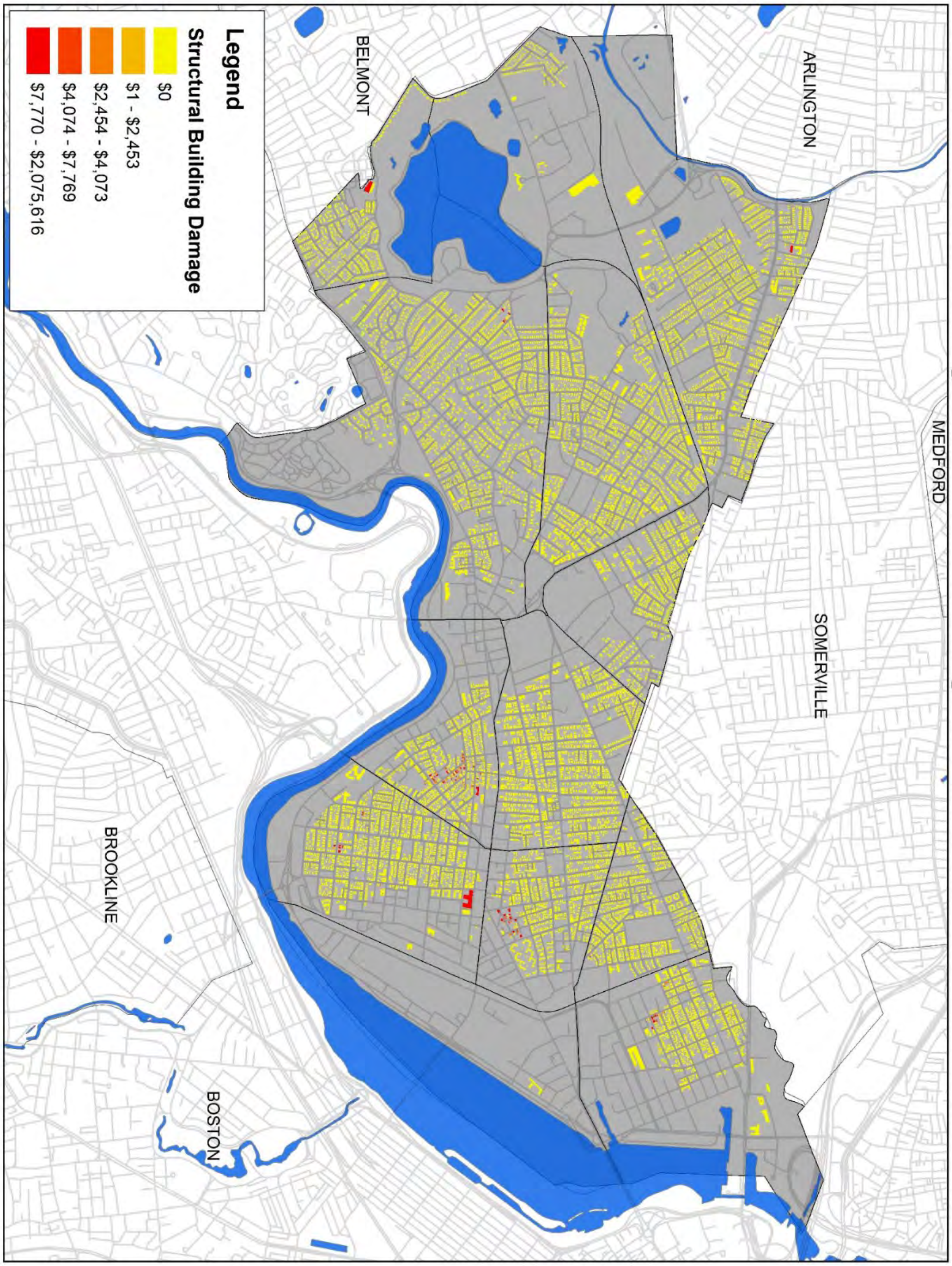
Estimate of Structural Damage to All Buildings from 24-Hour 100-Year Rainfall Event in 2030

Estimate of Structural Damage to All Buildings from 24-Hour 10-Year Rainfall Event in 2070



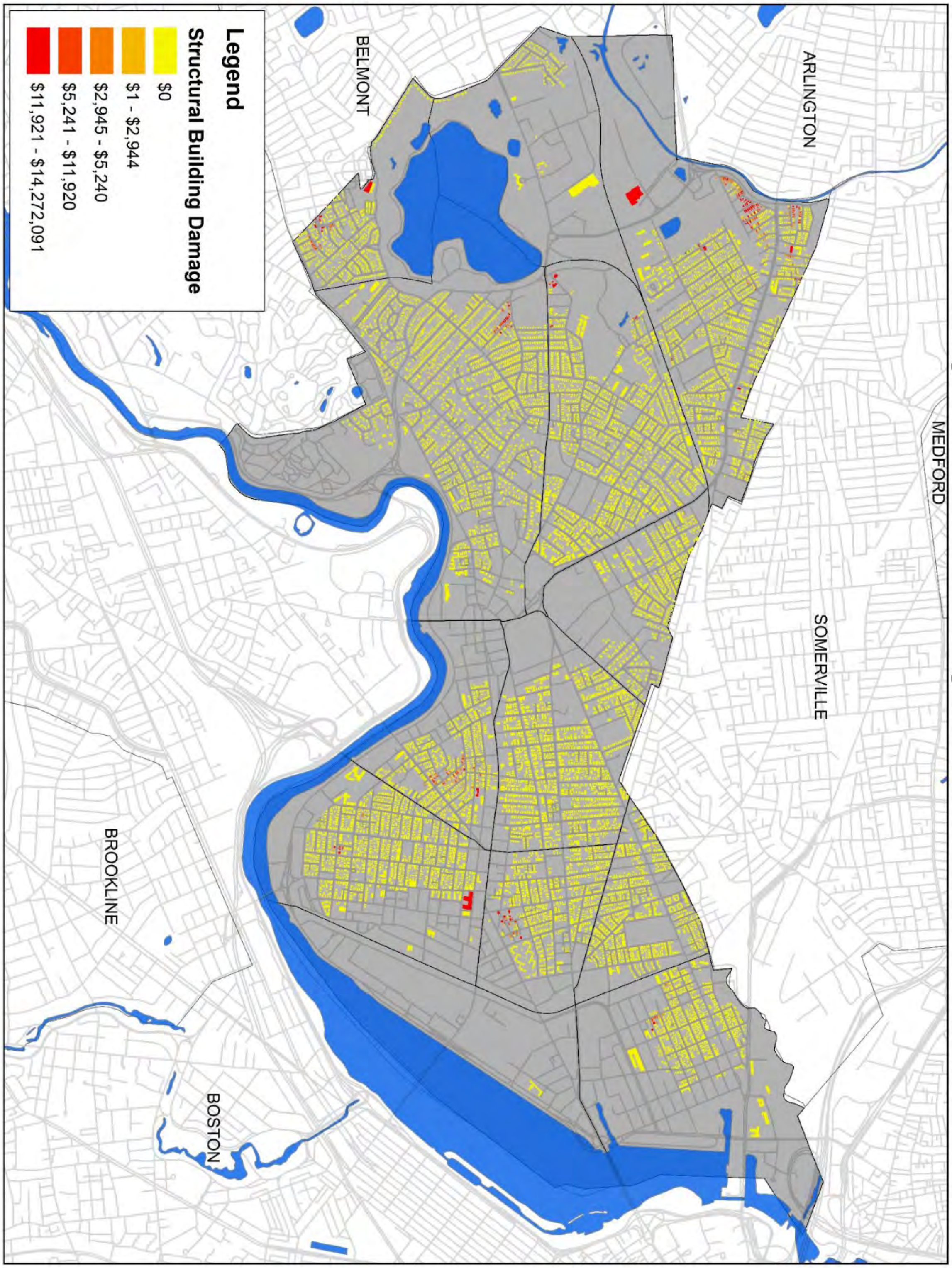
Estimate of Structural Damage to All Buildings from 24-Hour 100-Year Rainfall Event in 2070



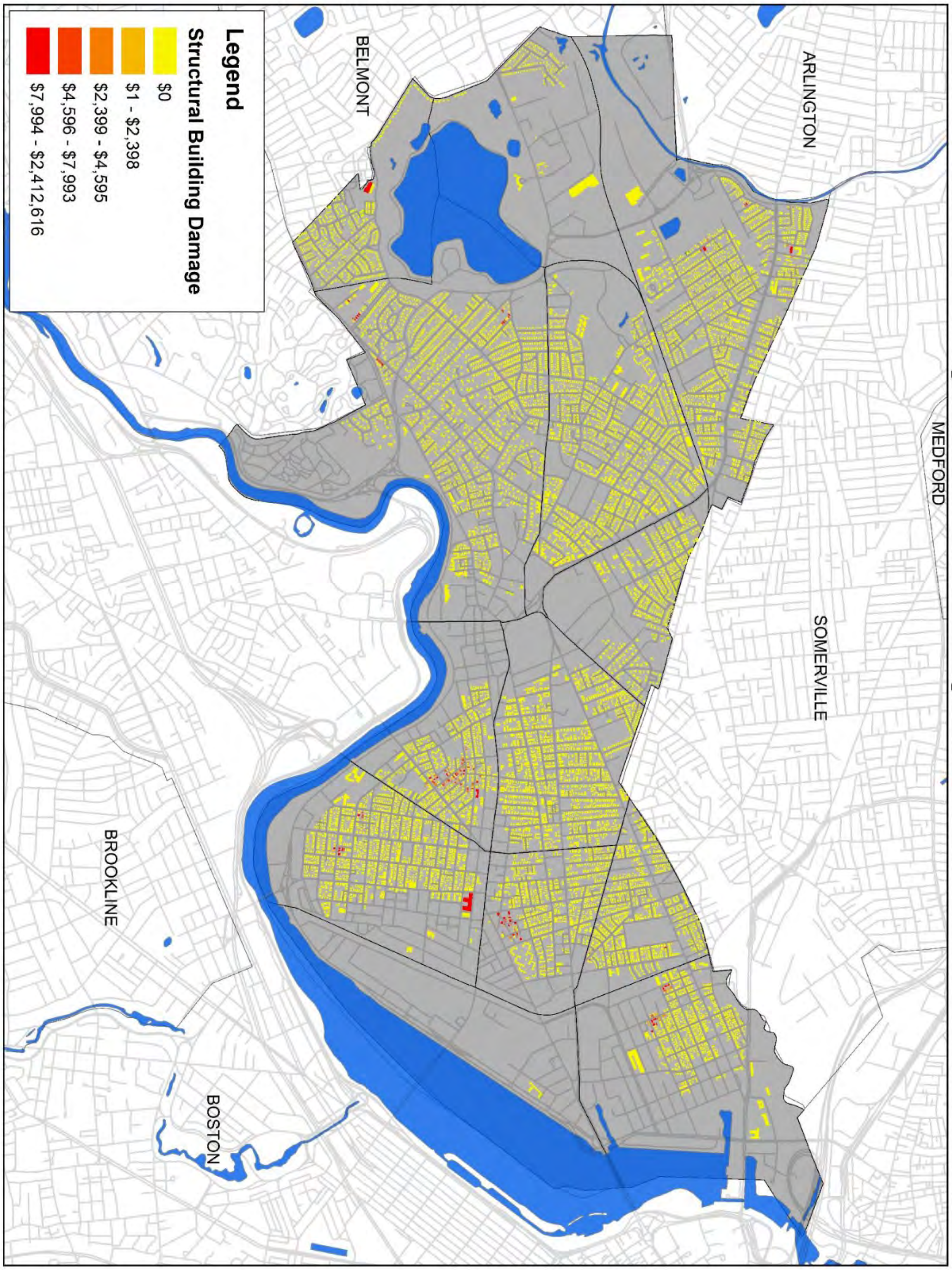


Estimate of Structural Damage to Residential Buildings from 24-Hour 10-Year Rainfall Event in 2030

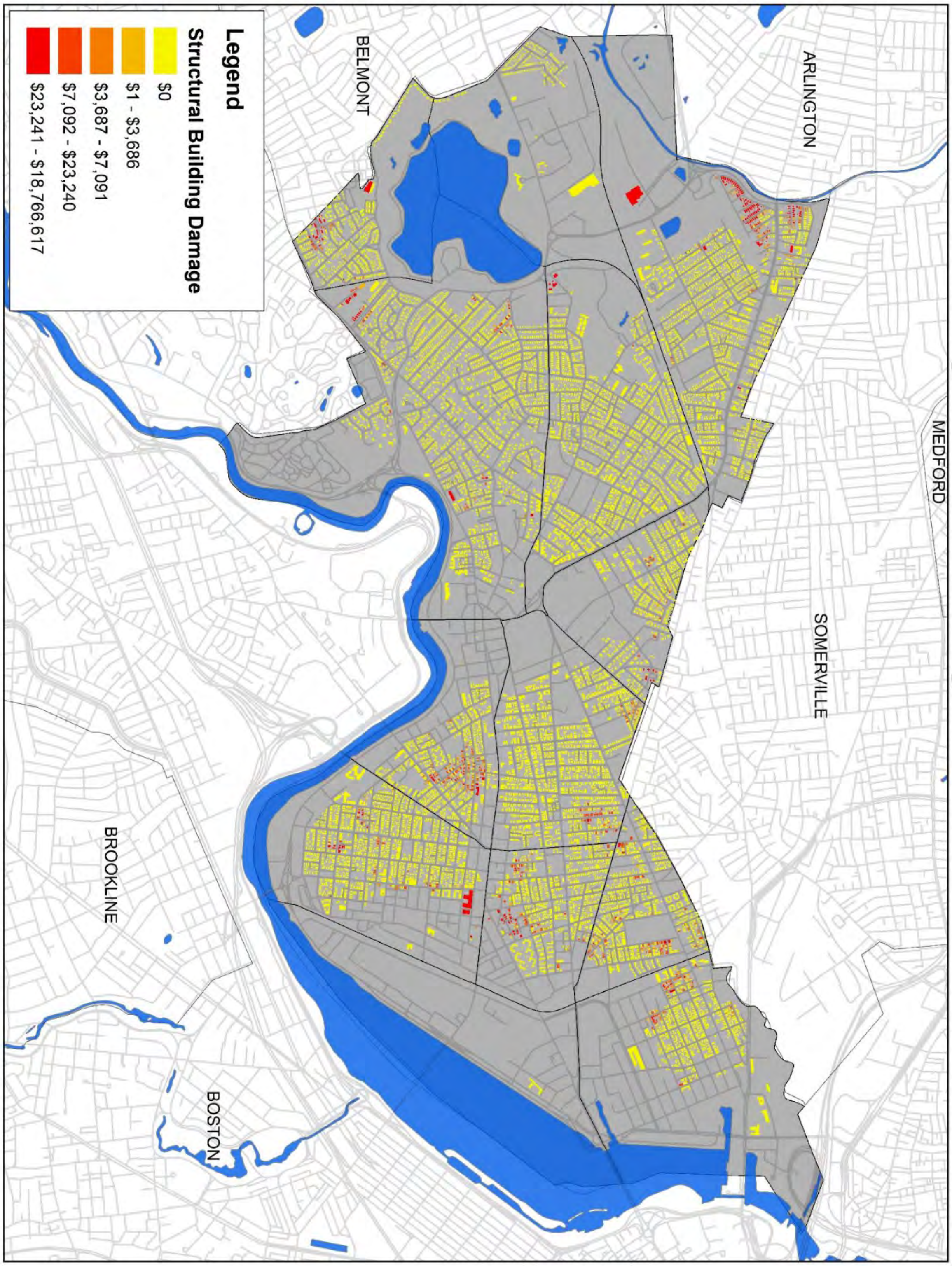
Estimate of Structural Damage to Residential Buildings from 24-Hour 100-Year Rainfall Event in 2030

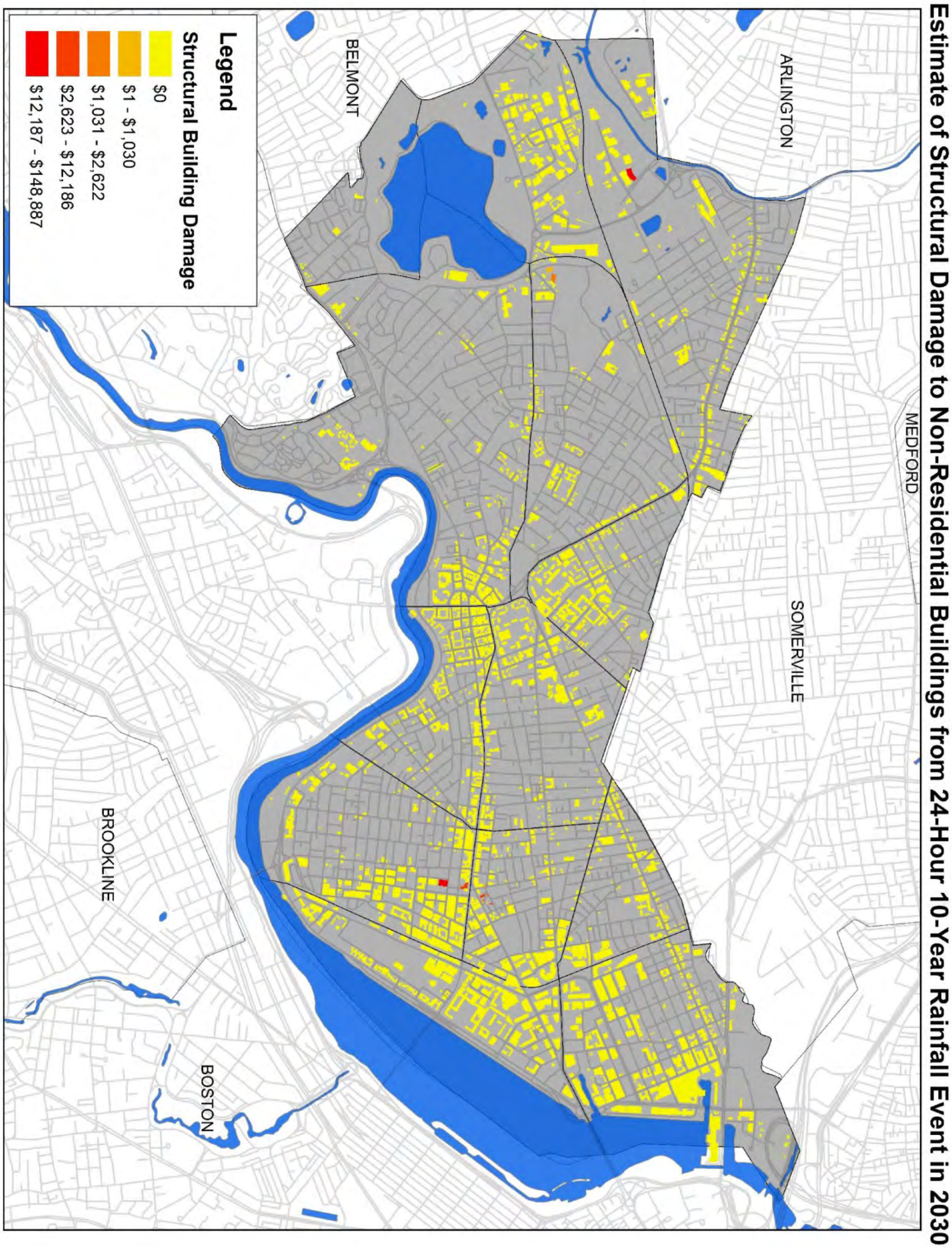


Estimate of Structural Damage to Residential Buildings from 24-Hour 10-Year Rainfall Event in 2070

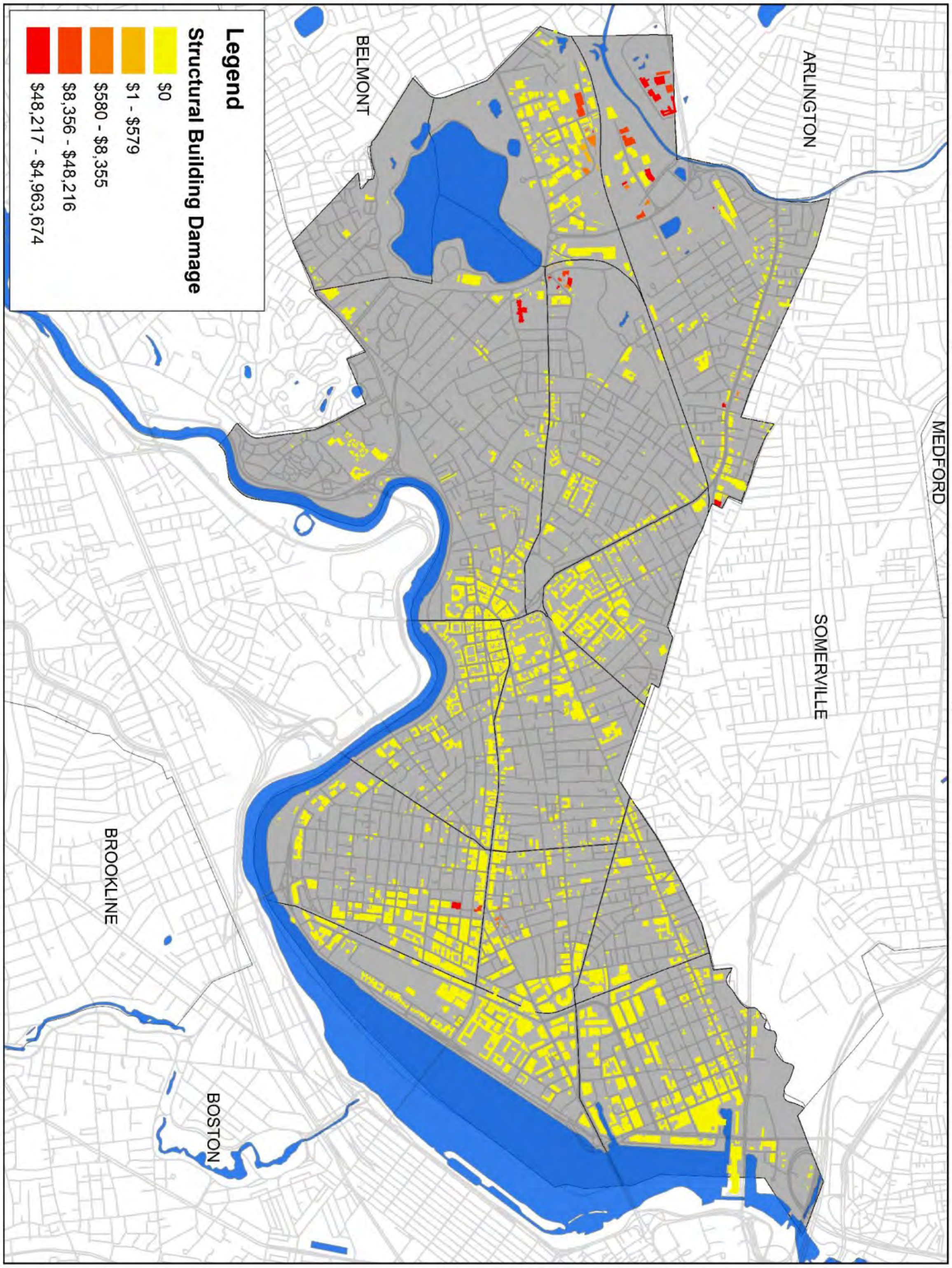


Estimate of Structural Damage to Residential Buildings from 24-Hour 100-Year Rainfall Event in 2070

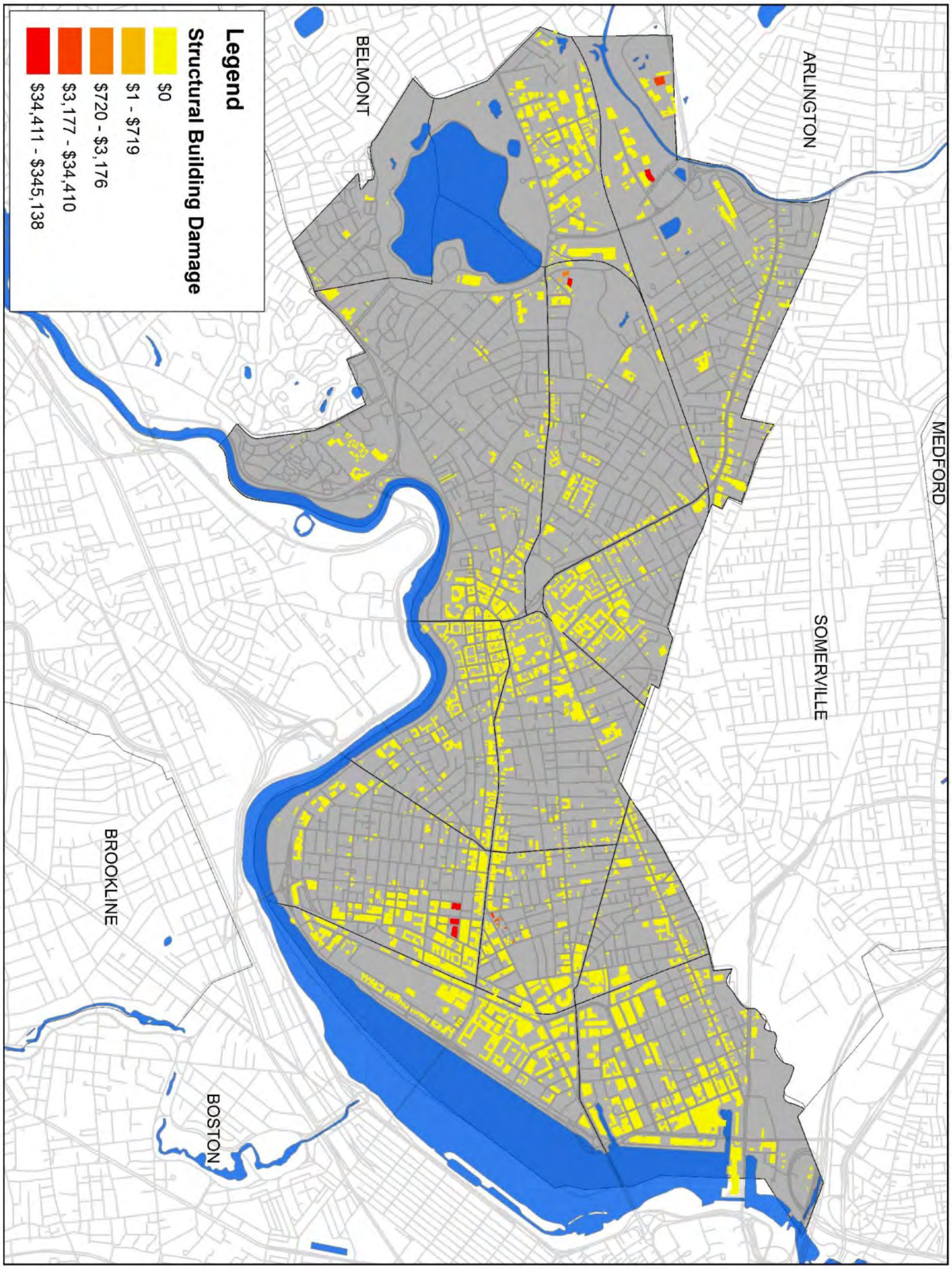



Estimate of Structural Damage to Non-Residential Buildings from 24-Hour 10-Year Rainfall Event in 2030
Legend
Structural Building Damage
$0
$1 - $1,030
$1,031 - $2,622
$2,623 - $12,186
$12,187 - $148,887
ARLINGTON
BELMONT
MEDFORD
SOMERVILLE
BROOKLINE
BOSTON

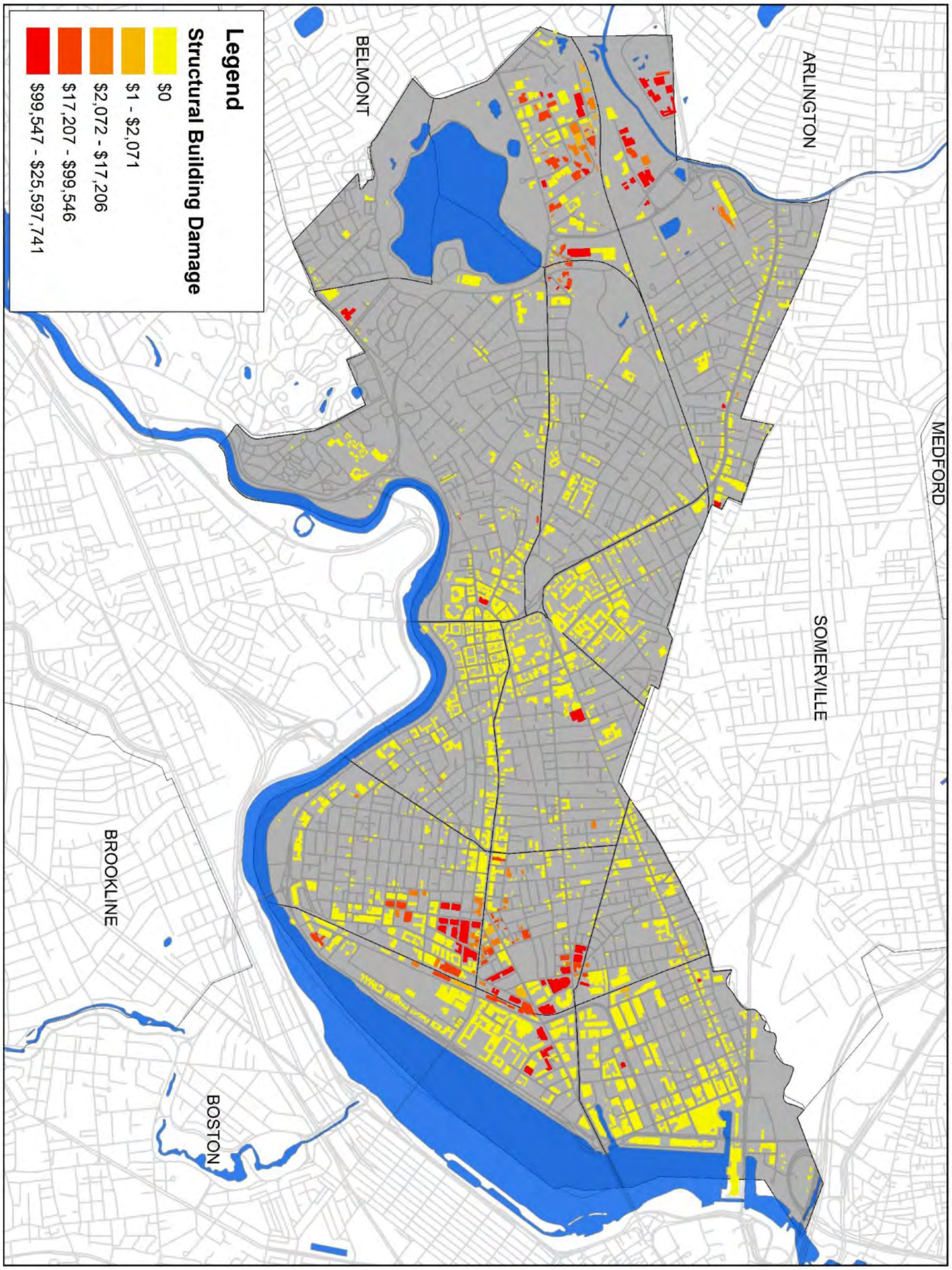
Estimate of Structural Damage to Non-Residential Buildings from 24-Hour 100-Year Rainfall Event in 2030

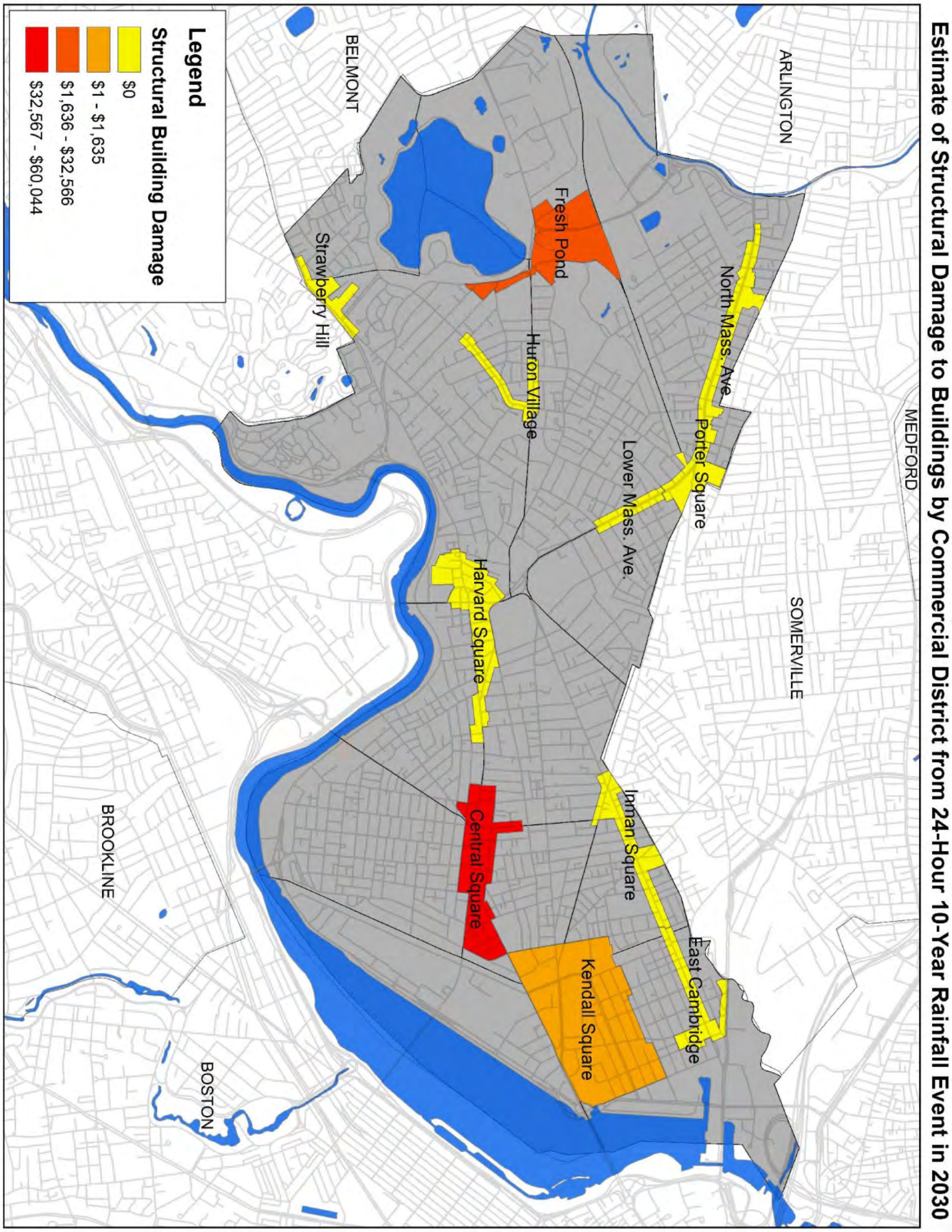


Estimate of Structural Damage to Non-Residential Buildings from 24-Hour 10-Year Rainfall Event in 2070

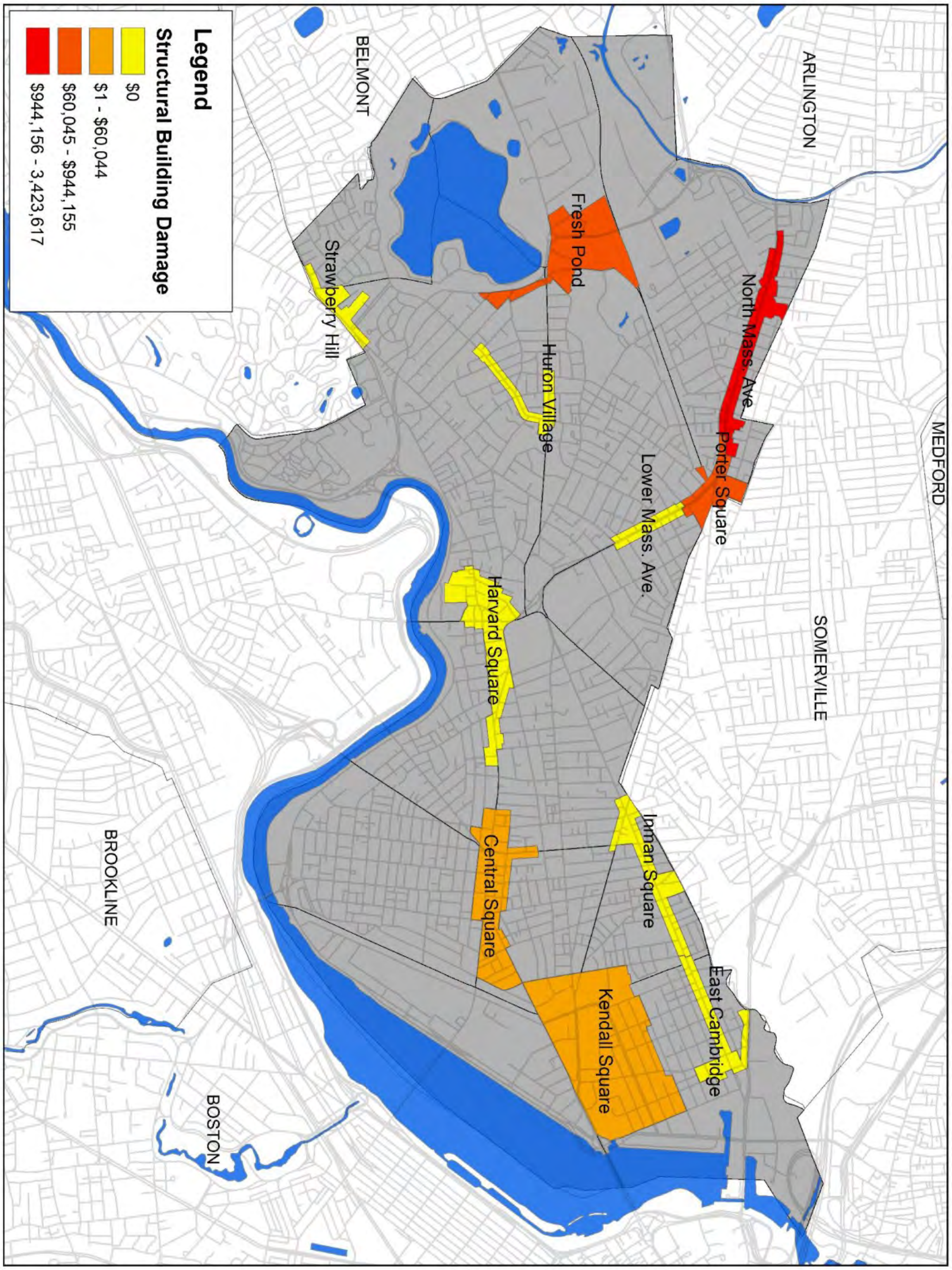


Estimate of Structural Damage to Non-Residential Buildings from 24-Hour 100-Year Rainfall Event in 2070

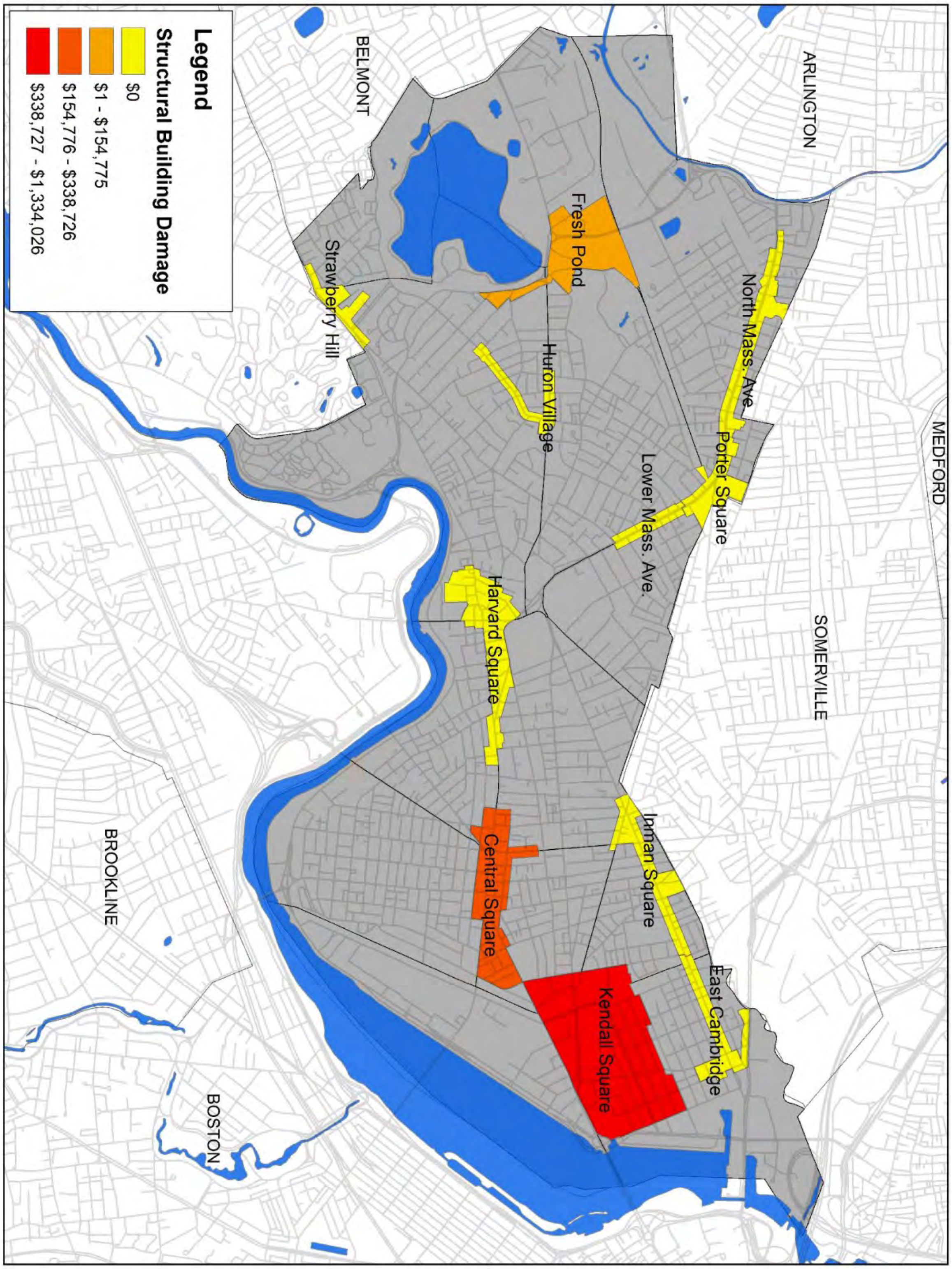


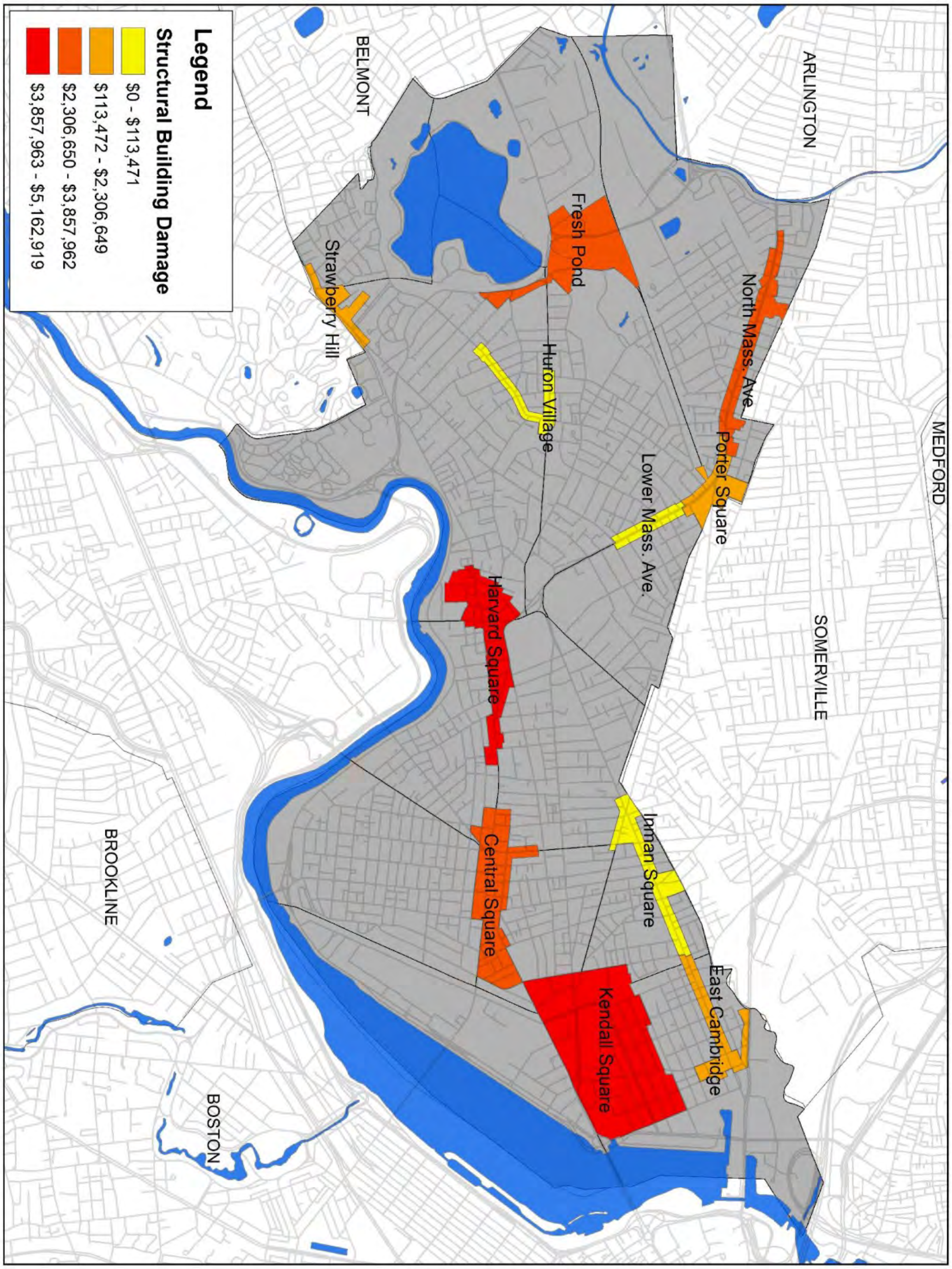

Estimate of Structural Damage to Buildings by Commercial District from 24-Hour 10-Year Rainfall Event in 2030
Legend
Structural Building Damage
$0
$1 - $1,635
$1,636 - $32,566
$32,567 - $60,044
ARLINGTON
MEDFORD
SOMERVILLE
BELMONT
BROOKLINE
BOSTON
Fresh Pond
Strawberry Hill
Huron Village
North Mass. Ave
Porter Square
Lower Mass. Ave.
Harvard Square
Inman Square
Central Square
East Cambridge
Kendall Square

Estimate of Structural Damage to Buildings by Commercial District from 24-Hour 100-Year Rainfall Event in 2030



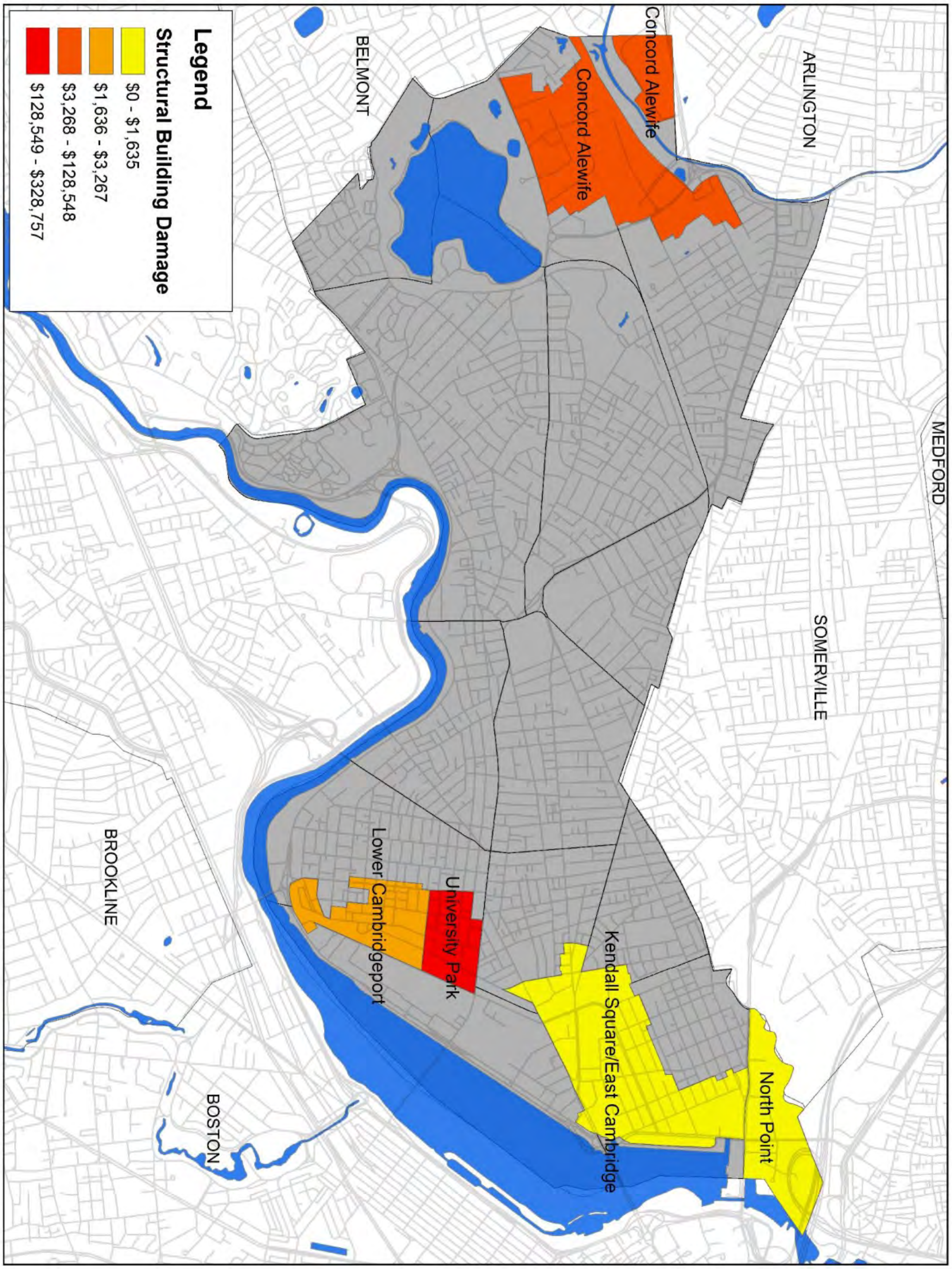
Estimate of Structural Damage to Buildings by Commercial District from 24-Hour 10-Year Rainfall Event in 2070



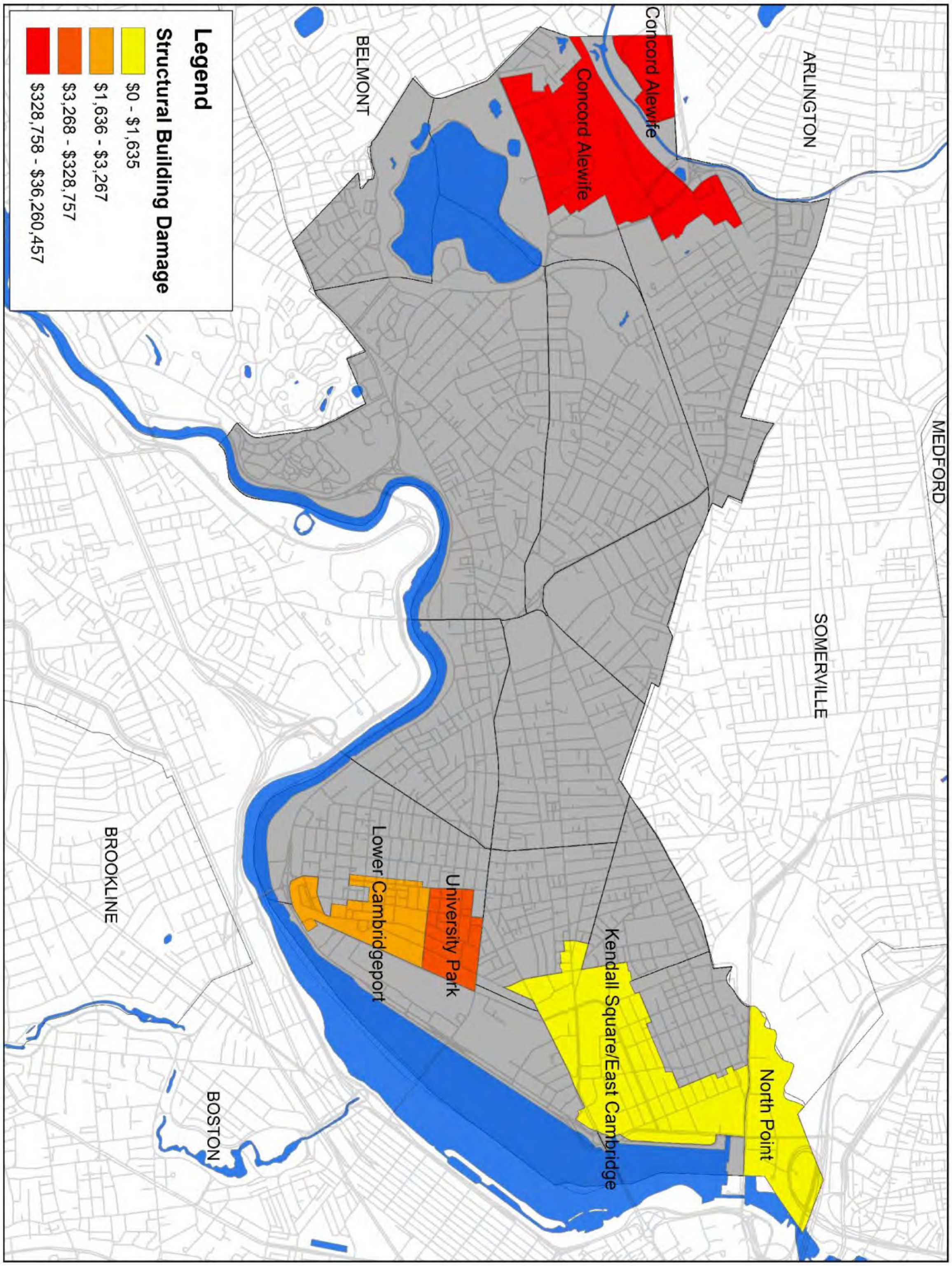


Estimate of Structural Damage to Buildings by Commercial District from 24-Hour 100-Year Rainfall Event in 2070

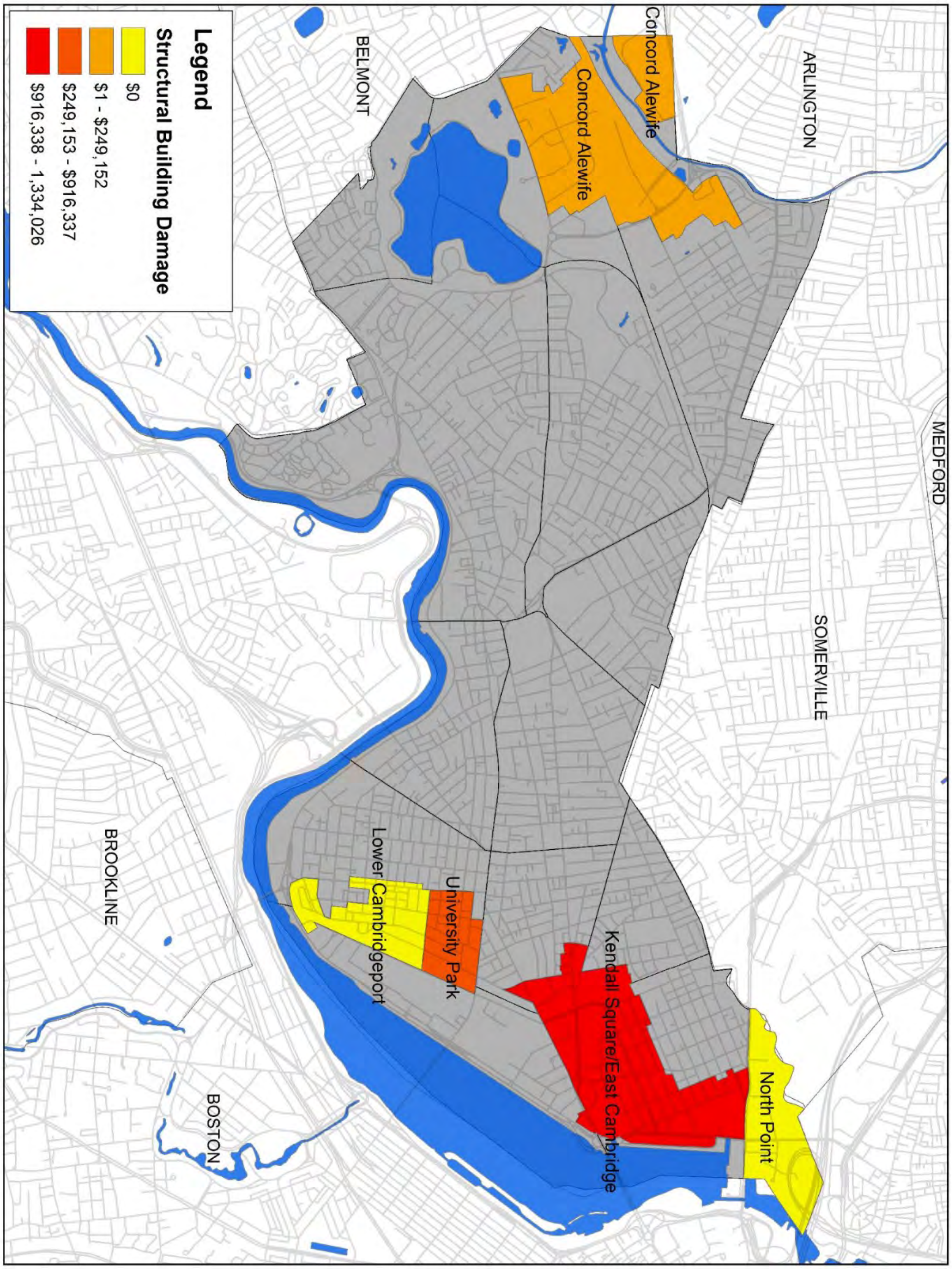
Estimate of Structural Damage to Buildings by Development District from 24-Hour 10-Year Rainfall Event in 2030

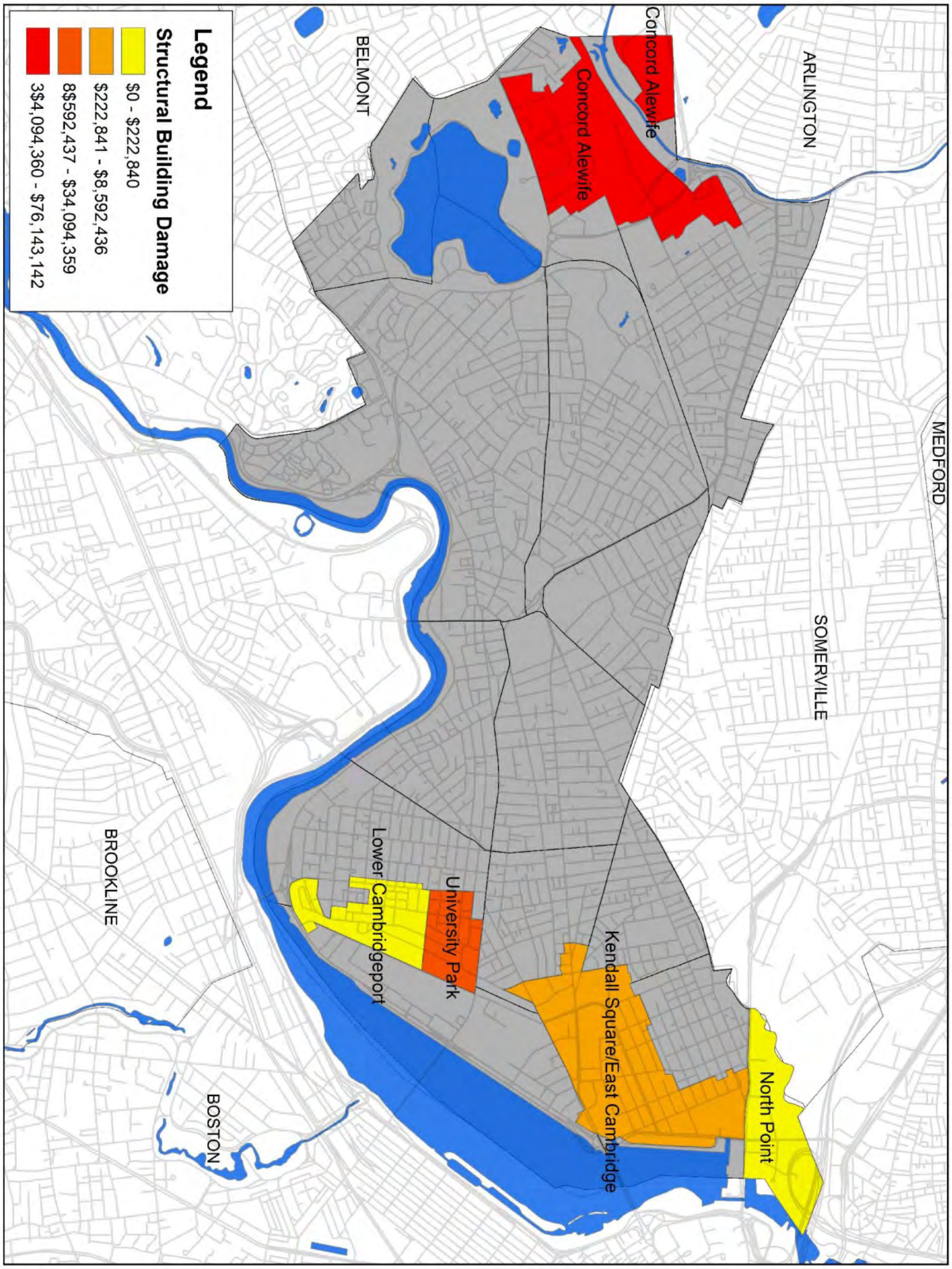


Estimate of Structural Damage to Buildings by Development District from 24-Hour 100-Year Rainfall Event in 2030

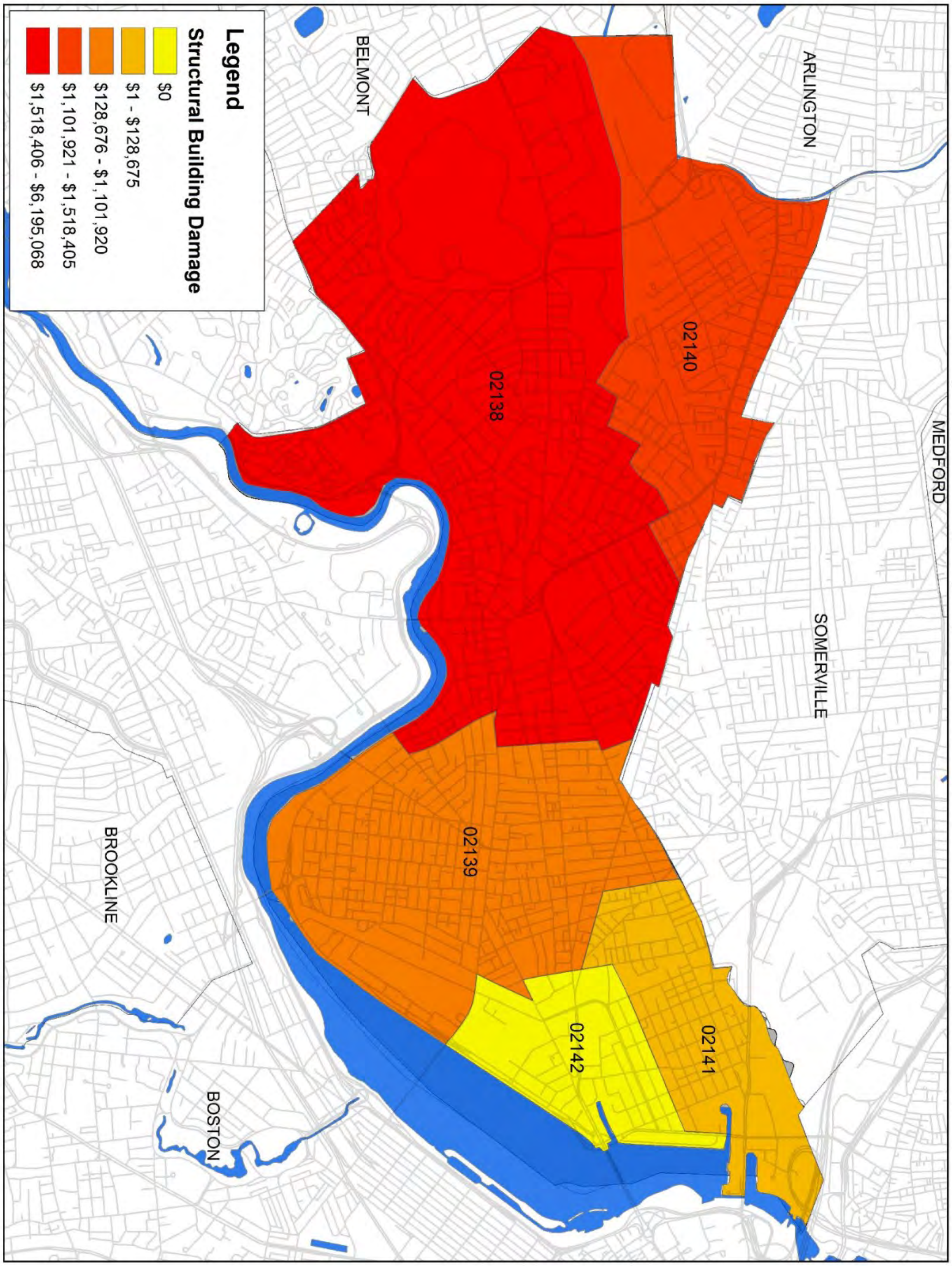


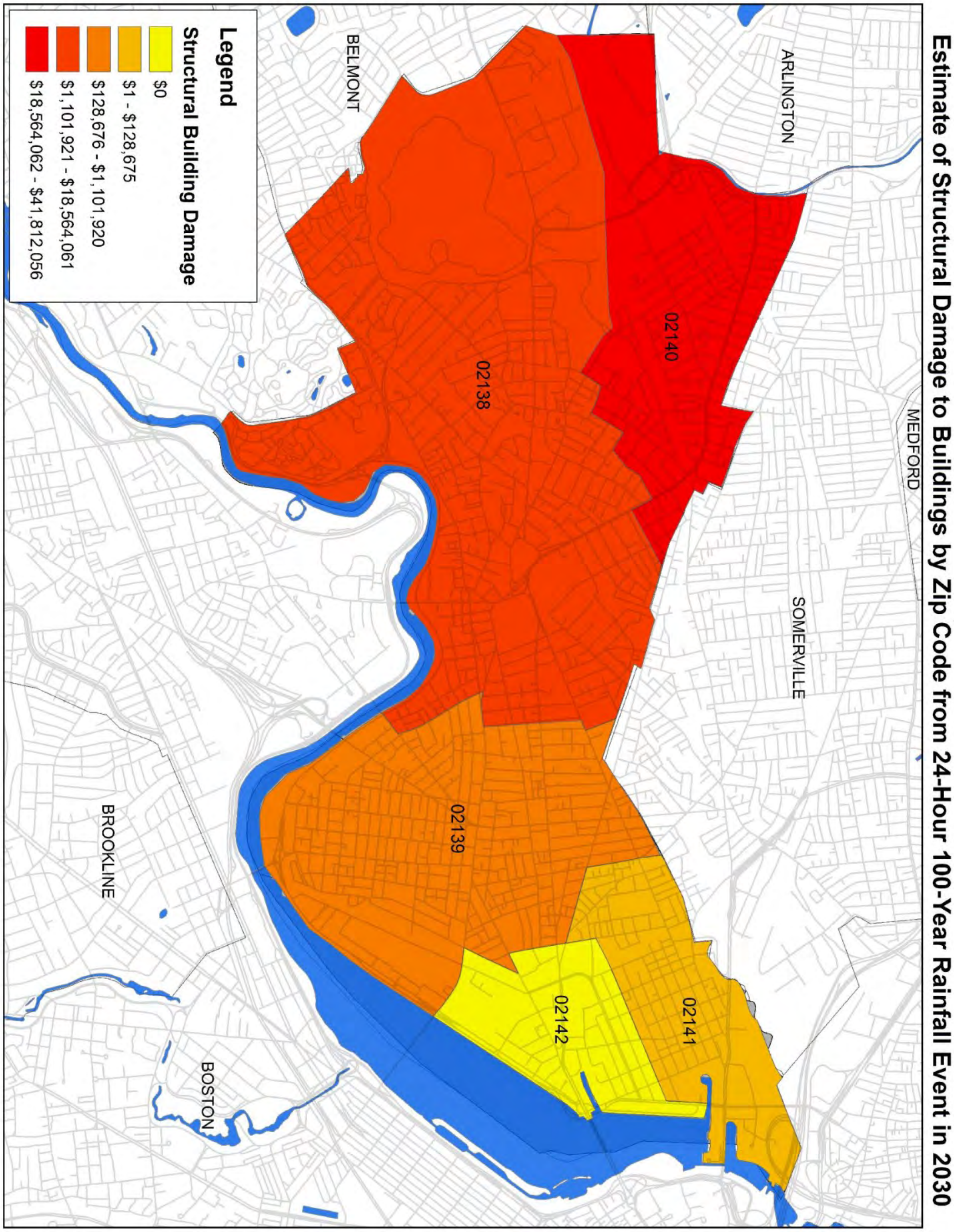
Estimate of Structural Damage to Buildings by Development District from 24-Hour 10-Year Rainfall Event in 2070

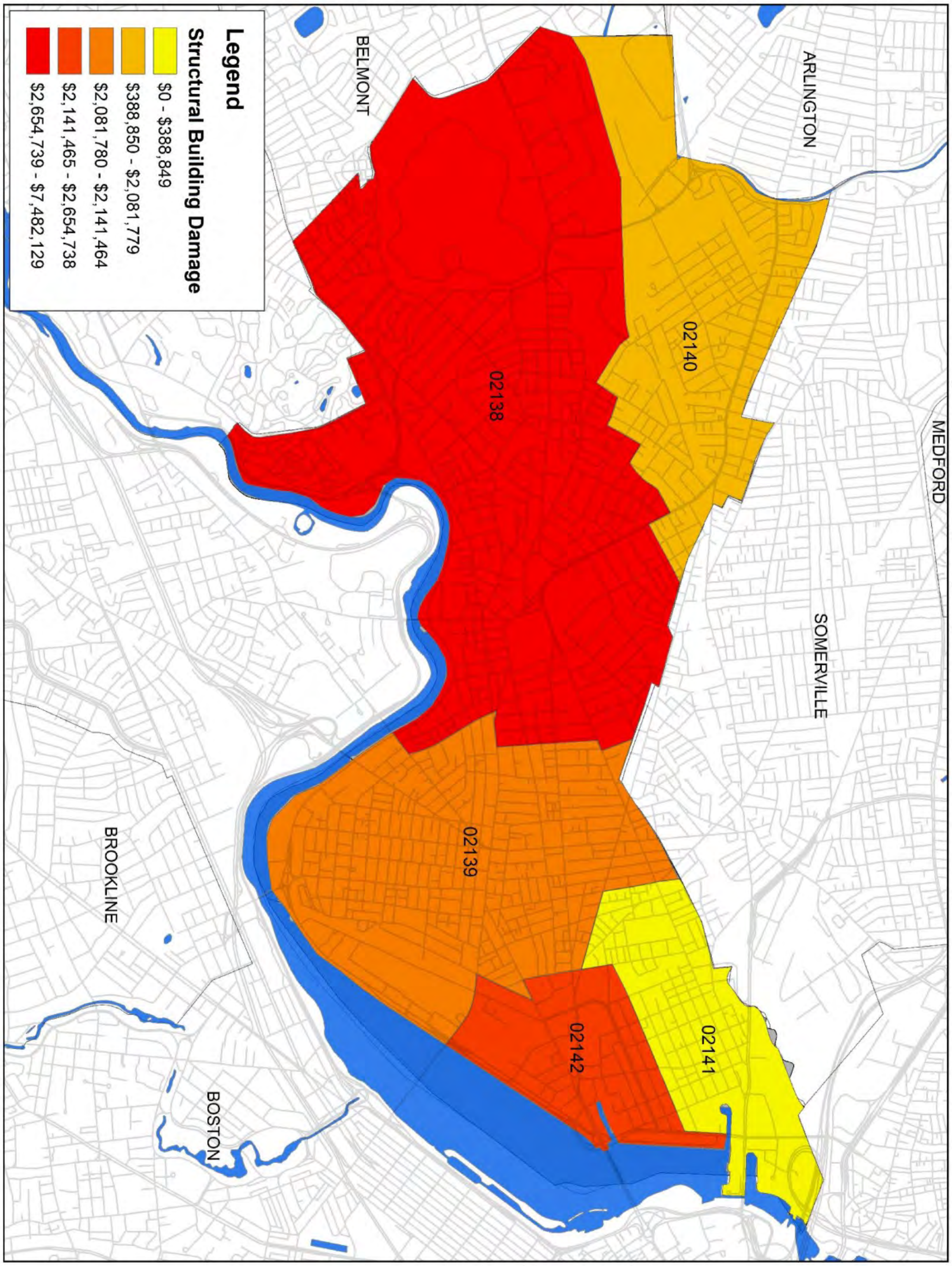


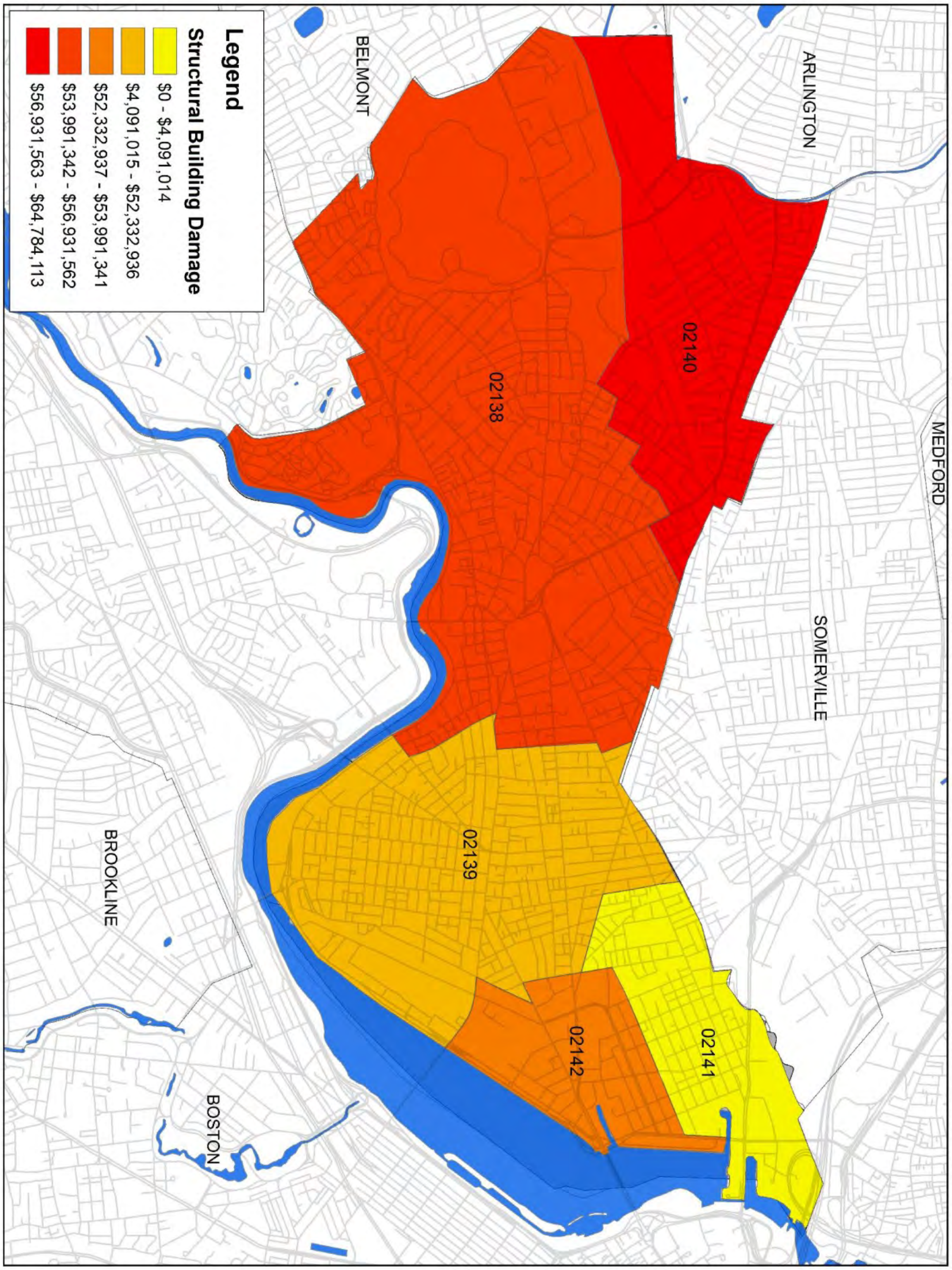


Estimate of Structural Damage to Buildings by Development District from 24-Hour 100-Year Rainfall Event in 2070

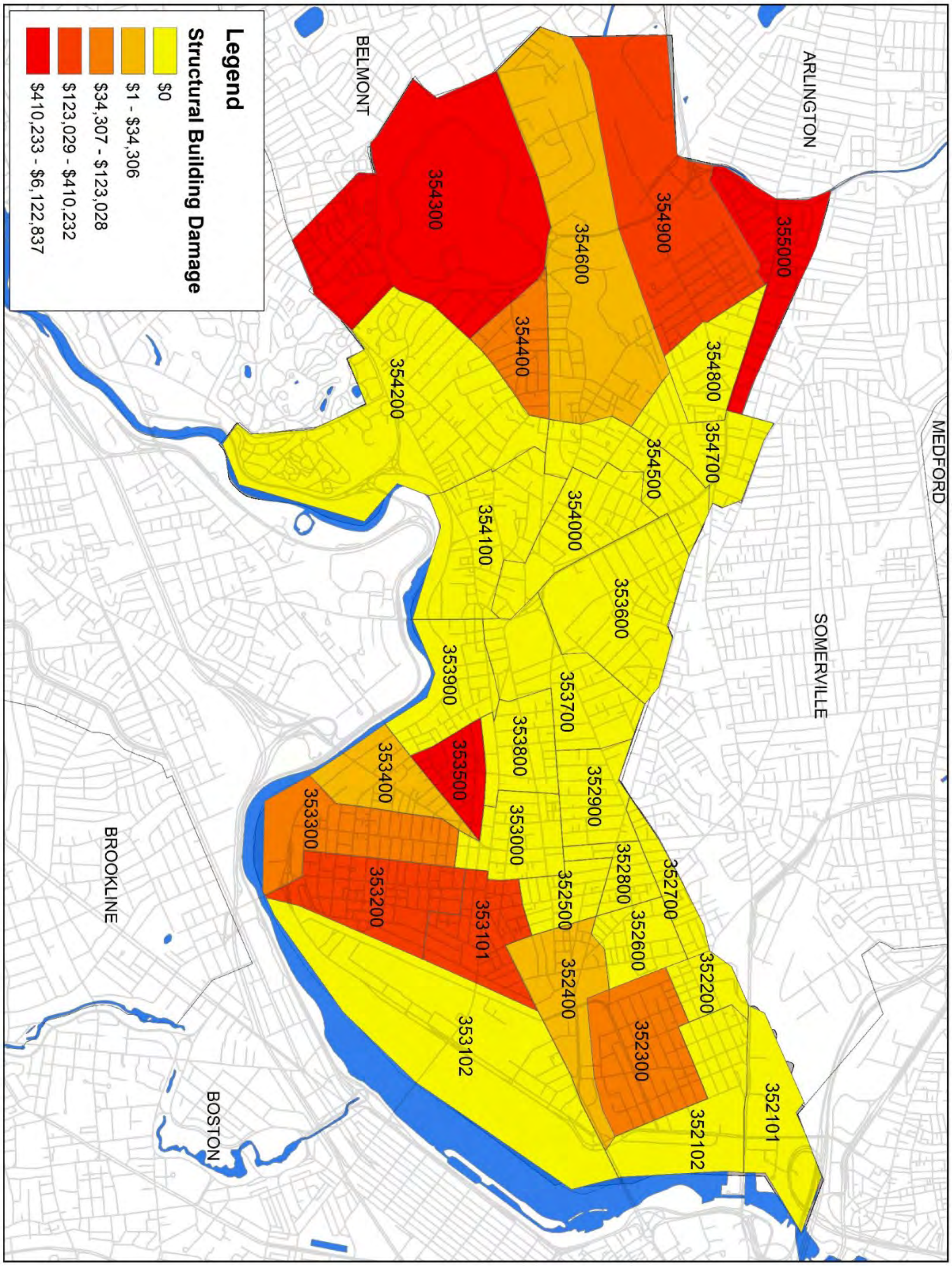

Estimate of Structural Damage to Buildings by Zip Code from 24-Hour 10-Year Rainfall Event in 2030
Legend
Structural Building Damage
$0
$1 - $128,675
$128,676 - $1,101,920
$1,101,921 - $1,518,405
$1,518,406 - $6,195,068
ARLINGTON
BELMONT
MEDFORD
SOMERVILLE
BROOKLINE
BOSTON
02140
02138
02139
02141
02142

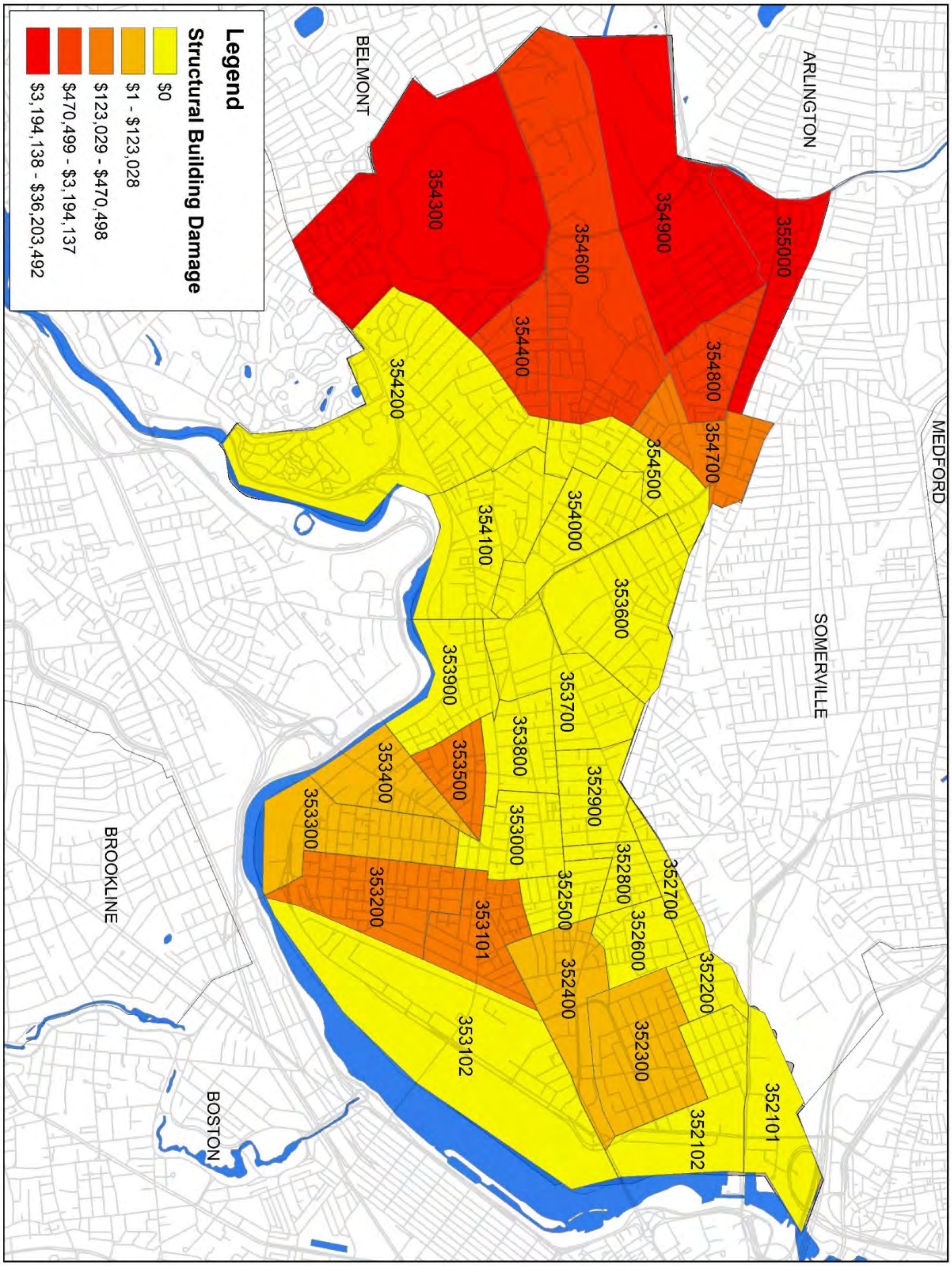

Estimate of Structural Damage to Buildings by Zip Code from 24-Hour 100-Year Rainfall Event in 2030
Legend
Structural Building Damage
$0
$1 - $128,675
$128,676 - $1,101,920
$1,101,921 - $18,564,061
$18,564,062 - $41,812,056
ARLINGTON
BELMONT
MEDFORD
SOMERVILLE
BROOKLINE
BOSTON
02140
02138
02139
02142
02141


Estimate of Structural Damage to Buildings by Zip Code from 24-Hour 10-Year Rainfall Event in 2070
Legend
Structural Building Damage
$0 - $388,849
$388,850 - $2,081,779
$2,081,780 - $2,141,464
$2,141,465 - $2,654,738
$2,654,739 - $7,482,129
ARLINGTON
BELMONT
MEDFORD
SOMERVILLE
BROOKLINE
BOSTON
02140
02138
02139
02142
02141


Estimate of Structural Damage to Buildings by Zip Code from 24-Hour 100-Year Rainfall Event in 2070
Legend
Structural Building Damage
$0 - $4,091,014
$4,091,015 - $52,332,936
$52,332,937 - $53,991,341
$53,991,342 - $56,931,562
$56,931,563 - $64,784,113
ARLINGTON
BELMONT
MEDFORD
SOMERVILLE
BROOKLINE
BOSTON
02140
02138
02139
02141
02142

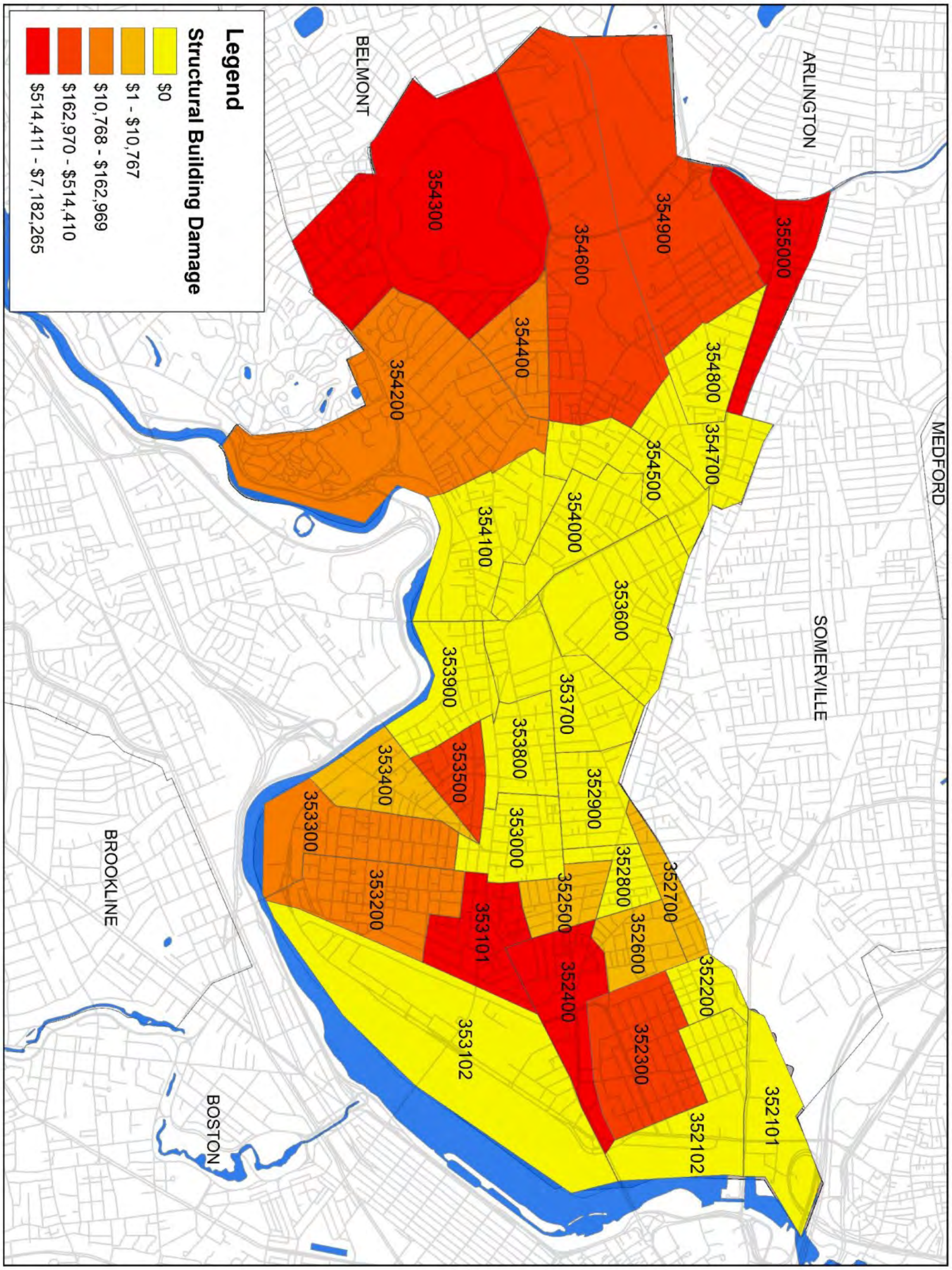
Estimate of Structural Damage to Buildings by Census Tract from 24-Hour 10-Year Rainfall Event in 2030

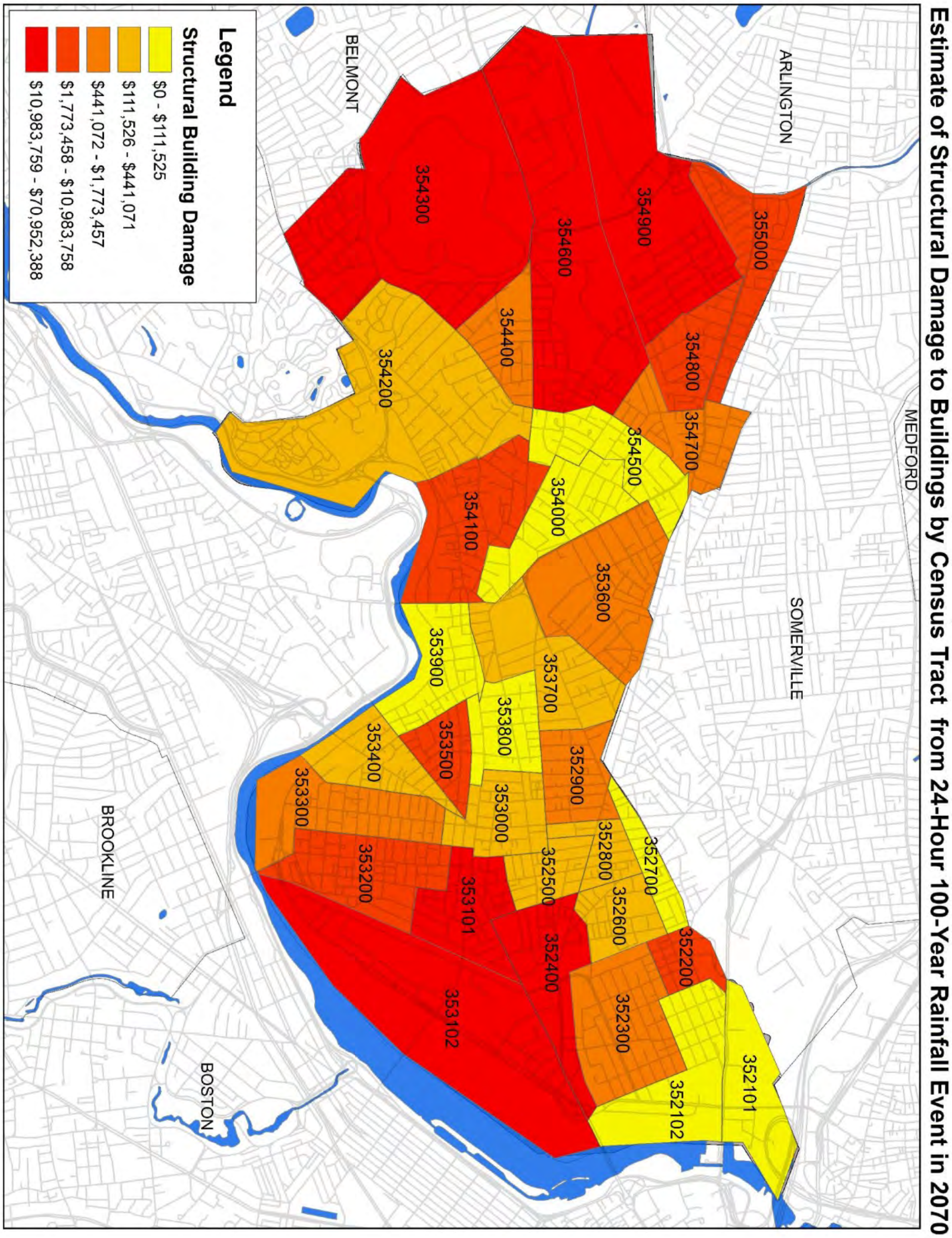




Estimate of Structural Damage to Buildings by Census Tract from 24-Hour 100-Year Rainfall Event in 2030

Estimate of Structural Damage to Buildings by Census Tract from 24-Hour 10-Year Rainfall Event in 2070




Estimate of Structural Damage to Buildings by Census Tract from 24-Hour 100-Year Rainfall Event in 2070
Legend
Structural Building Damage
$0 - $111,525
$111,526 - $441,071
$441,072 - $1,773,457
$1,773,458 - $10,983,758
$10,983,759 - $70,952,388
ARLINGTON
BELMONT
MEDFORD
SOMERVILLE
BROOKLINE
BOSTON
355000
354900
354600
354300
354800
354400
354200
354700
354500
354000
354100
353600
353900
353700
353800
353500
353400
352900
353300
353000
352800
352700
353200
352500
352600
353101
352400
352200
353102
352300
352101
352102