Washington County, Vermont
Multi-Hazard Analysis

A Washed Out Road in Waitsfield, VT after Tropical Storm Irene in 2011 (Sandy Macys, AP Photo)

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Background

The goal of this project was to prepare a multi-hazard analysis for Washington 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 State Geologist and further developed using ArcGIS. HAZUS-MH version 4.2 currently does not offer support for landslides.

Objectives

The objectives for this project were as follows:

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

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

c) Create report, power point presentation, maps and tables detailing results.

Methodology

The results for Washington 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 provided by the Vermont State Geologist. The landslide inventory (Springston, 2017)[1] includes sites identified in previous

[1] Springston, G., 2017, Landslide Inventory of Washington County, Central Vermont: Vermont Geological Survey Open File Report VG2017-7. Report and map available on-line at http://dec.vermont.gov/geological-survey/publication-gis/ofr

studies of the Mad River Valley and the Great Brook, surficial geologic mapping projects, individual site visits and data from the Vermont Rivers Program.

The HAZUS-MH scenario used for earthquake was a magnitude 5.0 earthquake event epicentered in Middlebury 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 Washington 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. For Washington County, there were no areas that experienced greater than strong ground shaking so only those areas located in the strong category were used. After running the earthquake scenario, strong ground shaking was selected from the PGA contour layer. Strong ground shaking areas have PGA values between 9.2 and 18.

Next, the Vermont E911 Building data was brought in as a shapefile. Using the Select by Location tool, buildings within strong 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 strong ground shaking areas were selected and mapped. Because the census block layer does not completely line up with the strong ground shaking areas, the blocks were clipped to fit within the strong 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 strong 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. Based on recommendations from the Vermont State Geologist, these points were buffered 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

Four 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.

Figure 2 shows the total number of buildings located in strong ground shaking areas. Because of the location of the epicenter, the strong ground shaking areas were primarily in the southwestern part of the county. As a result, there were 417 buildings located in strong ground shaking areas spread across the towns of Fayston, Waitsfield and Warren.

The Town of Warren contained the overwhelming majority of buildings, 390 of 417, located in strong ground shaking areas. Because of the density of the buildings in these locations, Figure 2 may spatially underestimate the total number of buildings located in these high ground shaking areas due to the scale of the map. Although it is difficult to clearly show all of the buildings individually at this scale, Figure 3 provides a better idea of the density and number of potentially impacted buildings in Warren.

To understand the effect that the scenario earthquake could have on population within the area, census block data was used. Census blocks within strong ground shaking areas were identified, selected and clipped to fit entirely within strong 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 (2.3) then multiplying it by the sum of residential buildings (272) and mobile homes (10) within strong ground shaking areas resulted in a total estimate of 649 people. For Washington County, only parts of Fayston, Waitsfield and Warren had strong ground shaking areas. There were not many census blocks located here, which consisted mainly of both rural and mountainous terrain, resulting in a low estimate of people located in strong ground shaking areas. Figure 4 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 Town of Warren contains the most buildings, with the majority of them being residential. Table 1 shows the count of buildings in strong 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 417 buildings, about 65% were residential, 11.5% were commercial and 13% were recreational. Figure 5 breaks down the occupancy classes of buildings within strong ground shaking areas.

Flood

Three maps were created for flood. Figure 6 shows the inundation of the 500-year flood scenario, described in the methodology section.

Figure 7 shows the buildings located within the flood inundation area. The Winooski River and some of its major tributaries, the North Branch, Dog and Mad Rivers, run through the cities of Montpelier and Barre City. It is important to note that every town in Washington County has rivers that run through them, leading to every town having buildings within the flood inundation area. As a result, there were 5,088 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 (2.3) and multiplying it by the sum of residential buildings (3,037) and mobile homes (462) within the flood inundation area. Every town had census blocks within the flood inundation area, especially along the Winooski River, resulting in an estimated 8,048 people located within the flood inundation area. Figure 8 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. Montpelier had over 1,000 buildings in the flood inundation area and Barre City had 875. More than half of 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 5,088 buildings, about 60% were residential, 18% were commercial and 9% were residential mobile homes. Figure 9 breaks down the occupancy class of buildings by percentage located within the flood inundation area.

Landslide

Two maps were created for landslide. Figure 10 shows the location of the landslide sensitive sites with the 30 meter buffer, described in the methodology section.

Figure 11 shows the buildings located within 30 meters of a landslide sensitive site. Because of their relatively remote locations and small size not many buildings were found within the landslide sensitive sites. Only 9 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 9 buildings were spread between 6 different towns, with 4 being commercial, 4 recreational, and 1 commercial. 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 44%, recreational 44% and commercial 11%. This is illustrated in Figure 12.

Multi-Hazard

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 13.

A Venn diagram was also created to show the total number of buildings affected by each hazard and combination of hazards. There were 61 total buildings exposed to multiple hazards: 1 for earthquake and landslide, 2 for flood and landslide, and 58 for earthquake and flood. When looking at this breakdown by town, Warren contained the only building exposed to earthquake and landslide and all 58 for earthquake and flood, Barre City contained 1 for flood and landslide, and Barre Town contained 1 for flood and landslide. Figure 14 shows the distribution of buildings exposed to multiple hazards.

Conclusions and Recommendations

Using Vermont E911 Building data and HAZUS-MH provided a reasonable multi-hazard analysis for Washington 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, which 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 Middlebury Scenario did not yield a significant amount of strong ground shaking in Washington County due to its epicenter location and moderate strength. This scenario was initially used for an analysis of Addison County, Vermont, of which the Town of Middlebury is centrally located within it. Using a similar scenario with an epicenter near Montpelier would provide higher ground shaking levels and a better understanding of how a local moderate sized earthquake might affect Washington County.

For flood, the HAZUS-MH flood model is able to analyze all the major rivers in a study region, but sometimes its estimations can differ slightly from other models and FEMA's Flood Insurance Rate Maps (FIRM) maps. It is important to obtain the most accurate results as possible, and one way is to compare HAZUS-MH results to FEMA'S FIRM maps, which are the standard for flood mapping purposes. FIRM maps are done regionally by FEMA based on local site and hydrologic conditions and input from local officials. However, for Washington County, there were no Digital FIRM maps available. This makes it difficult to identify where some of the potential discrepancies in HAZUS-MH may be located. With FEMA FIRM map coverage, Washington County officials and residents would have a better knowledge and understanding of how flood events may affect them.

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.

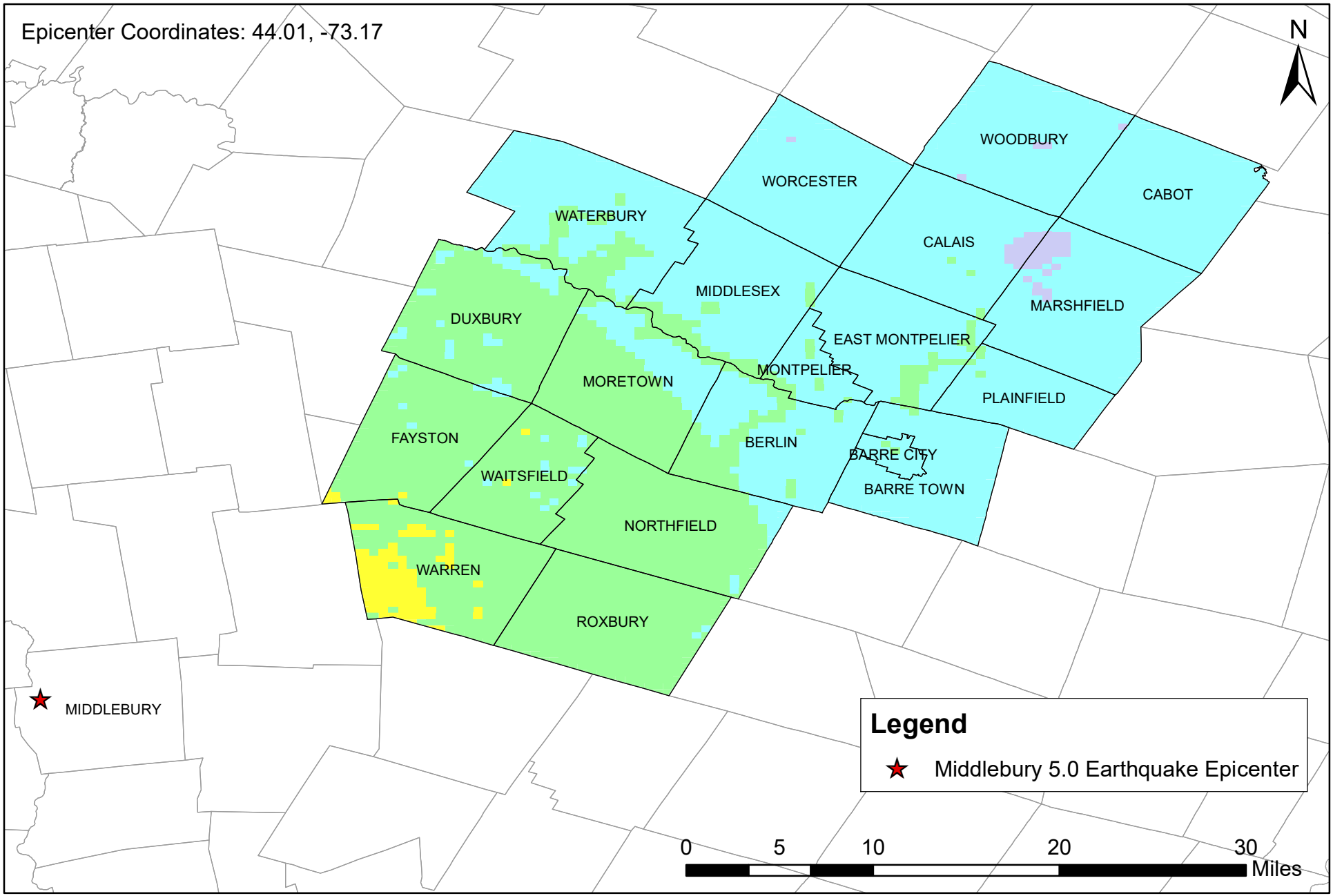
Figures and Tables

FIGURES:

TABLES:

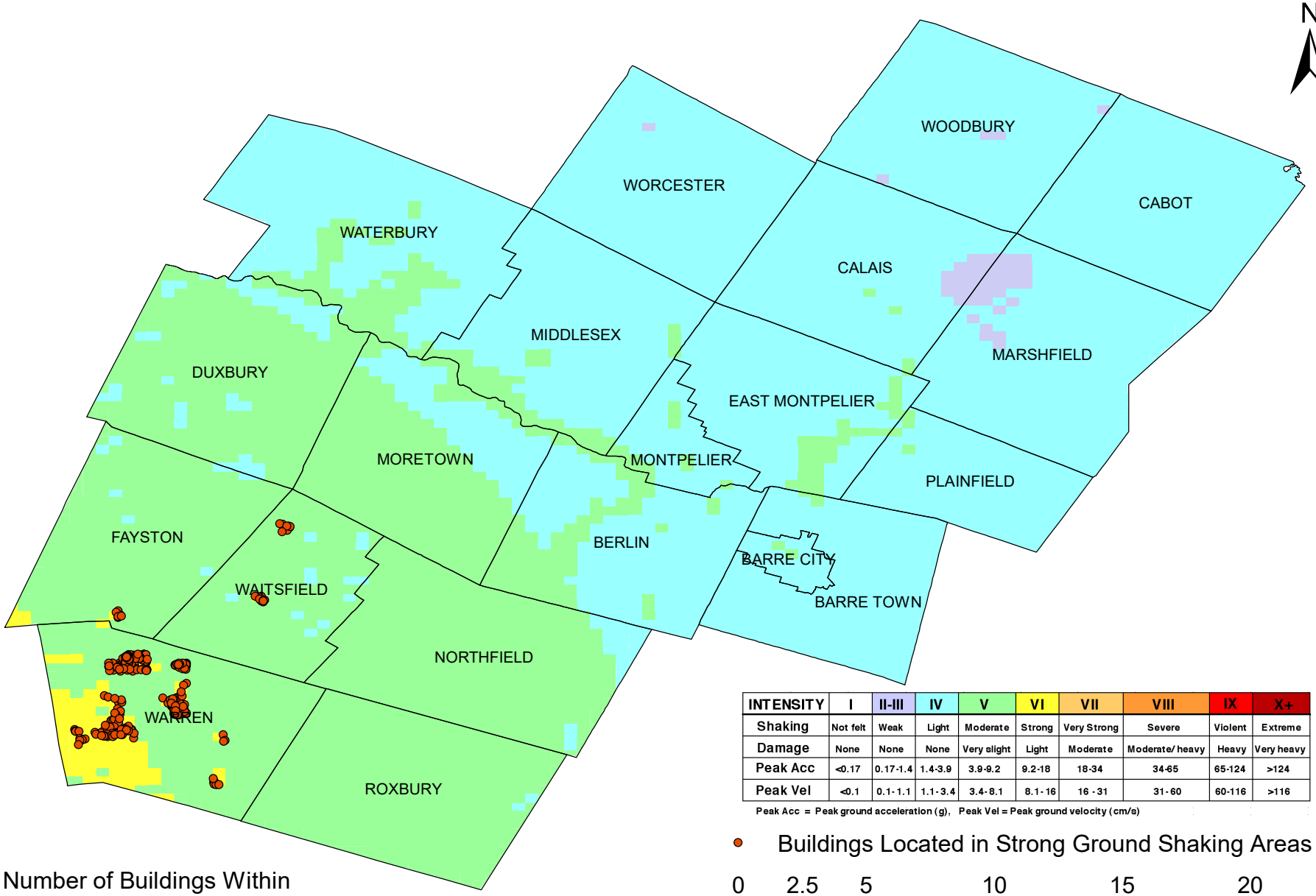
Middlebury 5.0 Earthquake Event
Washington County, Vermont

Figure 1



Buildings Located in Strong Ground Shaking Areas
Washington County, Vermont

Figure 2

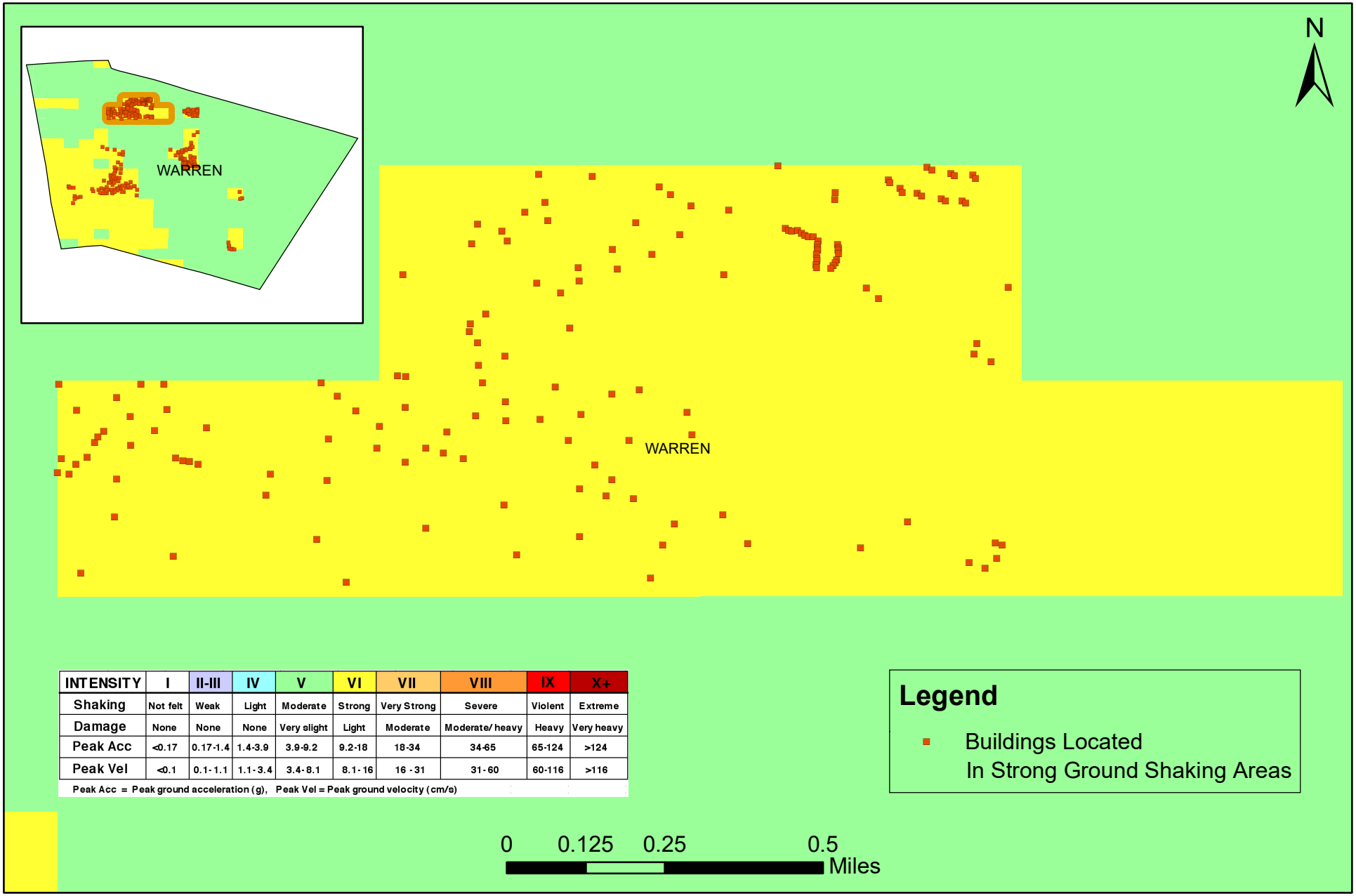


INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Damage	None	None	None	Very slight	Light	Moderate	Moderate/ heavy	Heavy	Very heavy
Peak Acc	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
Peak Vel	<0.1	0.1-1.1	1.1-3.4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

Town of Warren Building Concentrations
Washington County, Vermont

Figure 3



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
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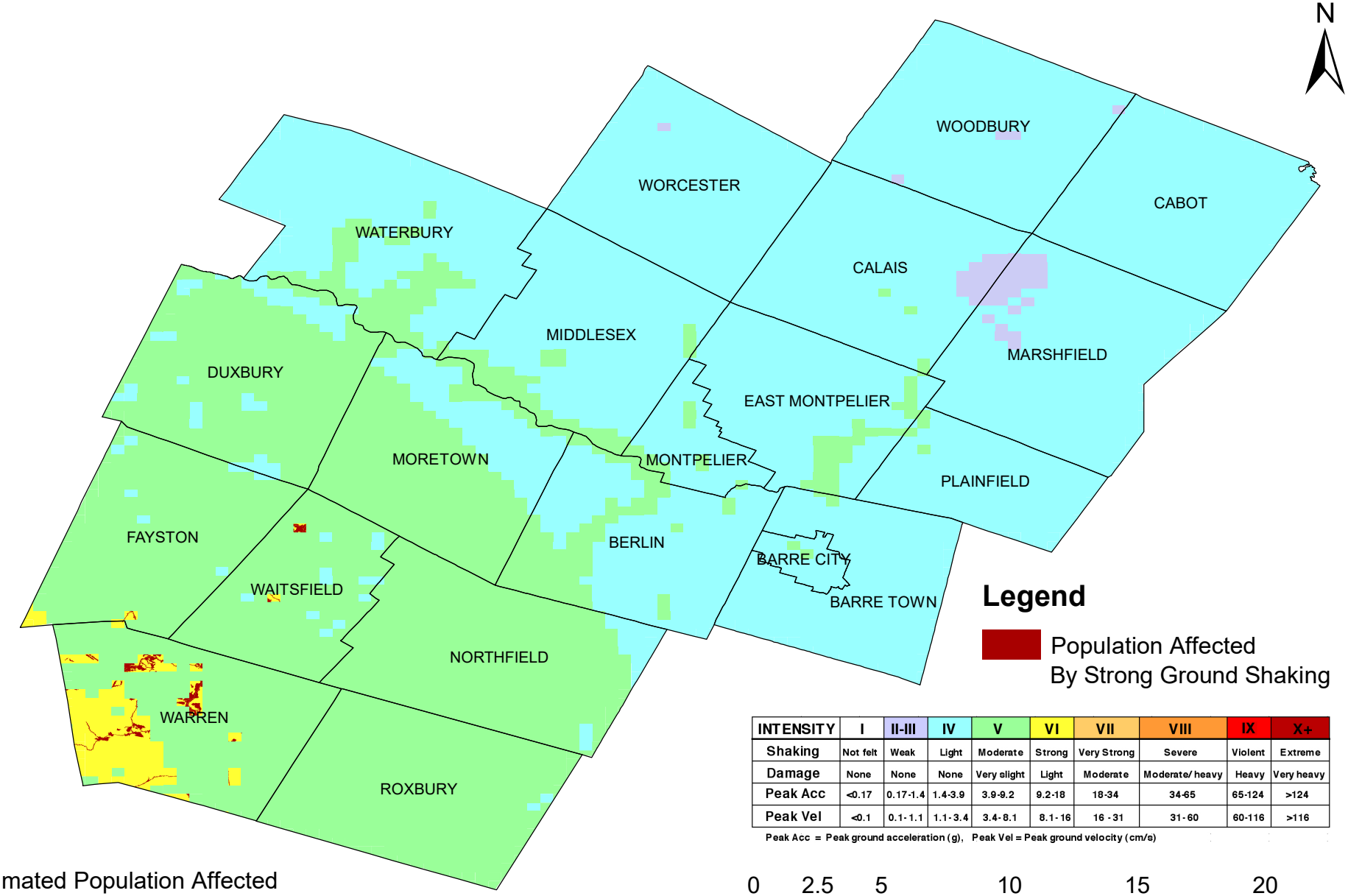
Peak Vel	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116

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

Estimated Population Affected by Strong Ground Shaking
Washington County, Vermont

Figure 4



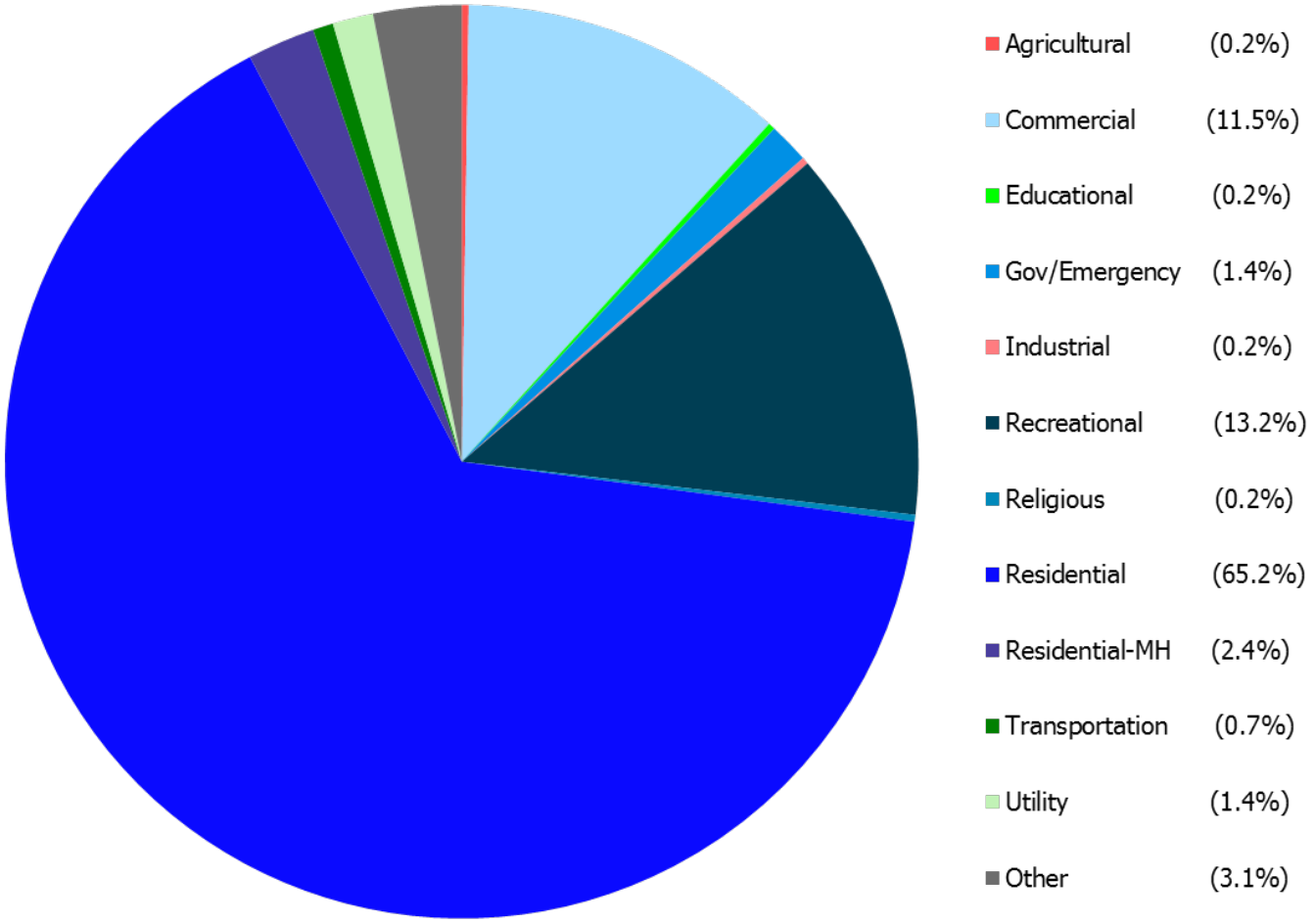
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Damage	None	None	None	Very slight	Light	Moderate	Moderate/ heavy	Heavy	Very heavy
Peak Acc	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
Peak Vel	<0.1	0.1-1.1	1.1-3.4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

Estimated Population Affected
By Strong Ground Shaking: 649

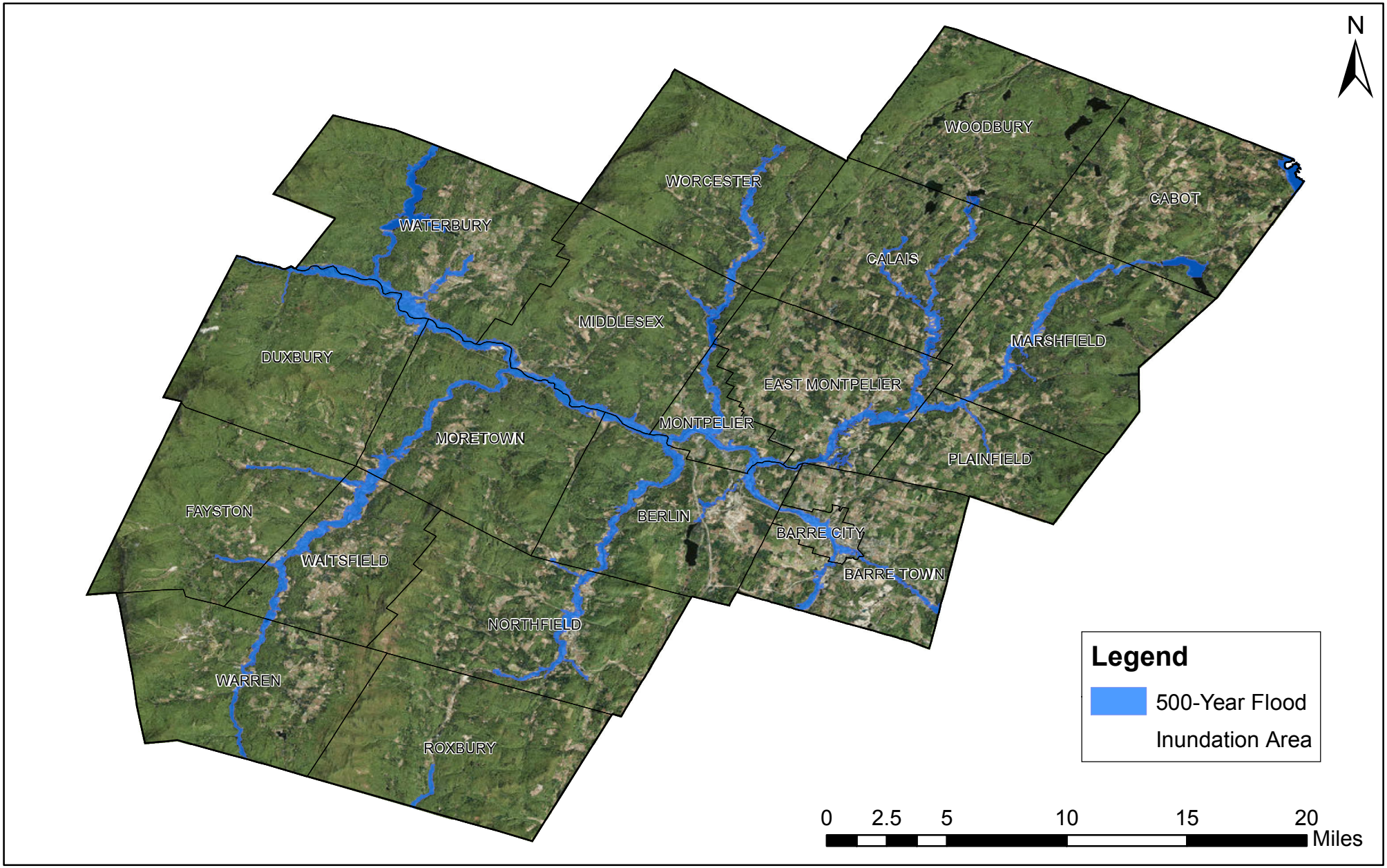
Figure 5

Occupancy Class Breakdown of Washington County Buildings Located in Strong Earthquake Ground Shaking Areas from the Middlebury 5.0 Scenario



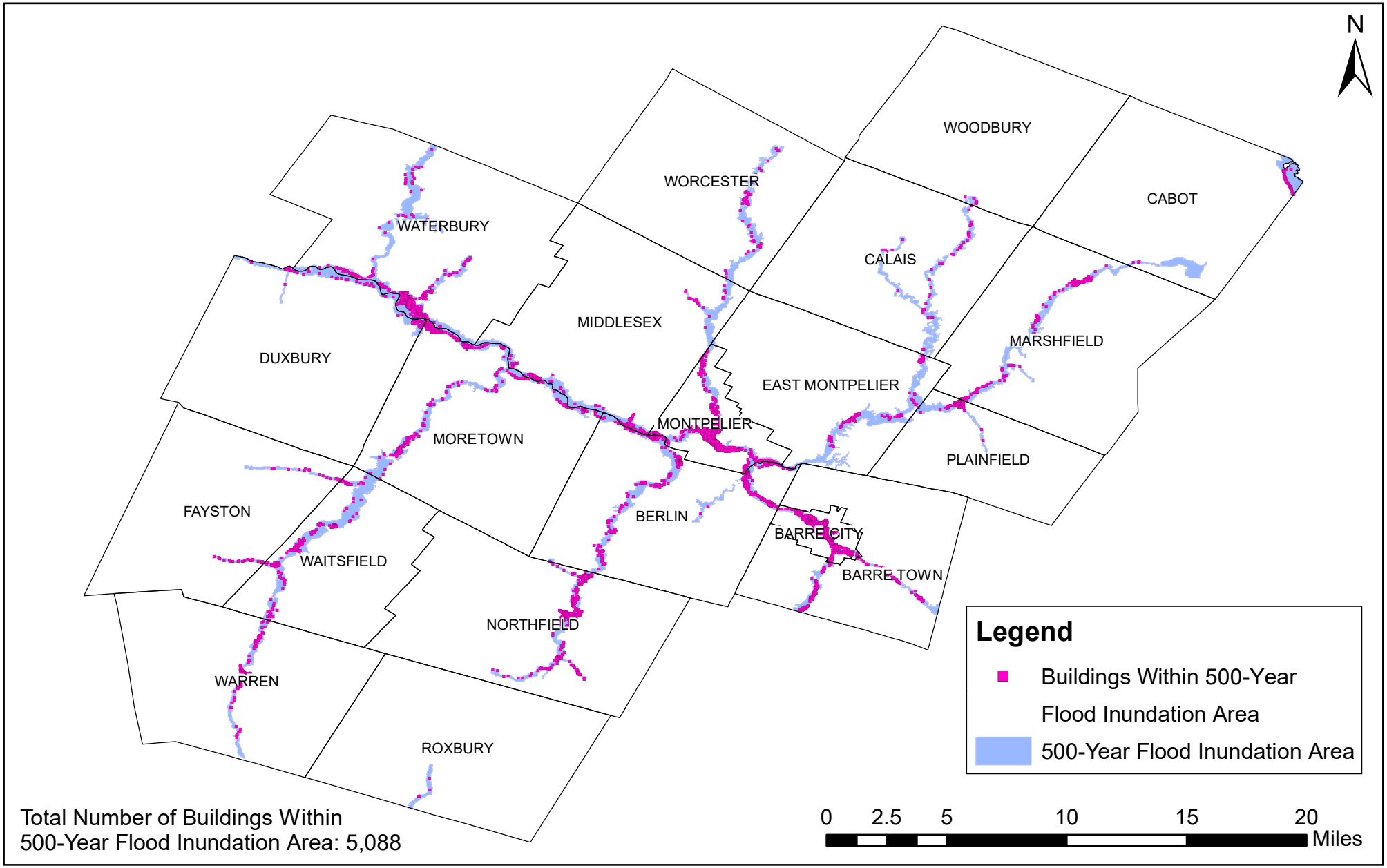
500-Year HAZUS Modeled Flood Inundation Area
Washington County, Vermont

Figure 6



Buildings Located Within 500-Year Inundation Area
Washington County, Vermont

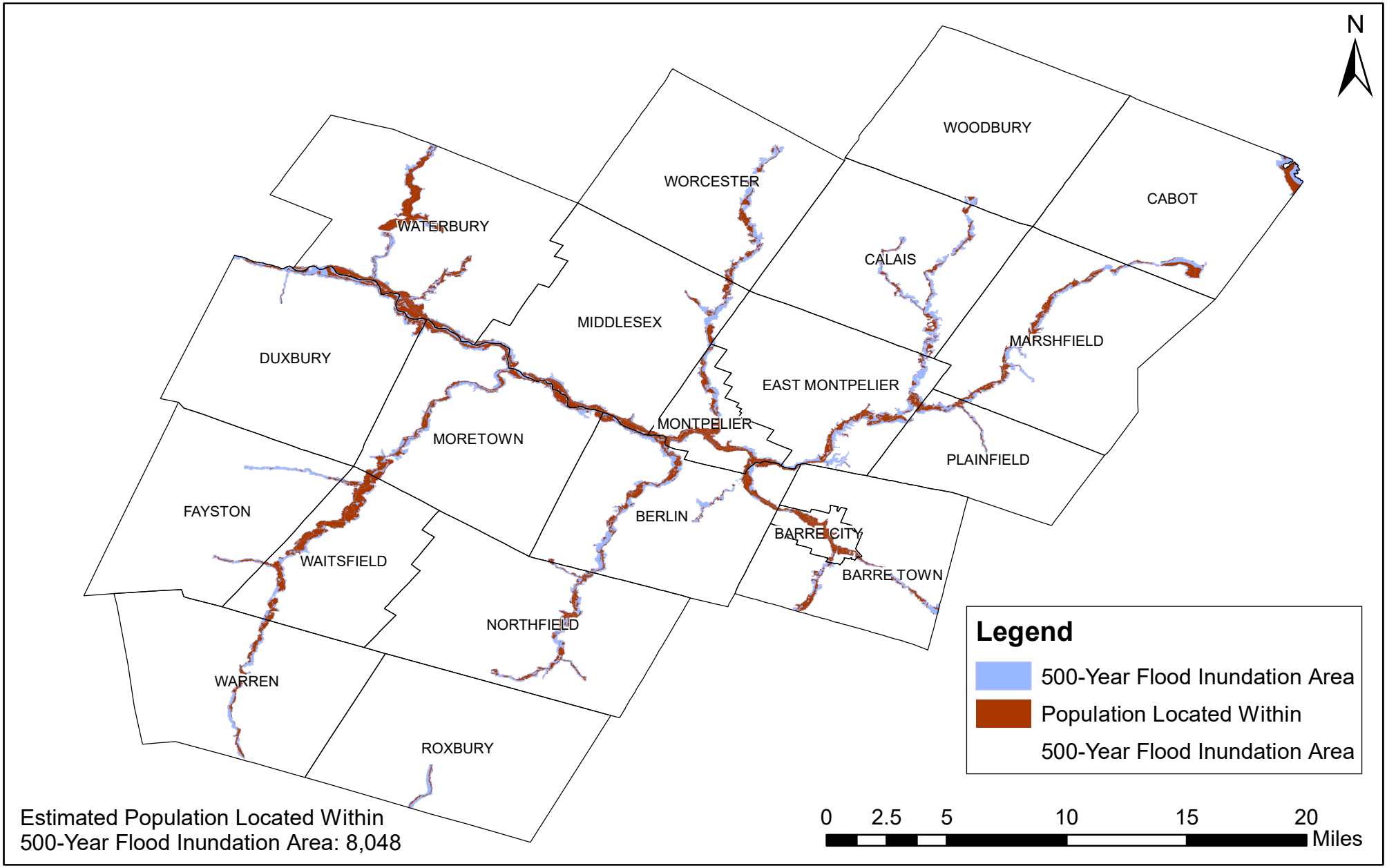
Figure 7



Total Number of Buildings Within 500-Year Flood Inundation Area: 5,088

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

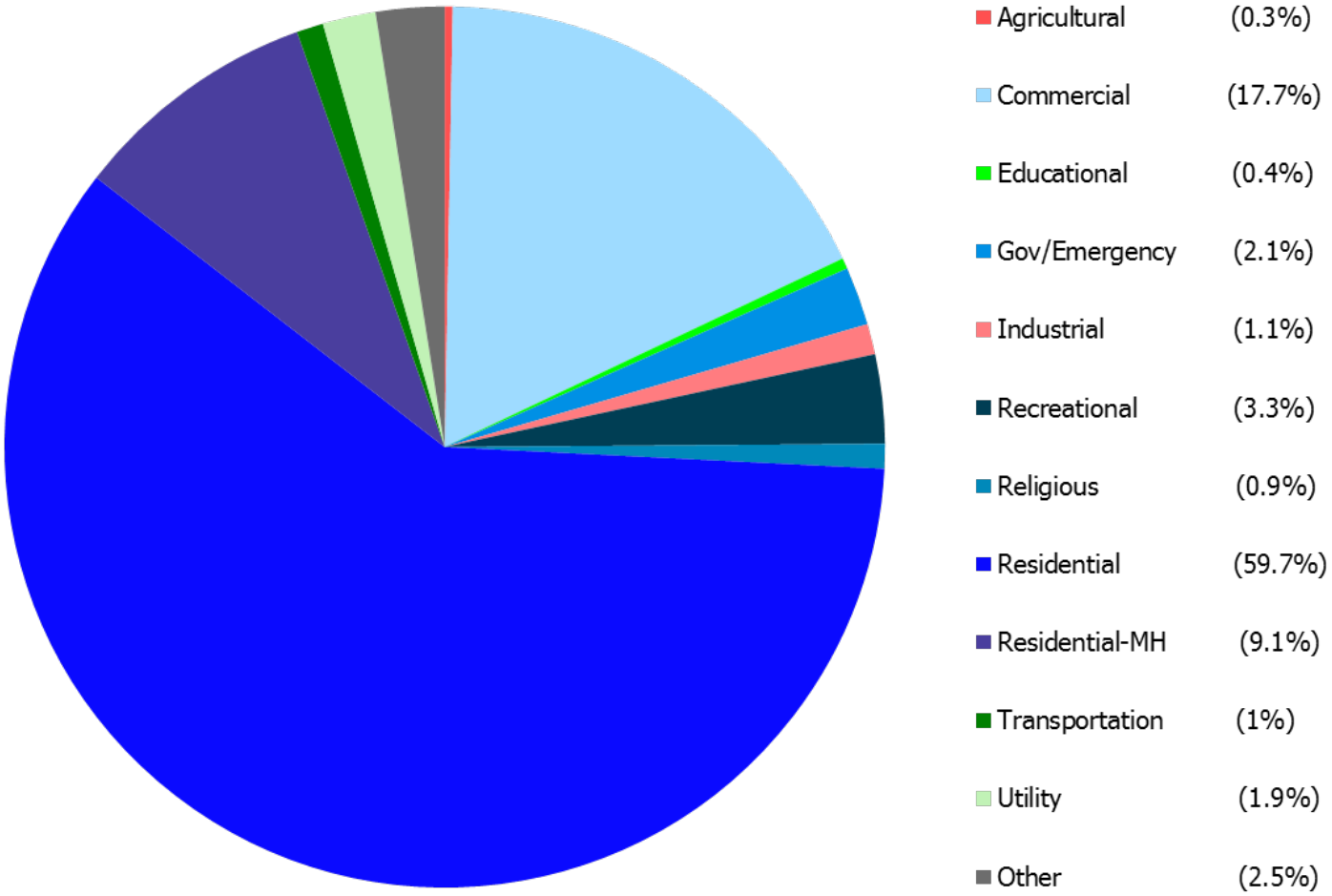
Figure 8



Estimated Population Located Within
500-Year Flood Inundation Area: 8,048

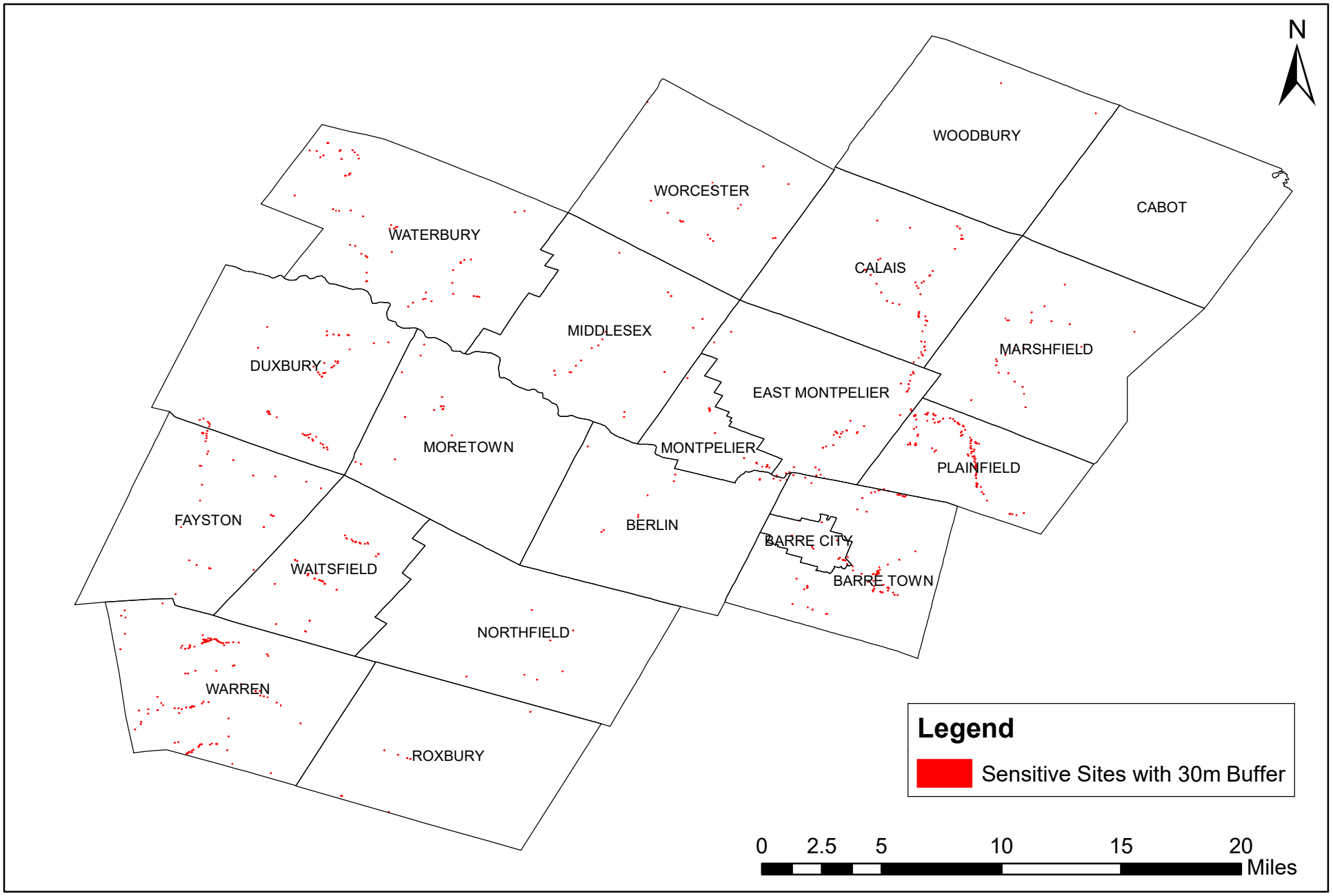
Figure 9

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



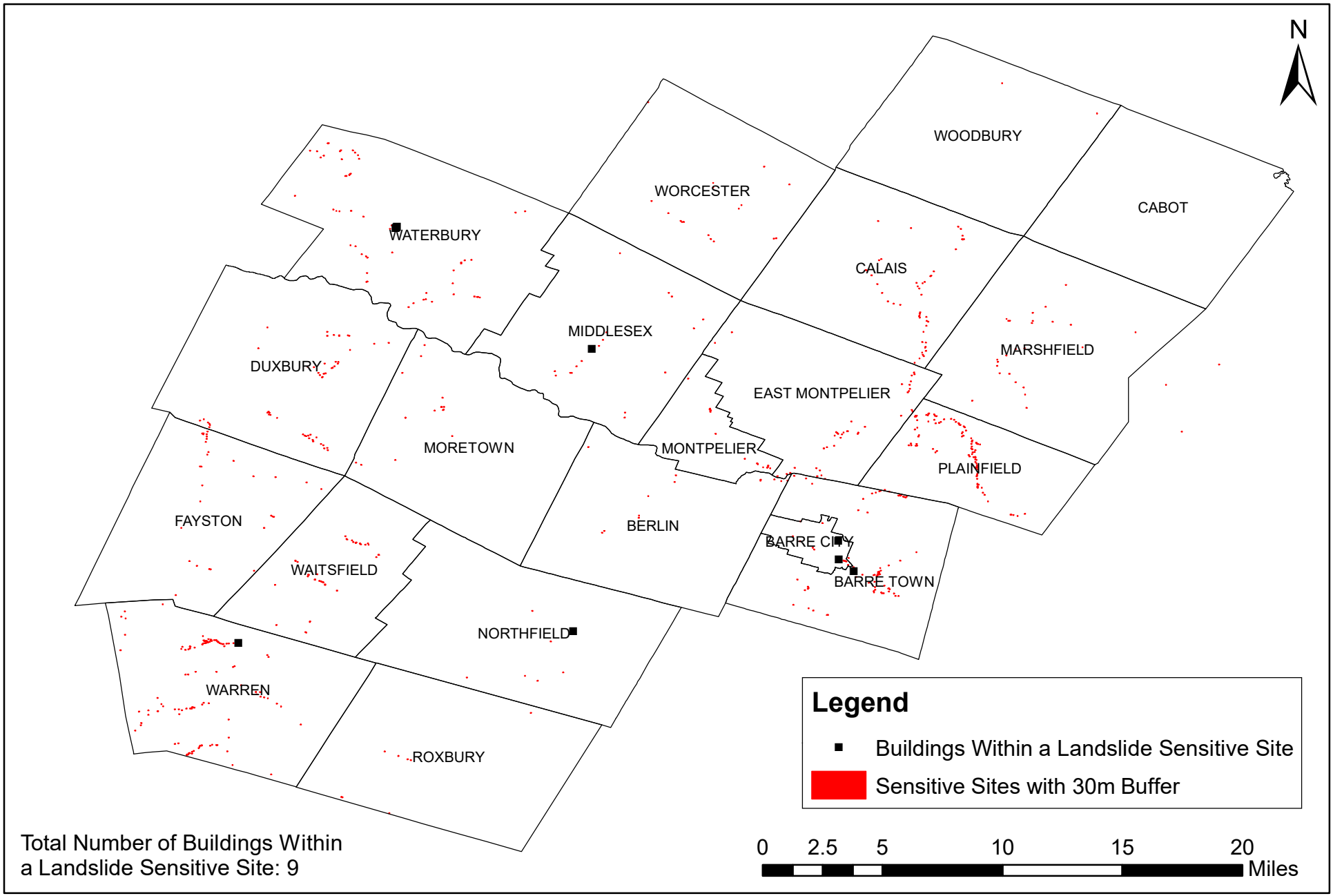
Landslide Sensitive Sites and Potential Impacted Area
Washington County, Vermont

Figure 10



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

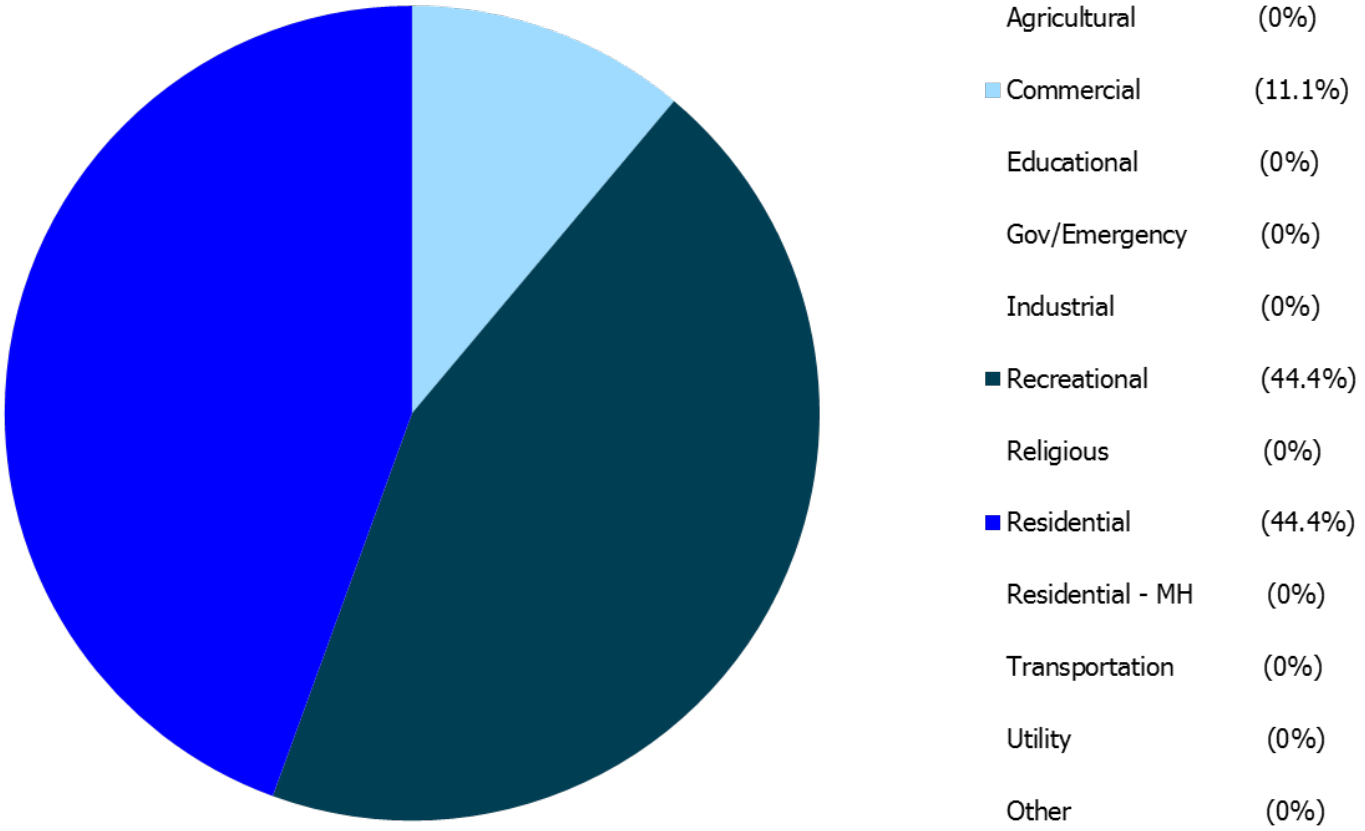
Figure 11



Total Number of Buildings Within
a Landslide Sensitive Site: 9

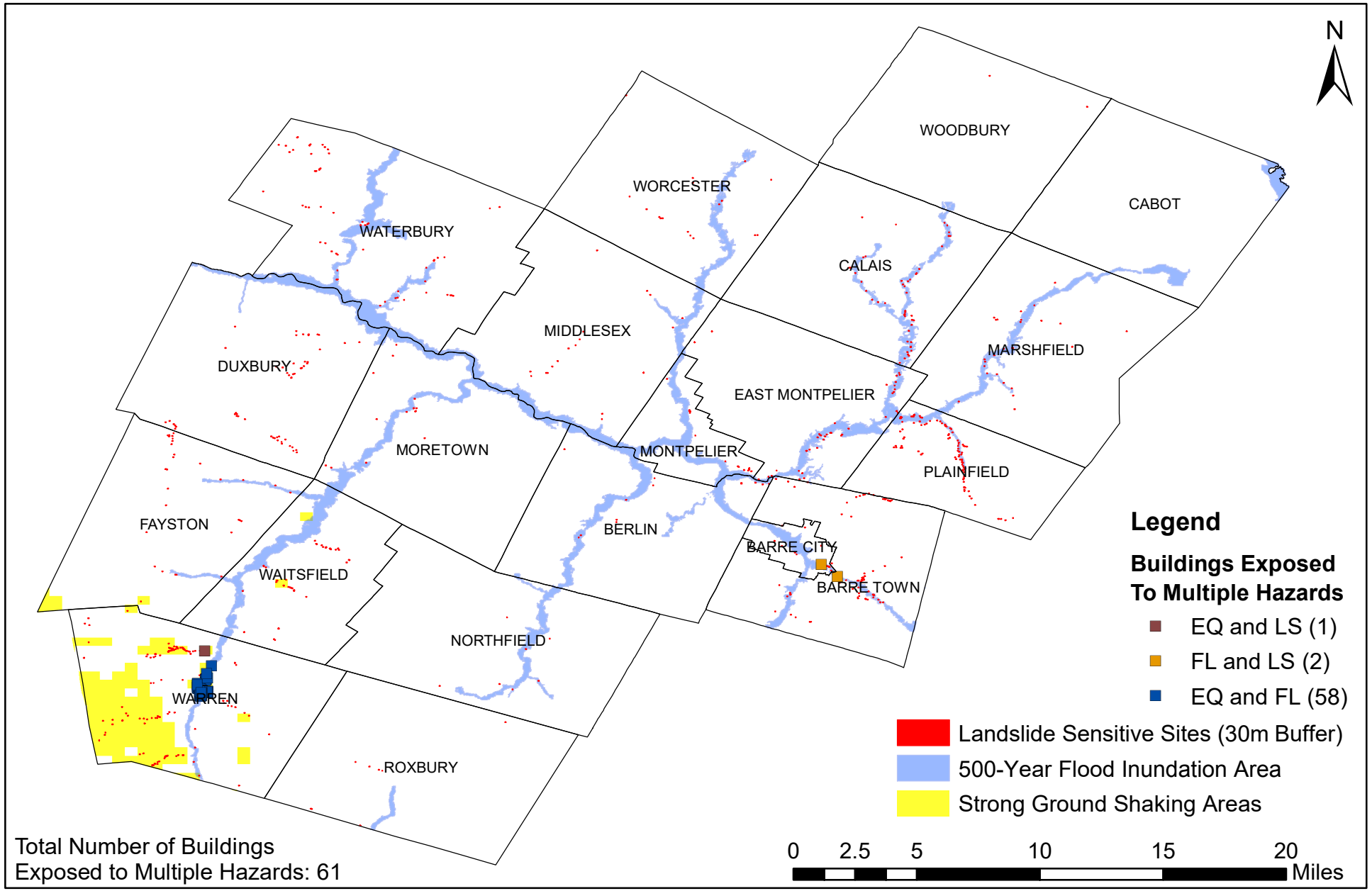
Occupancy Class Breakdown of Washington County Buildings Located Within 30 Meters of a Landslide Sensitive Site

Figure 12



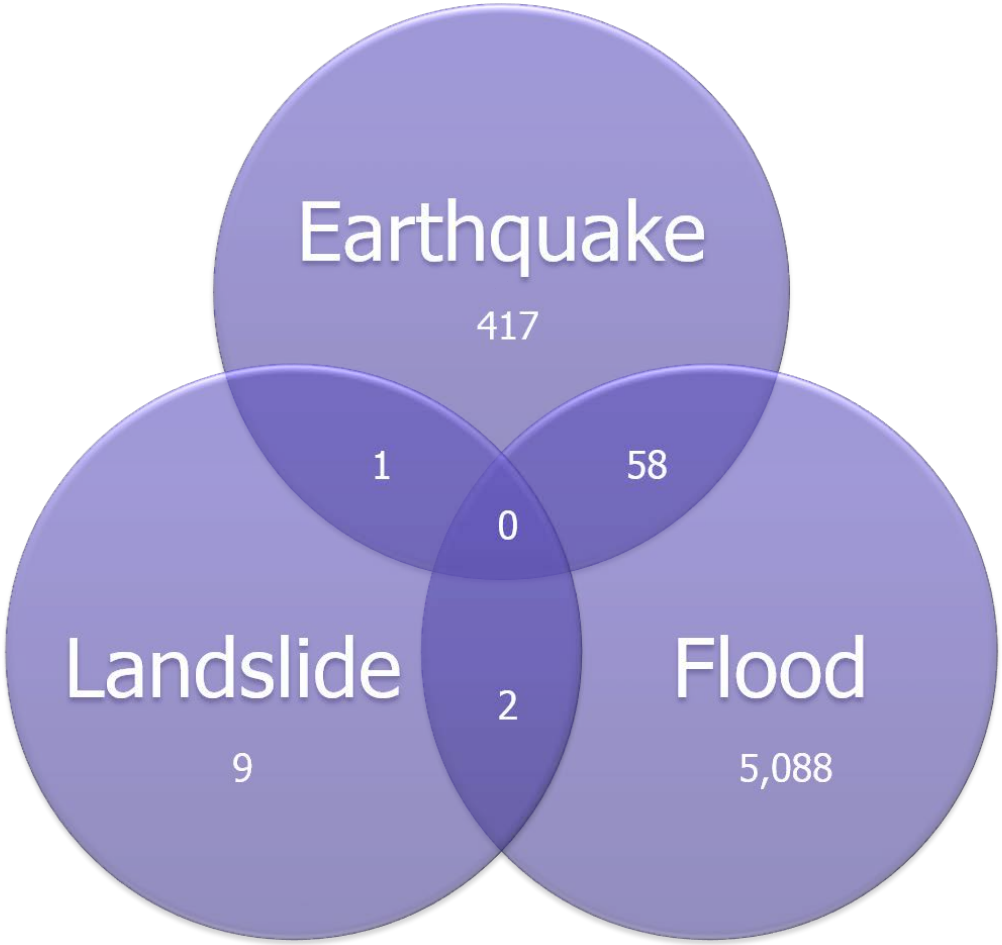
Buildings Exposed to Multiple Hazards
Washington County, Vermont

Figure 13



Total Number of Buildings
Exposed to Multiple Hazards: 61

Total Building Count by Hazard
Washington County, Vermont



Buildings Located in Strong Ground Shaking Areas by Town and Occupancy Washington County, Vermont

Table 1

Occupancy Type

Town Name	Agricultural	Commercial	Educational	Gov - Emergency	Industrial	Recreational	Religious	Residential	Residential - MH	Transportation	Utility	Other	Total
BARRE CITY	0	0	0	0	0	0	0	0	0	0	0	0	0
BARRE TOWN	0	0	0	0	0	0	0	0	0	0	0	0	0
BERLIN	0	0	0	0	0	0	0	0	0	0	0	0	0
CABOT	0	0	0	0	0	0	0	0	0	0	0	0	0
CALAIS	0	0	0	0	0	0	0	0	0	0	0	0	0
DUXBURY	0	0	0	0	0	0	0	0	0	0	0	0	0
EAST MONTPELIER	0	0	0	0	0	0	0	0	0	0	0	0	0
FAYSTON	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**8**
MARSHFIELD	0	0	0	0	0	0	0	0	0	0	0	0	0
MIDDLESEX	0	0	0	0	0	0	0	0	0	0	0	0	0
MONTPELIER	0	0	0	0	0	0	0	0	0	0	0	0	0
MORETOWN	0	0	0	0	0	0	0	0	0	0	0	0	0
NORTHFIELD	0	0	0	0	0	0	0	0	0	0	0	0	0
PLAINFIELD	0	0	0	0	0	0	0	0	0	0	0	0	0
ROXBURY	0	0	0	0	0	0	0	0	0	0	0	0	0
WAITSFIELD	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**15**	**2**	**0**	**0**	**0**	**19**
WARREN	**0**	**47**	**1**	**6**	**1**	**55**	**1**	**249**	**8**	**3**	**6**	**13**	**390**
WATERBURY	0	0	0	0	0	0	0	0	0	0	0	0	0
WOODBURY	0	0	0	0	0	0	0	0	0	0	0	0	0
WORCESTER	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**1**	**48**	**1**	**6**	**1**	**55**	**1**	**272**	**10**	**3**	**6**	**13**	**417**

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

Table 2

Occupancy Type

Town Name	Agricultural	Commercial	Educational	Gov - Emergency	Industrial	Recreational	Religious	Residential	Residential - MH	Transportation	Utility	Other	Total
BARRE CITY	0	171	5	9	28	16	12	584	11	15	13	11	875
BARRE TOWN	0	41	0	2	0	1	0	113	10	0	4	0	171
BERLIN	3	96	0	5	1	1	1	128	200	4	9	12	460
CABOT	0	1	0	0	0	42	0	4	2	0	0	0	49
CALAIS	1	0	0	1	0	4	0	17	11	0	7	5	46
DUXBURY	2	3	1	0	1	4	2	57	9	0	3	6	88
EAST MONTPELIER	0	20	0	2	1	0	0	64	7	0	3	4	101
FAYSTON	1	7	0	1	0	4	0	26	5	0	1	1	46
MARSHFIELD	2	15	0	2	1	2	3	102	9	2	4	2	144
MIDDLESEX	0	23	0	3	3	5	2	77	13	0	5	3	134
MONTPELIER	0	249	7	37	12	11	12	658	5	8	18	14	1031
MORETOWN	2	30	1	7	1	3	3	252	24	2	4	6	335
NORTHFIELD	0	54	2	7	2	5	4	286	77	8	8	19	472
PLAINFIELD	0	9	0	1	1	3	1	80	4	1	1	4	105
ROXBURY	0	0	0	0	0	0	0	2	0	0	2	0	4
WAITSFIELD	3	56	3	6	1	9	2	86	37	2	2	4	211
WARREN	0	27	0	4	1	1	1	83	8	1	3	8	137
WATERBURY	0	96	1	22	4	45	3	381	25	7	11	28	623
WOODBURY	0	0	0	0	0	6	0	2	0	0	0	0	8
WORCESTER	1	1	0	0	0	4	0	35	5	0	1	1	48
Totals	**15**	**899**	**20**	**109**	**57**	**166**	**46**	**3037**	**462**	**50**	**99**	**128**	**5088**

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

Table 3

Occupancy Type

Town Name	Agricultural	Commercial	Educational	Gov - Emergency	Industrial	Recreational	Religious	Residential	Residential - MH	Transportation	Utility	Other	Total
BARRE CITY	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**
BARRE TOWN	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
BERLIN	0	0	0	0	0	0	0	0	0	0	0	0	0
CABOT	0	0	0	0	0	0	0	0	0	0	0	0	0
CALAIS	0	0	0	0	0	0	0	0	0	0	0	0	0
DUXBURY	0	0	0	0	0	0	0	0	0	0	0	0	0
EAST MONTPELIER	0	0	0	0	0	0	0	0	0	0	0	0	0
FAYSTON	0	0	0	0	0	0	0	0	0	0	0	0	0
MARSHFIELD	0	0	0	0	0	0	0	0	0	0	0	0	0
MIDDLESEX	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**
MONTPELIER	0	0	0	0	0	0	0	0	0	0	0	0	0
MORETOWN	0	0	0	0	0	0	0	0	0	0	0	0	0
NORTHFIELD	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**
PLAINFIELD	0	0	0	0	0	0	0	0	0	0	0	0	0
ROXBURY	0	0	0	0	0	0	0	0	0	0	0	0	0
WAITSFIELD	0	0	0	0	0	0	0	0	0	0	0	0	0
WARREN	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
WATERBURY	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**3**
WOODBURY	0	0	0	0	0	0	0	0	0	0	0	0	0
WORCESTER	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**0**	**1**	**0**	**0**	**0**	**4**	**0**	**4**	**0**	**0**	**0**	**0**	**9**