Chittenden County, Vermont

Multi-Hazard Analysis

Flood Damage in Jericho, VT on May 23, 2013 (Photo: NWS, Burlington)

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Background

The goal of this project was to prepare a multi-hazard analysis for Chittenden County, Vermont. The hazards that were analyzed include earthquake, flood and landslide. Earthquake and flood results were achieved using the Federal Emergency Management Agency's (FEMA) HAZUS-MH Loss Estimation Software (HAZUS-MH) Version 4.2 and ArcGIS. Landslide results were achieved using landslide point data provided by the Vermont Open Geodata Portal and further developed using ArcGIS. HAZUS-MH version 4.2 currently does not offer support for landslides.

These hazards were chosen for their close relationship with each other. Earthquakes can cause floods and landslides, floods can cause landslides, and landslides can cause floods which can damage buildings and threaten people's lives. For example, an earthquake can cause dams to fail, which can lead to flooding in the surrounding areas. Earthquakes that occur near cliffs and steep slopes can also cause landslides. If a landslide is triggered, it could cause floods if its debris impedes the flow of a river. Lastly, floods can erode at river banks and loosen soils, leading to landslides.

Objectives

The objectives for this project were as follows:

a) Analyze, compare and contrast the earthquake hazard in Chittenden County with flooding and landslides.

b) Identify total estimated number and type of buildings affected in each hazard scenario.

c) Create report, maps and tables detailing results.

Methodology

The results for Chittenden County, Vermont were compiled utilizing the HAZUS-MH methodology Version 4.2. HAZUS-MH is FEMA's nationally applicable standardized loss estimation methodology that contains models for estimating potential impact and losses from earthquakes, floods, and hurricanes. HAZUS-MH uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. The Federal Emergency Management Agency (FEMA) developed HAZUS-MH under contract with the National Institute of Building Sciences and it is widely accepted as a leading earthquake and other hazards loss assessment software platform.

Vermont E911 Building data, provided by the Vermont Open Geodata Portal, was used as the primary source to determine the count and type of buildings located in each defined hazard scenario. Since there were over 100 different building types in this database, they were sorted and simplified into 12 general occupancy types as follows: agricultural, commercial, educational, government/emergency, industrial, recreational, religious, residential, mobile homes (residential – MH), transportation, utility, and other.

Other data used was Landslide Sensitive Sites point data also provided by the Vermont Open Geodata portal. This data was compiled by existing county-wide landslide inventories, Vermont Geological Survey surficial geologic maps and publications, and sites from Vermont Agency of Natural Resources Stream Geomorphic Assessment. It also includes historic documented sites and those verified in the field or by remote sensing.

The HAZUS-MH scenario used for earthquake was a magnitude 5.8 earthquake event epicentered in Plattsburgh, New York with Vermont State Geologist NEHRP Soil Classifications Layer A to E imported into HAZUS-MH. The HAZUS-MH scenario used for flood was the 500 -Year Flood Inundation for all major rivers in Chittenden County. For landslide, the sensitive sites points provided by the State Geologist were brought directly into ArcGIS. A 30 meter estimated inundation buffer was incorporated for each of the landslide sensitive points.

The first step was to create a HAZUS-MH multi-hazard region consisting of both earthquake and flood. (See HAZUS-MH–MH User Manual for detailed instructions on how to create a new region). For the earthquake scenario, the total estimated number of buildings affected was determined by how many were located in areas that experienced strong or greater ground shaking. This is based on peak ground acceleration (PGA), where strong PGA correlates to light building damage. Chittenden County contained areas that experienced both strong and very strong ground shaking (also referred to as high ground shaking for this report). After running the earthquake scenario, these areas were selected from the PGA contour layer. The lowest threshold for strong ground shaking has a PGA value of 9.2.

Next, the Vermont E911 Building data was brought in as a shapefile. Using the Select by Location tool, buildings within high ground shaking areas were selected and mapped. In addition to buildings, the estimated population affected was also examined. To see the geographic area of where people were affected, a population layer by census blocks was added from the HAZUS-MH default database by selecting Inventory > Demographics > Map. In an earthquake scenario, population is represented by census tracts, so a block layer was brought in from the flood scenario. Using the Select by Location tool again, census blocks within high ground shaking areas were selected and mapped. Because the census block layer does not completely line up with the ground shaking areas, the blocks were clipped to fit within the strong or greater ground shaking boundaries. To estimate the population affected, a calculation was performed by taking the county average number of people per household and multiplying it by the number of residential buildings and mobile homes in high ground shaking areas.

For the flood scenario, a similar process was followed. The total estimated number of potentially impacted buildings was determined by how many were located in the 500-year flood inundation area. Depth was not considered for this analysis. After running the flood scenario, the Vermont E911 Building shapefile layer was brought into the scenario. Using the Select by Location tool, buildings within the flood inundation area were selected and mapped. To estimate the approximate number of people affected, a population layer by census blocks was added from the HAZUS-MH default database by selecting Inventory > Demographics > Map. Using the Select by Location tool again, census blocks within the flood inundation area were selected and mapped. Since the census blocks do not completely align with the flood inundation area, they were clipped to fit the inundation boundary. A calculation based on the county average number of households and buildings within the inundation area was performed to estimate the number of people within the 500-year flood inundation area. This process resulted in various maps and tables.

For landslide, the Landslide Sensitive Sites point data was brought into ArcGIS. In conjunction with the Vermont State Geologist, it was determined to buffer these points 30 meters to create more realistic representation of the potential inundation for landslide sensitive areas. The Vermont E911 Building shapefile was then brought in, and using the Select by Location tool, buildings within the 30 meter landslide sensitive areas were selected and mapped. This resulted in various maps and tables.

The final component of this project was to locate the buildings exposed to each individual hazard as well as multiple hazards. This was done by using the Select by Location tool separately for each hazard as well as all possible combinations of the three hazards in this project: earthquake and landslide, flood and landslide, earthquake and flood. Maps and Venn diagrams were produced to reflect these results.

Results

Earthquake

Three maps were created for the earthquake hazard. Figure 1 illustrates the epicenter location and the earthquake ground shaking for the scenario, described in the methodology section. Appendix 1 shows the USGS description and damage based on the Modified Mercalli Scale (as used in Figure 1). Moderate shaking is described as being felt by nearly everybody and waking many. The damage is very slight, with unstable objects overturned, and some dishes or windows broken. Strong shaking is described as being felt by all and frightening many. The damage is slight and may move heavy furniture or cause plaster to fall. Very strong shaking is described as causing slight to moderate damage in well-built structures, and considerable damage in poorly built or badly designed structures, and causing some chimneys to break.

Figure 2 shows the total number of buildings located in strong or greater ground shaking areas. Because of the location of the epicenter and the magnitude of the event, a large portion of the county experienced high ground shaking areas. The high ground shaking areas were primarily in the western part of the county. As a result, there were 46,039 buildings located in strong or greater ground shaking areas spread across 15 out of 18 total communities. The City of Burlington contained the most buildings with 12,609, followed by South Burlington with 7,592 and Colchester with 6,628 located in strong or greater ground shaking areas.

To understand the effect that the scenario earthquake could have on population within the area, census block data was used. Census blocks within high ground shaking areas were identified, selected and clipped to fit entirely within high ground shaking areas. In order to more accurately estimate the population within the clipped census blocks, a calculation was made. Using the county average number of people per household (2.37) then multiplying it by the sum of residential buildings (36,908) and mobile homes (1,590) within strong or greater ground shaking areas resulted in a total estimate of 91,241 people. For Chittenden County, parts of Burlington, Charlotte, Colchester, Essex, Milton, Shelburne, South Burlington and Winooski had very strong ground shaking areas. Parts of Bolton, Hinesburg, Jericho, Richmond, St. George, Underhill, Westford and Williston had strong ground shaking areas. Chittenden County is the most populous county in Vermont and contains Vermont's two most populous cities, Burlington and South Burlington, and towns, Essex and Colchester. As a result, it was estimated that many people would be located in high ground shaking areas. Figure 3 shows the geographic location of population in these areas.

After estimating the total population affected, a table was created to display the total number and type of buildings located in strong ground shaking areas by town. The City of Burlington contains the most buildings, with the majority of them being residential. Table 1 shows the count of buildings in high ground shaking areas.

Finally, a pie chart was created detailing the occupancy class breakdown of buildings located in strong ground shaking areas. Out of the 46,039 buildings, about 80% were residential, 6% were commercial and 2% were recreational. Figure 4 breaks down the occupancy classes of buildings within high ground shaking areas.

Flood

Three maps were created for flood. Figure 5 shows the inundation of the 500-year flood scenario, described in the methodology section.

Figure 6 shows the buildings located within the flood inundation area. The Winooski River runs through the most populous part of Vermont, forming boundaries for cities and towns like Burlington, Winooski and Essex. Another significant river is the Lamoille, which runs through the northwestern part of the county. Almost all of the communities in Chittenden County have rivers and buildings located in the flooded area. As a result there were 467 buildings located in the 500-year flood inundation area.

As completed for the earthquake scenario, a population map was created based on census blocks situated in the flood inundation area. The same process used in the earthquake scenario was applied here to find the estimated population located in the flood inundation area: using the county average of number of people per household (2.37) and multiplying it by the sum of residential buildings (240) and mobile homes (88) within the flood inundation area. Every town had census blocks within the flood inundation area, especially along the Winooski River, resulting in an estimated 778 people located within the flood inundation area. Figure 7 shows the population located within the flood inundation area.

A table was then created to show the total number and type of buildings located in the flood inundation area by town. Richmond had about 150 buildings in the flood inundation area, Huntington had 122, and Milton had 77. More than half of all the buildings were residential. Table 2 shows the count of buildings, by town and occupancy, located in the flood inundation area.

Finally, a pie chart was created showing the occupancy class breakdown of buildings located in the flood inundation area. Out of the 467 buildings, about 60% were residential, 19% were residential mobile homes and 5% were commercial. Figure 8 breaks down the occupancy class of buildings by percentage located within the flood inundation area.

<u>Landslide</u>

Two maps were created for landslide. Figure 9 shows the location of the landslide sensitive sites with the 30 meter buffer, described in the methodology section.

Figure 10 shows the buildings located within 30 meters of a landslide sensitive site. Because of their small size at this scale not many buildings were found within the landslide sensitive sites. Only 39 buildings were located within a landslide sensitive site.

A table was created to show the total number and type of buildings located in the 30 meter buffered sensitive sites. The 39 buildings were spread between 7 different towns, with 25 being residential, 13 being residential mobile homes, and 1 being other. This breakdown is in Table 3. Lastly, a pie chart showing the occupancy class breakdown of buildings located in the 30 meter buffered sensitive sites was created. Residential buildings made up about 64%, mobile homes were 33% and other were 3%. This is illustrated in Figure 11.

<u>Multi-Hazard</u>

The final component of this project was to identify the buildings affected by multiple hazards in various combinations: earthquake and landslide, flood and landslide, earthquake and flood, or all three hazards. The analysis indicated that there were no buildings exposed to all three hazards. This resulted in producing a map that shows all three hazards and the buildings that are located in each hazard combination, with the buildings in each combination represented by a different color. This is shown in Figure 12.

A Venn diagram was also created to show the total number of buildings affected by each hazard and combination of hazards. There were 146 total buildings exposed to multiple hazards: 36 for earthquake and landslide and 110 for earthquake and flood. There were no buildings exposed to flood and landslide or all three hazards. However, earthquakes can cause floods and landslides, and landslides can cause floods, which HAZUSS-MH did not take into account. When looking at this breakdown by town, for earthquake and landslide, Milton had the most buildings with 20, and Burlington was second with 8. For earthquake and flood, Milton had the most with 76, and Burlington and Colchester each had 8. Figure 13 shows the distribution of buildings exposed to multiple hazards.

<u>Conclusions and Recommendations</u>

Using Vermont E911 Building data and HAZUS-MH provided a reasonable multi-hazard analysis for Chittenden County, Vermont. It is important to note that these results are estimates based on three hypothetical scenarios and may not reflect the actual impact of the occurrence of the hazards studied. Additionally, there were other limitations to this analysis that affected these results. The HAZUS-MH census blocks layer only shows the dasymetric areas, or the densest population concentrations within a block, and therefore the entire block is not shown. This can distort the overall accuracy of size of individual blocks, and make it difficult to distinguish between block boundaries. More importantly, by only showing dasymetric areas, this leaves the potential for overlooking some populated areas. This, in accordance with no population distribution information, made it difficult to compile an accurate population estimate within the strong ground shaking and 500-year flood inundation areas. For more information on limitations, refer to the disclaimer section.

For earthquake, the Plattsburgh M5.8 Scenario yielded a significant amount of strong or greater ground shaking in Chittenden County due to its epicenter location and strength. The location and magnitude (5.8) used for this event is based on scenarios developed by Professor John Ebel, Boston College, Weston Observatory, and was deemed the worst-case credible scenario for an event in this area. This scenario was based on a magnitude 5.3 earthquake that occurred near Plattsburgh in 2002 and caused significant damage surrounding its epicenter. Its intensity at the epicenter was a VII on the Modified Mercalli Intensity Scale, indicating very strong ground shaking. People in Burlington, VT responded that they felt moderate ground shaking, indicating an intensity of V on the same scale. Approximately 10,000 people felt the event including locations all across New England, into Southern Canada, and as far West as Ohio and as far South as Virginia.

For Chittenden County, officials should be aware that such an event occurred and is likely to occur again in the future. The 2017 Chittenden County Hazard Mitigation Plan states the risk of earthquakes is low enough for this area that it should not invest in mitigation techniques. Although earthquakes do not occur here frequently, Chittenden County is the most likely part of Vermont to have an earthquake occur. The City of Burlington would be the most at risk due to its large concentration of people and high unreinforced masonry building count, which perform the worst in earthquakes. The Hazard Mitigation Plan should explore the risk of earthquakes further in the future.

For flood, the HAZUS-MH flood model is able to analyze all the major rivers in a study region, but its estimations can sometimes differ slightly from other models such as FEMA’s Flood Insurance Rate Maps (FIRM). FEMA’s HAZUS-MH program can determine all the major rivers in a study region using slope and Digital Elevation Models (DEMs), which can then be easily analyzed using GIS, which is why it was chosen for this study. FEMA’s FIRM maps are primarily used for flood insurance purposes and are not as readily compatible with GIS as HAZUS-MH outputs, and therefore were not used for this study.

For landslide, the sensitive sites data was in point format, which limits the accuracy of the analysis. As point data, every site has the same characteristics, especially size and area, which is not the case for actual landslide sites. Although a 30 meter buffer represents a reasonable approximation of exposure, it is not as accurate as an exposure polygon based on site specific field analysis. It would be beneficial to have these sites represented as polygons, which would be more realistic and true to the actual sites. Running an analysis with sensitive sites polygons could better determine which buildings are potentially exposed to landslides.

Disclaimer

The earthquake and flood hazard layers contained in this presentation are based on FEMA HAZUS-MH Version 4.2 that utilizes 2010 census data and current scientific and engineering knowledge. The landslide layer was based on point data rather than specific field analysis. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled earthquake ground shaking and flood inundation results and the actual results following a specific event. It is important to note that the Vermont E911 Building data was the only concrete data used for this analysis and the rest of the layers and results were purely estimations based on HAZUS-MH and ArcGIS geoprocessing analyses.

Figures and Tables

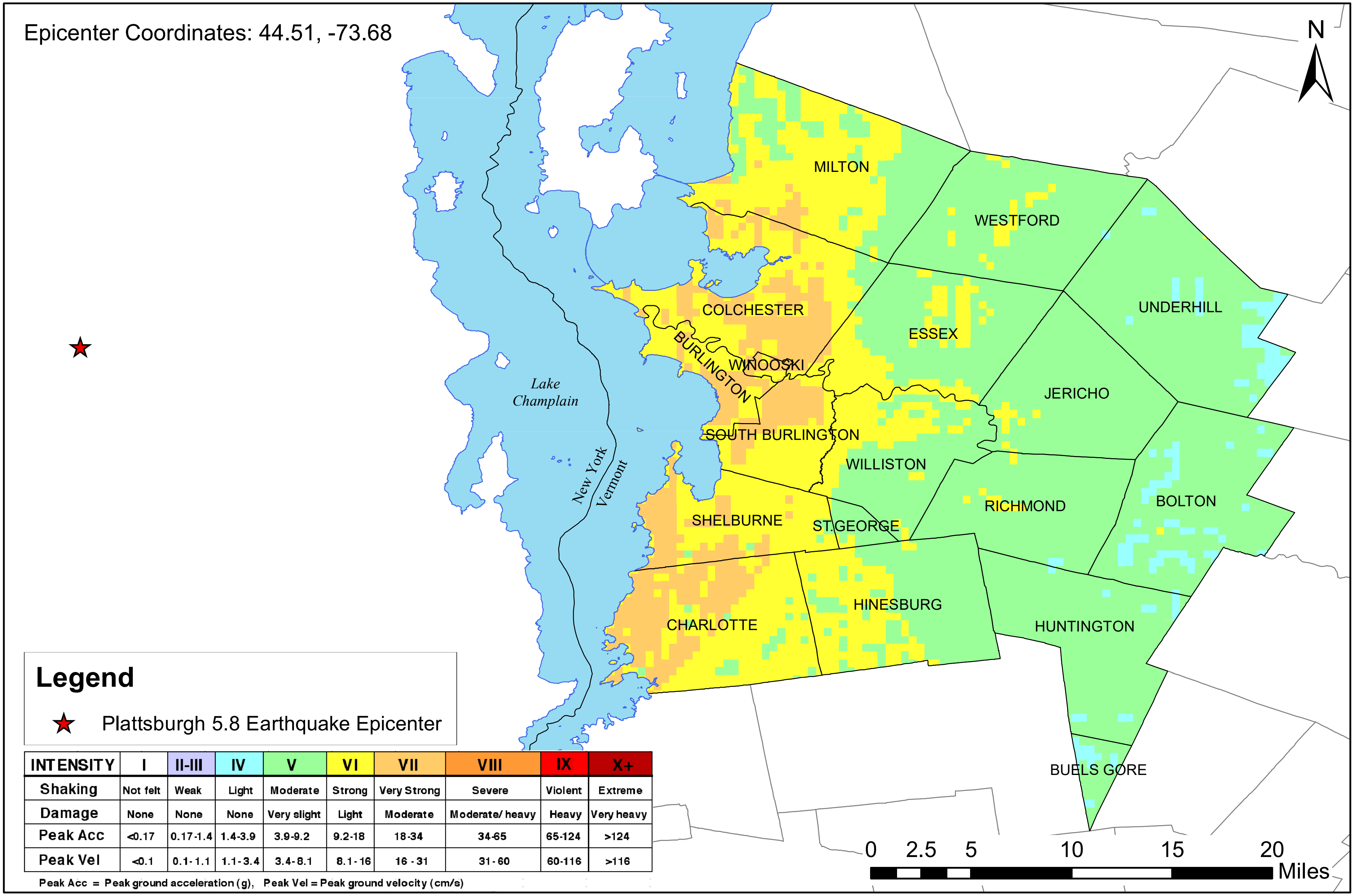
FIGURES:

TABLES:

APPENDIX:

Plattsburgh 5.8 Earthquake Event
Chittenden County, Vermont

Figure 1

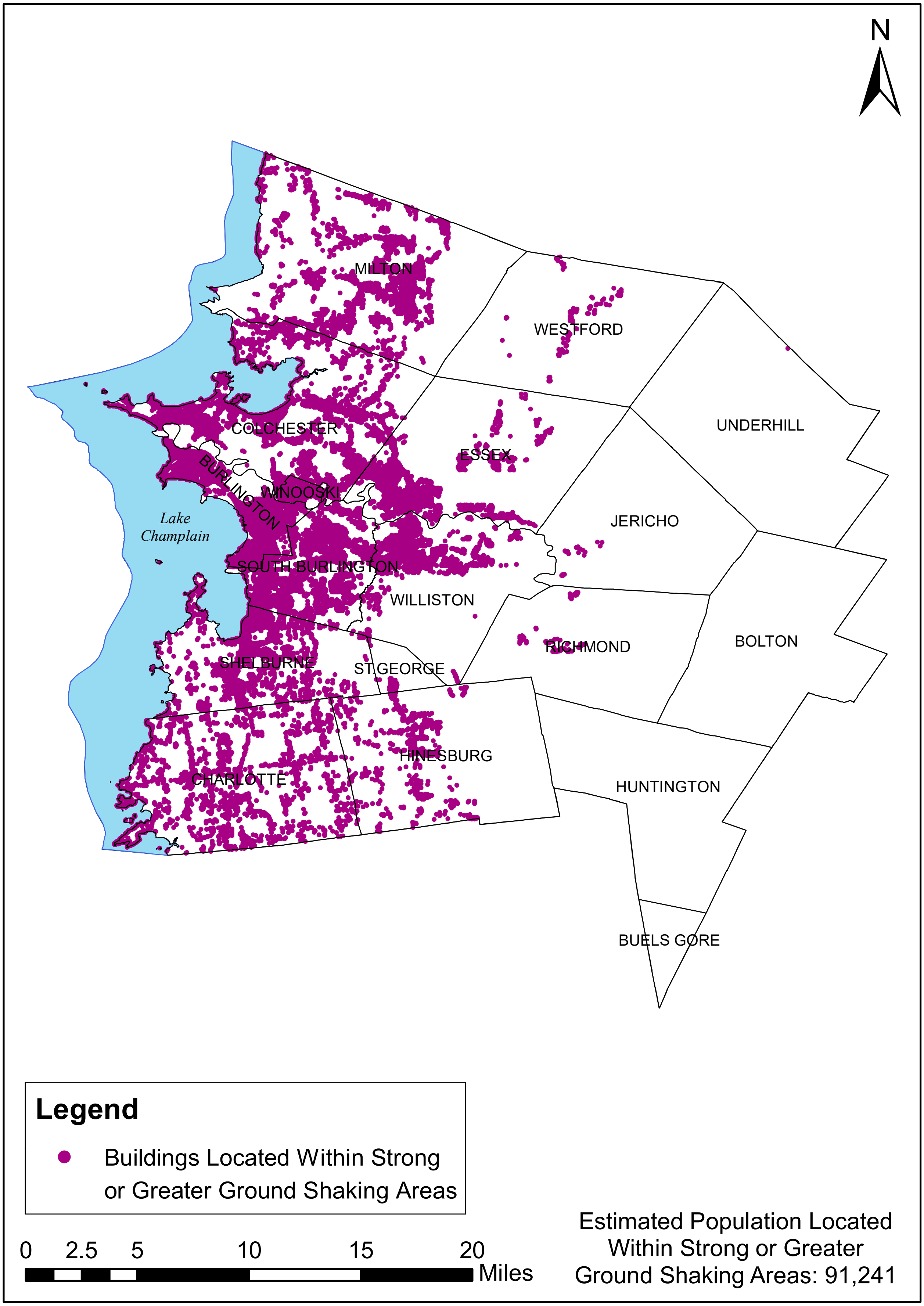


INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Damage	None	None	None	Very slight	Light	Moderate	Moderate/ heavy	Heavy	Very heavy
Peak Acc	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
Peak Vel	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116

Peak Acc = Peak ground acceleration (g), Peak Vel = Peak ground velocity (cm/s)

Buildings Located Within Strong or Greater Ground Shaking Areas Chittenden County, Vermont

Figure 2



Estimated Population Located Within Strong or Greater Ground Shaking Areas: 91,241

Estimated Population Located Within Strong or Greater Ground Shaking Areas Chittenden County, Vermont

Figure 3

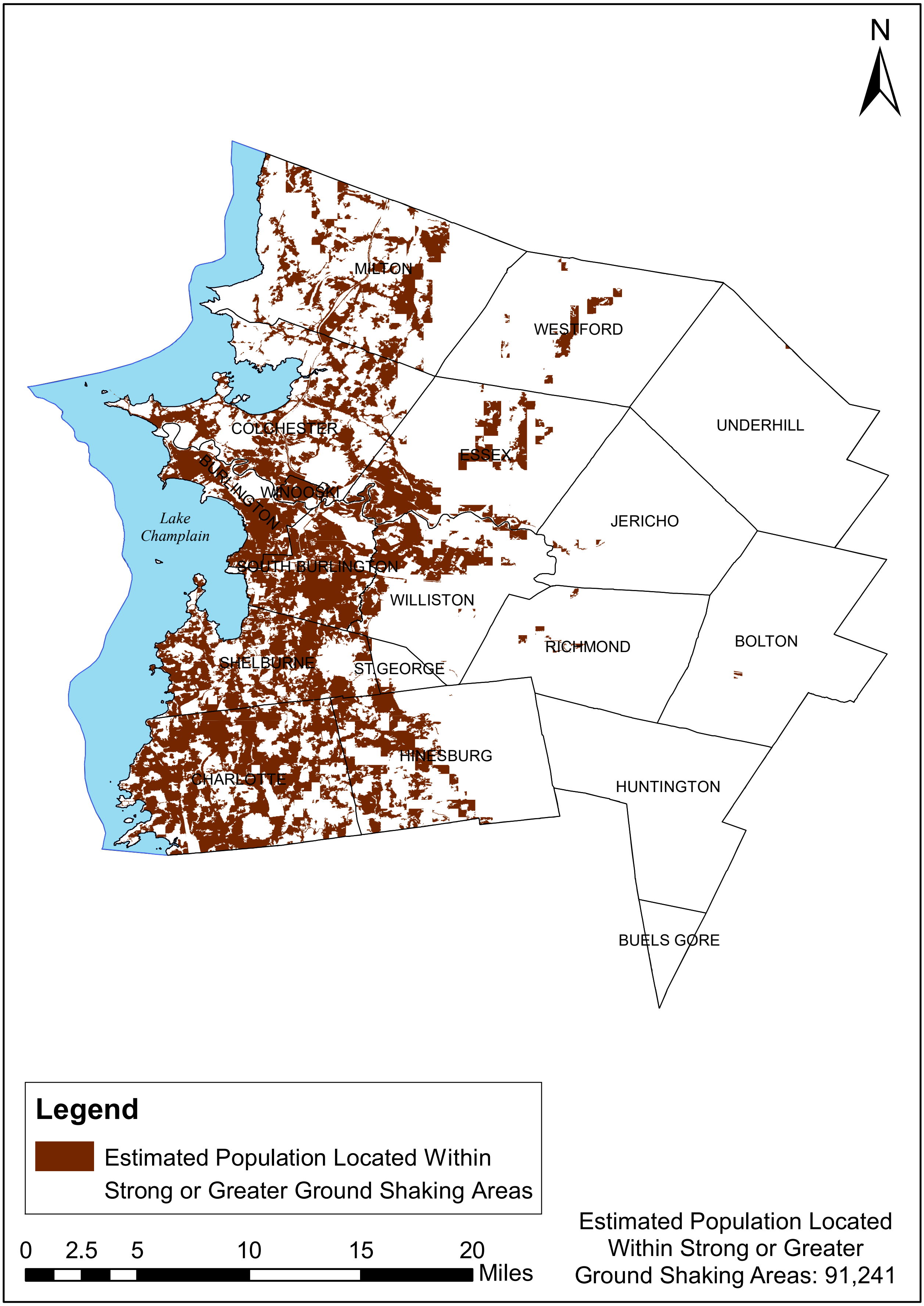
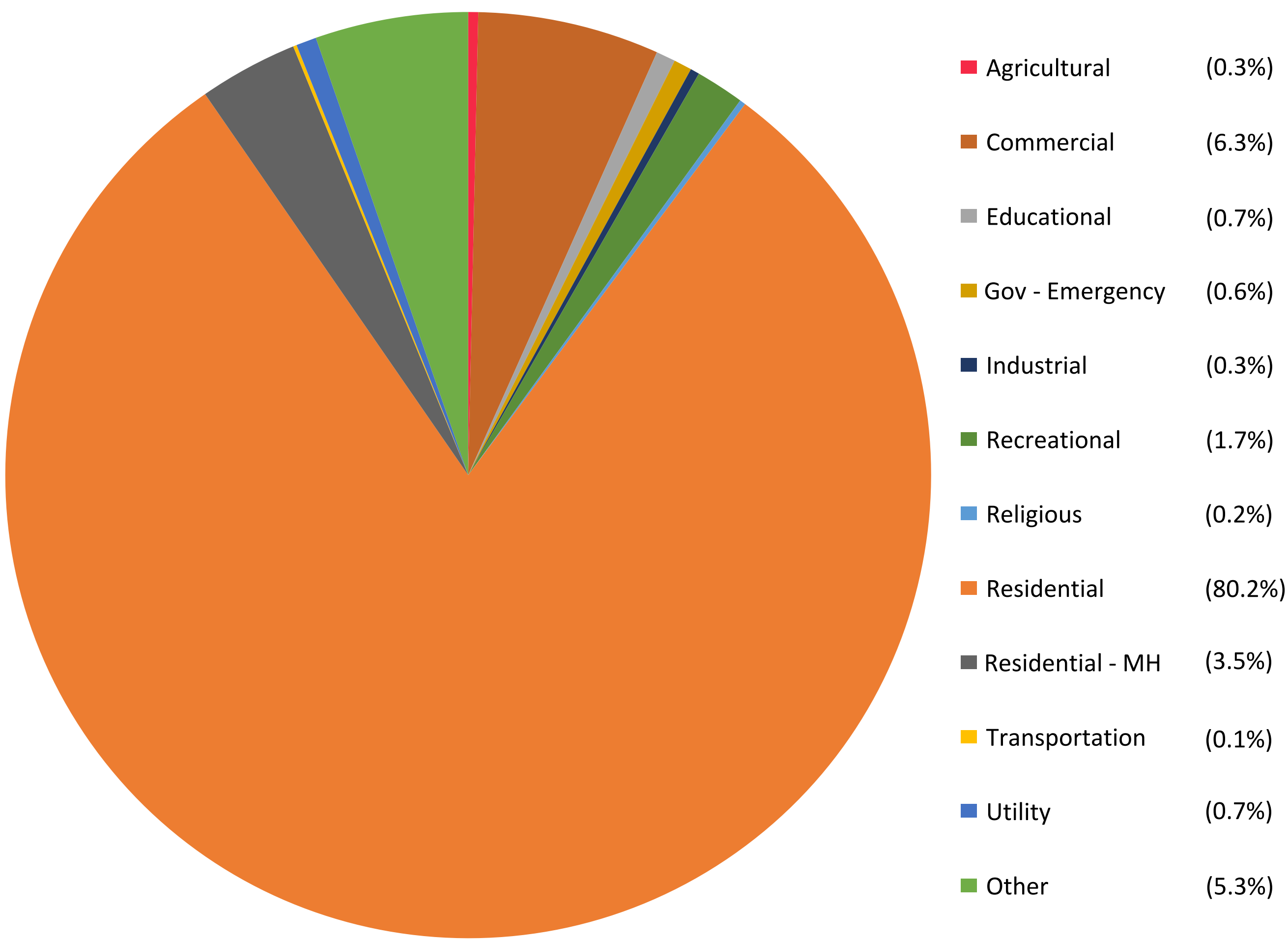


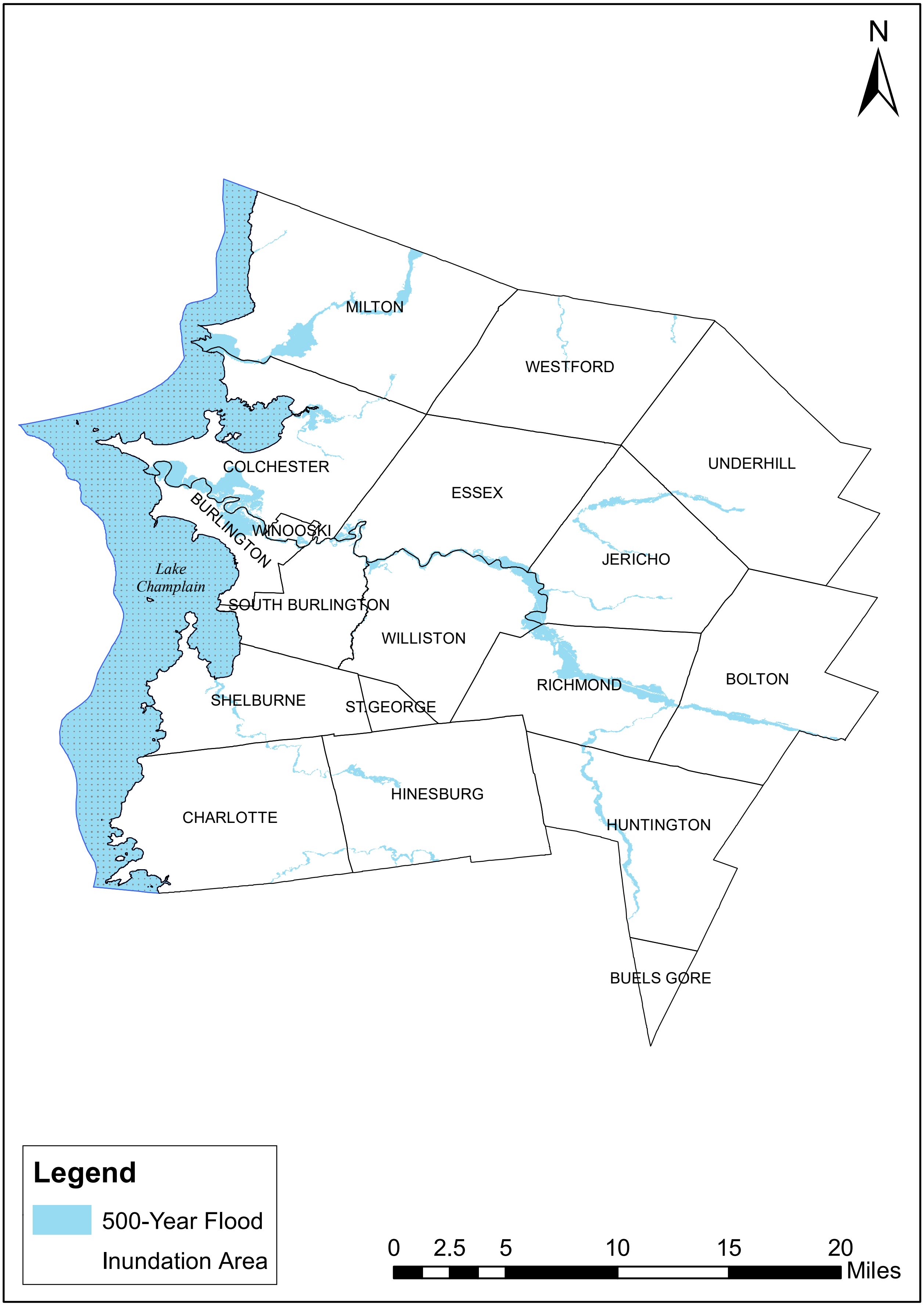
Figure 4

Occupancy Class Breakdown of Chittenden County Buildings Located in Strong or Greater Earthquake Ground Shaking Areas from the Plattsburgh, NY 5.8 Scenario



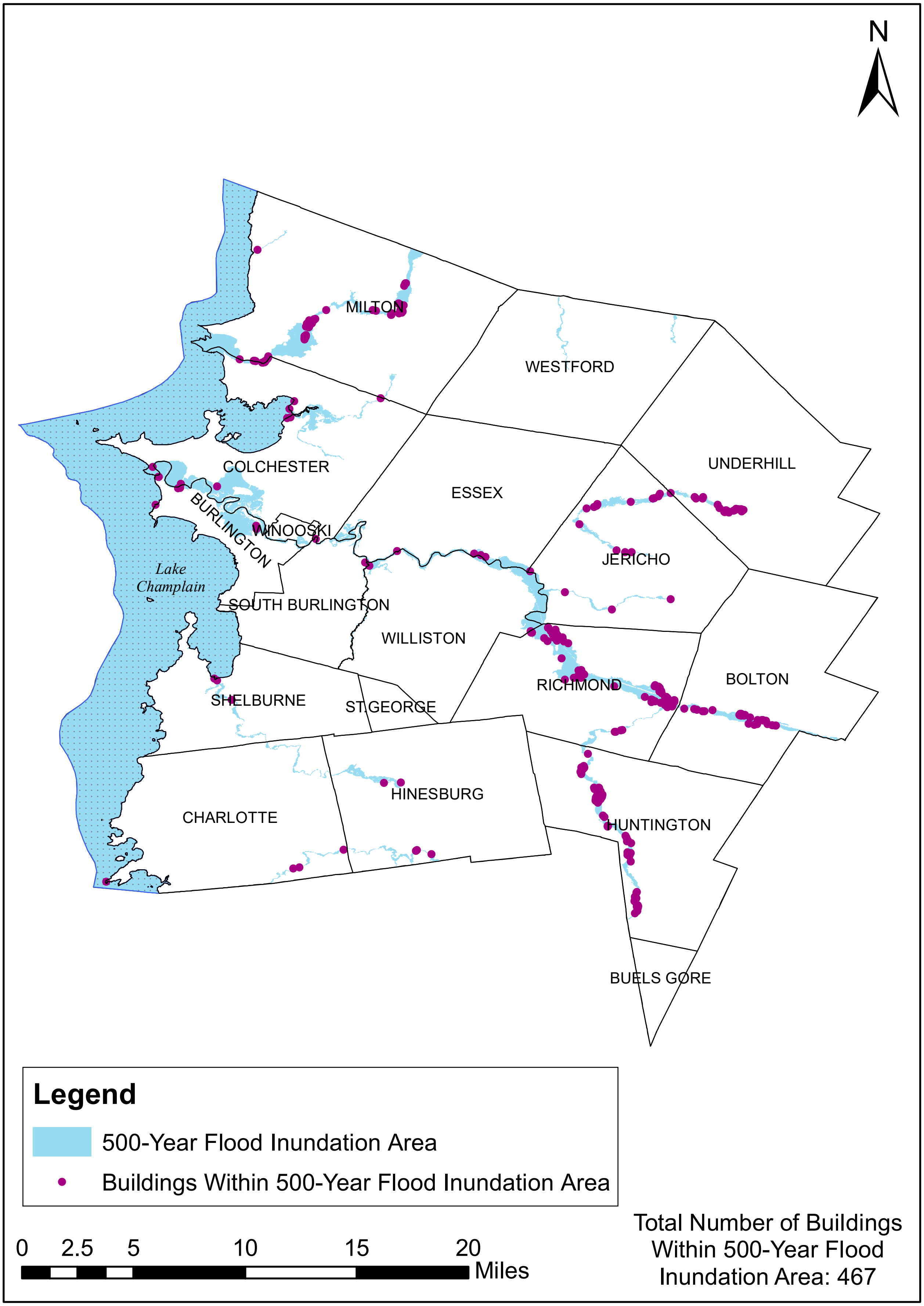
500-Year HAZUS Modeled Flood Inundation Area Chittenden County, Vermont

Figure 5



Buildings Located Within 500-Year Flood Inundation Area Chittenden County, Vermont

Figure 6



Estimated Population Located Within 500-Year Flood Inundation Area Chittenden County, Vermont

Figure 7

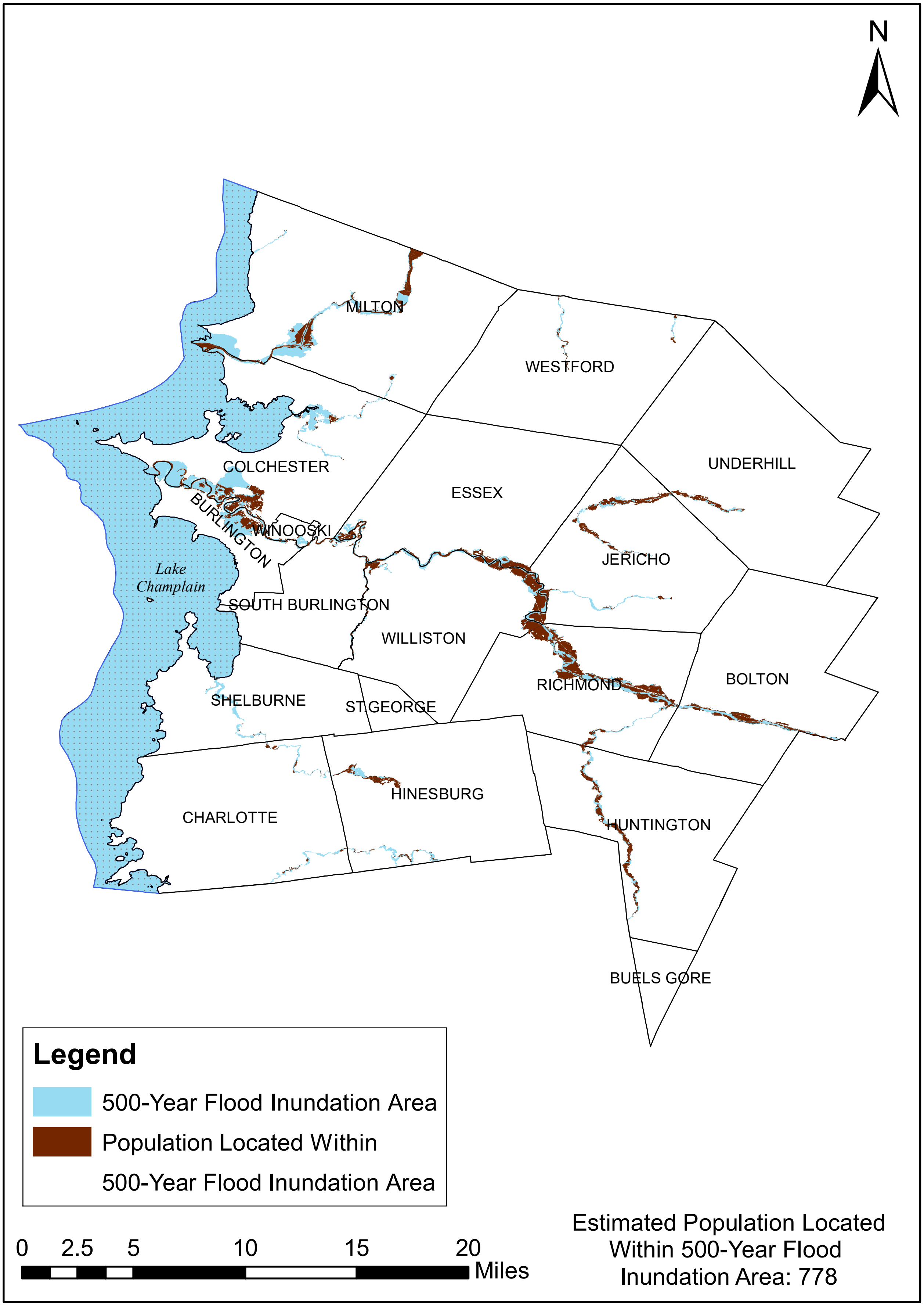
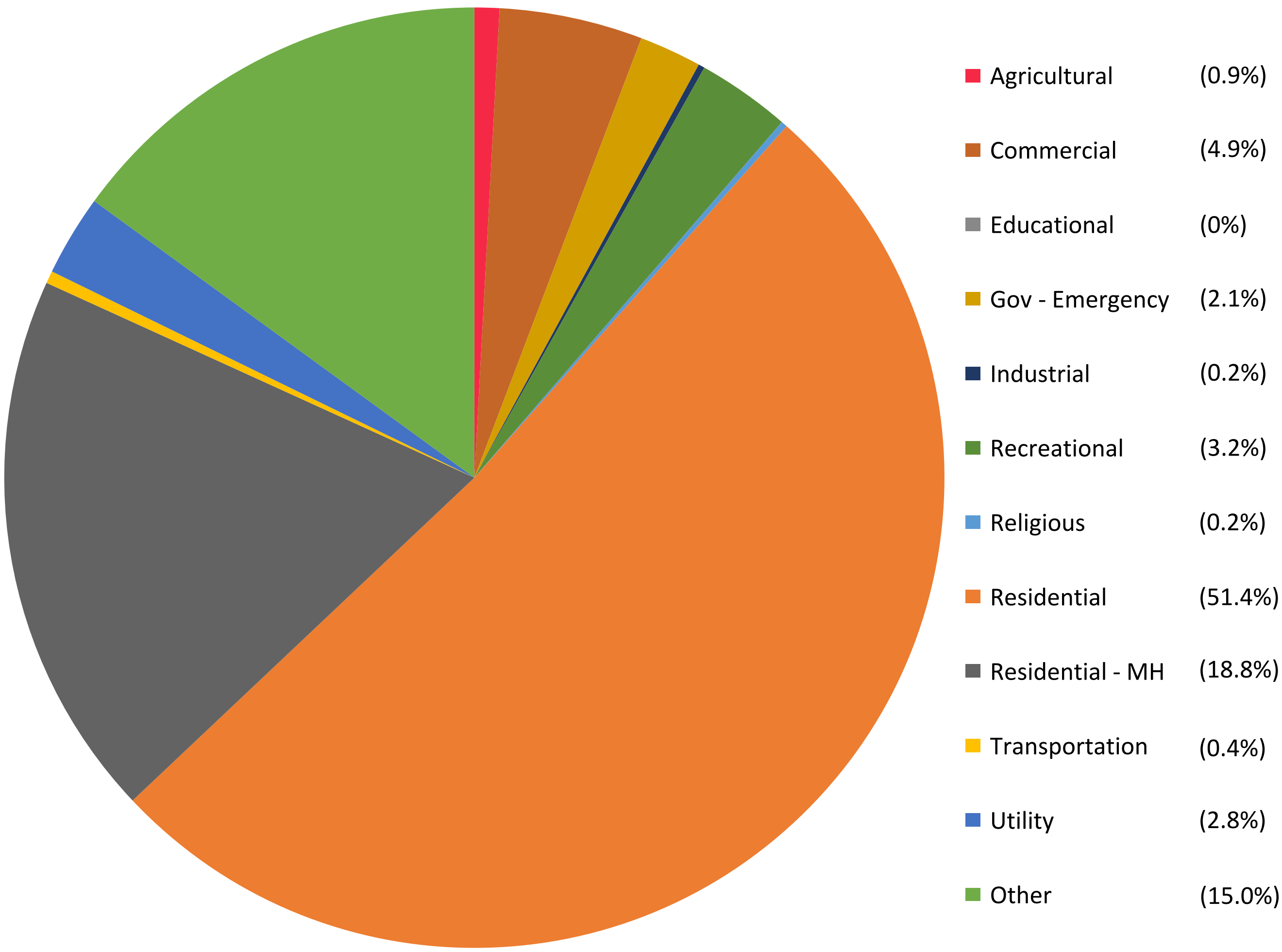


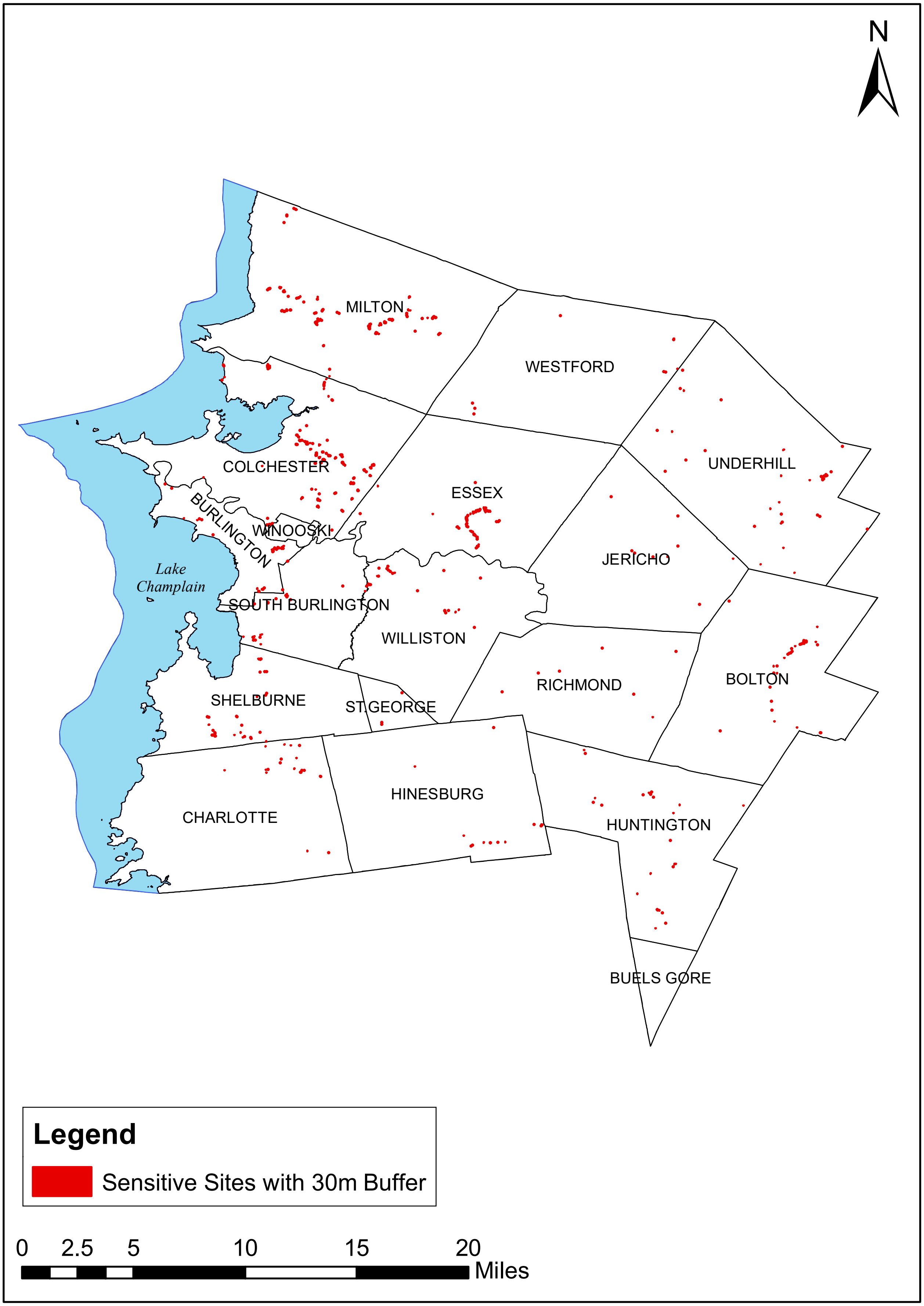
Figure 8

Occupancy Class Breakdown of Chittenden County Buildings Within the HAZUS-MH Modeled 500-Year Flood Scenario



Landslide Sensitive Sites and Potential Impacted Area Chittenden County, Vermont

Figure 9



Buildings Located Within 30 Meters of a Landslide Sensitive Site Chittenden County, Vermont

Figure 10

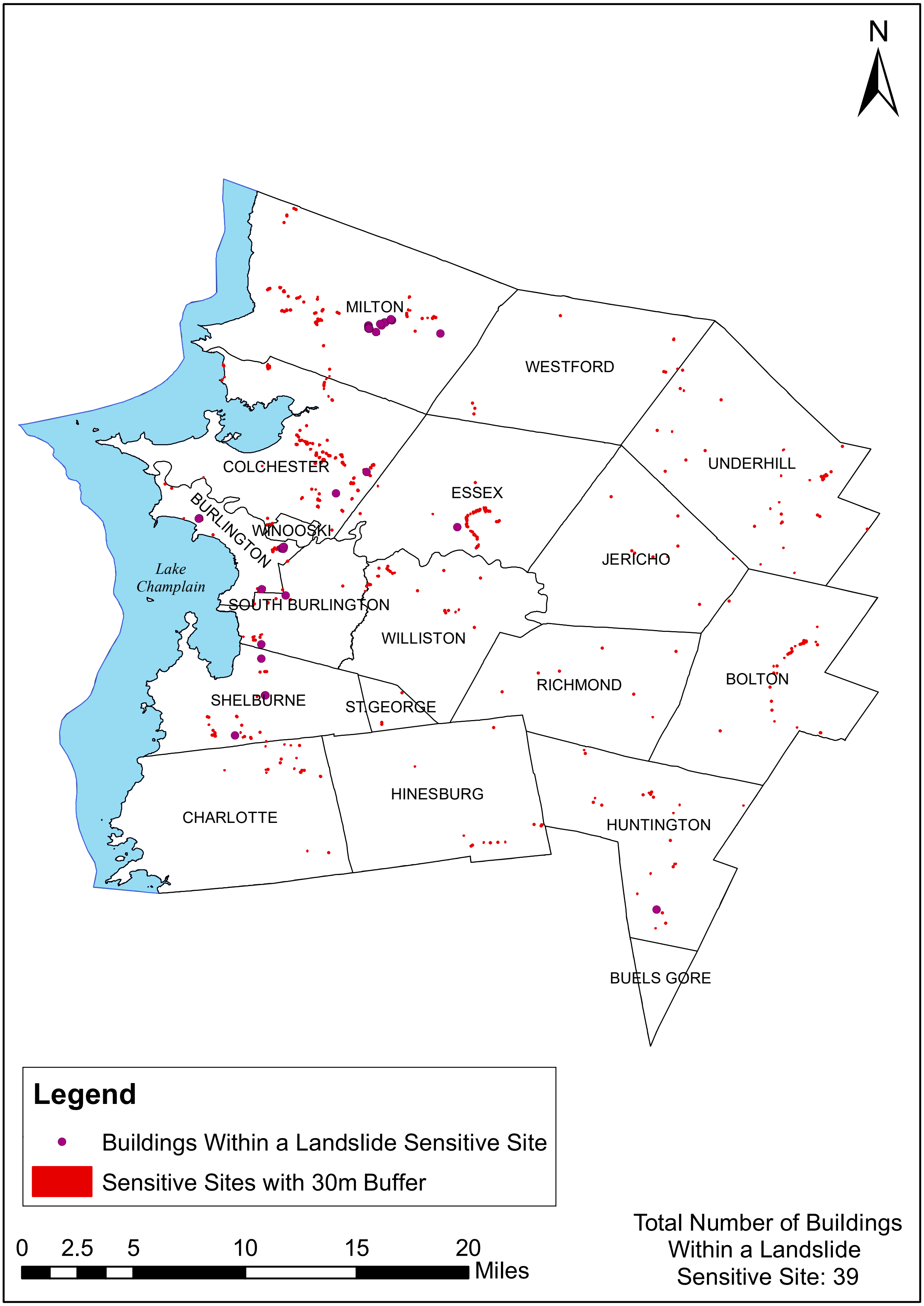


Figure 11

Occupancy Class Breakdown of Chittenden County Buildings Within 30 Meters of a Landslide Sensitive Site

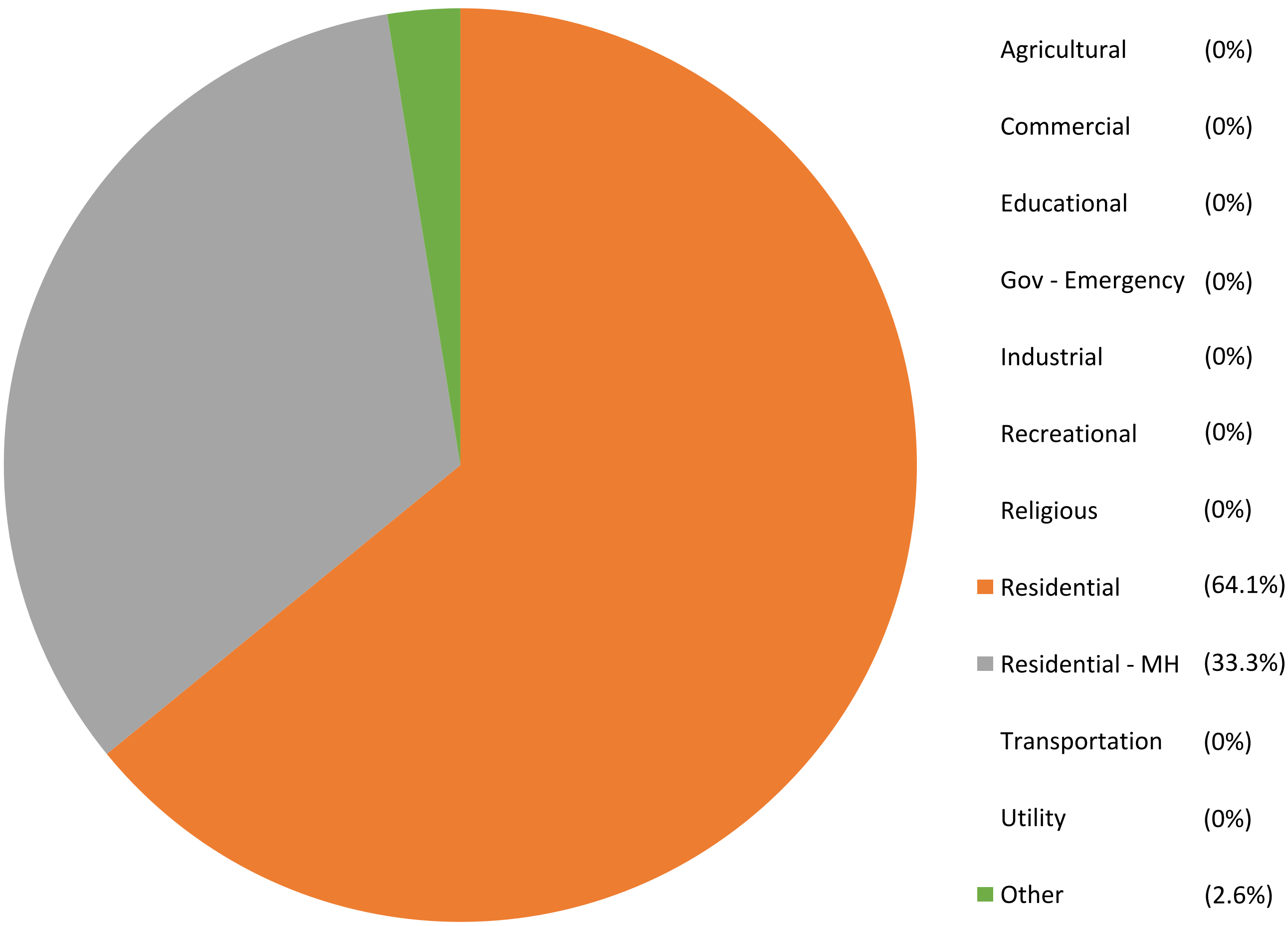
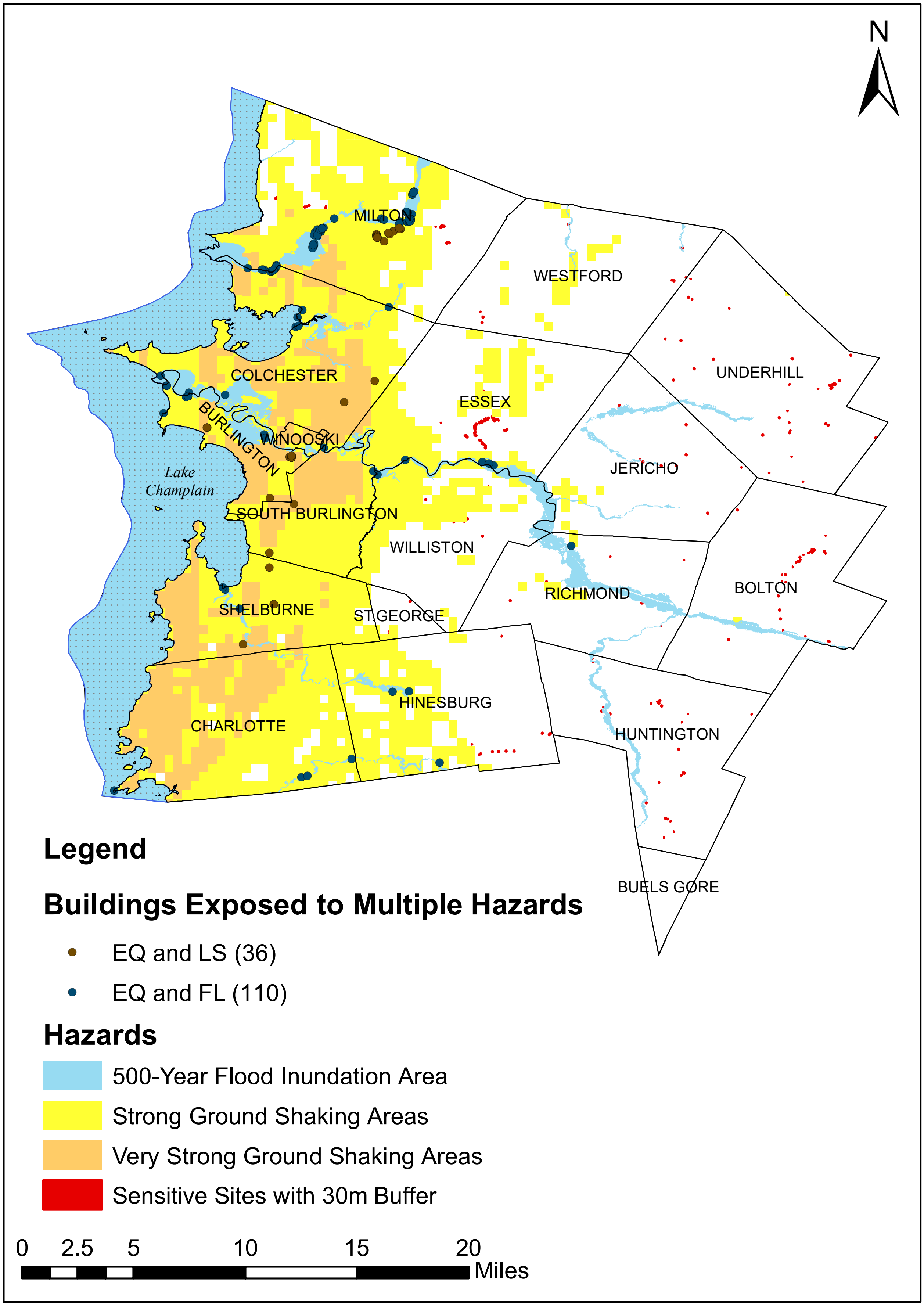


Figure 12

Buildings Exposed to Multiple Hazards Chittenden County, Vermont



Total Building Count by Hazard
Chittenden County, Vermont

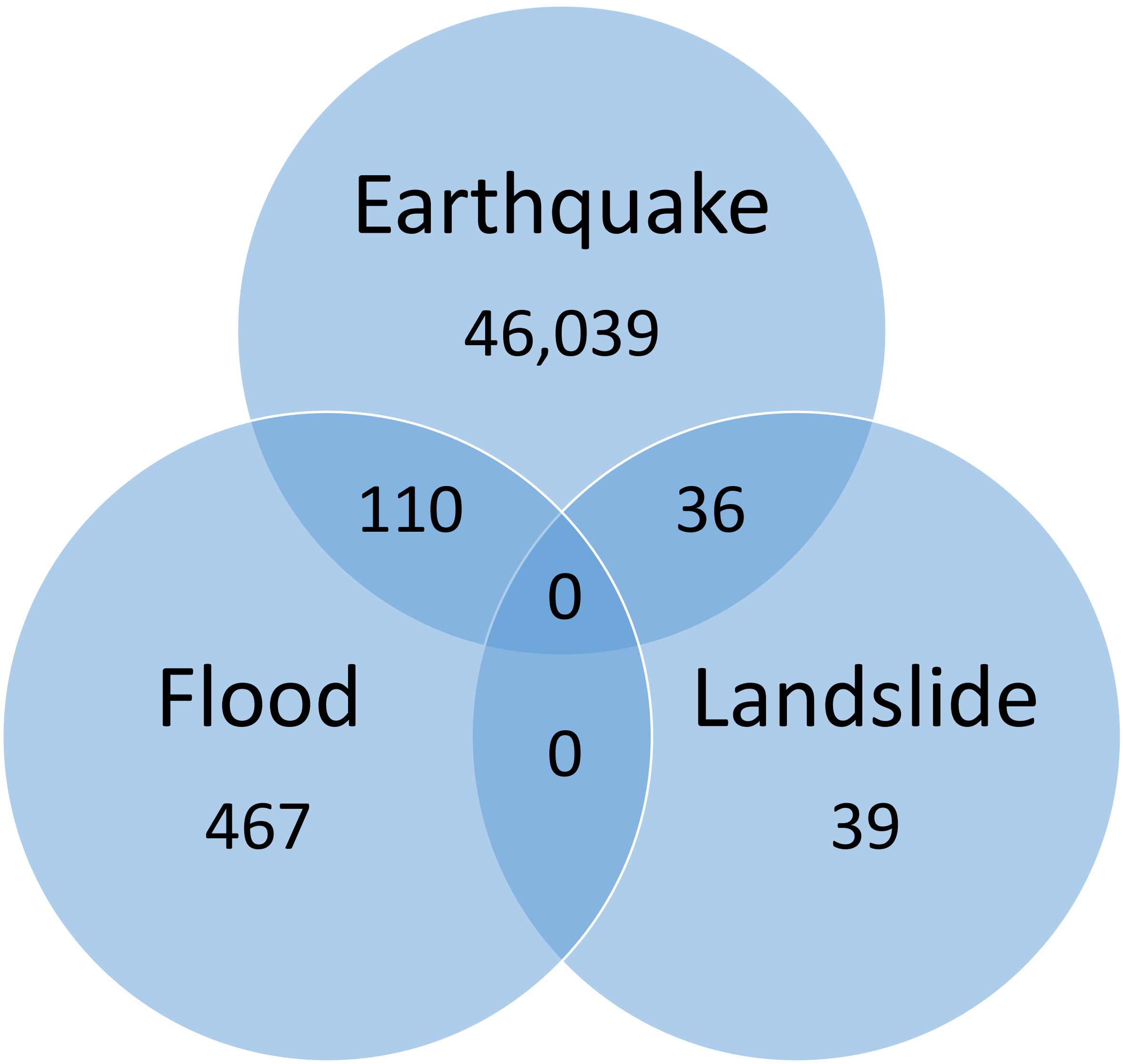


Table 1

Buildings Located in Strong or Greater Ground Shaking Areas
by Town and Occupancy
Chittenden County, Vermont

Occupancy Type

Town Name

TOWN NAME	Agricultural	Commercial	Educational	Gov - Emergency	Industrial	Recreational	Religious	Residential	Residential - MH	Transportation	Utility	Other	Total
Bolton	0	0	0	0	0	0	0	0	0	0	0	0	0
Buel's Gore	0	0	0	0	0	0	0	0	0	0	0	0	0
Burlington	0	755	181	59	19	26	23	10,580	122	8	38	798	**12,609**
Charlotte	50	34	4	7	0	45	4	1,644	37	2	13	256	**2,096**
Colchester	19	308	56	64	26	510	13	4,758	649	8	64	153	**6,628**
Essex	16	328	18	39	41	14	10	3,572	37	4	20	67	**4,166**
Hinesburg	15	32	8	8	3	31	5	563	11	1	14	34	**725**
Huntington	0	0	0	0	0	0	0	0	0	0	0	0	0
Jericho	0	1	0	0	0	0	0	19	0	0	0	1	**21**
Milton	10	137	2	13	18	39	7	2,854	452	3	32	302	**3,869**
Richmond	0	2	0	2	0	1	0	73	33	0	0	2	**113**
Shelburne	31	195	5	10	9	45	7	2,777	120	1	27	83	**3,310**
South Burlington	12	522	12	67	14	36	15	6,290	1	22	84	517	**7,592**
St. George	0	0	0	0	0	0	0	58	10	0	2	1	**71**
Underhill	0	0	0	0	0	0	0	1	0	0	0	0	**1**
Westford	2	4	0	1	0	0	1	70	7	1	1	37	**124**
Williston	5	507	22	15	15	23	5	2,040	103	3	26	89	**2,853**
Winooski	0	93	3	5	0	10	6	1,609	8	4	5	118	**1,861**
Totals	**160**	**2,918**	**311**	**290**	**145**	**780**	**96**	**36,908**	**1,590**	**57**	**326**	**2,458**	**46,039**

Table 2

Buildings Located in HAZUS-MH Modeled 500-Year Flood Scenario Chittenden County, Vermont

Occupancy Type

Town Name

TOWN NAME	Agricultural	Commercial	Educational	Gov - Emergency	Industrial	Recreational	Religious	Residential	Residential - MH	Transportation	Utility	Other	Total
Bolton	1	2	0	1	0	2	0	21	3	0	1	4	**35**
Buel's Gore	0	0	0	0	0	0	0	0	0	0	0	0	0
Burlington	0	1	0	0	0	0	0	5	0	0	0	2	**8**
Charlotte	0	0	0	0	0	0	0	3	0	0	0	1	**4**
Colchester	0	0	0	0	0	5	0	3	0	0	0	0	**8**
Essex	1	0	0	1	1	0	0	0	0	0	0	1	**4**
Hinesburg	0	0	0	0	0	0	0	4	0	0	1	0	**5**
Huntington	0	2	0	1	0	1	1	48	29	0	2	38	**122**
Jericho	1	1	0	0	0	0	0	14	1	1	0	1	**19**
Milton	0	3	0	1	0	3	0	45	2	0	4	19	**77**
Richmond	1	11	0	5	0	1	0	68	53	1	3	4	**147**
Shelburne	0	1	0	0	0	1	0	1	0	0	0	0	**3**
South Burlington	0	0	0	0	0	1	0	0	0	0	1	0	**2**
St. George	0	0	0	0	0	0	0	0	0	0	0	0	0
Underhill	0	1	0	1	0	1	0	25	0	0	0	0	**28**
Westford	0	0	0	0	0	0	0	0	0	0	0	0	0
Williston	0	1	0	0	0	0	0	3	0	0	1	0	**5**
Winooski	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**4**	**23**	**0**	**10**	**1**	**15**	**1**	**240**	**88**	**2**	**13**	**70**	**467**

Table 3

Buildings Located Within 30 Meters of a Landslide Sensitive Site Chittenden County, Vermont

Occupancy Type

Town Name

TOWN NAME	Agricultural	Commercial	Educational	Gov - Emergency	Industrial	Recreational	Religious	Residential	Residential - MH	Transportation	Utility	Other	Total
Bolton	0	0	0	0	0	0	0	0	0	0	0	0	0
Buel's Gore	0	0	0	0	0	0	0	0	0	0	0	0	0
Burlington	0	0	0	0	0	0	0	8	0	0	0	0	**8**
Charlotte	0	0	0	0	0	0	0	0	0	0	0	0	0
Colchester	0	0	0	0	0	0	0	2	0	0	0	0	**2**
Essex	0	0	0	0	0	0	0	1	0	0	0	0	**1**
Hinesburg	0	0	0	0	0	0	0	0	0	0	0	0	0
Huntington	0	0	0	0	0	0	0	1	0	0	0	0	**1**
Jericho	0	0	0	0	0	0	0	0	0	0	0	0	0
Milton	0	0	0	0	0	0	0	9	11	0	0	1	**21**
Richmond	0	0	0	0	0	0	0	0	0	0	0	0	0
Shelburne	0	0	0	0	0	0	0	2	2	0	0	0	**4**
South Burlington	0	0	0	0	0	0	0	2	0	0	0	0	**2**
St. George	0	0	0	0	0	0	0	0	0	0	0	0	0
Underhill	0	0	0	0	0	0	0	0	0	0	0	0	0
Westford	0	0	0	0	0	0	0	0	0	0	0	0	0
Williston	0	0	0	0	0	0	0	0	0	0	0	0	0
Winooski	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**25**	**13**	**0**	**0**	**1**	**39**

USGS Description/Damage of Earthquake by Modified Mercalli Scale Intensity

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Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest,especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Abridged from *The Severity of an Earthquake*, USGS General Interest Publication 1989-288-913