EARTHQUAKE DAMAGE COST ANALYSIS OF BUILDING INVENTORY IN KAMLOOPS BC

by

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ABSTRACT

Earthquake damage predictions are done to help understand how advantageous embarking on mitigation might be. This kind of prediction is mostly done for large metropolitan areas or for high earthquake-risk areas. It is not clear how damaging an earthquake event might be for smaller cities like Kamloops with moderate seismicity since estimations are less likely to be done for smaller cities or for places with moderate seismic risks.

The focus of this thesis is on estimating possible building damage as a consequence of a moderate earthquake in the Kamloops region.

The input parameters for the different earthquake scenarios are designed according to the type of analysis. Two types of analysis – the probabilistic seismic hazard analysis (PSHA) and the deterministic seismic hazard analysis (DSHA) are used in this thesis to produce damage results for Kamloops. The PSHA examine damage results from a design moment magnitude, M_w (M_w= 6.5) with occurrence probability of 2% in 50years (1 in 2500 years). The DSHA consider damage results brought by 13 "what if" earthquake scenarios; modelled to look like real-life ground motion events using the Abrahamson and Silva 2008 (AS08) ground motion prediction equation (GMPE), to foresee possible damages for Kamloops if any of such events were to happen in the future.

The main variables of this study are: the earthquake magnitudes with moment magnitudes (M_w) = 5, 6.5 ,6.7 and 6.9, the earthquake epicenters: at Kamloops coordinate location and the location coordinates of three (3) different past earthquake events that have happened at places near Kamloops, and the liquefaction and landslide vulnerability levels. These variables are analyzed using the HAZUS-MH 2.1 software methodology to estimate potential earthquake damage results for Kamloops which includes: damaged buildings count, the damage levels expected (none, slight, moderate, extensive or complete) and damage costs expressed in Canadian dollars ($).

Narrow regional studies are completed for three (3) distinct geographical areas in Kamloops: Aberdeen, Northshore and Downtown areas because of the geotechnical reports in these places and their importance to Kamloops - population and economic contributions.

It is hoped that the damage results from the simulations will assist Kamloops city planners in creation of earthquake response plans.

KEYWORDS: Earthquake, Building damage, Kamloops

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LIST OF ABREVIATIONS

M_w	Moment magnitude
GMPE	Ground Motion Prediction Equation
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
Sa	Spectral acceleration
PSHA	Probabilistic Seismic Hazard Analysis
DSHA	Deterministic Seismic Hazard Analysis
HAZUS-MH 2.1	HAZUS – Multi Hazard 2.1
AS08	Abrahamson and Silva 2008
BA08	Boore and Atkinson 2008
NBCC	National Building Code of Canada
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
NEHRP	National Earthquake Hazard Reduction Program
PSA	Peak Spectral Acceleration
NGA	Next Generation Attenuation
US PEER	United States Pacific Earthquake Engineering Research

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DEDICATION

This thesis is dedicated to God almighty (GOD OF IMPOSSIBILITIES) and in loving memory of Mrs. Chinenye Laura Onwuasomba

TERMS USED FOR THIS STUDY

Damage cost analysis

The estimation of value of building damage to be expected from a specified earthquake scenario in a way to point out the vulnerability level of a studied area and show how much mitigation is needed (Nastev 2014; Ulmi et al. 2014) .

Earthquake magnitude and Ground motion intensity

Earthquake scenarios can be expressed in terms of the amount of seismic energy released (magnitude) or by how it is perceived in the surrounding earth crust (ground motion intensity) (Journeay et al. 2015). The amount of energy released can be measured by moment magnitude, M_w (Ulmi et al. 2014); while the intensity of ground motion can be estimated by the ground's response using the parameters: peak ground acceleration (PGA), peak ground velocity (PGV) or spectral acceleration (Sa) at different times/frequencies (Journeay et al. 2015).

Earthquake scenario

The earthquake event used for damage cost analysis (Ulmi et al. 2014). There are two approaches to specifying earthquake scenario for damage cost analysis: Probabilistic Seismic Hazard Analysis (PSHA) and Deterministic Seismic Hazard Analysis (DSHA).

Probabilistic Seismic Hazard Analysis (PSHA)

Earthquake magnitudes and probability are chosen from published earthquakes expected for the study area. The Seismic hazard map database provided by the Natural Resources Canada provides justified data to be used for analysis of earthquakes in different places across Canada.

Deterministic Seismic Hazard Analysis (DSHA)

Involves the use of hypothetical scenarios to analyze and predict the performance of the study area should a similar event occur in the future (J.M. Journeay et al. 2015). This approach is used to produce more detailed assessments of risks and potential damage costs facing the study area and guide mitigation decisions.

Ground Motion Prediction Equation (GMPE)

Ground Motion Prediction Equations (GMPEs) are expressions of the attenuation relationship between earthquake magnitude, fault and fault characteristics, location and other site information that will mimic the qualities of a real ground motion event for a specified area (Kaklamanos, Baise, and Boore 2011).

Potentially induced hazards

These are possible additional hazards triggered by an earthquake in the study area e.g. liquefaction and landslide. The possibility of additional damage contribution from liquefaction and landslide are included in earthquake damage estimation using their susceptibility index or ratings.

Liquefaction Susceptibility Index (LSI)

The Liquefaction Susceptibility Index (LSI) rates the chance of liquefaction occurring at a particular seismic acceleration given the soil condition of the area from 0 to 5 (Bird et al. 2006), where zero (0) means no liquefaction will occur.

Landslide Susceptibility rating

The software describes the landslide probability by the range from low (0) to very high (10), zero (0) means no chance of landslide occurring.

Damage levels

HAZUS-MH 2.1 predicts damage to buildings by 5 damage levels: None, slight, moderate, extensive and complete

Building inventory

This study focuses on the general building stock; which consist of the building qualities (material, age, height etc.) and usage types (industrial, residential, educational etc.) in the study area (Federal Emergency Management Agency 2015).

Census tract and Dissemination areas

Census tracts are geographical units used to represent small areas of similar socioeconomic characteristics and population ranging between 2,500 and 8,000 the census tracts are further broken-down to smaller geographical levels like census dissemination areas or neighborhoods (Statistics Canada).

Chapter 1. INTRODUCTION

General

Kamloops is situated in the Thompson Nicola regional district of the Thompson - Okanagan in British Columbia (BC Government 2011). Kamloops is the main location within the regional district for most businesses, mining, industries and important infrastructures like government buildings and colleges/university which attract more people to the city (City of Kamloops 2015). Kamloops is also referred to as a "hub city" due to its connection to four highways (Trans-Canada, Highway 5, Yellowhead and Highway 97), available railways and the airport that serve Kamloops and the neighboring communities (City of Kamloops 2015). Due to its usefulness and economic functions, most communities within the district depend on Kamloops. Earthquake damage or disruption in the city will affect Kamloops and the communities that depend on it. People can get hurt or lose their lives, or can be affected in other ways, such as business / livelihood damages, property losses or other forms of city function disruption.

Kamloops is described as a region of moderate seismicity (Onur 2004; Onur and Seemann 2008); and moderate seismicity implies a high chance for moderate magnitude earthquakes which could range from 5 to 6.9 ($5 \leq M_w \leq 6.9$). Moderate magnitude earthquakes can damage buildings with inadequate seismic resistance (Adams 2011); or have the ability to produce high ground motion intensity that can affect nearby buildings (Arnold 2014; Foti 2015). Higher magnitude earthquakes can happen in a place that had lower magnitudes in the past (Atkinson et al. 2015). Kamloops seismicity is believed to be caused by natural crustal movements within the North American plate (Dostal et al. 2001; Dostal et al. 2003; Onur 2004; Halchuk, Adams, and Anglin 2007).

Recently, on the 16th of December 2015, an earthquake occurred near Kamloops with magnitude of 3.4; located 18 kilometers east of Ashcroft (Natural Resources Canada 2015). Other earthquakes have been reported near Kamloops in the past but none caused physical damage (Natural Resources Canada 2016). However, there is a chance that future earthquakes could occur with higher than past-experienced magnitudes and cause damage to Kamloops.

Buildings built prior to modern seismic design (built earlier or within the 1980s) are more vulnerable to earthquake damage than the newer buildings (Kovacs 2010; J.M.

Journeay et al. 2015). More than 55% of buildings in Kamloops were built by 1980 (City of Kamloops 2011). (see figure1-1). However, there is limited knowledge of the degree of mitigation (whether complete reconstruction or the addition of structural supports) required by the existing older buildings in Kamloops. Earthquake damage estimation for Kamloops will provide better understanding of the potential physical/economic risks that Kamloops could face if higher magnitude than the previous earthquakes happen in the future; and guide the choice of mitigation against future occurrence.

In this research, the HAZUS-MH 2.1 loss estimation methodology will be used to estimate earthquake damage to building inventory in the Kamloops area.

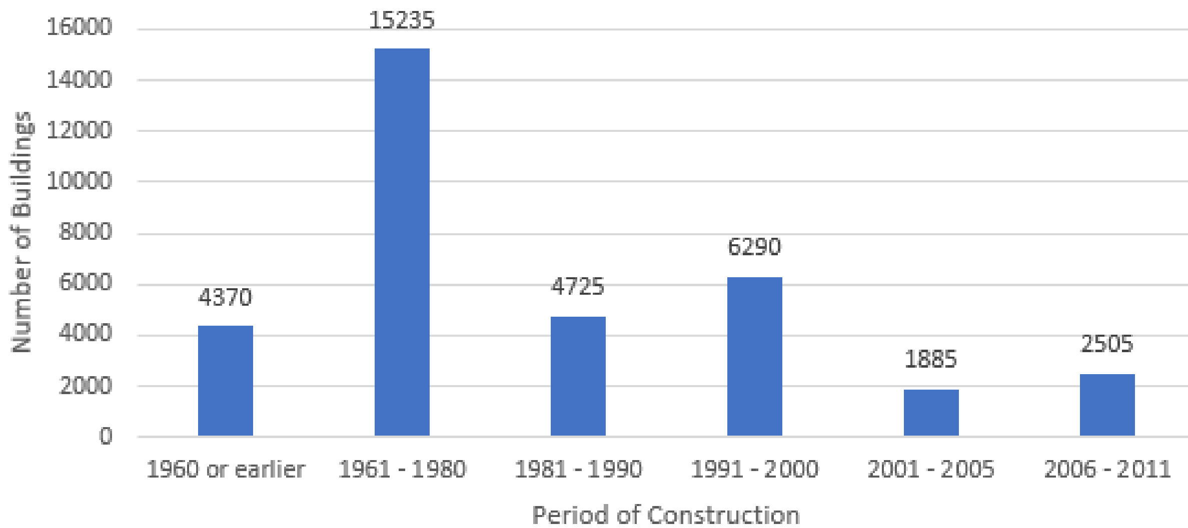


Figure 1-1. Kamloops dwellings by period of construction (City of Kamloops 2011)

Statement of the Problem

Kamloops has experienced some earthquakes in the past. From reports on the Natural Resources Canada website, earthquakes felt within or near Kamloops between 1985 to 2015, ranged from 2.1 – 3.7 magnitudes (Halchuk 2009; Natural Resources Canada 2016). None of the reported earthquakes have posed any direct threat, which could affect the judgement of earthquake risks in Kamloops or the need for mitigation. This study will help to estimate the possible damage impacts that can arise from a moderate earthquake occurrence in the future. For crustal earthquake events in western Canada, the local magnitude, M_L (Table 1-1) below is the same as moment magnitude, M_w (Goda, Hong, and Atkinson 2010). Depth, Table 1-1, is measured in in kilometers, however “g” – denotes assigned depth or fixed by seismologist.

Date	Time(UT)	Lat	Long	Depth	Magnitude	Region and Comment
2015/12/16	09:48:17	50.828	-121.008	5.0g	3.4ML	51 km WNW of Kamloops
2003/07/09	05:12:23	50.221	-120.466	5.0g	2.1ML	Near Merritt
1993/09/19	11:24:04	50.175	-120.359	10.0g	3.7ML	Southern British Columbia near Merritt. Felt

Table 1-1 Earthquakes felt in Kamloops (www.earthquakescanada.nrcan.gc.ca).

S/N	Place Description	Latitude	Longitude	Approx. Distance from Kamloops, (Km)
1	WNW of Kamloops	50.828	-121.008	52
2	Near Merritt	50.221	-120.466	55
3	Near Merritt (south B.C)	50.175	-120.359	58

Table 1-2. Distance of past near earthquakes from Kamloops.

Regional and Study Area Seismicity

British Columbia is considered as the province with the highest seismic risks in Canada. The main contributors of the high seismic risks are the subducting ocean plates at the Cascadia subduction zone, offshore fault lines, and crustal movements/activities (Earthquakes Canada 2016). These risk contributors affect places within the province differently, some places like the interior cities are affected chiefly by crustal movements, while places like the lower main land areas are affected by all 3 causes (Cascadia subduction, offshore fault lines and crustal movements) (Goda, Hong, and Atkinson 2010; Earthquakes Canada 2016). Hence, different parts of British Columbia are grouped in to seismic source zones. These groupings are used to identify the likely causes and characteristics of earthquakes that can be expected for each location (Goda, Hong, and Atkinson 2010). In earthquake modelling or earthquake damage estimation, the earthquake's epicenter can be chosen randomly within areas of same zone; since, it is assumed that there is an equal chance of the same earthquake magnitude occurrence spread uniformly under each zone (Goda, Hong, and Atkinson 2010).

Kamloops falls within the South-West Canada crustal area source zone (Halchuk et al. 2014; Halchuk, Adams, and Allen 2015) where the main earthquake hazards are the small near earthquakes at short period and the large distant earthquakes at long period (Adams and

Atkinson 2003; Adams and Halchuk 2003; Halchuk, Adams, and Anglin 2007). These earthquakes are mostly shallow crustal earthquakes. Details of the location of fault lines for crustal earthquakes in British Columbia are unclear, but reports from Natural Resources Canada and other publications agree on the presence of offshore fault lines (J.M. Journeay et al. 2015; S Halchuk, Adams, and Allen 2015; Earthquakes Canada 2016). It is believed that the occurrence of some shallow crustal earthquake events in different cities across British Columbia could be possible indicators of the presence of blind active faults (Molnar et al. 2014). Molnar et al. 2014 inferred from examination of past earthquake patterns that the likely fault orientation for most large shallow crustal earthquakes in British Columbia are the strike-slip or thrust fault style.

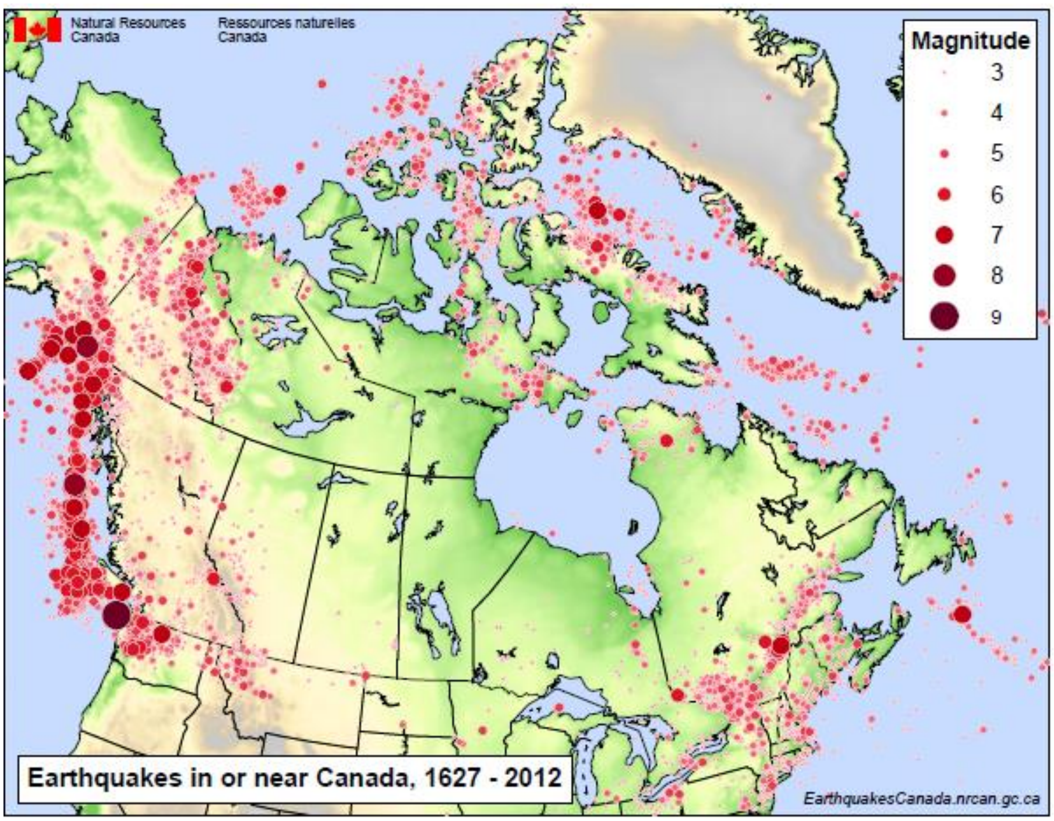


Figure 1-2. Map showing earthquakes in Canada (Earthquakes Canada 2009).

Kamloops Area

Kamloops coordinate location is on latitude 50.70° N and longitude -120.30° W; and it has a population of over 90,000 people (BC Stats 2015). Kamloops is classified as a

Census Agglomeration (CA) based on its population size and the distribution of the population (Statistics Canada). A greater percentage of the buildings in Kamloops are residential, 58.3% of which are single detached buildings, 16.3% apartment buildings and 6.4% duplexes (Statistics Canada 2012).

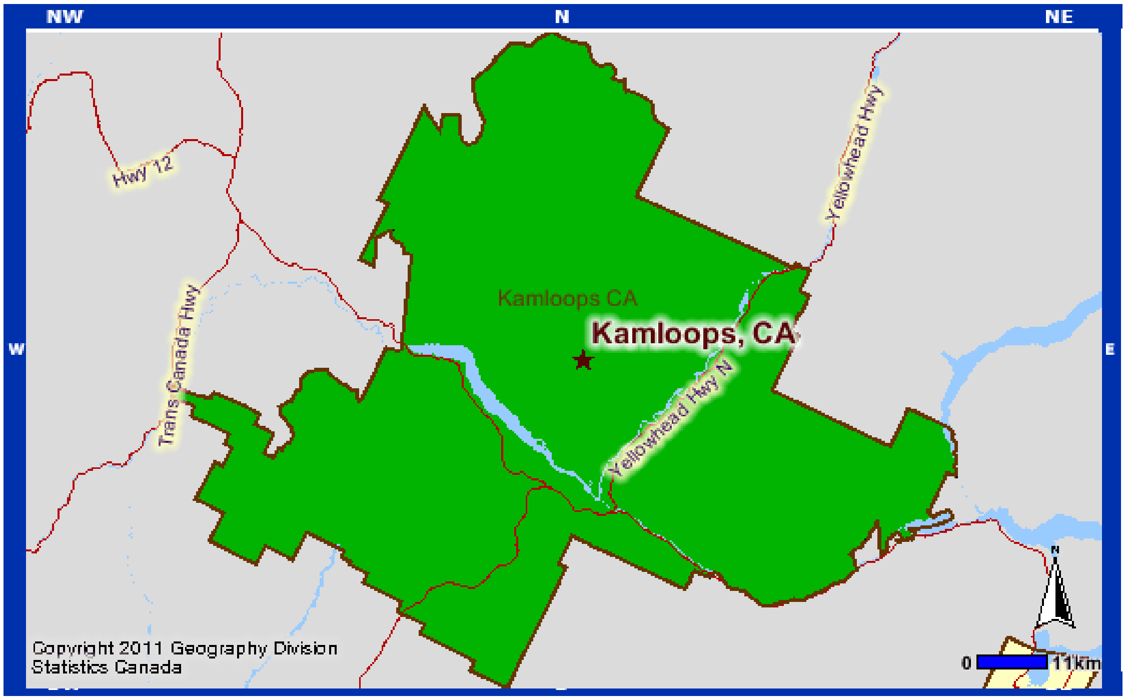


Figure 1-3. Map of Kamloops area (Statistics Canada 2012)

Many buildings in Kamloops, like other cities across Canada, were built prior to modern seismic design; studies have been directed towards continuous improvements in the National Building Code of Canada (NBCC) seismic design requirements making newer buildings relatively more resistant to earthquakes (Allen, Adams, and Halchuk 2015).

The first NBCC, which was published in the early 1960s (Meligrana 2003), has since undergone many historical developments (Allen, Adams, and Halchuk 2015); but there are increasing concerns for the buildings built prior to the first code and for the buildings built with older codes (before 1980) (Adams 2011). Over 55% of the residential buildings in Kamloops were constructed by 1980, and more than 600 dwellings were built between 1947 and 1959 (Meligrana 2003); up to 45% of the private buildings in the Downtown area were built by 1960 (City of Kamloops 2011).

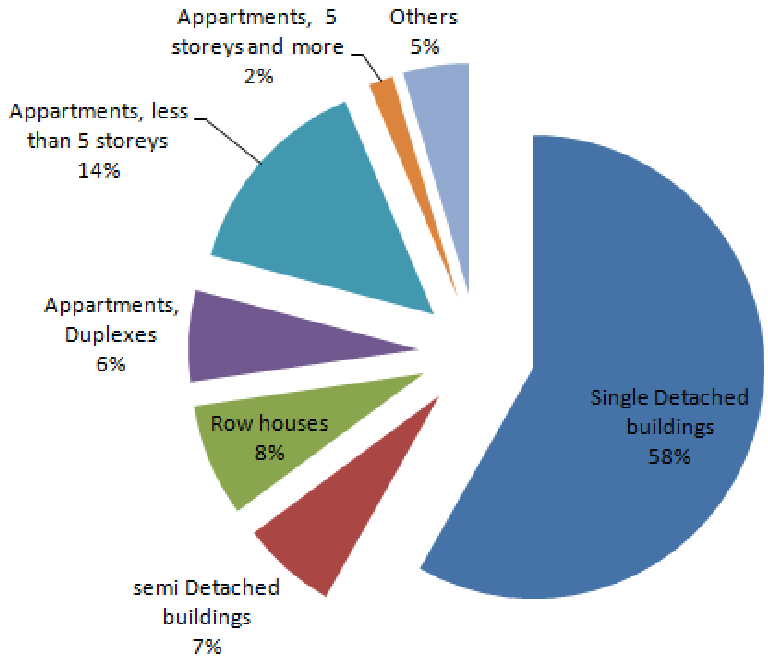


Figure 1-4. Distribution of Kamloops residences (dwellings) by building type (Statistics Canada 2012)

According to a study on the implications of code improvements and mitigation done by Adams (2011); it was found that highly seismic communities with high mitigation requirements will recover from earthquakes better than moderate seismic communities if adequate mitigation is not used. With the background of the previous studies, it will be beneficial for damage cost analysis be done for Kamloops to understand the extent of mitigation (whether complete reconstruction or the addition of structural supports) required.

Scope of study

The goal of damage cost analysis is to support mitigation options and identify areas likely to incur the biggest losses (high vulnerability) (Federal Emergency Management Agency 2012; Ulmi et al. 2014). High building damage costs indicate high vulnerability from an earthquake event (Croope 2009; Federal Emergency Management Agency 2012). Two analysis approaches: probabilistic seismic hazard analysis (PSHA) and deterministic seismic hazard analysis (DSHA) are used to estimate the potential building losses. This thesis is based on the HAZUS-MH 2.1 building inventory for Kamloops region with over 31 thousand buildings (HAZUS REPORT). The Kamloops region for this study is defined by the list of census neighborhood / dissemination tracts that form the Kamloops census agglomeration (CA) region and so extends beyond the Kamloops city area. This study focuses on buildings only; other important units like people population (demographics) and transportation facilities (roads, bridges) are excluded in this study.

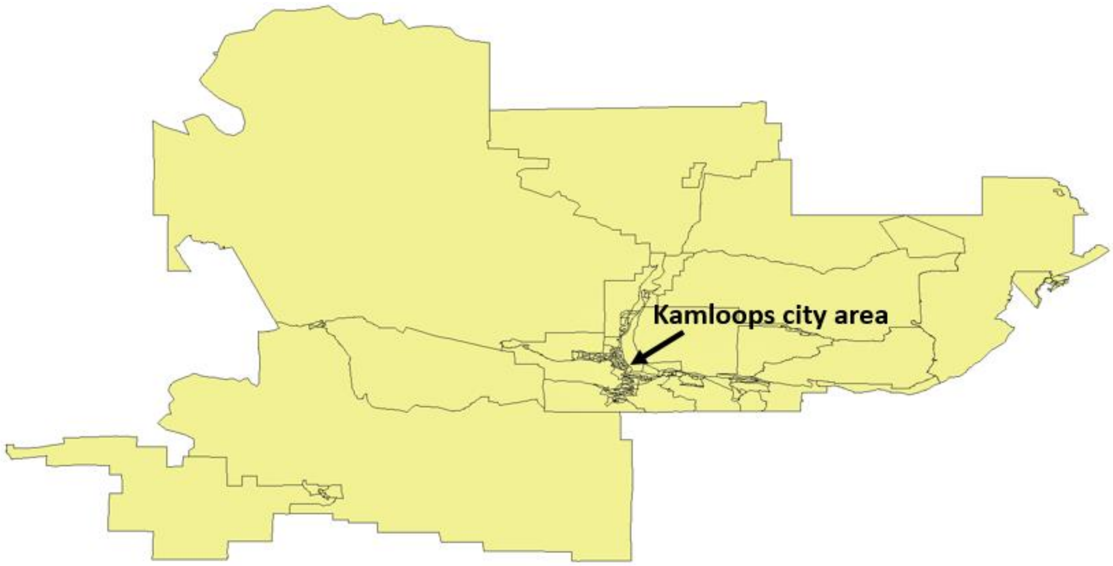


Figure 1-5. Kamloops region map showing the neighborhood tracts (created in HAZUS-MH 2.1)

The HAZUS-MH 2.1 building inventory for this study is derived from a collection of the data on buildings found within the Kamloops region. The building data are organized by:

1) Building occupancy (residential, commercial, industrial etc.); HAZUS-MH 2.1 use 33 occupancy codes to identify the unique usage description of buildings. The type of building occupancy is used to understand the building's function and the estimate the possible contents worth. (Table 1-2)
2) Building material type (wood, concrete, steel etc.); which are identified in the software using codes according to the construction description- height and style of building construction. (Table 1-3)
3) Building age/code based on the year the building was built (pre-code , low-code, moderate-code and high-code) (Ulmi et al. 2014; Federal Emergency Management Agency 2015). In this thesis, pre-code buildings refer to buildings built before 1941, low-code buildings refer to those built between 1941-1969, moderate-code buildings refer to buildings constructed between 1970 -1989, high-code buildings refer to those built after 1990. (see Table 1-4).

Damage results for this study are outlined according to their damage levels; which, are grouped into 5 damage levels: None, slight, moderate, extensive and complete (Federal Emergency Management Agency 2015).

General Building Stock Classification

Building Occupancy Classes | Model Building Types

Table

	Occupancy	General Occupancy	Description
1	AGR1	Agriculture	Agriculture
2	COM1	Commercial	Retail Trade
3	COM10	Commercial	Parking
4	COM2	Commercial	Wholesale Trade
5	COM3	Commercial	Personal and Repair Services
6	COM4	Commercial	Professional/Technical Services
7	COM5	Commercial	Banks
8	COM6	Commercial	Hospital
9	COM7	Commercial	Medical Office/Clinic
10	COM8	Commercial	Entertainment & Recreation
11	COM9	Commercial	Theaters
12	EDU1	Education	Grade Schools
13	EDU2	Education	Colleges/Universities
14	GOV1	Government	General Services
15	GOV2	Government	Emergency Response
16	IND1	Industrial	Heavy
17	IND2	Industrial	Light
18	IND3	Industrial	Food/Drugs/Chemicals
19	IND4	Industrial	Metals/Minerals Processing
20	IND5	Industrial	High Technology
21	IND6	Industrial	Construction
22	REL1	Religion	Churches and Other Non-profit Org.
23	RES1	Single Family	Single Family Dwelling
24	RES2	Residential	Manuf. Housing
25	RES3A	Residential	Duplex
26	RES3B	Residential	Triplex / Quads
27	RES3C	Residential	Multi-dwellings (5 to 9 units)
28	RES3D	Residential	Multi-dwellings (10 to 19 units)
29	RES3E	Residential	Multi-dwellings (20 to 49 units)
30	RES3F	Residential	Multi-dwellings (50+ units)
31	RES4	Residential	Temporary Lodging
32	RES5	Residential	Institutional Dormitory
33	RES6	Residential	Nursing Home

Table 1-3. Description of the 33 occupancy codes used by the HAZUS MH-2.1 software

General Building Stock Classification

Building Occupancy Classes | **Model Building Types**

Table

	Building Type	General Building Type	Description
1	C1H	Concrete	Concrete Moment Frame High-Rise
2	C1L	Concrete	Concrete Moment Frame Low-Rise
3	C1M	Concrete	Concrete Moment Frame Mid-Rise
4	C2H	Concrete	Concrete Shear Walls High-Rise
5	C2L	Concrete	Concrete Shear Walls Low-Rise
6	C2M	Concrete	Concrete Shear Walls Mid-Rise
7	C3H	Concrete	Concrete Frame with Unreinforced Masonry Infill Walls High-Rise
8	C3L	Concrete	Concrete Frame with Unreinforced Masonry Infill Walls Low-Rise
9	C3M	Concrete	Concrete Frame with Unreinforced Masonry Infill Walls Mid-Rise
10	DFLT	DFLT	Default (Wood)
11	MH	MH	Manufactured Home
12	PC1	Precast	Precast Concrete Tilt-Up Walls
13	PC2H	Precast	Precast Concrete Frames with Concrete Shear Walls High-Rise
14	PC2L	Precast	Precast Concrete Frames with Concrete Shear Walls Low-Rise
15	PC2M	Precast	Precast Concrete Frames with Concrete Shear Walls Mid-Rise
16	RM1L	RM	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms Low-Rise
17	RM1M	RM	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms Mid-Rise
18	RM2H	RM	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms High-Rise
19	RM2L	RM	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms Low-Rise
20	RM2M	RM	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms Mid-Rise
21	S1H	Steel	Steel Moment Frame High-Rise
22	S1L	Steel	Steel Moment Frame Low-Rise
23	S1M	Steel	Steel Moment Frame Mid-Rise
24	S2H	Steel	Steel Braced Frame High-Rise
25	S2L	Steel	Steel Braced Frame Low-Rise
26	S2M	Steel	Steel Braced Frame Mid-Rise
27	S3	Steel	Steel Light Frame
28	S4H	Steel	Steel Frame with Cast-in-Place Concrete Shear Walls High-Rise
29	S4L	Steel	Steel Frame with Cast-in-Place Concrete Shear Walls Low-Rise
30	S4M	Steel	Steel Frame with Cast-in-Place Concrete Shear Walls Mid-Rise
31	S5H	Steel	Steel Frame with Unreinforced Masonry Infill Walls High-Rise
32	S5L	Steel	Steel Frame with Unreinforced Masonry Infill Walls Low-Rise
33	S5M	Steel	Steel Frame with Unreinforced Masonry Infill Walls Mid-Rise
34	URML	URM	Unreinforced Masonry Bearing Walls Low-Rise
35	URMM	URM	Unreinforced Masonry Bearing Walls High-Rise
36	W1	Wood	Wood, Light Frame (= 5,000 sq. ft.)
37	W2	Wood	Wood, Commercial and Industrial Wood (>5,000 sq. ft.)

Table 1-4. List of building construction types used in the HAZUS MH-2.1 software

	Year Built				
Building Type	**2005-Onward**	**1990-2004**	**1970-1989**	**1941-1969**	**Pre-1941**
Wood, Steel, or Concrete		**HS** (Special High-Code)	**MS** (Special Moderate-Code)	**LS** (Special Low-Code)	
Masonry, Mobile, Others		**HC** (High-Code)	**MC** (Moderate-Code)	**LC** (Low-Code)	
All Building Types	**HS** (Special High-Code)				**PC** (Pre-Code)

Table 1-5. Building construction age (Ulmi et al. 2014)

Earthquake damage impact factors

These are factors that determine how an earthquake will affect an area. To understand earthquake damage results, it is important to consider the factors that can influence the impact of earthquakes on an area. The earthquake size, distance, soil profile and geology will determine the level of shaking and damage that can result.

Earthquake size

Earthquake size can be expressed in terms of the amount of seismic energy released (magnitude) or by how it is perceived (ground motion intensity) (Journeay et al. 2015). The amount of released can be measured by moment magnitude (M_w) (Ulmi et al. 2014); while the intensity of ground motion can be estimated by the ground's response using the parameters: peak ground acceleration (PGA), peak ground velocity (PGV) or spectral acceleration,Sa at different periods (Journeay et al. 2015). Ground's response varies based on the distance from the source, soil condition and other geologic attributes of the area (Journeay et al. 2015).

HAZUS-MH 2.1 software analyses earthquake magnitude as moment magnitude or with the use of ground intensity parameters: peak ground acceleration (PGA), peak ground velocity (PGV) and spectral acceleration at 0.3seccs and 1.0secs. (Federal Emergency Management Agency 2012; Ulmi et al. 2014). The HAZUS-MH 2.1 software methodology use fundamental periods, of 0.3 seconds and 1 second to analyze the lateral responds of short buildings (1-3 storey-buildings) and tall buildings respectively following the design provision in the National building code of Canada (Office of Housing and Construction Standards and National Research Council Canada 2012).

Distance

During an earthquake, ground motion waves travel through the soil to the base of buildings (Arnold 2014). Buildings closer to the epicenter will feel higher ground motion intensity than farther buildings (Arnold 2014; Foti 2015); hence, buildings nearer to an earthquake epicenter will suffer more damage from the same earthquake event.

Geology

Geology is an important factor for assessing earthquake damage for an area. It also used to estimate likely susceptibilities to other induced hazards like liquefaction and landslides.

Kamloops lies at the meeting of two major rivers (West flowing South Thompson river and South flowing North Thompson river) with a cross section of different elevations

Era	Period	Epoch	Years Ago
Cenozoic	Quaternary	Holocene	
			11,700
		Pleistocene	
			2.6 M
	Tertiary	Pliocene	
		Milocene	
		Oligocene	
		Eocene	
		Paleocene	
			65.5 M
Mesozoic	Cretaceous	Late	
		Early	
			145 M
	Jurassic	Late	
		Middle	
		Early	
			200 M
	Triassic	Late	
		Early	
			251 M
Paleozoic			

Table 1-6. Geologic time scale (Wair, Dejong, and Shantz 2012).

from the shores of the Thompson rivers to valleys and plateaus across the Kamloops area landscape (Turner et al. 2008). Within the Kamloops area elevations range from below 700m in the low lands and up to more than 1500m for high land both measured above sea level (Fulton 1967). The Thompson rivers carry sediments leading to stretches of alluvial soil (mixture of few gravel, sand and silt) on the sides of the rivers (Mathews and Monger 2005). The main earth materials found in Kamloops area are grouped into: rocks, ice age silts and river eroded sediments (Turner et al. 2008); a large part of the land area is covered with alluvial deposits and the rest by rocks (Turner et al. 2008). The rock forms found around Kamloops are mainly sedimentary and volcanic rocks ranging from basalt to rhyolite (Dostal et al. 2003).

Kamloops lies within the inter-montane belt with Eocene bedrock features which is common in most cities in the interior of British Columbia (Mathews and Monger 2005). Some of the rocky areas of Kamloops are overlain by Eocene igneous rocks running from

NW United States up into British Columbia, passing through Kamloops (Challis-Kamloops belt) up to the south of Yukon and Alaska (Dostal et al. 2003). Isolated Eocene sedimentary rocks like shale occur at few places along the North Thompson river (Mathews and Monger 2005). Sandy gravel deposits within Downtown, and some other parts are covered by glacial sediments (Fulton 1976). Most of the built-up areas within the Thompson river valley floors are covered by alluvial soil (Fulton 1976; Mathews and Monger 2005); which is commonly found on near rivers. Places along the sides of the Thompson rivers: Brocklehurst, North shore, Westsyde lie within the alluvial plain, landslide deposits are found around elevated areas; there are also places with exposed rocks on the higher elevations (Fulton 1967).

Soil group

The characteristics of soil in the study area play an important role in the conduction of earthquake wave, since in certain soils the rate of travel is faster than in others. These soils conditions are grouped by letters, (A – F) using the National Earthquake Hazard Reduction Program (NEHRP) table, which is adopted by Canada from the United States System (Ploeger, Atkinson, and Samson 2010). The soil group is determined by where the average shear wave velocity, V_S falls on the table. Soil properties like the shear wave velocity (V_S) and the depth of soil layer affects the transmission rate of waves and intensity of ground motion (Wair, Dejong, and Shantz 2012); which are important considerations for damage estimation.

Soil Group	Name of Soil Profile	Average Shear Wave Velocity, V_{S30} (m/s) in top 30m
A	Hard Rock	$V_{S30} > 1500$
B	Rock / Firm soil	$760 < V_{S30} \leq 1500$
C	Very dense soil / Soft Rock (sandstone / limestone)	$360 < V_{S30} < 760$
D	Stiff Soil (sand, silt, gravel etc.)	$180 < V_{S30} < 360$
E	Soft Soil (artificial fill and water saturated earth)	$V_{S30} < 180$
F	Other Soil	Sensitive soil (Examination of soil required).

Table 1-7. soil classification table (FEMA 2015).

Soils are classified using the shear wave velocity at the top 30m of soil (V_{S30}). The top 30m is used in engineering design to give an approximate representation of the full soil profile shear wave velocity (Abrahamson and Silva 2008).

V_{S30} is used to estimate total time expected for shear wave to travel through each soil layer from a depth of 30m to the ground surface (Wair, Dejong, and Shantz 2012). The lower shear wave velocity soil group (Soft soils) e.g. soil group E and F will increase ground shaking during an earthquake since earthquake waves take longer time travelling through soft soils than rock soils or higher shear wave velocity soils (group A and B). The longer the time it takes, the bigger the wave grows causing more ground shaking. Therefore, the soil (Soft soils) are likely to suffer more severe ground movement than the rest of the groups. Shear wave velocity (V_{S30}) values is preferably derived by on-site/ field assessment. However, where direct or on-site assessment of shear wave velocity (V_{S30}) is unavailable, suitable V_{S30} value can be selected from published data with similar geologic characteristics (Wills and Clahan 2006; Wair, Dejong, and Shantz 2012).

Shear wave velocity (V_{S30}) can also be calculated from equations like the shear wave velocity–depth equation using the surficial geology information (geologic time scale, soil material at each layer and the depth of each layer) (Wair, Dejong, and Shantz 2012; Nastev et al. 2016) . The shear wave velocity–depth equation:

$$V_{S30} = \frac{30}{\Sigma\left(\frac{d}{V_S}\right)} \qquad \text{Equation 1-1}$$

where d is the depth of soil layer, V_S is the shear wave velocity for soil layer.

Research Goals

Presently, there is a growing need for mitigation against future earthquakes (Bendimerad 2001; Tantala et al. 2008) which is common in high risk areas. The high earthquake risk in places like the lower main land of British Columbia have resulted in many earthquake damage estimation studies geared at calculating the probabilities and potential earthquake consequences (Seemann, Onur, and Cloutier-Fisher 2011; J.M. Journeay et al. 2015; Journeay et al. 2015). Damage estimation provides the needed understanding of potential earthquake consequences to arrive at suitable mitigation planning / management strategies (Nastev 2014).

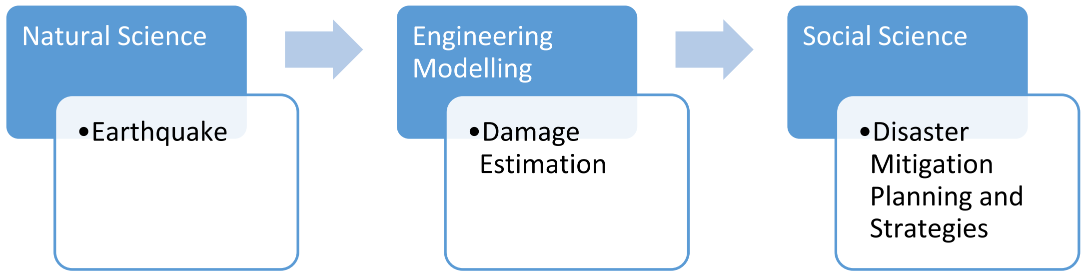


Figure 1-6. Role of damage estimation

Most of these studies use geographic information system (GIS) based software tools capable of mimicking real life ground motion events to predict potential damage (Bendimerad 2001). Case studies like the District of North Vancouver and the Municipality of Squamish, applied the HAZUS-MH 2.1 methodology successfully for earthquake damage estimations with results for socioeconomic losses, building damage potential and expected casualties (J.M. Journeay et al. 2015; Journeay et al. 2015). Both case studies identified the presence of aging infrastructure as one of causes of damage results. A greater percentage of predicted damage in both studies were from the residential sector with higher proportion of coming from the wood framed single family detached buildings. Mitigation recommendations were also tailored to the results from their studies (J.M. Journeay et al. 2015; Journeay et al. 2015).

The HAZUS-MH 2.1 methodology process involves the modelling of the ground motion to estimate damage results (Journeay et al. 2015). The results are then used to assess the study area's earthquake resilience capacity / mitigation needs (Journeay et al. 2015). In earthquake damage estimation, the contribution of possible earthquake caused hazards, e.g., liquefaction and landslide susceptibility are also assessed (Federal Emergency Management Agency 2012).

The way buildings are affected by an earthquake are described by their damage states (Federal Emergency Management Agency 2015). Buildings with no damage impact are classified under – None. Other damage states: slight, moderate, extensive and complete are used to describe the extent of damage or amount of repair required (Federal Emergency Management Agency 2012; Federal Emergency Management Agency 2015). Where complete damage is predicted, a total reconstruction would be needed (Federal Emergency Management Agency 2012; Federal Emergency Management Agency 2015). Damage is also assessed in HAZUS-MH 2.1 by the building occupancy classification, which is used to predict the value of the contents and other economic losses that could potentially happen if an earthquake were to occur in the future (Federal Emergency Management Agency 2015).

To perform this kind of study, appropriate earthquake scenario(s) would be needed. However, there are uncertainties associated in specifying adequate earthquake scenario(s) for a place like Kamloops; uncertainties with magnitude, location of epicenter and even the nature of ground motion that would be expected. For these reasons, more than one earthquake scenarios are required to reduce these uncertainties (Atkinson 2012).

Using the HAZUS-MH 2.1 software, different earthquake scenarios were developed for the Kamloops area with the aim of answering the following questions:

1) How many buildings would be damaged in each earthquake scenario? The damaged building estimates will give an idea of what to expect from each scenario and identify which building characteristics will produce the most damage; e.g. if a particular building material type (wood, concrete, etc.) suffers extensive to complete damage (Croope 2009).
2) Which of the occupancy types would be most affected? The different occupancy types (Residential, Commercial, Industrial, Agricultural, Religious, Governmental and Educational) determines the costs of damaged contents (Federal Emergency Management Agency 2012). For example, the cost of damaged contents for commercial occupancy is expected to be greater than residential occupancy (Federal Emergency Management Agency 2012. The occupancy results based on the level of damage will help with better understanding of the earthquake risks and the cost-benefits of mitigation (Adams 2011).
3) Lastly, which place(s) or part of Kamloops would incur the most damage costs? The identification of the vulnerable areas will help ensure that adequate mitigation is arranged for such place(s).

Description of the HAZUS-MH 2.1

There are different software tools that use geographic information systems (GIS) platform for earthquake damage estimation; one of them is the HAZUS-MH 2.1 software, which was created by the US National Institute of Building Science (NIBS) and US Federal

Emergency Management Agency (FEMA) as a controlled method for calculating losses from natural disasters like earthquakes, floods and hurricanes (Ulmi et al. 2014).

The HAZUS Multi-Hazard software has various US versions developed from ongoing improvement activities by FEMA. The HAZUS-MH 2.1 is one of the updated versions, and the Natural Research Council of Canada signed an agreement with FEMA in 2011 to develop a Canadian version adapted for earthquake loss estimation in Canada (Nastev 2014; Ulmi et al. 2014). The Canadian version of the HAZUS-MH 2.1 has Canadian census inventory, Canadian building arrangement data, Canada's geographic terminologies and earthquake data based on studied events and recommendations from the National Building Code of Canada (Ulmi et al. 2014). The HAZUS-MH 2.1 runs on Arc GIS 10.0, which is a GIS software that enables its efficient analysis of geographical database and transmission of loss estimate results (Ulmi et al. 2014). The software has a collection of earthquake attenuation functions also referred to as ground motion prediction equations (GMPE) used to develop ground shaking for a study area.

The HAZUS Multi-Hazard methodology has been successfully used for earthquake damage estimations with results for socioeconomic losses, building damage potential and expected casualties in different communities across Canada, e.g., the District of North Vancouver (Journeay et al. 2015), Downtown Ottawa (Ploeger, Atkinson, and Samson 2010) and Squamish District (Murray Journeay et al. 2015). Mitigation recommendations were also tailored to the results from their studies.

In an effort to increase my understanding of the HAZUS-MH 2.1 methodology, I tried reproducing the Squamish report; which is a collaborative study between the district municipality of Squamish and scientists from Natural resources Canada to estimate potential threats from Natural disasters (Earthquakes, flood, debris flow) (Journeay et al. 2015). I chose this report because it was done for a place situated in the same province (British Columbia) as my study area. However, the Squamish district is situated at the South western British Columbia, nearer to the Lower Mainland while Kamloops is situated in the interior.

From the report, the choice of inputs is selected from peer reviewed appropriate inputs for the Squamish area. The Boore and Atkinson 2008 (BA08) ground motion prediction equation (GMPE) was used for the Squamish study unlike the chosen attenuation function for this Kamloops study - Abrahamson and Silva 2008 (AS08), discussed later in chapters 2 and 3. The same BA08 ground attenuation function was also used for a similar study (earthquake damage estimation) for the District of North Vancouver.

In the HAZUS-MH 2.1 methodology, earthquakes scenario specification could be in form of ground motion maps (if available) or by computing hazard values that describes the earthquake scenario (Ulmi et al. 2014; Federal Emergency Management Agency 2015). In the same vein, this study will follow similar methodology to estimate earthquake damage cost to building inventory in Kamloops.

Research design

This study involves GIS-based modelling of earthquake scenarios over the Kamloops area. The Kamloops study area is created in HAZUS-MH 2.1 software by the aggregation of the HAZUS-MH 2.1 tract (list of census dissemination areas) identification codes that define the Kamloops area. The census dissemination identification codes are converted to their respective HAZUS-MH 2.1 tract identification codes. The building inventory (occupancy, building characteristics, etc.) for each tract are added automatically from the database of the software just by selecting the tract codes that define the study area. The software's building inventory data are based on the Census 2006 information (Ulmi et al. 2014). The use of recent census information is ideal, however buildings built from 1990 and beyond 2005 with the 2005 National Building Code or with more recent codes are considered "high-code" buildings (Ulmi et al. 2014). High-code buildings are the least likely to suffer damage unlike "low-code" (1941-1969) and pre-code (pre 1941) buildings (Goda, Hong, and Atkinson 2010; Ulmi et al. 2014; Allen, Adams, and Halchuk 2015).

Other additional inputs like earthquake scenario inputs (magnitude, fault etc.) and induced hazard susceptibility (liquefaction and landslide susceptibility) are selected in the software. Different epicenters are chosen as follows: at the center of Kamloops and the others at the coordinate locations of different past earthquake events that occurred near Kamloops (coordinates of the past WNW of Kamloops, Southern BC and near Merritt earthquake events) details in Table 1-1 above. This study considers damage results for the entire Kamloops census area and excludes the possible impacts on surrounding towns. The choices of epicentral locations does not exclude the possibility of future occurrences at other locations. The inputs for this study are derived theoretically from reviewed publications with the help of the HAZUS-MH 2.1 manual. Damage cost analysis is then performed for the entire Kamloops area using the specified earthquake scenarios; building inventory damage results are calculated by the software with the aid of the software's damage functions (Ulmi et al. 2014; Federal Emergency Management Agency 2015).

Following similar steps for analyzing the entire Kamloops area, isolated analyses will also be done for three areas of Kamloops: Downtown, Northshore (Brocklehurst neighborhood is included in the Northshore area for this study) and Aberdeen areas. The Downtown, Northshore and Aberdeen areas will each be created by selecting their required unique tracts. And analyzed using two deterministic earthquake scenarios. These separate analyses are considered for this research due to the population and economic importance of these areas to Kamloops.

Thesis organization

Chapter 1. INTRODUCTION: introduces the problems and usefulness of this study, the research goals and design. It also gives an overview of the study area/regional seismicity and discusses the factors that determine how an earthquake will affect an area.

Chapter 2. HAZUS-MH 2.1 EARTHQUAKE HAZARD MODELLING AND ASSESSMENT STEPS: describes the methods and procedure used for this study.

Chapter 3. DATA PREPARATION AND ANALYSIS: explains the steps taken in the study area generation and the choice of hazard inputs.

Chapter 4. RESULTS: presents results from analysis.

Chapter 5. CONCLUSION: discusses the results, challenges with the study and recommendations.

REFERENCES

Abrahamson N, Silva W. 2008. Summary of the Abrahamson & Silva NGA ground-motion relations. Earthq. Spectra 24:67–97.

Adams J. 2011. Seismic hazard estimation in Canada and its contribution to the Canadian building code: Implications for code development in countries such as Australia. Aust. J. Struct. Eng. 11:267–282.

Adams J, Atkinson G. 2003. Development of Seismic Hazard maps for the proposed 2005 edition of the National Building code of Canada. J. Civ. Eng. 30:255–272.

Adams J, Halchuk S. 2003. Fourth generation seismic hazard maps of Canada: Values for over 650 Canadian localities intended for the 2005 National Building Code of Canada. Geol. Surv. Canada (OPEN FILE 4459).

Allen TI, Adams J, Halchuk S. 2015. The seismic hazard model for Canada : Past , present and future. Proc. Tenth Pacific Conf. Earthq. Eng. 2005:1–8.

Arnold C. 2014. The Nature of Ground Motion and Its Effect on Buildings. Natl. Inf. Serv. Earthq. Eng.:27.

Atkinson G. 2012. Seismic Hazard Assessment for Canadian Urban Centres. Can. Seism. Res. Netw.

Atkinson G, Assatourians K, Cheadle B, Greig W. 2015. Ground Motions from Three Recent Earthquakes in Western Alberta and Northeastern British Columbia and Their Implications for Induced-Seismicity Hazard in Eastern Regions. Seismol. Res. Lett. 86:1022–1031.

BC Stats. 2015. 2015 Sub-Provincial Population Estimates. 2015:5–10.

Bendimerad F. 2001. Loss estimation: A powerful tool for risk assessment and mitigation. Soil Dyn. Earthq. Eng. 21:467–472.

Bird JF, Bommer JJ, Crowley H, Pinho R. 2006. Modelling liquefaction-induced building damage in earthquake loss estimation. Soil Dyn. Earthq. Eng. 26:15–30.

City of Kamloops. 2011. City of Kamloops Statistical Report Final Version.

City of Kamloops. 2015. City of Kamloops: Kamloops Site Selector Guide. Ventur. Kamloops.

Croope S V. 2009. Working with HAZUS - MH. :1–61.

Dostal J, Breitsprecher K, Church BN, Thorkelson D, Hamilton TS. 2003. Eocene melting of

Precambrian lithospheric mantle: Analcime-bearing volcanic rocks from the Challis-Kamloops belt of south central British Columbia. J. Volcanol. Geotherm. Res. 126:303–326.

Dostal J, Church BN, Reynolds PH, Hopkinson L. 2001. Eocene volcanism in the Buck Creek Basin, Central British Columbia (Canada): Transition from arc to extensional volcanism. J. Volcanol. Geotherm. Res. 107:149–170.

Earthquakes Canada. 2009. Earthquakes in or near Canada, 1627 - 2009. Nat. Resour. Canada:1.

Earthquakes Canada. 2016. Seismic zones in Western Canada. Nat. Resour. Canada. [accessed 2017 Jan 14]. http://www.earthquakescanada.nrcan.gc.ca/zones/westcan-en.php

Federal Emergency Management Agency. 2012. Hazus-MH 2.1 User Manual. Multi-hazard Loss Estimation Methodology: Earthquake Model.

Federal Emergency Management Agency. 2015. Hazus–MH 2.1: Technical Manual. :718.

Foti D. 2015. Local ground effects in near-field and far-field areas on seismically protected buildings. Soil Dyn. Earthq. Eng. 74:14–24.

Fulton RJ. 1967. Deglaciation Studies in Kamloops Region, An Area of Moderate Relief, British Columbia.

Fulton RJ. 1976. Surficial Geology, Kamloops Lake, West of sixth Meridian, British Columbia. In: Geological Survey of Canada, “A” Series Map 1394A. p. 1 sheet.

Goda K, Hong HP, Atkinson GM. 2010. Impact of using updated seismic information on seismic hazard in western Canada. Can. J. Civ. Eng. 37:562–575.

Halchuk S. 2009. Seismic Hazard Earthquake Epicenter File (SHEEF) used in the fourth generation seismic hazard maps of Canada. Geol. Surv. Canada (OPEN FILE 6208):1–16.

Halchuk S, Adams J, Anglin F. 2007. Revised deaggregation of seismic hazard for selected Canadian cities. 9th Can. Conf. Earthq. Eng. 432:420–432.

Halchuk S, Adams, Allen. 2015. Fifth Generation Seismic Hazard Model for Canada: National Building Code of Canada. Natl. Build. Code Canada.

Halchuk S, Allen TI, Adams J, Rogers GC. 2014. Fifth generation seismic hazard model input files as proposed to produce values for the 2015 National Building Code of Canada (draft). Open File 7576:15.

HAZUS REPORT. Hazus-MH : Earthquake Event Report.

Journeay JM, Dercole F, Mason D, Weston M, Prieto JA, Wagner CL, Hastings NL, Chang SE, Lotze A, Ventura CE. 2015. A Profile of Earthqquake Risk for the District of North Vancouver, British Columbia. Geoloical Surv. Canada Open File:223p.

Journeay JM, Talwar S, Brodaric B, Hastings NL. 2015. Disaster Resilience by Design: A framework for integrated assessment and risk-based planning in Canada. :336.

Kaklamanos J, Baise LG, Boore DM. 2011. Estimating unknown input parameters when implementing the NGA ground-motion prediction equations in engineering practice. Earthq. Spectra 27:1219–1235.

Kovacs P. 2010. Reducing the risk of earthquake damage in Canada : Lessons from Haiti and Chile.

Mathews B, Monger J. 2005. Roadside geology of southern British Columbia. Missoula, Mont. : Mountain Press Pub. Co.

Meligrana JF. 2003. Developing A Planning Strategy And Vision For Rural-Urban Fringe Areas : A Case Study Of British Columbia. Can. J. Urban Res. 12:119–141.

Molnar S, Cassidy JF, Olsen KB, Dosso SE, He J. 2014. Earthquake ground motion and 3D Georgia basin amplification in Southwest British Columbia: Deep Juan de Fuca Plate scenario earthquakes. Bull. Seismol. Soc. Am. 104:301–320.

Nastev M. 2014. Adapting Hazus for seismic risk assessment in Canada. Can. Geotech. J. 51:217–222. [accessed 2015 Jan 29]. http://www.nrcresearchpress.com/doi/abs/10.1139/cgj-2013-0080

Nastev M, Parent M, Ross M, Howlett D, Benoit N. 2016. Geospatial modelling of shear-wave velocity and fundamental site period of Quaternary marine and glacial sediments in the Ottawa and St. Lawrence Valleys, Canada. Soil Dyn. Earthq. Eng. 85:103–116.

Natural Resources Canada. 2015. Earthquake Report (2015-12-16). [accessed 2016 Feb 6]. http://www.earthquakescanada.nrcan.gc.ca/recent_eq/2015/20151216.0948/index-eng.php

Natural Resources Canada. 2016. Search the Earthquake Database. [accessed 2017 Jan 12]. http://www.earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bull-en.php

Office of Housing and Construction Standards, National Research Council Canada. 2012. British Columbia Building Code 2012.

Onur T SM. 2004. Probabilities Of Significant Earthquake Shaking In Communities Across

British Columbia : Implications For. 13th world Conf. Earthq. Eng.

Ploeger SK, Atkinson GM, Samson C. 2010. Applying the HAZUS-MH software tool to assess seismic risk in downtown Ottawa, Canada. Nat. Hazards 53:1–20.

Seemann M, Onur T, Cloutier-Fisher D. 2011. Earthquake shaking probabilities for communities on Vancouver Island, British Columbia, Canada. Nat. Hazards 58:1253–1273.

Statistics Canada. Census tract (CT) - Census Dictionary. Stat. Canada. [accessed 2016 Jan 29]. http://www12.statcan.gc.ca/census-recensement/2011/ref/dict/geo013-eng.cfm

Statistics Canada. 2012. GeoSearch 2011 Census. Stat. Canada Cat. no. 92-142-xwe. [accessed 2017 Jan 6]. http://geodepot.statcan.gc.ca/GeoSearch2011-GeoRecherche2011/GeoSearch2011-GeoRecherche2011.jsp?lang=E&otherLang=F&searchGeocode=925&searchGeocode1=&searchGeocode2=&layerSelected=cmaca&searchTheme=GeoCode&searchPass=2&boundaryType=

Statistics Canada. 2012 Feb 8. Focus on Geography Series, 2011 Census - Census agglomeration of Kamloops. [accessed 2016 Oct 6]. https://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Facts-cma-eng.cfm?LANG=Eng&GK=CMA&GC=925

Tantala MW, Nordenson GJP, Deodatis G, Jacob K. 2008. Earthquake loss estimation for the New York City Metropolitan Region. Soil Dyn. Earthq. Eng. 28:812–835.

Tuna Onur, Seemann MR. 2008. Probabilities of Significant Earthquake Shaking in Communities Across British Columbia : Implications for. 14 th World Conf. Earthq. Eng.

Turner RJW, Anderson RG, Franklin R, Cathro M, Madu B, Frey E, Favrholdt K, Turner RJW, Anderson RG, Franklin R, et al. 2008. GeoTour guide for Kamloops , British Columbia. Geol. Surv. Canada (OPEN FILE 5810).

Ulmi M, Wagner CL, Wojtarowicz M, Bancroft JL, Hastings NL, Chow W, Rivard JR, Prieto J, Journeay JM, Struik LC, et al. 2014. Hazus-MH 2.1 Canada user and technical manual: earthquake module.

Wair BR, Dejong JT, Shantz T. 2012. Guidelines for Estimation of Shear Wave Velocity Profiles. Pacific Earthq. Eng. 8:68.

Wills CJ, Clahan KB. 2006. Developing a Map of Geologically Defined Site-Condition Categories for California. Bull. Seismol. Soc. Am. 96:1483–1501.

Chapter 2. HAZUS – MH 2.1 EARTHQUAKE MODELLING STEPS

This research uses the HAZUS-MH 2.1 methodology to estimate the consequences of earthquake scenarios to building inventory within Kamloops by the following steps: Create the Kamloops region, Specification of Earthquake scenarios for Kamloops and potentially induced hazards assessment (Liquefaction and Landslide susceptibility) (Federal Emergency Management Agency 2012).

The first step is to create the Kamloops area in HAZUS -MH 2.1 by the aggregation of the list of neighborhood tracts that make up the Kamloops area (building inventory variables are embedded in the tracts). HAZUS- MH 2.1 tracts are formed from the census dissemination units comprising the area (Ulmi et al. 2014).

The next step is to specify earthquake scenarios for Kamloops using two approaches: Deterministic Seismic Hazard Analysis (DSHA) and the Probabilistic Seismic Hazard Analysis (PSHA) (Ploeger, Atkinson, and Samson 2010; J.M. Journeay et al. 2015; J. Murray Journeay et al. 2015).

Deterministic Seismic Hazard Analysis, DSHA provides a detailed assessment of the damage costs and is used to observe the study area's degree of resistance or readiness to overcome a specified earthquake scenario (Journeay et al. 2015). To perform deterministic analysis, different real-life earthquake event values or hypothetical scenarios are modelled to produce results (Journeay et al. 2015). The chosen earthquake magnitude, fault information, soil data are some the key inputs for deterministic analysis. These inputs are coordinated into a ground motion with the aid of an attenuation function also referred to as ground motion prediction equation (GMPE) (Ploeger, Atkinson, and Samson 2010).

Probabilistic Seismic Hazard Analysis, PSHA is done based on the theoretical information of earthquakes in the region of interest, and it is used to express the chances of event reoccurrence (Ulmi et al. 2014; Journeay et al. 2015). The probabilistic seismic hazard inputs in Canada are assigned by location. The assigned hazard inputs are based on the National Building Code of Canada (NBCC) seismic hazard maps assessable in the Natural Resources Canada hazard calculator website (Earthquakes Canada 2016). The required probabilistic hazard inputs in HAZUS-MH 2.1 are moment magnitude and probability which are not enough inputs to mimic a real earthquake scenario but useful for preliminary analysis (Ulmi et al. 2014).

The added damage impacts from other hazards that could result from the earthquake scenario (liquefaction and landslide) are gotten from separate susceptibility assessments (Federal Emergency Management Agency 2015) and then included in the overall damage estimation. The earthquake damage cost analysis is then done with the aid of damage functions embedded in HAZUS-MH 2.1 software. The damage functions consist of the building fragility curve and building capacity curve that enable the software predict damage. The results of the analysis are then used to draw conclusions and review options for mitigation.

Specification of Kamloops area

The Kamloops region is divided into census tracts which are units used to represent small geographic areas of similar socioeconomic characteristics and population ranging between 2,500 and 8,000 (Statistics Canada) the census tracts are further broken-down to smaller geographical levels like census dissemination areas or neighborhoods. The Kamloops area is formed from 160 neighborhoods (census dissemination areas). In HAZUS-MH 2.1, these are 160 HAZUS-MH 2.1 tracts. Building inventory data are embedded for each selected tract; which are organized by their building materials (wood, concrete, and masonry, pre-constructed and steel buildings) and their occupancy classifications (Residential, Commercial, Industrial, Agricultural, Religious, Governmental and Educational classes) (Ulmi et al. 2014; Federal Emergency Management Agency 2015).

Specification of Earthquake Scenario

Earthquake size can be specified in HAZUS-MH 2.1 by the earthquake's moment magnitude, M_w or by using the ground motion intensity which is the intensity of earth's movement due to the energy released during an earthquake (Ulmi et al. 2014). The software then calculates earthquake damage using the intensity of ground motion caused by the specified earthquake size on the area; and the ground motion is expressed by peak ground acceleration (PGA), peak ground velocity (PGV) and spectral acceleration (Sa) (Federal Emergency Management Agency 2012). In the HAZUS-MH 2.1 methodology, earthquakes scenario specification involves the use of inputs which could be in form of hazard maps or by computing hazard values that describes the earthquake scenario (Ulmi et al. 2014; Federal

Emergency Management Agency 2015). To choose earthquake scenario for this study, the first step is to consider the seismic source zone. The source zone determines the acceptable earthquake scenario inputs of a place; the magnitudes, probability, and attenuation functions (ground motion prediction equation) are determined by the characteristics of earthquakes expected (Atkinson 2012; Atkinson and Adams 2013).

The HAZUS-MH 2.1 manual recommends 2 approaches to damage cost analysis: Probabilistic Seismic Hazard Analysis and Deterministic Seismic Hazard Analysis. To choose earthquake scenarios for this study, it is necessary to consider the seismic source zone for Kamloops.

Kamloops Seismic Source zone

Seismic source zone involves the grouping of geographic locations by the likely contributors to their seismicity (Goda, Hong, and Atkinson 2010). These groupings are used to identify the likely causes and characteristics of earthquakes that can be expected for each location. Seismic source zones in British Columbia are defined based on sources and characteristics of earthquakes that will affect such places across the province (Goda, Hong, and Atkinson 2010).

Potential sources of earthquakes that can affect Kamloops fall within the South-West Canada crustal area source zone (Halchuk et al. 2014; Halchuk, Adams, and Allen 2015) where the main earthquake hazards are the small near earthquakes at short period and the large distant earthquakes at long period (Adams and Atkinson 2003; Adams and Halchuk 2003; Halchuk, Adams, and Anglin 2007). The acceptable magnitude range for hazard analysis in Western Canada which is form M_w 6.5 to 7.5 (Atkinson and Adams 2012).

In earthquake estimations, there are uncertainties in specifying earthquake scenario: the probability, magnitude and location of occurrence. To control the uncertainty, it is assumed that for each probability level, there is an equal chance of similar earthquake magnitude occurrence spread uniformly across a zone; and so earthquake locations (sources) can be chosen randomly in areas of same zone (Goda, Hong, and Atkinson 2010).

Probabilistic Seismic Hazard Analysis

The probabilistic seismic hazard inputs in HAZUS-MH 2.1 are mainly the moment magnitude and probability level. The National Building Code of Canada (NBCC) seismic hazard maps found in the Natural Resources Canada hazard calculator website (Earthquakes Canada 2016) provide different seismic input values for each location coordinates in Canada at different probability levels. These seismic input values are mainly values that measure the size of ground movement (shaking) which include: the mean values of peak ground velocity, peak ground acceleration, spectral acceleration at 0.05,0.1, 0.2, 0.3, 0.5, 1.0, 2.0, 5.0 and 10.0 seconds with probabilities of 2% in 50years (1 in 2475 years) , 40% in 50 years (1 in 100 years), 10% in 50 years (1 in 475 years), 5% in 50 years (Earthquakes Canada 2016).

However, HAZUS-MH 2.1 uses ground motion parameters like peak ground acceleration, peak ground velocity, spectral acceleration at 0.3 and 1.0 with probabilities of 1 in 100, 250, 500, 750, 1000, 2000 and 2500 (Ulmi et al. 2014); where the ground motion probabilities like 1 in 2475 (2% in 50 years) and 1 in 475 (10% in 50 years) are represented in HAZUS-MH 2.1 as 1 in 2500 (2% in 50 years) and 1 in 500 (10% in 50 years) respectively. The results from probabilistic seismic hazard analysis are used mostly for preliminary studies and for comparison with results from other method of analysis (Ulmi et al. 2014).

Deterministic Seismic Hazard Analysis

The Deterministic approach is used to produce more detailed assessments of likely earthquake damage costs and risks (J.M. Journeay et al. 2015). Deterministic Seismic Hazard Analysis (DSHA) involves the modelling of a real-life earthquake event or the creation of a “what if” earthquake scenario with the aid of a ground motion prediction equation (GMPE) (Journeay et al. 2015). Usually the “what if” earthquake scenarios are conjectural scenarios used to analyze and predict the performance of the study area should such event occur in the future. The ground motion prediction equations (GMPEs); which are expressions of the attenuation relationship between earthquake magnitude, fault and fault characteristics, location and other site information are used to imitate real ground motion for a specified area (Kaklamanos, Baise, and Boore 2011).

In Canada, different ground motion prediction equations are recommended based on the seismic source zone. The Western Crustal North America GMPEs are recommended for crustal cities in British Columbia (Atkinson 2012; Atkinson and Adams 2013). These recommended GMPEs are from the Next Generation Attenuation (NGA) collection developed by researchers at the United States Pacific Earthquake Engineering Research (PEER) center in 2008 for the estimation of ground motion in North America crustal tectonic regions (Kaklamanos, Baise, and Boore 2011; Atkinson and Adams 2013). The NGA project team developed equations using earthquake data from the NGA file; which is a compilation of earthquake records in the US and other locations worldwide (Boore and Atkinson 2008; Power et al. 2008; Campbell et al. 2009). Five (5) sets of attenuation equations or GMPEs were produced from the 2008 project: Abrahamson and Silva 2008 (AS08), Boore and Atkinson 2008 (BA08), Campbell and Bozorgnia 2008 (CB08), Chiou and Youngs 2008 (CY08) and Idriss 2008 (I08) (Abrahamson et al. 2008; Power et al. 2008; Kaklamanos, Baise, and Boore 2011). However, Abrahamson and Silva 2008 (AS08), Boore and Atkinson 2008 (BA08), Campbell and Bozorgnia 2008 (CB08), Chiou and Youngs 2008 (CY08) GMPEs are used in most design studies because they consider the effects of soil shear wave velocity (V_{S30}) (Power et al. 2008; Atkinson and Adams 2012).

There are uncertainties associated with choosing the right attenuation function from the collection since each of the 2008 GMPEs will predict different damage results (Atkinson and Adams 2013). To reduce uncertainty in damage results, it is recommended that three (3) different GMPEs from the recommended NGA collection (listed above) are chosen; or, a single GMPE is selected as the central GMPE and then scaled up and down by a log factor (approx.+/- 0.1log units) to get the upper GMPE / lower GMPE values respectively (Atkinson and Adams 2013). The Boore and Atkinson 2008, (BA08) equation from the NGA collection is often chosen as the central GMPE because the BA08 equation is simpler and requires the least inputs compared to the other GMPEs in the collection (Atkinson 2012; Atkinson and Adams 2013).

The chosen ground motion equation for this study is the Abrahamson and Silva 2008, (AS08) since all the GMPEs (BA08, AS08, CB08, CY08) have the “same degree of validity” (Atkinson and Adams 2013) and the choice of one does not mean that it is superior to the others.

Abrahamson and Silva 2008 (AS08)

Abrahamson and Silva 2008, (AS08) estimates ground motion of a location based on magnitude, depth to rupture, the fault type (Abrahamson et al. 2008; Abrahamson and Silva 2008). The AS08 equation was developed from NGA compilation of shallow crustal earthquakes recorded in places around the world on the assumption that all near earthquakes (less than 100km) will behave the same; hence the equation can be applied other places with similar seismic characteristics (Abrahamson and Silva 2008) .

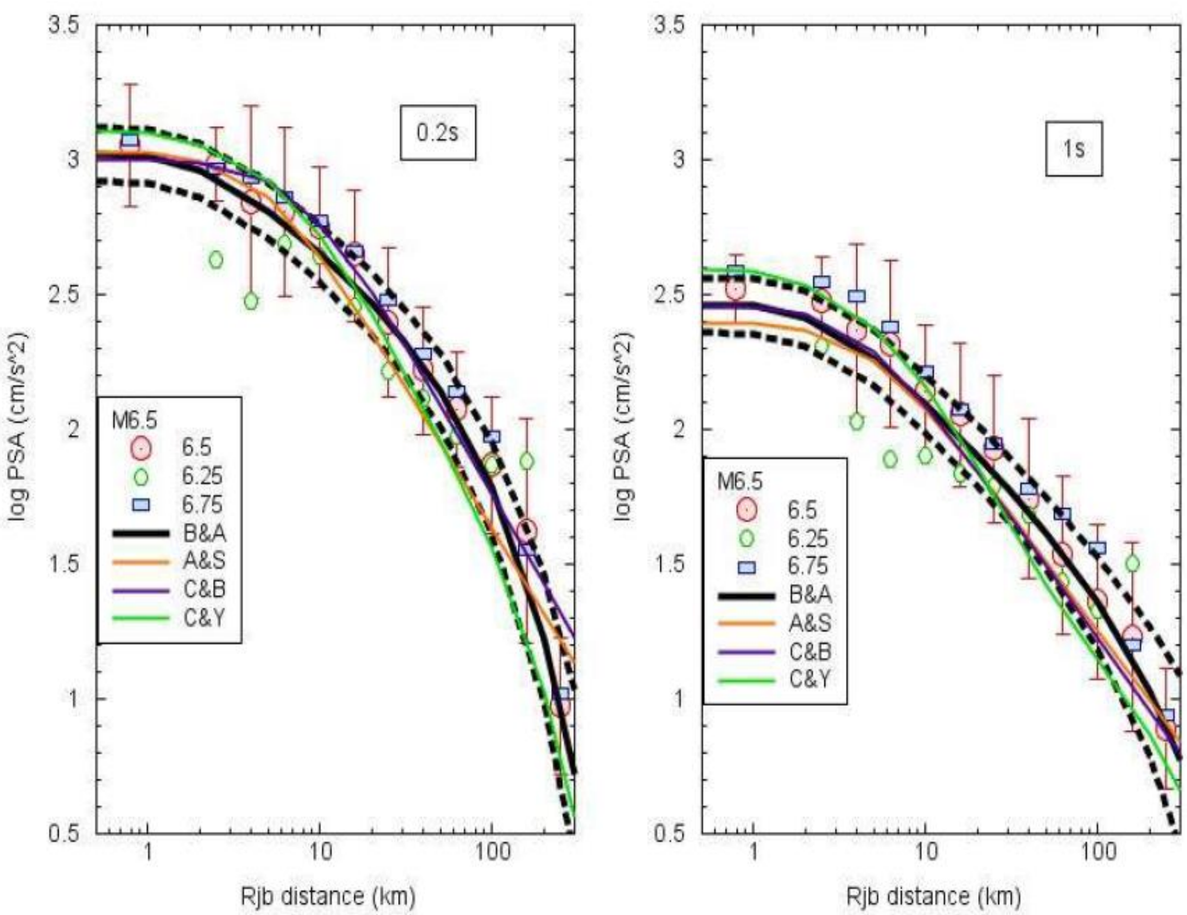


Figure 2-1. Comparison of ground motion produced by the GMPES from the NGA 2008 collection: Boore and Atkinson, Abrahamson and Silva, Campbell and Bozorgnia, and Chiou and Youngs (Atkinson and Adams 2013)

The AS08, like the BA08 attenuation model and other recommended attenuation models (GMPEs from the NGA 2008 collection) was developed from same NGA earthquake database; only that besides the mainshock events in database, it also includes the effects of aftershock and foreshock (Abrahamson and Silva 2008).

Abrahamson and Silva 2008, (AS08) categorizes sites by the shear wave velocity in the top 30m soil (V_{S30}) and depth to rock ($Z_{1.0}$) which makes it sensitive to different depths (Abrahamson and Silva 2008). The Abrahamson and Silva 2008, (AS08) can be used to estimate ground motion in both soil sites and rock sites (Abrahamson et al. 2008; Abrahamson and Silva 2008).

The AS08 considers three (3) types of distance in its ground motion prediction which are: the closest distance to the rupture plane (R_{rup}), the closest horizontal distance to the surface projection of the rupture (R_{jb}) and the horizontal distance from the top edge measured perpendicular to the fault strike (R_x)(Abrahamson and Silva 2008; Kaklamanos, Baise, and Boore 2011). Description of the distance in the illustration in the figure 2-2 below.

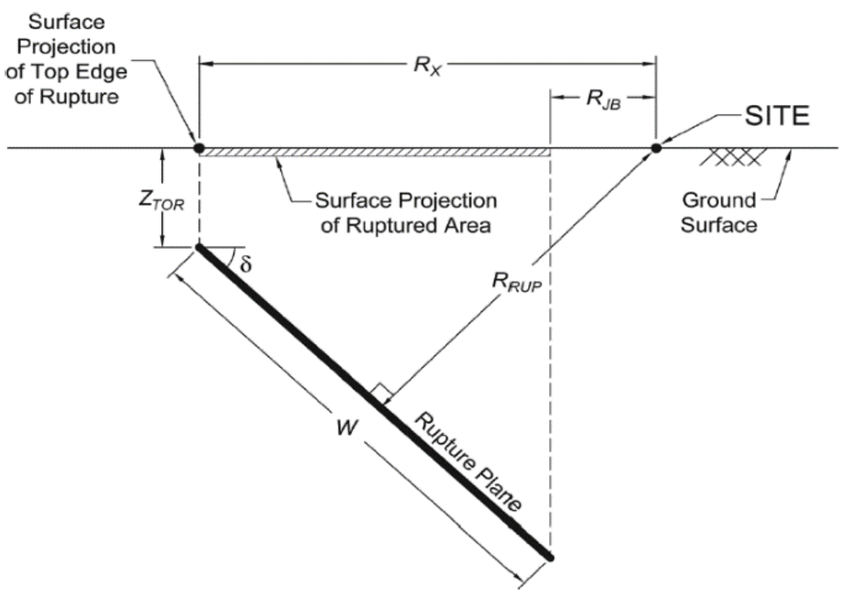


Figure 2-2 Illustration of vertical cross section through a fault plane, fault measurements and earthquake distance from site location (Kaklamanos, Baise, and Boore 2011).

where δ is the fault angle of dip, W is the fault rupture width, Z_{TOR} is the hypo central depth, Rx is the horizontal distance from the surface projection to the site of interest, and R_{RUP} is the shortest slant distance from the rupture plane, and R_{JB} is the horizontal distance of the surface projection of the rupture, or Joyner-Boore distance.

The AS08 ground motion attenuation equation from Abrahamson and Silva (2008) is given as:

$$\ln Sa(g) = f_1(M, R_{rup}) + a_{12}F_{RV} + a_{13}F_N + a_{15}F_{AS} + f_5(PGA_{1100}, V_{S30}) + F_{HW}f_4(R_{jb}, R_{rup}, R_x, W, dip, Z_{top}, M) + F_{RV}f_6(Z_{top}) + (1 - F_{RV})f_7(Z_{top}) + f_8(R_{rup}) + f_{10}(Z_{1.0}, V_{S30})$$ Equation 2-1

shere a_{12}, a_{13} and a_{15} are the Reverse style faulting factor, Normal style faulting factor and aftershock factor respectively; f_1, f_5, f_4, f_6, f_7, f_8, f_{10} are functional forms of the following base relations: f_1 – magnitude-distance, f_5 – site response, f_4 – Hanging wall effect, f_6, f_7 – depth to top rupture; f_8 – attenuation at large distance; f_{10} – soil depth; and Sa is the spectral acceleration.

The description of the parameters for the equation are found in Table 2-1 below.

Parameter	Definition	Notes
M	Moment magnitude	
R_{rup}	Rupture distance (km)	
R_{jb}	Joyner-Boore distance (km)	
R_x	Horizontal distance (km) from top edge of rupture	Measured perpendicular to the fault strike
Z_{top}	Depth-to -top of rupture (km)	
F_{RV}	Flag for reverse faulting earthquakes	1 for reverse and reverse/oblique earthquakes defined by rake angles between 30 and 150 degrees, 0 otherwise
F_N	Flag for normal faulting earthquakes	1 for normal earthquakes defined by rake angles between -60 and -120 degrees, 0 otherwise
F_{AS}	Flag for aftershocks	1 for aftershocks, 0 for mainshocks, foreshocks, and swarms (see Table 1)
F_{HW}	Flag for hanging wall sites	1 for sites on the hanging wall side of the fault, 0 otherwise. The boundary between the FW and HW is defined by the vertical projection of the top of the rupture. For dips of 90 degrees, F_{HW} =0
Dip	Fault dip in degrees	
V_{S30}	Shear-wave velocity over the top 30 m (m/s)	
$Z_{1.0}$	Depth to V_S=1.0 km/s at the site (m)	
$P\hat{G}A_{1100}$	Median peak acceleration (g) for V_{S30}=1100 m/s	
W	Down-dip rupture width (km)	

Table 2-1. Description of the parameters for the AS08 equation (Abrahamson and Silva 2008)

Details of the development and application guidelines for the Abrahamson and Silva 2008 can be found in the Abrahamson and Silva (2008). The HAZUS-MH2.1 software has the AS08 among its list of equations and simplifies it such that only a few key inputs are required for its ground motion estimation. These inputs are explained later in this work.

Potentially Induced Hazards Susceptibility: liquefaction and landslide

Landslides and liquefaction are described as important potential hazards associated with past earthquake events recorded in Canada. An example of such events is the 1946 Vancouver Island earthquake with magnitude 7.3 that was felt throughout the province; it wrecked structural damage on near buildings and induced hazards like liquefaction and landslides (Clague 2002). The likely contribution of potentially induced hazards like liquefaction and landslide are considered for earthquake damage estimations in locations across British Columbia. Another hazard that can be induced by earthquake is the tsunami, where the seismic waves travel through a large body of water and are more likely to occur in oceanic regions or cities near oceans (Federal Emergency Management Agency 2012). Kamloops is not within such regions; therefore, tsunami induced damage will not be considered for this study.

Landslide and Liquefaction assessments are done separately; the results of both assessments are then included in the HAZUS-MH 2.1 hazard inventory in the form of susceptibility ratings to be combined with the earthquake scenario inputs (Journeay et al. 2015; Federal Emergency Management Agency 2015).

Liquefaction

Liquefaction can be explained as the loss of soil strength leading to the soil mimicking liquid behaviour which could be soil- flow, lateral movement and settlement of the soil particles causing huge damage to the structures built upon it (Federal Emergency Management Agency 2012). This liquid behavior is caused by the reduced stress between soil particles and increased pore pressure (Youd and Perkins 1978). From previous scientific studies, liquefaction is more likely to happen at specific geological settings when exposed to certain magnitudes of ground motion. These specific settings are determined by their soil characteristics (soil material, grain size distribution and density) and ground water characteristics (depth of ground water) (Journeay et al. 2015). Liquefaction is more likely to happen at areas closer to rivers and around the coastlines.

A study area classification table was developed by Youd and Perkins in 1978 to assess the likelihood of different soils to liquefy under ground motion (refer to Table 2-2). To assess Liquefaction Susceptibility Index (LSI), the first step is to determine the vulnerability rating (from very low to very high) of the soil material in the area and probability of occurrence (refer to Table 2-2) (Federal Emergency Management Agency 2012). Soil maps containing geologic data and water level are helpful to rate if the soil is liquefiable (Youd and Perkins 1978; Federal Emergency Management Agency 2012).

Probability of earthquake-caused liquefaction is then examined based on the relationship between the vulnerability rating and peak ground acceleration to get the Liquefaction Susceptibility Index (LSI) (Bird et al. 2006; Federal Emergency Management Agency 2012). Liquefaction Susceptibility Index (LSI) rates the chance of liquefaction occurring at a particular seismic acceleration (Bird et al. 2006).

Type of deposit (1)	sediments in deposits (2)	<500 yr (3)	Holocene (4)	Pleis-tocene (5)	pleis-tocene (6)
(*a*) Continental Deposits					
River channel	Locally variable	Very high	High	Low	Very low
Flood plain	Locally variable	High	Moderate	Low	Very low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very low
Marine terraces and plains	Widespread	—	Low	Very low	Very low
Delta and fan-delta	Widespread	High	Moderate	Low	Very low
Lacustrine and playa	Variable	High	Moderate	Low	Very low
Colluvium	Variable	High	Moderate	Low	Very low
Talus	Widespread	Low	Low	Very low	Very low
Dunes	Widespread	High	Moderate	Low	Very low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very low	Very low
Tuff	Rare	Low	Low	Very low	Very low
Tephra	Widespread	High	High	?	?
Residual soils	Rare	Low	Low	Very low	Very low
Sebka	Locally variable	High	Moderate	Low	Very low
(*b*) Coastal Zone					
Delta	Widespread	Very high	High	Low	Very low
Esturine	Locally variable	High	Moderate	Low	Very low
Beach					
High wave energy	Widespread	Moderate	Low	Very low	Very low
Low wave energy	Widespread	High	Moderate	Low	Very low
Lagoonal	Locally variable	High	Moderate	Low	Very low
Fore shore	Locally variable	High	Moderate	Low	Very low

Table 2-2. likelihood of different soils to liquefy under ground motion (Youd and Perkins 1978)

The potential influence by the water depth level is analyzed using the guidelines explained in Youd and Perkins (1978) study where considering seasonal variations like rainfall, the chances of liquefaction is low for water depths greater than 10m (33ft). The liquefaction susceptibility index assessment is shown below as described in the HAZUS-MH 2.1 technical manual:

$$P[Liquefaction] = \frac{[P\ Liquefaction\ |PGA = a]}{K_M \cdot K_W}\ P_{ML} \qquad \text{Equation 2-2}$$

$[P\ Liquefaction\ |PGA = a]$ is the liquefaction probability at a specified peak ground acceleration. P_{ML} is the proportion of map area susceptible to liquefaction, K_M is the moment magnitude correction factor and K_W is the ground water depth correction factor. K_M has a functional form depending on M, the Moment magnitude of event.

$$K_M = 0.0027M^3 - 0.0267M^2 - 0.2055M + 2.9188 \qquad \text{Equation 2-3}$$

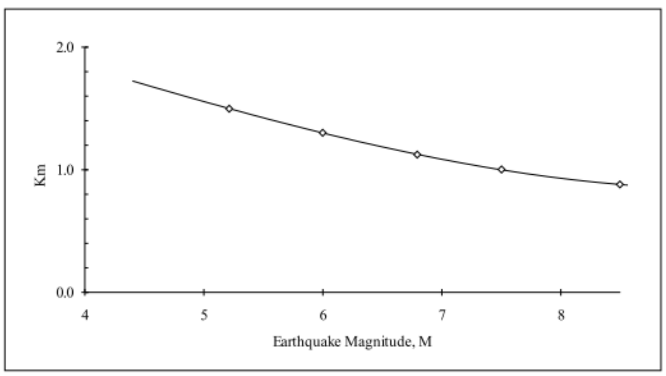


Figure 2-3. Moment magnitude correction factor, K_M (FEMA 2015).

KW has a function form depending on the depth of ground water, d_W, in feet

$$K_W = 0.022d_W + 0.93 \qquad \text{Equation 2-4}$$

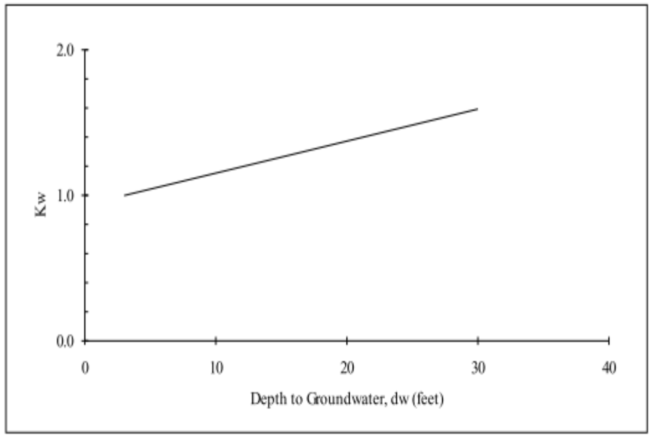


Figure 2-4. Ground water depth correction factor, KW (FEMA 2015).

Susceptibility Category	P [Liquefaction |PGA = a]
Very High	0 ≤ 9.09 a - 0.82 ≤ 1.0
High	0 ≤ 7.67a - 0.92 ≤ 1.0
Moderate	0 ≤ 6.67a -1.0 ≤ 1.0
Low	0 ≤ 5.57a -1.18 ≤ 1.0
Very Low	0 ≤ 4.16a - 1.08 ≤ 1.0
None	0.0

Table 2-3. Liquefaction Probability at Specified Peak Ground Acceleration = a (FEMA 2015).

The Liquefaction Susceptibility Index (LSI) rates the chance of liquefaction occurring at a particular seismic acceleration given the soil condition of the area from 0 to 5 (Bird et al. 2006) which is used in the HAZUS methodology, where zero (0) means no liquefaction will occur. To assign a value, the size of the fraction of the study area with liquefiable soils is compared to the overall area, as large fraction size of liquefiable soil coverage indicates higher liquefaction damage for the study area (Federal Emergency Management Agency 2015).

Mapped Relative Susceptibility	Proportion of Map Unit
Very High	0.25
High	0.20
Moderate	0.10
Low	0.05
Very Low	0.02
None	0.00

Table 2-4. Proportion of map area susceptible to liquefaction (PML) (FEMA 2015).

Landslide

A landslide can be described as the downslide movement of land features from higher elevated locations to the lower areas (Federal Emergency Management Agency 2012). Landslides hazard occurs due to low movement resistance (Chrisman, Schwarzenegger, and Luther 2008). Landslide movement resistance can be lowered by: ground water level (leading to pore-water pressure and low resistance), unstable steep areas, and nature of soil / geologic material (certain soil / rock material allow easier movement) (Keefer 1984; Chrisman, Schwarzenegger, and Luther 2008; Federal Emergency Management Agency 2015). Landslide hazard can be triggered by different reasons other than earthquakes e.g. intense rainfall and erosion. However, this loss estimation study focuses on Kamloops' damage potential (probability) from seismically triggered landslide. Seismically triggered landslide probability is determined by the geologic group (rock and soil form), topography (slope angle), critical acceleration (landslide triggering acceleration), and ground water level (Federal Emergency Management Agency 2015). Landslide susceptibility rating assessment is shown below as described in the HAZUS-MH 2.1 technical manual by considering the geologic group and then the triggering acceleration (critical acceleration) to determine the susceptibility category.

Geologic Group		Slope Angle, degrees					
		0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)	None	None	I	II	IV	VI
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)	None	III	IV	V	VI	VII
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)	None	III	VI	VII	VIII	VIII
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)	V	VIII	IX	IX	IX	X
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)	VII	IX	X	X	X	X

Table 2-5. Landslide Susceptibility rating (FEMA 2015)

Susceptibility Category	None	I	II	III	IV	V	VI	VII	VIII	IX	X
Critical Accelerations (g)	None	0.60	0.50	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05

Table 2-6. Landslide Critical Acceleration (FEMA 2015)

To assign a rating value for landslide, the size of the fraction of the study area with landslide slide susceptibility is considered (Federal Emergency Management Agency 2015). HAZUS-MH 2.1 describes earthquake-caused landslide probability by the range from low (0) to very high (10), zero (0) means no chance of landslide occurring.

Susceptibility Category	None	I	II	III	IV	V	VI	VII	VIII	IX	X
Map Area	0.00	0.01	0.02	0.03	0.05	0.08	0.10	0.15	0.20	0.25	0.30

Table 2-7 Proportion of Landslide Susceptible area (FEMA 2015)

Special considerations for Aberdeen, Northshore and Downtown areas of Kamloops

The Aberdeen, Northshore (with Brocklehurst neighborhood included) and Downtown areas of Kamloops are known for their large population sizes and their economic importance (City of Kamloops 2011; City of Kamloops 2015). It is necessary to assess the potential seismic impact to Aberdeen, Northshore and Downtown areas since any negative impact in these areas would have adverse consequences to Kamloops. There also exist geotechnical issues associated with these areas.

The Aberdeen area of Kamloops has had stability problems caused by upslope developments and ground water pressure increase (City of Kamloops 2008). In 1995, a ground slide movement occurred causing damage to some buildings in the Van Horne area of Aberdeen. This led to the installation of pump wells to control the ground water level; and piezometers for constant monitoring of the Aberdeen area (City of Kamloops 2008).There have been many in-fill constructions after the ground slide event due to new building constructions. Thus, most of the Aberdeen area rely on the proper functioning of the pumped wells to maintain stability. Power generator sets have been installed to provide backup electricity power for the pumped wells (City of Kamloops 2008).

The Northshore area of Kamloops lies along the sides of the Thompson rivers; the soil characteristics are described as alluvial with sand, silt and scattered gravel deposited by the rivers (Fulton 1976) which have amplified ground shaking and liquefaction potentials. An earthquake event near this location could be as damaging as the Christchurch, New Zealand earthquake event that caused damage from both liquefaction and ground shaking (Maurer et al. 2014; Wotherspoon et al. 2015).

The Downtown area of Kamloops, compared to the Northshore area, may have firmer soil; since, most businesses and administrative buildings are in the Downtown, the estimation of potential impact of earthquake on the Downtown area is important.

Building damage functions

HAZUS-MH 2.1 uses special functions to calculate building damage. These functions are the fragility curve and the capacity curve (Nastev 2014; Federal Emergency Management Agency 2015). The extent of damage in the HAZUS-MH 2.1 methodology estimated based on the building age and building type which is grouped into 5 damage levels: None, slight, moderate, extensive and complete (Federal Emergency Management Agency 2015). Building damage could be because of ground motion or ground failure or both. Other factors like the distance of buildings from the earthquake and soil conditions can affect the rate of damage or building's ability to withstand earthquakes (Arnold 2014; Foti 2015).

The Fragility curve is used by the software to predict the likelihood of exceeding a damage state (Federal Emergency Management Agency 2012). While the capacity curve is used to estimate the buildings load resistance. These functions are embedded in the software to estimate damage when running the damage analysis.

Damage levels

The condition of a building after a possible earthquake is described in HAZUS-MH 2.1 as the damage state (Federal Emergency Management Agency 2015).The degree of damage (none, slight, moderate, extensive and complete) affects the damage cost results. The meaning of each damage state from the HAZUS-MH 2.1 manual are: None – means no damage; Slight – means nonstructural damage but requiring minor repairs e.g. Plastering of a few areas; Moderate – means minor structural damage and cracks; Extensive – means major structural damage, parts of the building may be buckled or deformed; Complete – means possible building collapse (Federal Emergency Management Agency 2015).

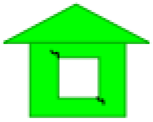
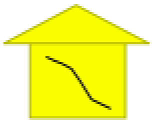
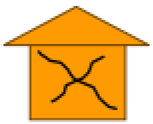
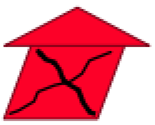
Damage State		Description
	**Slight**	Small plaster cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneers. Small cracks are assumed to be visible with a maximum width of less than 1/8 inch (cracks wider than 1/8 inch are referred to as "large" cracks).
	**Moderate**	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
	**Extensive**	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
	**Complete**	Structure may have large permanent lateral displacement or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundation; large foundation cracks. Three percent of the total area of buildings with Complete damage is expected to be collapsed, on average.

Table 2-8. The different levels of damage (FEMA 2015)

REFERENCES

Abrahamson N, Atkinson G, Boore D, Bozorgnia Y, Campbell K, Chiou B, Idriss IM, Silva W, Youngs R. 2008. Comparisons of the NGA ground-motion relations. Earthq. Spectra 24:45–66.

Abrahamson N, Silva W. 2008. Summary of the Abrahamson & Silva NGA ground-motion relations. Earthq. Spectra 24:67–97.

Adams J, Atkinson G. 2003. Development of Seismic Hazard maps for the proposed 2005 edition of the National Building code of Canada. J. Civ. Eng. 30:255–272.

Adams J, Halchuk S. 2003. Fourth generation seismic hazard maps of Canada: Values for over 650 Canadian localities intended for the 2005 National Building Code of Canada. Geol. Surv. Canada (OPEN FILE 4459).

Arnold C. 2014. The Nature of Ground Motion and Its Effect on Buildings. Natl. Inf. Serv. Earthq. Eng.:27.

Atkinson G, Adams J. 2012. Ground motion prediction equations for application to the 2015 Canadian national seismic hazard maps. Can. J. Civ. Eng.

Atkinson G, Adams J. 2013. Ground motion prediction equations for application to the 2015 Canadian national seismic hazard maps. Can. J. Civ. Eng. 40:988–998.

Atkinson GM. 2012. White paper on Proposed Ground-motion Prediction Equations (GMPEs) for 2015 National Seismic Hazard map. :1–51.

Bird JF, Bommer JJ, Crowley H, Pinho R. 2006. Modelling liquefaction-induced building damage in earthquake loss estimation. Soil Dyn. Earthq. Eng. 26:15–30.

Boore DM, Atkinson GM. 2008. Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s. Earthq. Spectra 24:99–138.

Campbell K, Abrahamson N, Power M, Chiou B, Bozorgnia Y, Shantz T, Roblee C. 2009. Next Generation Attenuation (NGA) Project : Empirical Ground Motion Prediction Equations For Active Tectonic Regions. Sixth Int. Conf. Urban Earthq. Eng.:5–11.

Chrisman M, Schwarzenegger A, Luther B. 2008. Guidelines for Evaluating and Mitigating Seismic Hazards. Spec. Publ. 117:81.

City of Kamloops. 2008. Aberdeen Groundwater Area Information Summary.

City of Kamloops. 2011. City of Kamloops Statistical Report Final Version.

City of Kamloops. 2015. City of Kamloops: Kamloops Site Selector Guide. Ventur. Kamloops.

Clague JJ. 2002. The Earthquake Threat in Southwestern British Columbia: A Geological Perspective. Nat. Hazards 26:7–34.

Earthquakes Canada. 2016. Determine 2015 National Building Code of Canada seismic hazard values. [accessed 2016 Feb 26]. http://www.earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/index_2015-en.php

Federal Emergency Management Agency. 2012. Hazus-MH 2.1 User Manual. Multi-hazard Loss Estimation Methodology: Earthquake Model.

Federal Emergency Management Agency. 2015. Hazus–MH 2.1: Technical Manual. :718.

FEMA. 2015. Technical and User's Manual of Advanced Engineering Building Module (AEBM) "Hazus MH 2.1." Fed. Emerg. Manag. Agency:121.

Foti D. 2015. Local ground effects in near-field and far-field areas on seismically protected buildings. Soil Dyn. Earthq. Eng. 74:14–24.

Fulton RJ. 1976. Surficial Geology, Kamloops Lake, West of sixth Meridian, British Columbia. In: Geological Survey of Canada, "A" Series Map 1394A. p. 1 sheet.

Goda K, Hong HP, Atkinson GM. 2010. Impact of using updated seismic information on seismic hazard in western Canada. Can. J. Civ. Eng. 37:562–575.

Halchuk S, Adams J, Anglin F. 2007. Revised deaggregation of seismic hazard for selected Canadian cities. 9th Can. Conf. Earthq. Eng. 432:420–432.

Halchuk S, Adams, Allen. 2015. Fifth Generation Seismic Hazard Model for Canada: National Building Code of Canada. Natl. Build. Code Canada.

Halchuk S, Allen TI, Adams J, Rogers GC. 2014. Fifth generation seismic hazard model input files as proposed to produce values for the 2015 National Building Code of Canada (draft). Open File 7576:15.

Journeay JM, Dercole F, Mason D, Weston M, Prieto JA, Wagner CL, Hastings NL, Chang SE, Lotze A, Ventura CE. 2015. A Profile of Earthqquake Risk for the District of North Vancouver, British Columbia. Geoloical Surv. Canada Open File:223p.

Journeay JM, Talwar S, Brodaric B, Hastings NL. 2015. Disaster Resilience by Design: A framework for integrated assessment and risk-based planning in Canada. :336.

Kaklamanos J, Baise LG, Boore DM. 2011. Estimating unknown input parameters when implementing the NGA ground-motion prediction equations in engineering practice.

Earthq. Spectra 27:1219–1235.

Keefer DK. 1984. Landslides caused by earthquakes. Geol. Soc. Am. Bull. 95:406–421.

Maurer BW, Green RA, Cubrinovski M, Bradley BA. 2014. Evaluation of the liquefaction potential index for assessing liquefaction hazard in Christchurch, New Zealand. J. Geotech. Geoenvironmental Eng. 140:1–11.

Nastev M. 2014. Adapting Hazus for seismic risk assessment in Canada. Can. Geotech. J. 51:217–222. [accessed 2015 Jan 29]. http://www.nrcresearchpress.com/doi/abs/10.1139/cgj-2013-0080

Ploeger SK, Atkinson GM, Samson C. 2010. Applying the HAZUS-MH software tool to assess seismic risk in downtown Ottawa, Canada. Nat. Hazards 53:1–20.

Power M, Chiou B, Abrahamson N, Bozorgnia Y, Shantz T, Roblee C. 2008. An overview of the NGA project. Earthq. Spectra 24:3–21.

Statistics Canada. Census tract (CT) - Census Dictionary. Stat. Canada. [accessed 2016 Jan 29]. http://www12.statcan.gc.ca/census-recensement/2011/ref/dict/geo013-eng.cfm

Ulmi M, Wagner CL, Wojtarowicz M, Bancroft JL, Hastings NL, Chow W, Rivard JR, Prieto J, Journeay JM, Struik LC, et al. 2014. Hazus-MH 2.1 Canada user and technical manual: earthquake module.

Wotherspoon LM, Orense RP, Green RA, Bradley BA, Cox BR, Wood CM. 2015. Assessment of liquefaction evaluation procedures and severity index frameworks at Christchurch strong motion stations. Soil Dyn. Earthq. Eng. 79:335–346.

Youd TL, Perkins D. M. 1978. Mapping Liquefaction-Induced Ground Failure Potential. J. Geotech. Eng. Div. ASCE 104:433–446.

Chapter 3. DATA PREPARATION AND ANALYSIS

HAZUS-MH 2.1 required inputs are grouped into: Study area inventory, Earthquake scenario inventory and induced hazard susceptibility (liquefaction and landslide susceptibility).

Study area inventory

Conversion to Hazus Tract Identification

The building Inventory data are organized into geographic levels based on census data. Census Canada arranges geographic levels from largest area to smallest unit: Province→ Census Subdivision→ Census tract→ Dissemination area which are uniquely assigned identification code numbers (Ulmi et al. 2014).

First 2 digits – British Columbia code – 59

Next – Census Division (for Kamloops is Thompson-Nicola) code- 033

Then, Census tract ID, for example tract 0001.00 is identified as 59033000100

Going further to the level of neighborhood block or dissemination area, each neighborhood found within each tract has an identification code number. There can be more than one neighborhood within a Census tract (Ulmi et al. 2014).

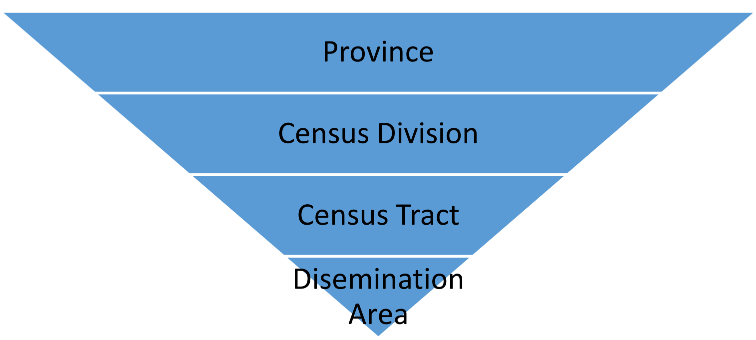


Figure 3-1. Geographic levels organized by census Canada

The HAZUS- MH 2.1 tract codes are formed from the: Province code + Census Division code + Neighborhood/Dissemination area code (based on the Census tract). Example for Census tract 0005.01 which is one of the tracts located in the upper Sahali area has the following neighborhood/dissemination areas identified by; 330045, 330047, 330048, 330049, 330050, 330051, and 330318. The neighborhoods are identified in Hazus as 59033330045, 59033330047, 59033330048, 59033330049, 59033330050, 59033330051, and

59033330318.The HAZUS tract identification codes are like the dissemination area identification numbers for Kamloops provided in the City of Kamloops website (www.kamloops.ca/downloads/maps/launch.htm).

Figure 3-2. Kamloops city area (Google map)

A total of 160 tracts were selected in HAZUS-MH 2.1 to create the Kamloops study area. The software's building inventory data are based on the Census 2006 information (Ulmi et al. 2014). Building inventory data are already embedded to tracts in the software. After selecting the required tracts, the building inventory are loaded automatically. Building inventory data are arranged by building material (wood, concrete, and masonry, pre-constructed and steel buildings) and building occupancy (Residential, Commercial, Industrial, Agricultural, Religious, Governmental and Educational) (Ulmi et al. 2014; Federal Emergency Management Agency 2015). Each type of building inventory has its assigned HAZUS-MH 2.1 code. The Aberdeen, Northshore/Brocklehurst and Downtown areas of Kamloops are also created using same procedure. The Aberdeen area is formed in HAZUS – MH 2.1 from 13 tracts, Northshore/Brocklehurst from 43 tracts and Downtown from 10 tracts. The selected tracts are listed in appendix 1.

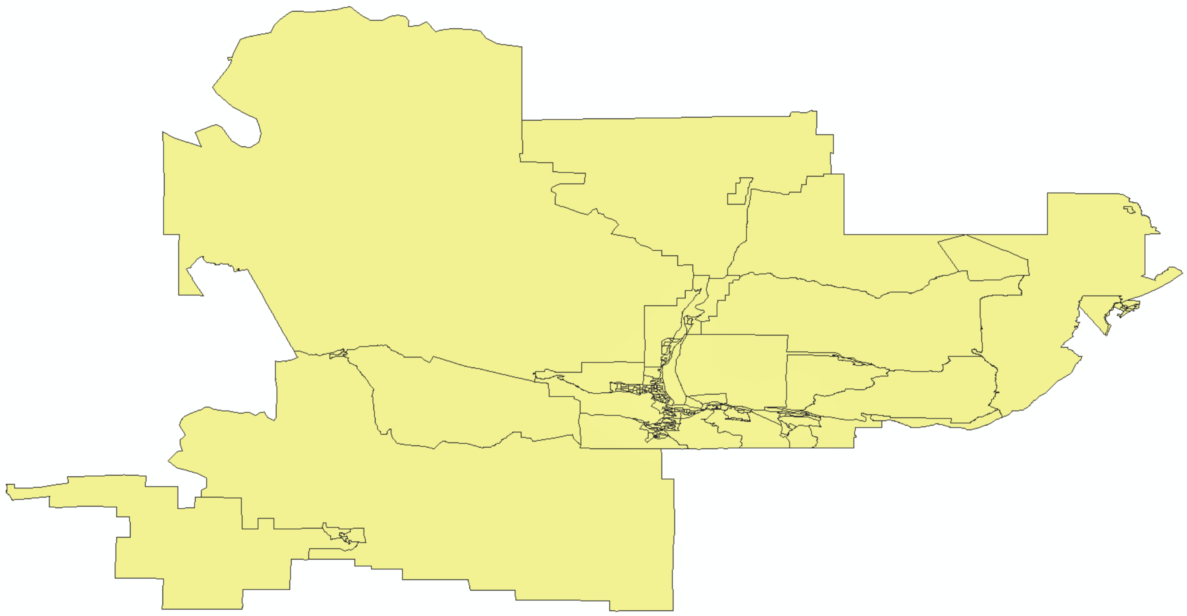


Figure 3-3. Picture of Kamloops region showing the tract units created in HAZUS-MH 2.1

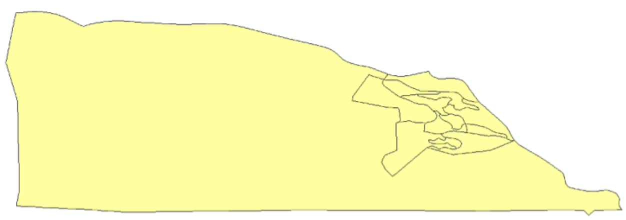


Figure 3-4. Picture of Aberdeen showing the tract units created in HAZUS-MH 2.1

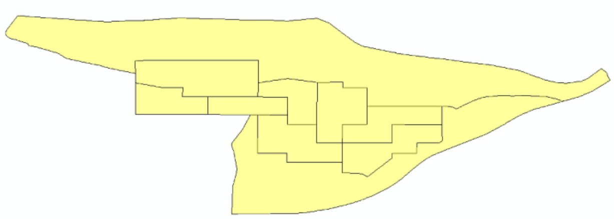


Figure 3-5. Picture of Downtown showing the tract units created in HAZUS-MH 2.1

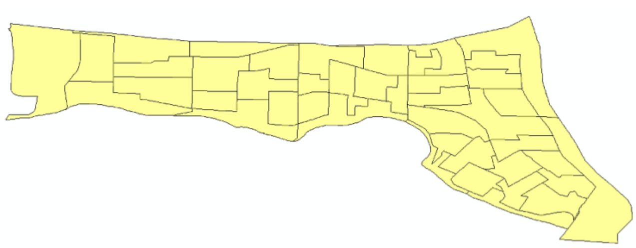


Figure 3-6. Picture of Northshore/Brocklehurst showing the tract units created in HAZUS-MH 2.1

The Kamloops region consist of 160 census tracts; which contain over 31 thousand buildings valued at 7,790 million dollars excluding value of contents (HAZUS REPORT). Up to 91% of buildings in Kamloops are used for residential purpose. The wood frame buildings are the most popular building construction type and constitute up to 83% of the total building constructions in Kamloops (HAZUS REPORT). Tables 3-1, 3-2 and 3-3 summary of the building inventory details from HAZUS considered for this study.

Building Type	Kamloops	Aberdeen	Downtown	Northshore/Brocklehurst
Wood	26387	2547	1715	6023
Steel	597	50	87	113
Concrete	717	58	108	140
Precast	538	41	90	92
Reinforced Masonry	1234	105	151	257
Unreinforced Masonry	288	22	46	55
Manufactured Housing	1988	133	97	316

Table 3-1. Summary of the total number of each building type considered for this study for Kamloops, Aberdeen, Downtown and Northshore/Brocklehurst

Building type	***Building Age***	
	1960 or earlier	1961 – 2005
Wood	436	25951
Steel	527	70
Concrete	487	230
Precast	410	128
Reinforced masonry	990	245
Unreinforced masonry	288	-
Manufactured housing	1153	834
Total built	**4291**	**27457**

Table 3-2. Summary of Kamloops building type by age used for this study

Building occupancy	Kamloops	Aberdeen	Downtown	Northshore/Brocklehurst
Agriculture	22	1	0	3
Commercial	2276	148	467	377
Education	57	3	7	11
Government	48	0	12	4
Industrial	283	31	24	42
Other residential	5188	503	310	1105
Religion	100	4	16	39
Single family	23775	2268	1457	5417

Table 3-3. Summary of general building occupancy: Kamloops, Aberdeen, Northshore/Brocklehurst, Downtown

Earthquake scenario inventory

The list of input parameters required depend on the approach of analysis to be performed in HAZUS-MH 2.1 (Ulmi et al. 2014). Probabilistic approach requires only the moment magnitude and probability. The probabilistic analysis (or PSHA- probabilistic seismic hazard analysis) for this study is done for 2% in 50 years probability; which is also used as the baseline probability for the seismic design for buildings recommended by the National Building Code of Canada (Halchuk, Adams, and Allen 2015) A design magnitude of 6.5 is chosen for the probabilistic analysis in this thesis.

Deterministic approach for DSHA (deterministic seismic hazard analysis) require the selection of ground motion prediction equation, which is the Abrahamson and Silva 2008 (AS08) attenuation equation for this study. Other inputs for deterministic analysis include:

- Moment magnitude, M_w
- Fault information,
- Location of source,
- Soil group.

Moment magnitude, (M_w)

The magnitudes selected follow the acceptable magnitude range for hazard analysis in Western Canada which is form M_w 6.5 to 7.5 (Atkinson and Adams 2012). The chosen magnitude: M_w 6.5, M_w 6.7 and M_w 6.9 at 0.2 increments. The lowest magnitude M_w 5 analyzed in HAZUS – MH 2.1 which is also the minimum design magnitude for North America (Halchuk and Adams 2010) is also included among the magnitudes list considered.

Fault information

A Blind thrust (reverse) fault orientation is chosen for this study. The fault orientation used for this study follows the 1994 magnitude 6.7 Northridge blind thrust earthquake which was inferred from Molnar et al. (2014) study that the event describes the likely fault characteristics to expect in most crustal North American earthquakes. A similar blind thrust faulting scenario was used in the Journeay et al. (2015) District of North Vancouver study. An average dip angle of 40° was chosen following recommendations by Kaklamanos, Baise, and Boore (2011) for specifying unknown earthquake input parameters.

Location of source

The epicenter location coordinates are modelled after recorded earthquakes near Kamloops provided on the Natural Resources Canada (www.earthquakescanada.nrcan.gc.ca) website. The different epicenters for the different earthquake scenarios include - at the center of Kamloops (Kamloops coordinate: 50.70, -120.30) and the others at the coordinate locations of different past earthquake events that occurred near Kamloops (coordinates of the past WNW of Kamloops (50.828, -121.008), Southern BC (50.175, - 120.359) and near Merritt earthquake events (50.221, -120.466). For this research, the depth of the focus will be less than 10km, which is the range for earthquakes that have occurred near Kamloops in the past.

S/N	Place Description	Latitude	Longitude	Location	Approx. Distance from Kamloops, (Km)
1	WNW of Kamloops	50.828	-121.008	WNW	52
2	Near Merritt	50.221	-120.466	S1	55
3	Near Merritt (south B.C)	50.175	-120.359	S2	58
4	Kamloops location	50.70	-120.3	K	-

Table 3-4 Earthquake scenario locations

S/N	Latitude Coordinate	Longitude coordinate	location	Moment magnitude (M_w)	GMPE	Earthquake Scenario
1	50.828	-121.008	WNW	6.5	AS08	AS08_WNW-6.5
2	50.828	-121.008		6.7	AS08	AS08_WNW-6.7
3	50.828	-121.008		6.9	AS08	AS08_WNW-6.9
4	50.221	-120.466	S1	6.5	AS08	AS08_S1-6.5
5	50.221	-120.466		6.7	AS08	AS08_S1-6.7
6	50.221	-120.466		6.9	AS08	AS08_S1-6.9
7	50.175	-120.359	S2	6.5	AS08	AS08_S2-6.5
8	50.175	-120.359		6.7	AS08	AS08_S2-6.7
9	50.175	-120.359		6.9	AS08	AS08_S2-6.9
10	50.7	-120.3	K	5	AS08	AS08_K-5
11	50.7	-120.3		6.5	AS08	AS08_K-6.5
12	50.7	-120.3		6.7	AS08	AS08_K-6.7
13	50.7	-120.3		6.9	AS08	AS08_K-6.9

Table 3-5 list of deterministic earthquake scenarios for this study

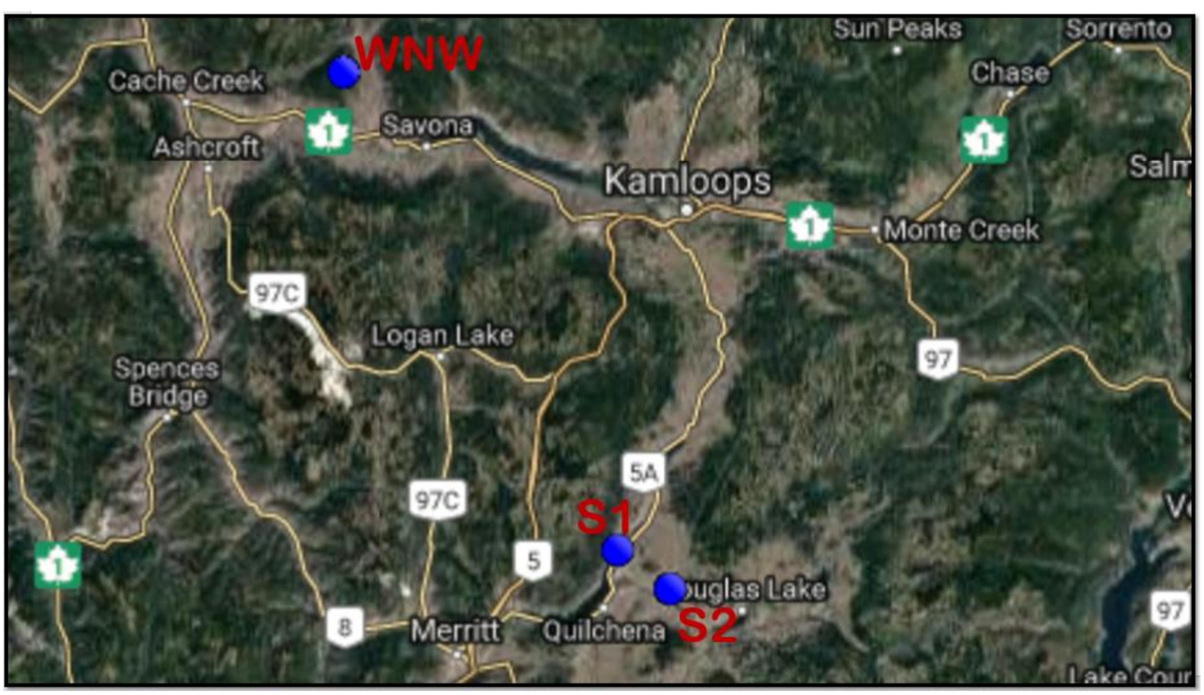


Figure 3-7. Map of epicenters at S1, S2 and WNW from previous events near Kamloops (Natural Resources Canada 2016)

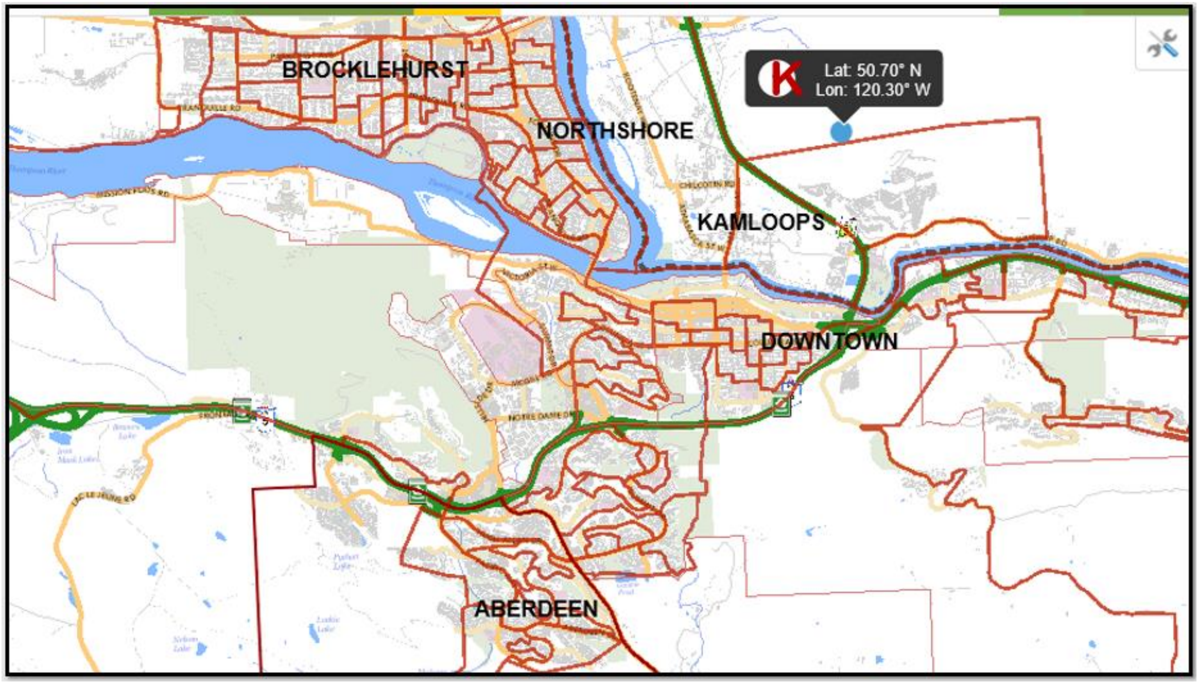


Figure 3-8. Location of epicenter K at Kamloops coordinate location (lat. 50.7N; long. -120.30W) (map created using the city of Kamloops interactive map)

Soil classification

Based on the geologic information for Kamloops, the V_{S30} design value for Kamloops is chosen from the from the Wills and Clahan (2006) published data of shear wave velocities which can be applied for most North American cities. The V_{S30} for Kamloops from the correlations by Wills and Clahan (2006) falls within the group B/C ($360 < V_{S30} < 760$ m/s) which is the reference V_{S30} used in the 2015 National Building Code of Canada (Halchuk, Adams, and Allen 2015). A uniform soil group C is then chosen for Kamloops in this study. Using a uniform soil classification for Kamloops, is only a representative of the average soil group. Based on the Kamloops geology described earlier in chapter 1, the Kamloops area has other soil groups ranging from soil group B to D scattered around Kamloops. Soil group B is refer those places within Kamloops with Eocene-rock like in Aberdeen (City of Kamloops 2008); places like the Northshore area with young silty-alluvial soil (Fulton 1976) will have less than 360 shear wave velocity ($V_{S30} < 360$) which can be classified as D.

Aberdeen, Northshore and Downtown areas of Kamloops

The actual shear wave velocities of these areas are unavailable making the selection of the appropriate soil group difficult. To get around this, the uniform soil group C is selected for all three areas. A second soil group is chosen for each based on the geologic reports of the place. The Northshore area is located near the Thompson rivers with young silty- alluvial soil formed from the rivers' deposits (Fulton 1976); will have possibly less than 360 shear wave velocity ($V_{S30} < 360$) which can be classified as D. The Aberdeen area is classified for this study as B since it has gravel deposits with Kamloops (Eocene) rocks (City of Kamloops 2008). The Downtown area soil is a combination of scattered gravel, silty sand and clay (Fulton 1976) which is firmer than the alluvial soil found in the Northshore; yet, since it is close to the Northshore, the Downtown is also classified for class D. Separate earthquake analyses are done for the different selected soil groups and the damage results are compared to the results from soil group C to view the damage effects from soil group difference.

Geologic Unit	Geologic Description	Unit V_{S30} (m/s)	Map Group V_{S30} (m/s)
Qi	Intertidal Mud including "bay mud"	160	160
Qal, deep, Imperial V.	Holocene alluvium in the Imperial Valley.	209	216
aft/qi	Artificial fill over intertidal mud around San Francisco Bay.	217	
Qal, fine	Fine grained Quaternary (Holocene) alluvium.	236	
Qal, deep	Quaternary (Holocene) alluvium in deep basins.	280	287
Qal, deep, LA Basin	Quaternary (Holocene) alluvium in the Los Angeles basin.	281	
Qs	Quaternary (Pleistocene) sand deposits.	302	
Qal, coarse	Coarse grained Quaternary (Holocene) alluvium	354	377
Qal, thin	Thin (Holocene) alluvium underlain by contrasting material within 30m.	349	
Qoa	Quaternary (Pleistocene) alluvium	387	
QT	Quaternary to Tertiary (Pleistocene - Pliocene) alluvial deposits.	455	489
Kss	Cretaceous sandstone.	566	
Tss	Tertiary sandstone.	515	
Tv	Tertiary volcanic rocks.	609	609
Serpentine	Serpentine.	653	
KJf	Franciscan complex rock.	782	760
Xtaline	Crystalline; including granitic and metamorphic rocks.	748	

Table 3-6. Shear wave velocity correlations (V_{S30}) by (Kalkan, Wills, and Branum 2010)

Liquefaction and Landslide Susceptibility

Only a small proportion of Kamloops area may have low – moderate liquefaction (land areas with alluvial soils found near the Thompson rivers e.g. Northshore, Brocklehurst etc.) and landslide vulnerability (elevated areas found in places like Aberdeen); so, zero (0) liquefaction and landslide rating is assumed for the entire Kamloops. However, to get an idea of the possible damage contribution from liquefaction and landslide, Aberdeen, Downtown and Northshore areas were assigned different liquefaction and landslide susceptibility values using their geology information.

Using the HAZUS-MH 2.1 liquefaction susceptibility rating 0 – 5 ("0" stands for no liquefaction - "5" for high liquefaction rating) and Landslide susceptibility rating 0 – 10 ("0" stands for no landslide - "10" for high landslide rating); the following values were assigned: Northshore – liquefaction 3 and landslide 0; Aberdeen – liquefaction 0 and landslide 6; Downtown – liquefaction 0 and landslide 0.

REFERENCES

Atkinson G, Adams J. 2012. Ground motion prediction equations for application to the 2015 Canadian national seismic hazard maps. Can. J. Civ. Eng.

City of Kamloops. 2008. Aberdeen Groundwater Area Information Summary.

City of Kamloops. 2011. City of Kamloops Statistical Report Final Version.

Federal Emergency Management Agency. 2015. Hazus–MH 2.1: Technical Manual. :718.

Fulton RJ. 1976. Surficial Geology, Kamloops Lake, West of sixth Meridian, British Columbia. In: Geological Survey of Canada, "A" Series Map 1394A. p. 1 sheet.

Halchuk S, Adams J. 2010. Mmin - Implications of its choice for Canadian seismic hazard and seismic risk. 9th U.S. Natl. 10th Can. Conf. Earthq. Eng.

Halchuk S, Adams J, Allen TI. 2015. Fifth generation seismic hazard maps of Canada: Maps and grid values to be used with the 2015 National Building Code of Canada. Geol. Surv. Canada Open File 7893:26p.

Journeay JM, Dercole F, Mason D, Weston M, Prieto JA, Wagner CL, Hastings NL, Chang SE, Lotze A, Ventura CE. 2015. A Profile of Earthqquake Risk for the District of North Vancouver, British Columbia. Geoloical Surv. Canada Open File:223p.

Kaklamanos J, Baise LG, Boore DM. 2011. Estimating unknown input parameters when implementing the NGA ground-motion prediction equations in engineering practice. Earthq. Spectra 27:1219–1235.

Kalkan E, Wills CJ, Branum DM. 2010. Seismic hazard mapping of California considering site effects. Earthq. Spectra 26:1039–1055.

Molnar S, Cassidy JF, Olsen KB, Dosso SE, He J. 2014. Earthquake ground motion and 3D Georgia basin amplification in Southwest British Columbia: Deep Juan de Fuca Plate scenario earthquakes. Bull. Seismol. Soc. Am. 104:301–320.

Ulmi M, Wagner CL, Wojtarowicz M, Bancroft JL, Hastings NL, Chow W, Rivard JR, Prieto J, Journeay JM, Struik LC, et al. 2014. Hazus-MH 2.1 Canada user and technical manual: earthquake module.

Wills CJ, Clahan KB. 2006. Developing a Map of Geologically Defined Site-Condition Categories for California. Bull. Seismol. Soc. Am. 96:1483–1501.

Chapter 4. RESULTS

Building damage results are determined by the HAZUS-MH 2.1 software calculations using the probabilistic and deterministic analysis approaches. For this thesis, the damage results are arranged by the damage levels (none, slight, moderate, extensive and complete) and by the economic losses produced for each kind of scenario. As described in Chapter 2, each of the damage levels: none, slight, moderate, extensive and complete will have different damage implications. “None” implies no damage, “slight” to “moderate” building damage is mainly non-structural; yet, may require some minor repairs (mostly aesthetic) depending on the degree of damage. Extensive damage refers to severe damage (mostly structural) and will require major structural repairs. Complete damage refers to building collapse or damage beyond repair. Both extensive and complete damage will require that occupants are moved. Damage costs / economic losses are represented in this study by their dollar($)values.

The damage results are arranged according to the different occupancy classifications - Residential, Commercial, Industrial, Agricultural, Religious, Government and Educational (Ulmi et al. 2014; Federal Emergency Management Agency 2015) so as to identify which sector of the Kamloops would most affected.

To view the possible effect of building material types, damage results are also organized by the different building material types: wood, steel, concrete, precast, reinforced masonry, unreinforced masonry and manufactured buildings.

For consistency, the damage results described are based on a uniform soil group, C for the entire region of Kamloops. The Hazus report are based on 2006 census information. Recent census would be ideal, however, is not expected to contribute much to damage results since newer buildings or buildings built after 2005 (also called “high code” buildings) are designed with earthquake resistant abilities (Ulmi et al. 2014).

Probabilistic Seismic Hazard Analysis (PSHA) Results

A probabilistic scenario for probabilistic seismic hazard analysis was chosen with 2% in 50 years chance of occurrence or 1 in 2500 years probability which is also the baseline probability used for the seismic design for buildings recommended by the National Building Code of Canada (Halchuk, Adams, and Allen 2015). The damage for the entire Kamloops area are predicted for this research from probabilistic analysis in HAZUS-MH 2.1 using a chosen design moderate moment magnitude, Mw (Mw= 6.5) for Kamloops which is also the lower magnitude range hazard analysis for cities in British Columbia (Mw 6.5 to 7.5) (Atkinson and Adams 2012). The Kamloops region for this study was created out of 160 census tracts; which contain over 31 thousand buildings.

The software estimates that residential occupancy, which takes up to 91% of the total Kamloops building inventory (see Table 3-2) will be the most affected occupancy: about 280 residential buildings are predicted to undergo extensive damage with nearly 19 buildings completely destroyed from the probabilistic scenario. In the order of damage result ranking, residential occupancy is followed by the commercial occupancy and then the industrial occupancy. (see Table 4-1).

Occupancy	***Damage level***				
	None	*Slight*	*Moderate*	*Extensive*	*Complete*
Agriculture	14	4	3	1	0
Commercial	1334	447	369	**116**	**10**
Education	37	10	8	2	0
Government	29	9	8	2	0
Industrial	165	53	49	15	1
Residential	21628	5195	1841	**280**	**19**
Religion	64	18	14	4	0
Total	**23271**	**5736**	**2292**	**420**	**30**

Table 4-1. Kamloops probabilistic damage result (a) building occupancy

Results show that out of the total buildings in Kamloops, about 73% of the total building inventory (23271 buildings) will be unaffected. Also from the probabilistic scenario, the manufactured buildings (buildings not constructed onsite e.g. mobile homes) are predicted to suffer the most damage followed by wood frame buildings. A few buildings from all the building types are predicted by the software to collapse from this scenario, however; when ranked by building type with the next highest collapse after the manufactured and wood frame buildings will be the unreinforced masonry. (see Table 4-2).

Building type	*Total (by building type)*	*Damage level*				
		None	*Slight*	*Moderate*	*Extensive*	*Complete*
Wood	26387	20447	4683	1158	**95**	**6**
Steel	597	341	103	115	33	3
Concrete	717	415	147	123	30	2
Precast	538	276	86	117	55	4
RM	1234	770	173	209	80	2
URM	288	146	64	53	20	5
MH	1988	876	480	517	**107**	**8**
Total	**31749**	**23271**	**5736**	**2292**	**420**	**30**

Table 4-2. Kamloops probabilistic damage result (b) building construction/material type

In Table 4-2 RM is reinforced masonry, URM is unreinforced masonry and MH is manufactured housing

The total building damage cost from the probabilistic scenario as estimated by HAZUS-MH 2.1 is valued at over 300 million dollars. The residential occupancy is also predicted to contribute about 51% of the total economic loss. (see figure 4-1)

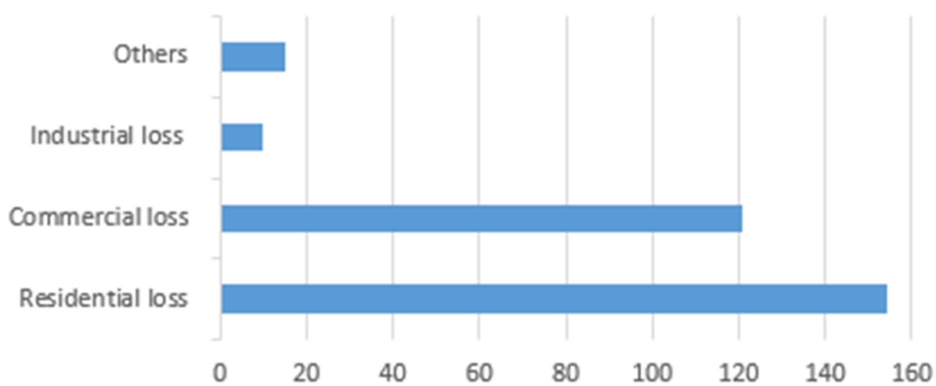


Figure 4-1. Kamloops probabilistic damage result (c) economic loss in millions of Dollars

Deterministic Seismic Hazard Analysis (DSHA) Results

A total of 13 earthquake scenarios were selected using the main variables of this study which are the: earthquake magnitudes (M_w 5, 6.5, 6.7, 6.9), the earthquake locations, the liquefaction and landslide vulnerability; for deterministic seismic hazard analysis (DSHA). The magnitude, M_w: 5 was used exclusively for the Kamloops location "K".

Different scenarios were chosen to determine which of the scenarios will contribute the most damage. Also, to predict the level of damage to expect and their possible economic impacts.

The summary of the number of buildings damaged at each damage level for all the 13 deterministic scenarios are shown in the table below. Details of each deterministic scenario results can be found in Appendix C. All 13 deterministic estimations for Kamloops are set for uniform soil condition: soil class C. All the deterministic scenarios were modelled using the Abrahamson and Silva 2008 (AS08) ground motion prediction equation. (see chapter 3 for location / epicenter description). The total economic loss from the likely scenario (AS08_K - 5) is valued at over 45 million dollars (Table 4-3).

Scenario Name	***Location***	***magnitude***	***Damage level***				***Total Damage (million dollars)***
			Slight	*Moderate*	*Extensive*	*Complete*	
AS08_WNW6.5	WNW	6.5	303	68	4	0	4.9
AS08_WNW6.7		6.7	515	120	8	0	9.2
AS08_WNW6.9		6.9	787	192	17	0	16
AS08_S1-6.5	S1	6.5	629	139	11	0	13
AS08_S1-6.7		6.7	1102	260	23	1	26
AS08_S1-6.9		6.9	1783	468	45	1	48
AS08_S2-6.5	S2	6.5	517	112	8	0	10
AS08_S2-6.7		6.7	919	211	18	0	20
AS08_S2-6.9		6.9	1509	378	35	1	38
AS08_K-5	K	5	1028	252	24	1	46
AS08_K-6.5		6.5	7365	4079	1075	156	630
AS08_K-6.7		6.7	7942	4865	1440	257	800
AS08_K-6.9		6.9	8315	5459	1750	365	950

Table 4-3. Kamloops deterministic results: Summary of the total number of damaged buildings at each damage level and the total economic losses produced by each 13 scenarios in millions of dollars (values reported to 2 sig fig.)

As expected, from the results of all the 13 deterministic scenarios, the scenarios with magnitudes at epicenter in Kamloops, “K” produced intense ground motion and significantly more damage even for magnitude as low as 5. The “K” epicentered scenarios are followed by the S1(near Merritt in British Columbia) epicentered scenarios and then the S2 (also near Merritt but a little farther from S1) epicentered scenarios according to damage, since, the nearer the buildings the more likely the experience of higher ground motion intensity thereby producing more damage (Arnold 2014; Foti 2015).

It is also not surprising that the damage results from the 13 different deterministic scenarios reflect that earthquake magnitude will influence the damage results; that higher magnitudes will produce higher damage consequences.

The total value of damage follows the same order (influenced by magnitude and location of epicenter). As expected, amount of damage (economic loss) is roughly linear on a logarithmic scale (Figure 4-2).

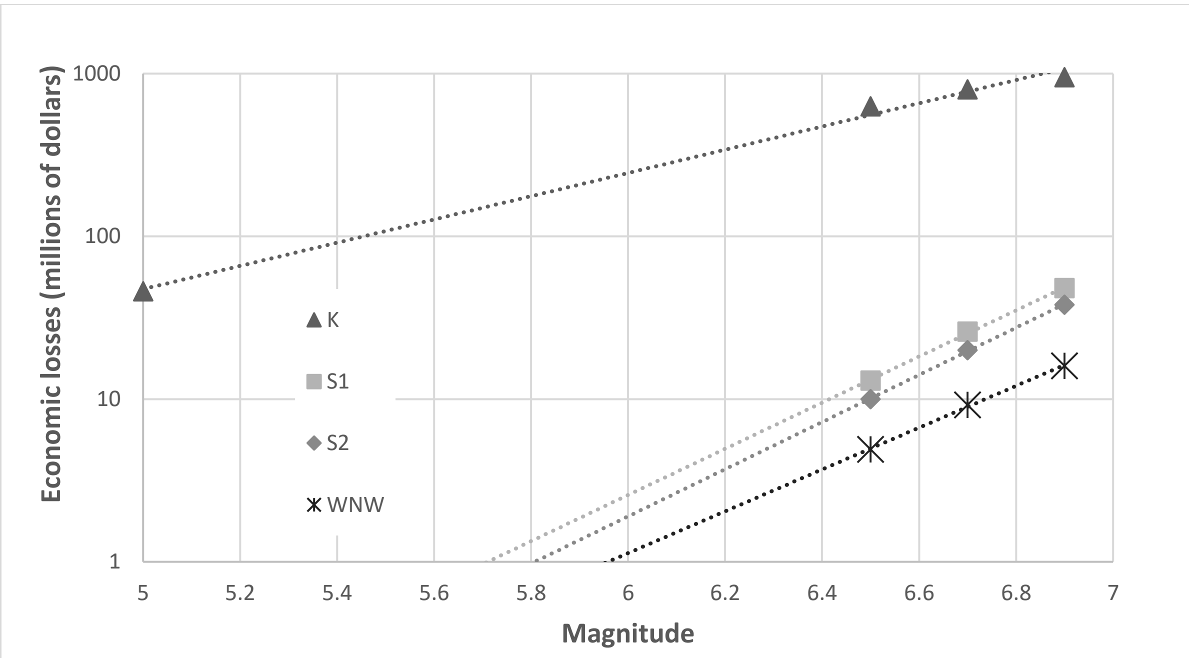


Figure 4-2 Economic losses produced by each 13 deterministic scenarios.

Economic losses are significantly higher from all deterministic scenarios with epicenter at location “K” (AS08_K-5, AS08_K-6.5, AS08_K-6.7, AS08_K-6.9). (see Table 4-3). Figure 4-2 shows the relationship between the damage costs (millions of dollars) produced at the different locations (K, S1, S2 and WNW). The points are connected using a trendlines to illustrate the increasing damage as the magnitude increases.

To identify the most vulnerable occupancy among different occupancies to the 13 scenarios, the result predictions for extensive and complete damage are considered which is summarized in Table 4-4. The residential occupancy type is predicted just like for the probabilistic estimation to have the most number of severely damaged buildings (extensive – complete building collapse) in all the 13 deterministic scenarios followed by the commercial occupancy. (see Table 4-4). The building type inventory in Kamloops are presented in Chapter 3 (Tables 3-1,3-2 and 3-3).

	Extensive - Complete building damage: Building occupancy						
Scenario Name	*Agric. N=22*	*Comm. N=2276*	*Edu. N=57*	*Gov. N=48*	*Industrial N=283*	*Residential N=28963*	*Religion N=100*
AS08_WNW6.5	0	2	0	0	0	2	0
AS08_WNW6.7	0	3	0	0	0	5	0
AS08_WNW6.9	0	6	0	0	1	10	0
AS08_S1-6.5	0	4	0	0	1	6	0
AS08_S1-6.7	0	9	0	0	2	13	0
AS08_S1-6.9	0	17	0	0	2	27	0
AS08_S2-6.5	0	4	0	0	0	4	0
AS08_S2-6.7	0	7	0	0	1	10	0
AS08_S2-6.9	0	14	0	0	2	20	0
AS08_K-5	0	10	0	0	1	14	0
AS08_K-6.5	2	290	6	5	35	882	11
AS08_K-6.7	3	386	9	8	46	1230	15
AS08_K-6.9	4	474	10	10	60	1539	18

Table 4-4. Number of extensive to completely damaged buildings for the different occupancies from all 13 deterministic scenarios.

	Extensive - Complete building damage: Building occupancy						
Scenario Name	*Agric. (%)*	*Comm. (%)*	*Edu. (%)*	*Gov. (%)*	*Industrial (%)*	*Residential (%)*	*Religion (%)*
AS08_WNW6.5	0	0.09	0	0	0	0	0
AS08_WNW6.7	0	0.13	0	0	0	0.02	0
AS08_WNW6.9	0	0.26	0	0	0.35	0.03	0
AS08_S1-6.5	0	0.18	0	0	0.35	0.02	0
AS08_S1-6.7	0	0.40	0	0	0.71	0.04	0
AS08_S1-6.9	0	0.75	0	0	0.71	0.09	0
AS08_S2-6.5	0	0.18	0	0	0	0.01	0
AS08_S2-6.7	0	0.30	0	0	0.35	0.03	0
AS08_S2-6.9	0	0.62	0	0	0.71	0.07	0
AS08_K-5	0	0.44	0	0	0.35	0.05	0
AS08_K-6.5	9	13	10	10	12	3.0	11
AS08_K-6.7	13	17	16	17	16	4.2	15
AS08_K-6.9	18	21	17	21	21	5.3	18

Table 4-5 Percentage extensive to completely damaged buildings for the different occupancies from all 13 deterministic scenarios.

Scenario Name	*Extensive - Complete building damage: Building material type*						
	Wood N=26387	*Steel N=597*	*Concrete N=717*	*Precast N=538*	*RM N=1234*	*URM N=288*	*MH N=1988*
AS08_WNW6.5	0	0	0	1	1	1	1
AS08_WNW6.7	1	0	0	2	2	1	2
AS08_WNW6.9	3	1	1	3	3	2	4
AS08_S1-6.5	3	1	0	2	2	2	1
AS08_S1-6.7	5	2	1	5	5	3	3
AS08_S1-6.9	9	5	2	8	9	5	8
AS08_S2-6.5	1	1	0	2	2	1	1
AS08_S2-6.7	3	2	1	4	3	3	2
AS08_S2-6.9	7	3	2	7	7	4	6
AS08_K-5	6	1	1	5	5	4	3
AS08_K-6.5	458	91	80	108	170	58	266
AS08_K-6.7	657	127	112	138	226	72	365
AS08_K-6.9	832	160	142	164	277	86	454

Table 4-6. Extensive to complete damage comparison for the different building type from all 13 deterministic scenarios

Scenario Name	*Extensive - Complete building damage: Building material type*						
	Wood (%)	*Steel (%)*	*Concrete (%)*	*Precast (%)*	*RM (%)*	*URM (%)*	*MH (%)*
AS08_WNW6.5	0	0	0	0.19	0.08	0.35	0.05
AS08_WNW6.7	0	0	0	0.37	0.16	0.35	0.10
AS08_WNW6.9	0.01	0.17	0.14	0.56	0.24	0.69	0.20
AS08_S1-6.5	0.01	0.17	0	0.37	0.16	0.69	0.05
AS08_S1-6.7	0.02	0.34	0.14	0.93	0.41	1.0	0.15
AS08_S1-6.9	0.03	0.84	0.28	1.5	0.73	1.7	0.40
AS08_S2-6.5	0	0.17	0	0.37	0.16	0.35	0.05
AS08_S2-6.7	0.01	0.34	0.14	0.74	0.24	1.0	0.10
AS08_S2-6.9	0.03	0.50	0.28	1.3	0.57	1.4	0.30
AS08_K-5	0.02	0.17	0.14	0.93	0.41	1.4	0.15
AS08_K-6.5	1.7	15	11	20	14	20	13
AS08_K-6.7	2.5	21	16	26	18	25	18
AS08_K-6.9	3.2	27	20	30	22	30	23

Table 4-7. Percentage extensive to complete damage comparison for the different building type from all 13 deterministic scenarios

From Table 4-6 above, several buildings from all the building construction types are predicted by the software to suffer extensive to complete damage.

Depending on the scenario type, however; when ranked by number of severely affected (extensive to complete damage prediction), the wood frame buildings had the highest damage prediction at locations: S1, S2 and K deterministic scenarios. The damage estimation for manufactured housing is slightly higher for scenarios at the WNW location.

Likely scenario for Kamloops

Here, the likely scenario is used to view the possible damage effects if Kamloops were to experience an earthquake in the future, and if the epicenter of that future earthquake is situated at Kamloops' center.

The AS08_K-5 scenario (with moment magnitude, M_w of 5; epicenter at Kamloops coordinate, "K") is assumed for this thesis as the most likely scenario for Kamloops since past earthquakes near Kamloops ranged below M_w of 5 (M_w < 5) (Halchuk 2009; Natural Resources Canada 2016). The Abrahamson and Silva 2008 (AS08) is also chosen for the ground motion attenuation to create the ground motion.

The likely scenario results for Kamloops discussed here is same as the AS08_K-5 scenario in Tables 4-3, 4-4, and 4-6. However, the focus is on the three most crucial damage levels: moderate, extensive and complete damage. HAZUS-MH 2.1 predict that if an event like the AS08_K-5 were to happen in Kamloops, the total damage results for all of Kamloops:

close to 252 buildings will be moderately damaged;
about 24 buildings will suffer extensive damage;
and at least 1 building will collapse completely. (see Tables 4-6 and 4-7)

Residential occupancy is predicted by the software to have the most number of affected buildings followed by commercial. The software also estimates that at least one residential building will be completely destroyed by the likely earthquake scenario. The commercial occupancy is followed distantly by industrial occupancy (Table 4-6).

From Table 4-7, the wood frame buildings are estimated to have the most number of damaged buildings followed by manufactured housing (buildings not constructed onsite). However, the unreinforced masonry, which is one of the least common building type, had a significant number of buildings estimated to suffer moderate to extensive damage. At least one unreinforced masonry building is predicted to collapse completely. Other building types are estimated to have some moderate to extensive damage but none of the building types are predicted to be completely damaged from the AS08_K -5 earthquake scenario except the unreinforced masonry buildings that may have at least 1 completely collapsed.

Occupancy	Occupancy total	Damage level					
		Moderate	*Moderate (%)*	*Extensive*	*Extensive (%)*	*Complete*	*Complete (%)*
Agriculture	22	0	0	0	0	0	0
Commercial	2276	53	**2.3**	**10**	**0.44**	**0**	**0**
Education	57	1	1.8	0	0	0	0
Government	48	1	2.1	0	0	0	0
Industrial	283	5	1.8	1	0.35	0	0
Residential	28963	190	**0.66**	**13**	**0.04**	**1**	**0**
Religion	100	2	2.0	0	0	0	0
Total	**31749**	**252**	**0.79**	**24**	**0.08**	**1**	**0**

Table 4-8. Number and percentage of damaged buildings by occupancy from likely scenario earthquake (AS08_K-5 scenario) on Kamloops

Building type	***Total***	***Moderate***	***Moderate (%)***	***Extensive***	***Extensive (%)***	***Complete***	***Complete (%)***
Wood	26387	99	0.38	6	0.02	0	0
Steel	597	10	1.7	1	0.17	0	0
Concrete	717	11	1.5	1	0.14	0	0
Precast	538	21	3.9	5	0.93	0	0
Unreinforced masonry	288	15	5.2	3	**1.0**	**1**	**0.35**
Reinforced masonry	1234	30	2.4	5	0.40	0	0
Manufactured housing	1988	66	3.3	3	0.15	0	0
Total	**31749**	**252**	**0.79**	**24**	**0.08**	**1**	**0**

Table 4-9. Number and percentage of damaged buildings by building type from a likely scenario (AS08_K-5 scenario) on Kamloops

Influence of building age

To understand how building age can affect results, the HAZUS-MH 2.1 software estimates building damage based on the code at the time the building was built:

Where, pre-code buildings refer to the buildings built before 1941; low-code buildings refer to those built between 1941 to 1969; moderate-code buildings refer to buildings built between 1970 to 1989; high-code buildings refer to newer buildings or those built 1990 and upwards.

Building type	**Moderate**		**Extensive**		**Complete**	
	Pre-code	**Low-Code**	**Pre-code**	**Low-Code**	**Pre-code**	**Low-Code**
Wood	2	97	0	6	0	0
Steel	10	0	1	0	0	0
Concrete	9	2	1	0	0	0
Precast	18	3	4	1	0	0
Unreinforced masonry	15	-	3	-	1	-
Reinforced masonry	26	4	5	0	0	0
Manufactured housing	49	17	2	1	0	0
Total damaged count	**129**	**123**	**16**	**8**	**1**	**0**

Table 4-10. Kamloops AS08_K-5 damage results: number of damaged pre-code buildings vs damaged low-code buildings

Summary of damage count for pre-code and low- code buildings from the AS08_K -5 earthquake scenario (likely scenario) are shown in Table 4-8. (see Appendix D for results details). Damage count for moderate-code and high-code buildings are not included in Table 4-8 since no damage was predicted for them by HAZUS-MH-2.1.

From Table 4-8, the software damage results predict that if a likely scenario that resembles the AS08_K-5 earthquake scenario were to occur in Kamloops, that buildings built before 1970 (consisting of pre-code and low-code buildings) will be most affected. And that such scenario might not have effect on moderate-code and high-code buildings. The sum of damaged count from pre-code and low-code buildings damage estimations (Table 4-8) alone form the total moderate, extensive and complete damage levels for the AS08_K-5 earthquake damage results (likely scenario).

The damage results in Table 4-8 above also appear to be influenced by the building type popularity at each period. An example is the prediction of 97 moderately damaged low code and 6 extensively damaged low-code wood frame buildings; while, in the pre-code only 2 moderately damaged with none extensively damaged wood frame. Normally, it is expected that more damage would come from pre-code and less from low- code, but the wood frame damage results show the reverse.

From the damage count report from HAZUS for pre-code and low-code (included in Appendix D), the pre-code estimations are done for buildings built in 1960 and earlier, while the low-code, focus on buildings constructed after 1961 (summary in Table 4-9). Before 1960,

Building type	***Building Age***	
	1960 or earlier	**1961 – 2005**
Wood	436	25951
Steel	527	70
Concrete	487	230
Precast	410	127
Reinforced masonry	990	245
Unreinforced masonry	288	-
Manufactured housing	1153	834
Total built	**4291**	**27457**

Table 4-11. Summary of Kamloops building type by age used for this study (HAZUS REPORT)

manufactured housing and reinforced masonry were the most common building type (Table 4-9). The popularity of the wood type buildings after 1960 (Table 4-9) could be the reason behind the damage results at low-code. Also, from HAZUS (in Table 4-9), the unreinforced masonry style of construction ended by 1960 which explains why no damage result: moderate, extensive or complete was predicted for unreinforced masonry in the low code.

Damage effect of the likely scenario (AS08_K-5) on Northshore, Aberdeen and Downtown

The downtown area of Kamloops, which is the central for most businesses and administrative offices in Kamloops is predicted by the software as the location to be highly impacted by the likely scenario due to the number of aged buildings with at least 53 buildings predicted to be moderately damaged from the scenario. (Table 4-9). Downtown area is estimated to incur the most commercial loss than any area in Kamloops. Downtown is predicted to contribute up to 48% of the total commercial losses. (Table 4-10).

Area of Kamloops	***Moderate***	***Extensive***	***Complete***
Northshore	34	3	0
Aberdeen	8	1	0
Downtown	**53**	**7**	**0**
Rest of Kamloops	157	13	1

Table 4-12. Damage count from AS08_K-5 scenario on Northshore, Aberdeen and Downtown

Occupancy	*Area of Kamloops* *Loss in millions of dollars*			
	Northshore	**Aberdeen**	**Downtown**	**Rest of Kamloops**
Residential	2.9	0.78	4.0	13
Commercial	1.6	0.28	**9.9**	8.8
Industrial	0.12	0.04	0.48	1.1
Others	0.26	0.01	0.91	1.4

Table 4-13. Economic losses from AS08_K-5 scenario on Northshore, Aberdeen and Downtown (values reported to 2 sig. fig.)

Aberdeen, Northshore and Downtown

To understand how ground conditions can affect the overall results, separate analyses were done for Aberdeen, Northshore and Downtown areas of Kamloops.

Separate deterministic analyses were done to calculate the damage impacts on Northshore, Aberdeen and Downtown area of Kamloops and, to consider the possible contribution of soil variability. Different soil groups which is determined by the soil's shear wave velocity (V_{S30}) (refer to Table 1-6 for the description soil groups) were assumed for Aberdeen, Northshore and Downtown based on geologic map and reports. Northshore was estimated for class D and Aberdeen for class B and soil class D for Downtown. (see chapter 3 for soil group selection).

The damage results from the different assigned soil groups are then compared to the damage result from uniform soil class (group): soil class C. The likely contribution of potentially induced hazards was also considered. Damage results are organized into: Damage from ground shaking only (i.e. without considering the possible contribution of liquefaction and landslide) and Damage from potentially induced hazards (i.e. considering the effects of liquefaction and landslide).

Northshore study

The damage to buildings from earthquake on the Northshore area were estimated using 2 deterministic scenarios AS08_K-6.5 and AS08_K-5 (both with same epicenter at Kamloops coordinate, "K" and moment magnitudes, M_w 6.5 and 5 respectively); since 6.5 is the recommended lower magnitude for damage estimation for Western Canada (Atkinson and Adams 2012) and M_w 5 is the minimum magnitude used for design of earthquake –

resistant structures for North America (Halchuk and Adams 2010). Each scenario with epicenter at the Kamloops coordinate are used to determine the building damage effect at Northshore area.

To arrive at proper estimation, separate analysis was done first considering soil effect and then the added effect of ground failure; the damage results from the separate analyses are grouped into: damage from ground shaking only and damage from ground shaking and ground failure (liquefaction and landslide) respectively.

Number of buildings damage from ground shaking only

	AS08_K-5		AS08_K-6.5	
Damage level	**Soil class C**	**Soil class D**	**Soil class C**	**Soil class D**
Slight	169	331	1573	1873
Moderate	34	72	680	958
Extensive	3	7	135	242
Complete	0	0	12	33

Table 4-14. Northshore (a) Number of building damage from ground shaking only

Number of buildings damage from ground shaking and ground failure (liquefaction – 3, landslide – 0)

Damage results prediction by HAZUS – MH 2.1 show minimal changes with the inclusion of liquefaction rating of 3 for soil classes C and D for Northshore.

	AS08_K-5		AS08_K-6.5	
Damage level	**Soil class C**	**Class D**	**Soil Class C**	**Soil Class D**
Slight	169	331	1572	1870
Moderate	34	72	680	958
Extensive	3	7	138	249
Complete	0	0	13	34

Table 4-15. Northshore (b) Number of building damage from ground shaking and ground failure (liquefaction – 3, landslide – 0)

Aberdeen study

The impact of earthquake on the Aberdeen area are estimated using 2 deterministic scenarios AS08_K-6.5 and AS08_K-5 same as Northshore above. Results are grouped into: damage from ground shaking only and damage from ground shaking and ground failure

	AS08_K-5		AS08_K-6.5	
Damage level	**Soil class C**	**Class B**	**Soil Class C**	**Soil Class B**
Slight	47	13	691	508
Moderate	8	2	300	170
Extensive	1	0	58	23
Complete	0	0	5	1

Table 4-16.Aberdeen (a) Number of building damage from ground shaking only

Damage results prediction by HAZUS – MH 2.1 remained the same as Table 4-14 even with the inclusion of landslide rating of 6 for soil classes C and B for Aberdeen.

Downtown study

The impact of earthquake on the Downtown area are estimated using 2 deterministic scenarios AS08_K-6.5 and AS08_K-5. Results are grouped into: damage from ground shaking only is considered for Downtown since the potential of liquefaction and landslide is relatively low.

	AS08_K-5		AS08_K-6.5	
Damage level	**Soil class C**	**Class D**	**Soil Class C**	**Soil Class D**
Slight	187	304	720	705
Moderate	53	100	567	643
Extensive	7	14	194	269
Complete	0	1	35	74

Table 4-17. Downtown: Number of building damage from ground shaking only

Results summary: Northshore, Aberdeen and Downtown areas

The AS08_K-6.5 produced greater damage than AS08_K-5 as expected. However, within the same magnitude level, soil group difference (e.g. for Northshore from soil group C to D) will increase damage results by over 1.5 times. Each of the results Table for Northshore, Aberdeen and Downtown areas - for ground movement alone (without considering the added possibility of ground failure) are predicted to accrue higher damage at the lower soil group (lower shear wave velocity, V_{S30}).

From the results with ground failure vulnerability included (Northshore – liquefaction 3 and landslide 0; Aberdeen – liquefaction 0 and landslide 6; Downtown – liquefaction 0 and landslide 0) show that for a magnitude of 5 (i.e. from AS08_K-5), that damage will come from mainly the ground movement and none from ground failure. But, at a magnitude of 6.5 (i.e. from AS08_K-6.5) the added ground failure vulnerability will somewhat increase the damage consequences.

Induced hazards like liquefaction and landslide hazard are supposed to increase damage during an earthquake event in general, yet, HAZUS-MH 2.1 predicts minimal contribution from induced hazards. In general, the software damage results show more sensitivity to ground shaking intensity which is influenced by earthquake epicenter closeness, earthquake magnitude and the soil type.

Chapter 5. CONCLUSION

Results from both deterministic and probabilistic analysis show that the residential sector will be the most affected from all the scenarios since a greater number of buildings in Kamloops are used for residential purpose. Kamloops region consist of over 31 thousand buildings out of which the residential buildings take up to 91% of the total number of buildings (Table 3-2) of which most of them are wood frame residences. The wood frame buildings are the most popular building construction type and constitute up to 83% of the total building constructions in Kamloops. (Table 3-1). The residential occupancy is followed by commercial occupancy (7% of the total Kamloops building stock). (Table 3-2).

The HAZUS-MH 2.1 building inventory data for this study is based on 2006 census information. A more recent building inventory data would have been preferred if available, but the results show; as expected, that recent building data will have minimal effect on the damage results. New buildings in general, are built with higher earthquake resistance capability and the software damage results imply that damage will come from mainly old buildings (before 1970).

An earthquake event with magnitude 5 in Kamloops (AS08_K-5 scenario) was used in this study as the likely scenario. The likely scenario is used to test Kamloops' resistance since it is assumed that at magnitude 5, no structural damage should be expected for earthquake resistant buildings. If an earthquake event like the AS08_K-5 scenario (likely scenario) were to occur in Kamloops, the residential and the commercial buildings will be most affected due to their relative building population compared to the other occupancies. The presence of old buildings built before 1970, with old building codes (pre-code or low-code); many of which are used as residences is another main cause.

Damage will be minor on the public buildings in Kamloops e.g. schools and government buildings since from the HAZUS report, none of the existing public buildings were built within the pre-low-code era (before 1970). The HAZUS software does not predict any severe damage on the public-used buildings, however, at least 1 from each of the public-used buildings may require aesthetic repairs from moderate damage.

The residential sector is also closely followed by the commercial buildings in terms of economic losses; more than 48% of the total commercial losses will come from businesses situated in the downtown area of Kamloops.

The wood frame buildings are estimated to have the most number of damaged buildings followed by manufactured housing (buildings not constructed onsite). However, the unreinforced masonry, which ended by 1960 (the oldest construction type) had a significant number of buildings estimated to incur extensive damage with at least one unreinforced masonry building is predicted to collapse completely (Table 4-7). The unreinforced masonry building type is also the only building type predicted that might collapse from the likely scenario making the unreinforced masonry the most vulnerable building type.

The damage results gotten for Kamloops follow a similar pattern like the Squamish study area in British Columbia where the residential sector had a higher proportion of damage coming from the wood framed residential buildings also due to the high proportion of residential buildings in the Squamish area.

The effect of damage results on people population is not included in this study since the time of earthquake occurrence is expected to affect results: during the daytime, more people will be at their work, businesses, schools etc., while at night, more people would be in their homes. However, from statistics Canada 2011 website, the average people population per dwelling is 2.4 and HAZUS predicts that up to 13 residential buildings will be extensively damaged with at least 1 building collapse from the likely scenario(AS08_K-5) (Table 4-6). Which implies that more than 30 people could be at risk of varying degrees of injuries at their homes, in the case of collapse, such injuries might be fatal. Both extensive (severe structural damage) and complete damage (collapse) will require the relocation of occupants. At least 30 people might need temporary residences until their homes are fixed or rebuilt. Severe damage to commercial buildings could lead to business stoppage, possible damage to business equipment and capital losses or the need for business relocation which can increase the economic losses.

If higher magnitude earthquake events than the likely scenario were to happen within Kamloops (similar to the deterministic earthquake events used in this study), the total damage and economic costs will be greater. Also, damage will be significant even when the earthquake event comes from areas outside Kamloops depending on the distance and magnitude of the earthquake.

Earthquake damage insurance coverage and other forms of insurance to prepare for different natural hazards might be necessary for most businesses in Kamloops especially those situated in old residential buildings in the downtown areas. Residential buildings and other occupancies may benefit from damage insurance as well.

The damage results also show the need for mitigation measures to be put in place since an event like the AS08_K-5 scenario (likely scenario) could produce considerable amount of damage.

Structural supports will be needed mostly for buildings predicted with the possibility of extensive damage. Added supports (retrofits) may be required for most building types that were constructed before 1970. Very old buildings (those built 1940 and earlier), especially the unreinforced masonry predicted to undergo collapse, may need to be reviewed for possible reconstruction to avoid any possible damage happenings in the future.

Limitations of this research:

The use of one ground motion prediction equation(GMPE)

For proper damage cost analysis, it is ideal to use different GMPES; or, another way is to scale up and scale down a central GMPE using the recommended factor value found in Atkinson and Adams (2013). Introducing GMPE variability is important to reduce uncertainty in ground attenuation specification. The selection of more than one ground motion prediction equation is a simpler way since the HAZUS-MH 2.1 software already has a library of different ground motion prediction equations. The scaling up and down of a central GMPE would require separate calculations and likely production of ground motion maps which would require a lot of expertise. Separate calculations as these may introduce more errors to the damage results. One of the advantages of using a damage estimation software tool is to avoid this kind of calculations. I had problems performing damage estimations using most of the recommended ground motion equations: Campbell and Bozorgnia 2008 (CB08), Boore and Atkinson 2008 (BA08), Chiou and Youngs 2008 (CY08) except for Abrahamson and Silva 2008 (AS08). I had tried earlier to reproduce the Squamish report by computing the earthquake scenario inputs that I understood were used in the report with Boore and Atkinson 2008 (BA08) (ground motion prediction equation used in the Squamish study). I repeatedly got no results from my trials of the deterministic analysis by computing inputs (since ground motion map option was unavailable). After a very long period of trying and no success, I tried contacting one of the authors of the report who acknowledged the problem and then recommended using EZFrisk, a "third -party" modelling software tool, to produce ground motion maps that can be imported into my analysis after setting up my study area.

From my investigation of the EZFrisk software, has similar earthquake damage estimation ability just like HAZUS-MH 2.1 with the added advantage of producing ground motion maps. After considering the possible difficulties that can arise from introducing maps from another software into HAZUS-MH 2.1, I decided to try running the Squamish study with other appropriate GMPEs like: Campbell and Bozorgnia 2008 (CB08), Chiou and Youngs 2008 (CY08), Abrahamson and Silva 2008 (AS08) from the list of recommended GMPEs for crustal cities in British Columbia (Atkinson 2012; Atkinson and Adams 2013) on the literature background that they all have "same degree of validity" (Atkinson and Adams 2013).While the AS08 ground motion prediction equation (GMPE) produced damage results, other ground motion prediction equations on the recommended list of GMPEs also gave zero damage results. The damage results from AS08, were not the same as the report; yet, it still expressed reasonable damage in such a way that I found useful for my Kamloops study.

I learnt from this challenge that ground motion maps (if available) would be a preferred way to run damage estimation in HAZUS-MH 2.1.

The use of a uniform soil group for the entire area

Kamloops is expected to have varying soil groups so the use of one soil group may provide useful estimations but not give very accurate results. This can be observed from the results from the separate analyses done for Aberdeen, Northshore and Downtown areas where soil type increased damage results remarkably. Results from soil surveys or direct measurement of soil shear wave velocity (V_{S30}) were unavailable for this study. A soil map of Kamloops will produce more accurate results.

REFERENCES

Arnold C. 2014. The Nature of Ground Motion and Its Effect on Buildings. Natl. Inf. Serv. Earthq. Eng.:27.

Atkinson G, Adams J. 2012. Ground motion prediction equations for application to the 2015 Canadian national seismic hazard maps. Can. J. Civ. Eng.

Atkinson G, Adams J. 2013. Ground motion prediction equations for application to the 2015 Canadian national seismic hazard maps. Can. J. Civ. Eng. 40:988–998.

Atkinson GM. 2012. White paper on Proposed Ground-motion Prediction Equations (GMPEs) for 2015 National Seismic Hazard map. :1–51.

City of Kamloops. 2008. Aberdeen Groundwater Area Information Summary.

Federal Emergency Management Agency. 2012. Hazus-MH 2.1 User Manual. Multi-hazard Loss Estimation Methodology: Earthquake Model.

Federal Emergency Management Agency. 2015. Hazus–MH 2.1: Technical Manual. :718.

Foti D. 2015. Local ground effects in near-field and far-field areas on seismically protected buildings. Soil Dyn. Earthq. Eng. 74:14–24.

Halchuk S. 2009. Seismic Hazard Earthquake Epicenter File (SHEEF) used in the fourth generation seismic hazard maps of Canada. Geol. Surv. Canada (OPEN FILE 6208):1–16.

Halchuk S, Adams J. 2010. Mmin - Implications of its choice for Canadian seismic hazard and seismic risk. 9th U.S. Natl. 10th Can. Conf. Earthq. Eng.

Halchuk S, Adams J, Allen TI. 2015. Fifth generation seismic hazard maps of Canada: Maps and grid values to be used with the 2015 National Building Code of Canada. Geol. Surv. Canada Open File 7893:26p.

Journeay JM, Talwar S, Brodaric B, Hastings NL. 2015. Disaster Resilience by Design: A framework for integrated assessment and risk-based planning in Canada. :336.

Natural Resources Canada. 2016. Search the Earthquake Database. [accessed 2017 Jan 12]. http://www.earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bull-en.php

Ulmi M, Wagner CL, Wojtarowicz M, Bancroft JL, Hastings NL, Chow W, Rivard JR, Prieto J, Journeay JM, Struik LC, et al. 2014. Hazus-MH 2.1 Canada user and technical manual: earthquake module.

APPENDIX A

HAZUS MH-2.1 CONVERSION FOR KAMLOOPS DISEMINATION AREAS

KAMLOOPS CENSUS TRACTS →List of Dissemination areas	HAZUS-MH 2.1 TRACTS
0001.00 → 330156	59033330156
0002.00 → 330151, 330157, 330158, 330159	59033330151, 59033330157, 59033330158, 59033330159
0003.00 → 330152, 330153, 330154, 330155	59033330152, 59033330153, 59033330154, 59033330155
0004.00 →330126, 330140, 330141, 330142, 330143, 330144, 330145, 330146, 330147, 330148, 330149, 330150	59033330126, 59033330140, 59033330141, 59033330142, 59033330143, 59033330144, 59033330145, 59033330146, 59033330147, 59033330148, 59033330149, 59033330150
0005.01 →330045, 330047, 330048, 330049, 330050, 330051, 330318	59033330045, 59033330047, 59033330048, 59033330049, 59033330050, 59033330051, 59033330318
0005.02 →330128, 330129, 330130, 330131, 330319	59033330128, 59033330129, 59033330130, 59033330131, 59033330319
0006.01 → 330040, 330041, 331657, 331656, 331655	59033330040, 59033330041, 59033331657, 59033331656, 59033331655
0006.02 →330042, 330043, 330133, 330134, 330135, 330136, 330137, 330138	59033330042, 59033330043, 59033330133, 59033330134, 59033330135, 59033330136, 59033330137, 59033330138
0007.00 → 330312, 330313	59033330312, 59033330313
0008.00 →330057, 330058, 330323	59033330057, 59033330058, 59033330323
0009.00 →330053, 330054, 330055, 330056, 331449	59033330053, 59033330054, 59033330055, 59033330056, 59033331449

0010.00 →330115, 330116, 330117, 330118, 330121, 330123, 330124, 330320	59033330115, 59033330116, 59033330117, 59033330118, 59033330121, 59033330123, 59033330124, 59033330320
0011.00 →330114, 330122	59033330114, 59033330122
0012.00 →330062, 330063, 330064, 330065, 330066, 330067, 330068,330074	59033330062, 59033330063, 59033330064, 59033330065, 59033330066, 59033330067, 95033330068, 59033330074
0013.00 → 330075, 330076, 330100, 330101, 330102, 330103, 330104, 330105	59033330075, 59033330076, 59033330100, 59033330101, 59033330102, 59033330103, 59033330104, 59033330105
0014.00 → 330061, 330069, 330070, 330071, 330072, 330073	59033330061, 59033330069, 59033330070, 59033330071, 59033330072, 59033330073
0015.00 → 330077, 330078, 330079, 330080, 330081, 330082, 330098, 330099	59033330077, 59033330078, 59033330079, 59033330080, 59033330081, 59033330082, 59033330098, 59033330099
0016.00 → 330083, 330084, 330085, 330086, 330087, 330088, 330092	59033330083, 59033330084, 59033330085, 59033330086, 59033330087, 59033330088, 59033330092
0017.00 →330089, 330090, 330091, 330093, 330094, 330095	59033330089, 59033330090, 59033330091, 59033330093, 59033330094, 59033330095
0018.00 → 330096, 330097, 330106, 330107, 330108, 330109, 330110	59033330096, 59033330097, 59033330106, 59033330107, 59033330108, 59033330109, 59033330110
0019.00 → 330166, 330170, 330171, 330172, 330173	59033330166, 59033330170, 59033330171, 59033330172, 59033330173
0020.00 → 330167, 330168, 330174, 330175, 330176, 330177	59033330167, 59033330168, 59033330174, 59033330175, 59033330176, 59033330177

0021.00 →331497, 331498, 331499, 331500, 331501, 331502, 331661, 331660, 331659	59033331497, 59033331498, 59033331499, 59033331500, 59033331501, 59033331502, 59033331661, 59033331660, 59033331659
0022.00 → 331496	59033331496
0100.00 → 331494, 331495, 331504, 331506, 331507, 331517, 331519, 331650, 331651, 331652	59033331494, 59033331495, 59033331504, 59033331506, 59033331507, 59033331517, 59033331519, 5933331650, 5933331651, 5933331652
0101.00 →331490, 331491, 331492	59033331490, 59033331491, 59033331492
0110.00 →331486, 331487, 331488, 331489	59033331486, 59033331487, 59033331488, 59033331489
0200.00 → 331512, 331513, 331514, 331515,331516, 331518	59033331512, 59033331513, 59033331514, 59033331515, 59033331516, 59033331518

KAMLOOPS BUILDING INVENTORY : OCCUPANCY by HAZUS-MH 2.1

Building Count (# of buildings)

By Occupancy | By Building Type

Table type: Number of Buildings per General Occupancy

Table

	Tract	Residential	Commercial	Industrial	Agriculture	Religion	Government	Educational	Total
1	59033330040	547	41	13	0	0	0	0	601
2	59033330041	290	23	5	1	1	0	0	320
3	59033330042	121	9	1	0	0	0	0	131
4	59033330043	291	18	2	0	2	0	0	313
5	59033330045	222	9	0	0	0	0	0	231
6	59033330047	257	9	2	0	0	0	0	268
7	59033330048	188	1	0	0	0	0	0	189
8	59033330049	293	6	0	0	0	1	0	300
9	59033330050	98	5	0	0	0	0	1	104
10	59033330051	90	2	0	0	0	0	0	92
11	59033330053	120	3	3	0	0	0	0	126
12	59033330054	162	10	0	0	0	0	0	172
13	59033330055	115	9	0	0	0	0	1	125
14	59033330056	145	3	0	0	0	0	0	148
15	59033330057	143	12	1	0	0	0	0	156
16	59033330058	85	4	0	0	0	0	0	89
17	59033330061	124	6	1	0	2	0	1	134
18	59033330062	121	33	6	1	5	0	0	166
19	59033330063	117	35	2	0	1	0	1	156
20	59033330064	127	7	1	0	1	0	0	136
21	59033330065	172	4	0	0	0	1	0	177
22	59033330066	124	2	0	0	1	0	0	127
23	59033330067	125	36	3	0	4	0	0	168
24	59033330068	139	14	3	0	2	0	1	159
25	59033330069	123	6	0	0	3	0	1	133
26	59033330070	106	1	0	0	1	0	0	108
27	59033330071	144	3	0	0	0	0	0	147
28	59033330072	104	6	0	0	1	1	0	112
29	59033330073	173	9	0	0	4	1	2	189
30	59033330074	193	29	1	0	1	0	0	224
31	59033330075	126	4	0	0	0	0	0	130
32	59033330076	118	6	0	0	2	0	0	126
33	59033330077	118	5	0	0	0	0	0	123
34	59033330078	197	3	0	0	0	0	1	201
35	59033330079	172	5	0	1	1	0	0	179
36	59033330080	130	1	0	0	0	0	0	131
37	59033330081	70	2	3	0	0	0	0	75
38	59033330082	259	5	2	0	2	0	0	268
39	59033330083	148	6	0	1	1	0	0	156
40	59033330084	134	7	1	0	1	0	0	143
41	59033330085	210	7	0	0	0	1	0	218
42	59033330086	157	9	0	0	0	0	0	166
43	59033330087	116	9	2	0	1	0	2	130
44	59033330088	140	6	2	0	0	0	0	148
45	59033330089	162	7	0	0	0	0	1	170
46	59033330090	170	5	4	0	2	0	0	181
47	59033330091	216	11	1	0	0	0	0	228
48	59033330092	170	3	1	0	0	0	0	174
49	59033330093	190	9	1	0	0	0	0	200
50	59033330094	155	7	2	0	0	0	0	164
51	59033330095	291	10	1	0	0	0	0	302
52	59033330096	87	1	0	0	0	0	0	88
53	59033330097	138	18	3	0	0	4	0	163

KAMLOOPS BUILDING INVENTORY : OCCUPANCY by HAZUS-MH 2.1 (contd)

Building Count (# of buildings)

By Occupancy | By Building Type

Table type: Number of Buildings per General Occupancy

Table

	Tract	Residential	Commercial	Industrial	Agriculture	Religion	Government	Educational	Total
53	59033330097	138	18	3	0	0	4	0	163
54	59033330098	178	5	1	0	1	0	1	186
55	59033330099	185	13	1	0	0	0	0	199
56	59033330100	117	3	0	0	0	0	0	120
57	59033330101	102	11	0	0	0	0	0	113
58	59033330102	145	8	1	0	0	0	1	155
59	59033330103	141	8	0	0	2	0	0	151
60	59033330104	141	7	1	0	0	0	0	149
61	59033330105	171	4	1	0	0	0	0	176
62	59033330106	156	8	1	0	0	0	1	166
63	59033330107	108	3	2	0	0	0	0	113
64	59033330108	307	17	3	0	0	0	0	327
65	59033330109	631	16	3	0	0	0	0	650
66	59033330110	90	2	1	0	0	0	0	93
67	59033330114	273	183	12	0	5	7	2	482
68	59033330115	125	14	1	0	1	0	0	141
69	59033330116	147	12	0	0	0	0	1	160
70	59033330117	138	5	0	0	0	0	0	143
71	59033330118	154	17	1	0	1	0	0	173
72	59033330121	146	14	0	0	3	0	1	164
73	59033330122	197	192	8	0	4	5	2	408
74	59033330123	142	7	1	0	0	0	0	150
75	59033330124	131	5	0	0	0	0	0	136
76	59033330126	234	37	2	1	2	0	0	276
77	59033330128	198	8	1	0	0	0	0	207
78	59033330129	208	6	0	0	0	0	0	214
79	59033330130	188	7	3	0	1	0	1	200
80	59033330131	139	4	0	0	1	0	0	144
81	59033330133	119	3	0	0	0	0	0	122
82	59033330134	199	5	1	0	0	0	1	206
83	59033330135	88	4	0	0	0	0	0	92
84	59033330136	124	7	2	0	1	0	0	134
85	59033330137	136	6	0	0	0	0	0	142
86	59033330138	126	4	1	0	0	0	0	131
87	59033330140	127	18	1	1	0	0	1	148
88	59033330141	101	8	0	0	1	3	1	114
89	59033330142	168	29	1	0	1	0	0	199
90	59033330143	100	6	3	0	0	0	0	109
91	59033330144	140	2	1	0	1	0	0	144
92	59033330145	85	14	0	0	1	0	0	100
93	59033330146	299	21	3	0	2	0	2	327
94	59033330147	151	4	0	0	0	0	1	156
95	59033330148	134	6	0	0	0	0	0	140
96	59033330149	389	36	0	1	4	0	0	430
97	59033330150	78	4	0	0	1	0	0	83
98	59033330151	249	17	1	0	0	0	1	268
99	59033330152	259	9	2	1	0	0	0	271
100	59033330153	141	8	2	0	0	0	0	151
101	59033330154	169	7	1	0	0	0	1	178
102	59033330155	164	13	1	0	0	0	0	178
103	59033330156	290	60	9	0	1	0	0	360
104	59033330157	179	8	0	0	0	0	1	188
105	59033330158	130	7	2	0	0	0	0	139

KAMLOOPS BUILDING INVENTORY : OCCUPANCY by HAZUS-MH 2.1 (contd)

Building Count (# of buildings)

By Occupancy | By Building Type

Table type: Number of Buildings per General Occupancy

Table

	Tract	Residential	Commercial	Industrial	Agriculture	Religion	Government	Educational	Total
105	59033330158	130	7	2	0	0	0	0	139
106	59033330159	91	10	1	1	0	0	0	103
107	59033330166	261	10	5	0	0	0	1	277
108	59033330167	170	8	2	0	1	0	0	181
109	59033330168	322	8	7	0	0	0	0	337
110	59033330170	152	4	3	0	0	0	2	161
111	59033330171	171	1	1	0	0	0	0	173
112	59033330172	238	14	6	1	0	0	0	259
113	59033330173	383	16	2	0	1	0	0	402
114	59033330174	174	8	1	0	3	0	1	187
115	59033330175	249	6	0	0	1	0	1	257
116	59033330176	94	8	2	0	0	1	0	105
117	59033330177	120	2	0	0	0	0	0	122
118	59033330312	429	182	26	0	0	7	3	647
119	59033330313	140	4	0	0	0	0	0	144
120	59033330318	363	11	2	0	1	0	1	378
121	59033330319	253	8	2	0	0	0	0	263
122	59033330320	315	17	1	0	2	1	1	337
123	59033330323	530	14	2	0	0	0	0	546
124	59033331449	316	37	4	1	0	6	2	366
125	59033331486	144	2	0	0	0	0	0	146
126	59033331487	229	1	0	0	0	1	0	231
127	59033331488	163	3	0	0	0	0	0	166
128	59033331489	217	1	1	0	2	0	1	222
129	59033331490	220	2	0	0	0	0	0	222
130	59033331491	229	0	0	0	0	0	0	229
131	59033331492	170	1	0	0	1	0	0	172
132	59033331494	220	5	0	0	0	0	0	225
133	59033331495	18	0	0	0	0	0	0	18
134	59033331496	127	7	3	0	0	0	0	137
135	59033331497	172	10	1	0	1	0	0	184
136	59033331498	120	4	2	0	0	0	1	127
137	59033331499	164	9	3	1	0	0	0	177
138	59033331500	115	8	3	0	0	0	0	126
139	59033331501	204	86	14	0	2	0	0	306
140	59033331502	182	39	10	1	0	3	2	237
141	59033331504	202	3	0	0	0	0	0	205
142	59033331506	146	40	5	5	2	0	1	199
143	59033331507	346	0	0	0	0	0	0	346
144	59033331512	188	105	11	0	6	6	5	321
145	59033331513	163	5	0	0	1	0	0	169
146	59033331514	146	24	2	0	1	0	1	174
147	59033331515	330	2	0	0	0	0	0	332
148	59033331516	122	1	0	0	0	0	0	123
149	59033331517	217	0	0	0	0	0	0	217
150	59033331518	0	0	0	0	0	0	0	0
151	59033331519	96	0	0	0	0	0	0	96
152	59033331650	224	21	3	0	1	0	1	250
153	59033331651	100	17	0	0	0	0	0	117
154	59033331652	131	0	1	0	0	0	1	133
155	59033331655	210	10	2	0	0	0	1	223
156	59033331656	132	2	0	0	0	0	0	134
157	59033331657	388	16	4	0	0	0	1	409

KAMLOOPS BUILDING INVENTORY : OCCUPANCY by HAZUS-MH 2.1 (contd)

Building Count (# of buildings)

By Occupancy | By Building Type

Table type: Number of Buildings per General Occupancy

Table

	Tract	Residential	Commercial	Industrial	Agriculture	Religion	Government	Educational	Total
108	59033330167	170	8	2	0	1	0	0	181
109	59033330168	322	8	7	0	0	0	0	337
110	59033330170	152	4	3	0	0	0	2	161
111	59033330171	171	1	1	0	0	0	0	173
112	59033330172	238	14	6	1	0	0	0	259
113	59033330173	383	16	2	0	1	0	0	402
114	59033330174	174	8	1	0	3	0	1	187
115	59033330175	249	6	0	0	1	0	1	257
116	59033330176	94	8	2	0	0	1	0	105
117	59033330177	120	2	0	0	0	0	0	122
118	59033330312	429	182	26	0	0	7	3	647
119	59033330313	140	4	0	0	0	0	0	144
120	59033330318	363	11	2	0	1	0	1	378
121	59033330319	253	8	2	0	0	0	0	263
122	59033330320	315	17	1	0	2	1	1	337
123	59033330323	530	14	2	0	0	0	0	546
124	59033331449	316	37	4	1	0	6	2	366
125	59033331486	144	2	0	0	0	0	0	146
126	59033331487	229	1	0	0	0	1	0	231
127	59033331488	163	3	0	0	0	0	0	166
128	59033331489	217	1	1	0	2	0	1	222
129	59033331490	220	2	0	0	0	0	0	222
130	59033331491	229	0	0	0	0	0	0	229
131	59033331492	170	1	0	0	1	0	0	172
132	59033331494	220	5	0	0	0	0	0	225
133	59033331495	18	0	0	0	0	0	0	18
134	59033331496	127	7	3	0	0	0	0	137
135	59033331497	172	10	1	0	1	0	0	184
136	59033331498	120	4	2	0	0	0	1	127
137	59033331499	164	9	3	1	0	0	0	177
138	59033331500	115	8	3	0	0	0	0	126
139	59033331501	204	86	14	0	2	0	0	306
140	59033331502	182	39	10	1	0	3	2	237
141	59033331504	202	3	0	0	0	0	0	205
142	59033331506	146	40	5	5	2	0	1	199
143	59033331507	346	0	0	0	0	0	0	346
144	59033331512	188	105	11	0	6	6	5	321
145	59033331513	163	5	0	0	1	0	0	169
146	59033331514	146	24	2	0	1	0	1	174
147	59033331515	330	2	0	0	0	0	0	332
148	59033331516	122	1	0	0	0	0	0	123
149	59033331517	217	0	0	0	0	0	0	217
150	59033331518	0	0	0	0	0	0	0	0
151	59033331519	96	0	0	0	0	0	0	96
152	59033331650	224	21	3	0	1	0	1	250
153	59033331651	100	17	0	0	0	0	0	117
154	59033331652	131	0	1	0	0	0	1	133
155	59033331655	210	10	2	0	0	0	1	223
156	59033331656	132	2	0	0	0	0	0	134
157	59033331657	388	16	4	0	0	0	1	409
158	59033331659	450	11	0	0	0	0	0	461
159	59033331660	63	1	0	0	1	0	0	65
160	59033331661	73	48	10	3	0	0	0	134

KAMLOOPS BUILDING INVENTORY : BUILDING CONSTRUCTION INVENTORY

Building Count (# of buildings)

By Occupancy **By Building Type**

Table

	Tract	W1	W2	S1L	S1M	S1H	S2L	S2M	S2H	S3	S4L	S4M	S4H	S5L	S5M	S5H	C1L	C1M	C1H	C2L	C2M	C2H	C3L	C3M	C3H	PC1	PC2L	PC2M	PC2H	RM1L	RM1M	RM2L	RM2M	RM2H	URML	URMM	MH	Total
1	59033330040	496	10	4	0	0	3	0	0	3	4	0	0	0	0	0	2	0	0	11	0	0	1	0	0	11	2	0	0	22	0	1	0	0	5	0	26	601
2	59033330041	264	7	2	0	0	1	0	0	2	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	4	1	0	0	12	0	0	0	0	3	0	13	320
3	59033330042	109	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	6	131
4	59033330043	261	4	1	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	3	1	0	0	12	0	0	0	0	3	0	14	313
5	59033330045	201	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	1	0	0	7	0	0	0	0	1	0	11	231
6	59033330047	232	3	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	0	0	9	0	0	0	0	2	0	13	268
7	59033330048	170	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	9	189
8	59033330049	265	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	0	0	9	0	0	0	0	2	0	14	300
9	59033330050	89	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	5	104
10	59033330051	81	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	5	92
11	59033330053	109	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	6	126
12	59033330054	146	3	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	1	0	0	6	0	0	0	0	1	0	8	172
13	59033330055	104	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	5	125
14	59033330056	131	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	7	148
15	59033330057	128	3	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	1	0	0	6	0	0	0	0	1	0	8	156
16	59033330058	77	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	3	0	0	0	0	1	0	4	89
17	59033330061	112	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	7	134
18	59033330062	112	8	3	0	0	2	0	0	1	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	7	2	0	0	11	0	1	0	0	4	0	6	166
19	59033330063	109	9	3	0	0	1	0	0	1	1	0	0	0	0	0	2	0	0	6	0	0	0	0	0	6	2	0	0	10	0	1	0	0	3	0	4	156
20	59033330064	115	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	7	136
21	59033330065	155	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	9	177
22	59033330066	113	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	6	127
23	59033330067	114	9	3	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	6	2	0	0	11	0	1	0	0	4	0	8	168
24	59033330068	127	3	2	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	3	1	0	0	7	0	0	0	0	2	0	6	159
25	59033330069	114	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	5	133
26	59033330070	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	6	108
27	59033330071	130	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	7	147
28	59033330072	95	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	5	112
29	59033330073	158	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	0	0	8	0	0	0	0	2	0	8	189
30	59033330074	176	7	2	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	6	0	0	0	0	0	4	1	0	0	11	0	1	0	0	3	0	8	224
31	59033330075	115	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	6	130
32	59033330076	108	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	6	126
33	59033330077	108	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	5	123
34	59033330078	178	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	9	201
35	59033330079	156	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	9	179
36	59033330080	117	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	7	131
37	59033330081	63	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	4	75
38	59033330082	234	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	0	0	8	0	0	0	0	2	0	13	268
39	59033330083	134	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	7	156
40	59033330084	121	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	7	143
41	59033330085	189	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	7	0	0	0	0	1	0	10	218
42	59033330086	143	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	7	166
43	59033330087	105	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	7	130
44	59033330088	128	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	6	148
45	59033330089	148	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	8	170
46	59033330090	155	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	1	0	8	181
47	59033330091	196	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	10	228
48	59033330092	154	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	8	174
49	59033330093	171	3	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	1	0	10	200
50	59033330094	141	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	8	164
51	59033330095	264	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	9	0	0	0	0	2	0	14	302
52	59033330096	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	5	88
53	59033330097	126	5	2	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	5	0	0	0	0	0	3	1	0	0	7	0	1	0	0	2	0	6	163
54	59033330098	162	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	8	186

Building Count (# of buildings)

By Occupancy | **By Building Type**

Table

	Tract	W1	W2	S1L	S1M	S1H	S2L	S2M	S2H	S3	S4L	S4M	S4H	S5L	S5M	S5H	C1L	C1M	C1H	C2L	C2M	C2H	C3L	C3M	C3H	PC1	PC2L	PC2M	PC2H	RM1L	RM1M	RM2L	RM2M	RM2H	URML	URMM	MH	Total
53	59033330097	126	5	2	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	5	0	0	0	0	0	3	1	0	0	7	0	1	0	0	2	0	6	163
54	59033330098	162	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	8	186
55	59033330099	168	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	8	199
56	59033330100	106	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	6	120
57	59033330101	93	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	5	113
58	59033330102	131	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	6	0	0	0	0	1	0	7	155
59	59033330103	128	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	7	151
60	59033330104	128	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	5	0	0	0	0	1	0	7	149
61	59033330105	154	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	9	176
62	59033330106	142	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	6	0	0	0	0	1	0	8	166
63	59033330107	98	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	3	0	0	0	0	1	0	5	113
64	59033330108	277	4	1	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	3	1	0	0	12	0	0	0	0	3	0	14	327
65	59033330109	569	5	1	0	0	0	0	0	2	3	0	0	0	0	0	1	0	0	8	0	0	1	0	0	3	1	0	0	20	0	0	0	0	4	0	32	650
66	59033330110	82	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	5	93
67	59033330114	249	47	15	0	0	5	0	0	5	7	0	0	0	0	0	7	0	0	31	0	0	1	0	0	29	8	0	0	46	0	3	0	0	17	0	12	482
68	59033330115	114	4	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	2	0	6	141
69	59033330116	131	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	6	0	0	0	0	1	0	10	160
70	59033330117	123	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	9	143
71	59033330118	138	5	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	9	173
72	59033330121	133	5	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	1	1	0	0	7	0	0	0	0	2	0	8	164
73	59033330122	179	48	14	0	0	6	0	0	4	7	0	0	0	0	0	8	0	0	30	0	0	1	0	0	28	8	0	0	44	0	3	0	0	18	0	10	408
74	59033330123	127	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	9	150
75	59033330124	117	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	9	136
76	59033330126	214	9	2	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	8	0	0	0	0	0	6	2	0	0	14	0	0	0	0	4	0	11	276
77	59033330128	179	3	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	1	0	0	7	0	0	0	0	1	0	9	207
78	59033330129	189	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	7	0	0	0	0	1	0	9	214
79	59033330130	171	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	7	0	0	0	0	1	0	9	200
80	59033330131	126	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	7	144
81	59033330133	108	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	6	122
82	59033330134	181	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	9	206
83	59033330135	79	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	5	92
84	59033330136	112	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	7	134
85	59033330137	122	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	7	142
86	59033330138	115	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	6	131
87	59033330140	114	4	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	3	1	0	0	8	0	0	0	0	2	0	6	148
88	59033330141	92	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	5	114
89	59033330142	154	7	2	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	4	1	0	0	10	0	0	0	0	3	0	7	199
90	59033330143	90	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	4	0	0	0	0	1	0	5	109
91	59033330144	127	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	7	144
92	59033330145	77	4	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	3	0	0	0	0	0	2	1	0	0	5	0	0	0	0	2	0	4	100
93	59033330146	271	5	2	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	4	1	0	0	13	0	1	0	0	3	0	14	327
94	59033330147	137	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	8	156
95	59033330148	122	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	6	140
96	59033330149	351	10	2	0	0	1	0	0	2	3	0	0	0	0	0	1	0	0	10	0	0	0	0	0	5	2	0	0	17	0	1	0	0	5	0	20	430
97	59033330150	71	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	3	0	0	0	0	1	0	4	83
98	59033330151	226	4	1	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	5	0	0	0	0	0	3	1	0	0	10	0	0	0	0	2	0	12	268
99	59033330152	236	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	12	271
100	59033330153	128	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	5	0	0	0	0	1	0	7	151
101	59033330154	153	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	1	0	0	6	0	0	0	0	1	0	9	178
102	59033330155	149	4	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	2	0	8	178
103	59033330156	263	15	5	0	0	3	0	0	2	3	0	0	0	0	0	2	0	0	11	0	0	0	0	0	13	3	0	0	18	0	1	0	0	5	0	14	360
104	59033330157	162	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	9	188
105	59033330158	118	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	6	139
106	59033330159	82	3	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	5	103
107	59033330166	236	3	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	9	0	0	0	0	2	0	14	277

Building Count (# of buildings)

By Occupancy | **By Building Type**

Table

	Tract	W1	W2	S1L	S1M	S1H	S2L	S2M	S2H	S3	S4L	S4M	S4H	S5L	S5M	S5H	C1L	C1M	C1H	C2L	C2M	C2H	C3L	C3M	C3H	PC1	PC2L	PC2M	PC2H	RM1L	RM1M	RM2L	RM2M	RM2H	URML	URMM	MH	Total
106	59033330159	82	3	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	5	103
107	59033330166	236	3	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	9	0	0	0	0	2	0	14	277
108	59033330167	155	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	1	0	8	181
109	59033330168	292	3	1	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	5	0	0	0	0	0	3	1	0	0	10	0	0	0	0	2	0	15	337
110	59033330170	138	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	7	161
111	59033330171	154	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	9	173
112	59033330172	216	5	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	5	0	0	0	0	0	3	1	0	0	9	0	0	0	0	2	0	12	259
113	59033330173	347	5	1	0	0	0	0	0	2	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	3	1	0	0	13	0	0	0	0	3	0	19	402
114	59033330174	158	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	7	0	0	0	0	1	0	10	187
115	59033330175	225	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	0	0	8	0	0	0	0	1	0	13	257
116	59033330176	86	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	5	105
117	59033330177	109	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	6	122
118	59033330312	388	47	14	0	0	7	0	0	6	8	0	0	0	0	0	7	0	0	33	0	0	1	0	0	38	8	0	0	48	0	4	0	0	17	0	21	647
119	59033330313	128	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	6	144
120	59033330318	329	3	1	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	5	0	0	0	0	0	2	1	0	0	12	0	0	0	0	2	0	18	378
121	59033330319	228	3	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	0	0	8	0	0	0	0	2	0	13	263
122	59033330320	284	4	1	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	3	1	0	0	12	0	0	0	0	3	0	17	337
123	59033330323	479	4	1	0	0	0	0	0	2	3	0	0	0	0	0	1	0	0	7	0	0	1	0	0	2	1	0	0	17	0	0	0	0	3	0	26	546
124	59033331449	287	11	4	0	0	2	0	0	2	3	0	0	0	0	0	2	0	0	10	0	0	0	0	0	5	2	0	0	17	0	1	0	0	5	0	15	366
125	59033331486	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	21	146
126	59033331487	190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	34	231
127	59033331488	136	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	23	166
128	59033331489	182	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	5	0	0	0	0	0	0	32	222
129	59033331490	180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	35	222
130	59033331491	185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	38	229
131	59033331492	139	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	27	172
132	59033331494	203	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	5	0	0	0	0	0	0	12	225
133	59033331495	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
134	59033331496	116	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	5	137
135	59033331497	157	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	1	0	8	184
136	59033331498	109	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	6	127
137	59033331499	149	3	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	1	0	8	177
138	59033331500	104	3	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	6	126
139	59033331501	132	19	7	0	0	5	0	0	2	3	0	0	0	0	0	3	0	0	13	0	0	0	0	0	19	4	0	0	20	0	2	0	0	7	0	69	306
140	59033331502	119	10	4	0	0	3	0	0	2	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	10	2	0	0	12	0	1	0	0	4	0	60	237
141	59033331504	186	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	12	205
142	59033331506	137	11	4	0	0	2	0	0	1	2	0	0	0	0	0	2	0	0	7	0	0	0	0	0	8	2	0	0	12	0	1	0	0	4	0	7	199
143	59033331507	319	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	20	346
144	59033331512	149	28	9	0	0	5	0	0	3	5	0	0	0	0	0	5	0	0	19	0	0	0	0	0	18	5	0	0	27	0	2	0	0	10	0	36	321
145	59033331513	127	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	32	169
146	59033331514	115	6	2	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	4	1	0	0	8	0	0	0	0	2	0	29	174
147	59033331515	259	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	63	332
148	59033331516	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	24	123
149	59033331517	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	13	217
150	59033331519	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	5	96
151	59033331650	204	5	2	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	4	1	0	0	9	0	1	0	0	2	0	14	250
152	59033331651	82	4	1	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	2	1	0	0	9	0	0	0	0	3	0	3	117
153	59033331652	122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	7	133
154	59033331655	190	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	10	223
155	59033331656	119	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	6	134
156	59033331657	352	3	2	0	0	1	0	0	2	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	4	1	0	0	14	0	0	0	0	3	0	19	409
157	59033331659	293	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	9	0	0	0	0	1	0	149	461
158	59033331660	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	21	65
159	59033331661	48	12	5	0	0	3	0	0	2	2	0	0	0	0	0	2	0	0	8	0	0	0	0	0	9	2	0	0	12	0	1	0	0	5	0	24	134

BUILDING TYPE DESCRIPTION CODES IN HAZUS-MH 2.1

General Building Stock Classification

Building Occupancy Classes | **Model Building Types**

Table

	Building Type	General Building Type	Description
1	C1H	Concrete	Concrete Moment Frame High-Rise
2	C1L	Concrete	Concrete Moment Frame Low-Rise
3	C1M	Concrete	Concrete Moment Frame Mid-Rise
4	C2H	Concrete	Concrete Shear Walls High-Rise
5	C2L	Concrete	Concrete Shear Walls Low-Rise
6	C2M	Concrete	Concrete Shear Walls Mid-Rise
7	C3H	Concrete	Concrete Frame with Unreinforced Masonry Infill Walls High-Rise
8	C3L	Concrete	Concrete Frame with Unreinforced Masonry Infill Walls Low-Rise
9	C3M	Concrete	Concrete Frame with Unreinforced Masonry Infill Walls Mid-Rise
10	DFLT	DFLT	Default (Wood)
11	MH	MH	Manufactured Home
12	PC1	Precast	Precast Concrete Tilt-Up Walls
13	PC2H	Precast	Precast Concrete Frames with Concrete Shear Walls High-Rise
14	PC2L	Precast	Precast Concrete Frames with Concrete Shear Walls Low-Rise
15	PC2M	Precast	Precast Concrete Frames with Concrete Shear Walls Mid-Rise
16	RM1L	RM	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms Low-Rise
17	RM1M	RM	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms Mid-Rise
18	RM2H	RM	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms High-Rise
19	RM2L	RM	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms Low-Rise
20	RM2M	RM	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms Mid-Rise
21	S1H	Steel	Steel Moment Frame High-Rise
22	S1L	Steel	Steel Moment Frame Low-Rise
23	S1M	Steel	Steel Moment Frame Mid-Rise
24	S2H	Steel	Steel Braced Frame High-Rise
25	S2L	Steel	Steel Braced Frame Low-Rise
26	S2M	Steel	Steel Braced Frame Mid-Rise
27	S3	Steel	Steel Light Frame
28	S4H	Steel	Steel Frame with Cast-in-Place Concrete Shear Walls High-Rise
29	S4L	Steel	Steel Frame with Cast-in-Place Concrete Shear Walls Low-Rise
30	S4M	Steel	Steel Frame with Cast-in-Place Concrete Shear Walls Mid-Rise
31	S5H	Steel	Steel Frame with Unreinforced Masonry Infill Walls High-Rise
32	S5L	Steel	Steel Frame with Unreinforced Masonry Infill Walls Low-Rise
33	S5M	Steel	Steel Frame with Unreinforced Masonry Infill Walls Mid-Rise
34	URML	URM	Unreinforced Masonry Bearing Walls Low-Rise
35	URMM	URM	Unreinforced Masonry Bearing Walls High-Rise
36	W1	Wood	Wood, Light Frame (= 5,000 sq. ft.)
37	W2	Wood	Wood, Commercial and Industrial Wood (>5,000 sq. ft.)

APPENDIX B

i) ABERDEEN KAMLOOPS TRACT LIST

59033330040, 59033330041, 59033330042, 59033330043, 59033330133, 59033330134, 59033330135, 59033330136, 59033330137, 59033330138, 59033331655, 59033331656, 59033331657

ABERDEEN BUILDING INVENTORY : OCCUPANCY

Building Count (# of buildings)

By Occupancy | By Building Type

Table type: Number of Buildings per General Occupancy

Table

	Tract	Residential	Commercial	Industrial	Agriculture	Religion	Government	Educational	Total
1	59033330040	547	41	13	0	0	0	0	601
2	59033330041	290	23	5	1	1	0	0	320
3	59033330042	121	9	1	0	0	0	0	131
4	59033330043	291	18	2	0	2	0	0	313
5	59033330133	119	3	0	0	0	0	0	122
6	59033330134	199	5	1	0	0	0	1	206
7	59033330135	88	4	0	0	0	0	0	92
8	59033330136	124	7	2	0	1	0	0	134
9	59033330137	136	6	0	0	0	0	0	142
10	59033330138	126	4	1	0	0	0	0	131
11	59033331655	210	10	2	0	0	0	1	223
12	59033331656	132	2	0	0	0	0	0	134
13	59033331657	388	16	4	0	0	0	1	409

ABERDEEN BUILDING INVENTORY : BUILDING CONSTRUCTION INVENTORY

Building Count (# of buildings)

By Occupancy | **By Building Type**

Table

	Tract	W1	W2	S1L	S1M	S1H	S2L	S2M	S2H	S3	S4L	S4M	S4H	S5L	S5M	S5H	C1L	C1M	C1H	C2L	C2M	C2H	C3L	C3M	C3H	PC1	PC2L	PC2M	PC2H	RM1L	RM1M	RM2L	RM2M	RM2H	URML	URMM	MH	Total
1	59033330040	496	10	4	0	0	3	0	0	3	4	0	0	0	0	0	2	0	0	11	0	0	1	0	0	11	2	0	0	22	0	1	0	0	5	0	26	601
2	59033330041	264	7	2	0	0	1	0	0	2	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	4	1	0	0	12	0	0	0	0	3	0	13	320
3	59033330042	109	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	6	131
4	59033330043	261	4	1	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	3	1	0	0	12	0	0	0	0	3	0	14	313
5	59033330133	108	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	6	122
6	59033330134	181	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	9	206
7	59033330135	79	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	5	92
8	59033330136	112	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	7	134
9	59033330137	122	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	7	142
10	59033330138	115	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	6	131
11	59033331655	190	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	10	223
12	59033331656	119	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	6	134
13	59033331657	352	3	2	0	0	1	0	0	2	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	4	1	0	0	14	0	0	0	0	3	0	19	409

NORTHSHORE KAMLOOPS TRACT LIST

59033330062, 59033330063, 59033330064, 59033330065, 59033330066, 59033330067, 59033330068, 59033330074, 59033330075, 59033330076, 59033330100, 59033330101, 59033330102, 59033330103, 59033330104, 59033330105, 59033330061, 59033330069, 59033330070, 59033330071, 59033330072, 59033330073, 59033330077, 59033330078, 59033330079, 59033330080, 59033330081, 59033330082, 59033330083, 59033330084, 59033330085, 59033330086, 59033330087, 59033330088, 59033330089, 59033330090, 59033330091, 59033330092, 59033330093, 59033330094, 59033330095, 59033330098, 59033330099

NORTHSHORE BUILDING INVENTORY : OCCUPANCY

Building Count (# of buildings)

By Occupancy | By Building Type

Table type: Number of Buildings per General Occupancy

Table

	Tract	Residential	Commercial	Industrial	Agriculture	Religion	Government	Educational	Total
1	59033330061	124	6	1	0	2	0	1	134
2	59033330062	121	33	6	1	5	0	0	166
3	59033330063	117	35	2	0	1	0	1	156
4	59033330064	127	7	1	0	1	0	0	136
5	59033330065	172	4	0	0	0	1	0	177
6	59033330066	124	2	0	0	1	0	0	127
7	59033330067	125	36	3	0	4	0	0	168
8	59033330068	139	14	3	0	2	0	1	159
9	59033330069	123	6	0	0	3	0	1	133
10	59033330070	106	1	0	0	1	0	0	108
11	59033330071	144	3	0	0	0	0	0	147
12	59033330072	104	6	0	0	1	1	0	112
13	59033330073	173	9	0	0	4	1	2	189
14	59033330074	193	29	1	0	1	0	0	224
15	59033330075	126	4	0	0	0	0	0	130
16	59033330076	118	6	0	0	2	0	0	126
17	59033330077	118	5	0	0	0	0	0	123
18	59033330078	197	3	0	0	0	0	1	201
19	59033330079	172	5	0	1	1	0	0	179
20	59033330080	130	1	0	0	0	0	0	131
21	59033330081	70	2	3	0	0	0	0	75
22	59033330082	259	5	2	0	2	0	0	268
23	59033330083	148	6	0	1	1	0	0	156
24	59033330084	134	7	1	0	1	0	0	143
25	59033330085	210	7	0	0	0	1	0	218
26	59033330086	157	9	0	0	0	0	0	166
27	59033330087	116	9	2	0	1	0	2	130
28	59033330088	140	6	2	0	0	0	0	148
29	59033330089	162	7	0	0	0	0	1	170
30	59033330090	170	5	4	0	2	0	0	181
31	59033330091	216	11	1	0	0	0	0	228
32	59033330092	170	3	1	0	0	0	0	174
33	59033330093	190	9	1	0	0	0	0	200
34	59033330094	155	7	2	0	0	0	0	164
35	59033330095	291	10	1	0	0	0	0	302
36	59033330098	178	5	1	0	1	0	1	186
37	59033330099	185	13	1	0	0	0	0	199
38	59033330100	117	3	0	0	0	0	0	120
39	59033330101	102	11	0	0	0	0	0	113
40	59033330102	145	8	1	0	0	0	1	155
41	59033330103	141	8	0	0	2	0	0	151
42	59033330104	141	7	1	0	0	0	0	149
43	59033330105	171	4	1	0	0	0	0	176

NORTHSHORE BUILDING INVENTORY : BUILDING CONSTRUCTION

Building Count (# of buildings)

By Occupancy | **By Building Type**

Table

	Tract	W1	W2	S1L	S1M	S1H	S2L	S2M	S2H	S3	S4L	S4M	S4H	S5L	S5M	S5H	C1L	C1M	C1H	C2L	C2M	C2H	C3L	C3M	C3H	PC1	PC2L	PC2M	PC2H	RM1L	RM1M	RM2L	RM2M	RM2H	URML	URMM	MH	Total
1	59033330061	112	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	7	134
2	59033330062	112	8	3	0	0	2	0	0	1	2	0	0	0	0	0	1	0	0	7	0	0	0	0	0	7	2	0	0	11	0	1	0	0	4	0	6	166
3	59033330063	109	9	3	0	0	1	0	0	1	1	0	0	0	0	0	2	0	0	6	0	0	0	0	0	6	2	0	0	10	0	1	0	0	3	0	4	156
4	59033330064	115	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	7	136
5	59033330065	155	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	9	177
6	59033330066	113	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	6	127
7	59033330067	114	9	3	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	6	2	0	0	11	0	1	0	0	4	0	8	168
8	59033330068	127	3	2	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	3	1	0	0	7	0	0	0	0	2	0	6	159
9	59033330069	114	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	5	133
10	59033330070	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	6	108
11	59033330071	130	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	7	147
12	59033330072	95	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	5	112
13	59033330073	158	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	0	0	8	0	0	0	0	2	0	8	189
14	59033330074	176	7	2	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	6	0	0	0	0	0	4	1	0	0	11	0	1	0	0	3	0	8	224
15	59033330075	115	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	6	130
16	59033330076	108	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	6	126
17	59033330077	108	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	5	123
18	59033330078	178	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	9	201
19	59033330079	156	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	9	179
20	59033330080	117	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	7	131
21	59033330081	63	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	4	75
22	59033330082	234	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	0	0	8	0	0	0	0	2	0	13	268
23	59033330083	134	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	7	156
24	59033330084	121	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	7	143
25	59033330085	189	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	7	0	0	0	0	1	0	10	218
26	59033330086	143	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	7	166
27	59033330087	105	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	7	130
28	59033330088	128	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	1	0	6	148
29	59033330089	148	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	8	170
30	59033330090	155	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	1	0	8	181
31	59033330091	196	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	10	228
32	59033330092	154	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	8	174
33	59033330093	171	3	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	1	0	10	200
34	59033330094	141	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	8	164
35	59033330095	264	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	1	0	0	9	0	0	0	0	2	0	14	302
36	59033330098	162	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	6	0	0	0	0	1	0	8	186
37	59033330099	168	2	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	8	199
38	59033330100	106	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	6	120
39	59033330101	93	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	1	0	0	5	0	0	0	0	1	0	5	113
40	59033330102	131	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	6	0	0	0	0	1	0	7	155
41	59033330103	128	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	7	151
42	59033330104	128	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	5	0	0	0	0	1	0	7	149
43	59033330105	154	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	9	176

ii) DOWNTOWN KAMLOOPS TRACT LIST

59033330114, 59033330115, 59033330116, 59033330117, 59033330118, 59033330121, 59033330123, 59033330124, 59033330122, 59033330320

DOWNTOWN BUILDING INVENTORY : OCCUPANCY

Building Count (# of buildings)

By Occupancy | By Building Type

Table type: Number of Buildings per General Occupancy

Table

	Tract	Residential	Commercial	Industrial	Agriculture	Religion	Government	Educational	Total
1	59033330114	273	183	12	0	5	7	2	482
2	59033330115	125	14	1	0	1	0	0	141
3	59033330116	147	12	0	0	0	0	1	160
4	59033330117	138	5	0	0	0	0	0	143
5	59033330118	154	17	1	0	1	0	0	173
6	59033330121	146	14	0	0	3	0	1	164
7	59033330122	197	192	8	0	4	5	2	408
8	59033330123	142	7	1	0	0	0	0	150
9	59033330124	131	5	0	0	0	0	0	136
10	59033330320	315	17	1	0	2	1	1	337

DOWNTOWN BUILDING INVENTORY : BUILDING CONSTRUCTION

Building Count (# of buildings)

By Occupancy | **By Building Type**

Table

	Tract	W1	W2	S1L	S1M	S1H	S2L	S2M	S2H	S3	S4L	S4M	S4H	S5L	S5M	S5H	C1L	C1M	C1H	C2L	C2M	C2H	C3L	C3M	C3H	PC1	PC2L	PC2M	PC2H	RM1L	RM1M	RM2L	RM2M	RM2H	URML	URMM	MH	Total
1	59033330114	249	47	15	0	0	5	0	0	5	7	0	0	0	0	0	7	0	0	31	0	0	1	0	0	29	8	0	0	46	0	3	0	0	17	0	12	482
2	59033330115	114	4	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	3	0	0	0	0	0	2	1	0	0	6	0	0	0	0	2	0	6	141
3	59033330116	131	3	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	6	0	0	0	0	1	0	10	160
4	59033330117	123	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4	0	0	0	0	1	0	9	143
5	59033330118	138	5	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	2	1	0	0	8	0	0	0	0	2	0	9	173
6	59033330121	133	5	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	1	1	0	0	7	0	0	0	0	2	0	8	164
7	59033330122	179	48	14	0	0	6	0	0	4	7	0	0	0	0	0	8	0	0	30	0	0	1	0	0	28	8	0	0	44	0	3	0	0	18	0	10	408
8	59033330123	127	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	5	0	0	0	0	1	0	9	150
9	59033330124	117	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	9	136
10	59033330320	284	4	1	0	0	1	0	0	1	2	0	0	0	0	0	1	0	0	6	0	0	0	0	0	3	1	0	0	12	0	0	0	0	3	0	17	337

APPENDIX C

Damage results as predicted in the HAZUS-MH 2.1 from 13 Deterministic earthquake scenarios

AS08_WNW6.5

Hazus estimates from the AS08_WNW 6.5. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	21	0.07	0	0.07	0	0.11	0	0.20	0	0.17
Commercial	2,222	7.08	38	12.67	13	19.38	2	39.57	0	52.77
Education	57	0.18	1	0.24	0	0.35	0	0.61	0	0.83
Government	48	0.15	1	0.25	0	0.34	0	0.54	0	0.81
Industrial	277	0.88	5	1.59	2	2.63	0	5.27	0	2.76
Other Residential	5,044	16.08	107	35.40	35	51.76	1	35.19	0	40.84
Religion	98	0.31	1	0.45	0	0.62	0	1.03	0	1.82
Single Family	23,607	75.24	150	49.32	17	24.81	1	17.59	0	0.00
Total	**31,374**		**303**		**68**		**4**		**0**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	26,213	83.55	161	53.06	14	20.82	0	6.14	0	0.00
Steel	584	1.86	9	3.08	3	4.75	0	8.25	0	0.54
Concrete	703	2.24	11	3.75	2	3.49	0	3.27	0	0.13
Precast	519	1.65	11	3.74	6	8.99	1	22.33	0	0.41
RM	1,206	3.85	19	6.21	8	12.54	1	23.09	0	0.01
URM	270	0.86	12	3.98	5	6.90	1	16.16	0	83.56
MH	1,878	5.99	79	26.18	29	42.51	1	20.76	0	15.35
Total	**31,374**		**303**		**68**		**4**		**0**	

Building damage cost

The software predicts total economic losses from AS08_WNW 6.5 valued at 4.9 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.01	0.33	0.01	0.03	0.38
	Capital-Related	0.00	0.01	0.26	0.00	0.00	0.27
	Rental	0.03	0.10	0.29	0.00	0.01	0.43
	Relocation	0.10	0.10	0.36	0.02	0.05	0.63
	Subtotal	**0.13**	**0.22**	**1.24**	**0.03**	**0.10**	**1.71**
Capital Stock Losses							
	Structural	0.22	0.15	0.43	0.04	0.05	0.88
	Non_Structural	0.90	0.41	0.49	0.04	0.08	1.92
	Content	0.17	0.05	0.12	0.02	0.02	0.38
	Inventory	0.00	0.00	0.00	0.00	0.00	0.01
	Subtotal	**1.29**	**0.61**	**1.04**	**0.10**	**0.15**	**3.19**
	Total	**1.41**	**0.82**	**2.28**	**0.13**	**0.25**	**4.90**

AS08_WNW6.7

Hazus estimates from the AS08_WNW 6.7. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	20	0.07	0	0.07	0	0.12	0	0.21	0	0.15
Commercial	2,189	7.04	60	11.71	22	18.55	3	35.81	0	48.35
Education	56	0.18	1	0.23	0	0.35	0	0.57	0	0.77
Government	47	0.15	1	0.23	0	0.33	0	0.50	0	0.79
Industrial	273	0.88	8	1.48	3	2.54	0	4.80	0	3.13
Other Residential	4,962	15.95	163	31.63	60	49.81	3	36.93	0	44.49
Religion	97	0.31	2	0.42	1	0.61	0	0.96	0	1.63
Single Family	23,460	75.42	279	54.21	33	27.69	2	20.21	0	0.68
Total	**31,106**		**515**		**120**		**8**		**0**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	26,054	83.76	304	58.96	29	24.52	1	10.34	0	0.02
Steel	576	1.85	15	2.91	6	4.81	1	7.97	0	1.92
Concrete	694	2.23	18	3.52	4	3.66	0	3.29	0	0.28
Precast	509	1.64	17	3.31	10	8.37	2	20.06	0	3.29
RM	1,190	3.83	28	5.50	14	11.85	2	21.05	0	0.80
URM	262	0.84	17	3.35	7	6.09	1	13.93	0	70.60
MH	1,821	5.85	116	22.44	49	40.70	2	23.37	0	23.08
Total	**31,106**		**515**		**120**		**8**		**0**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage cost

The software predicts total economic losses from AS08_WNW 6.7 valued at 9.25 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.02	0.57	0.01	0.05	0.66
	Capital-Related	0.00	0.01	0.45	0.01	0.01	0.47
	Rental	0.06	0.18	0.48	0.01	0.02	0.74
	Relocation	0.20	0.17	0.62	0.03	0.10	1.11
	Subtotal	**0.26**	**0.38**	**2.12**	**0.05**	**0.17**	**2.98**
Capital Stock Losses							
	Structural	0.43	0.25	0.72	0.06	0.08	1.54
	Non_Structural	1.82	0.80	0.95	0.09	0.16	3.82
	Content	0.37	0.11	0.30	0.05	0.06	0.89
	Inventory	0.00	0.00	0.01	0.01	0.00	0.02
	Subtotal	**2.62**	**1.16**	**1.98**	**0.21**	**0.30**	**6.27**
	Total	**2.87**	**1.54**	**4.09**	**0.27**	**0.48**	**9.25**

AS08_WNW6.9

Hazus estimates from the AS08_WNW 6.9. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	20	0.07	1	0.07	0	0.12	0	0.18	0	0.16
Commercial	2,151	6.99	85	10.79	34	17.62	5	29.59	0	42.34
Education	56	0.18	2	0.22	1	0.34	0	0.49	0	0.72
Government	47	0.15	2	0.22	1	0.33	0	0.45	0	0.79
Industrial	268	0.87	11	1.37	5	2.43	1	3.98	0	3.51
Other Residential	4,864	15.82	225	28.64	92	48.06	6	38.19	0	49.94
Religion	96	0.31	3	0.40	1	0.61	0	0.85	0	1.52
Single Family	23,252	75.61	459	58.30	59	30.49	4	26.28	0	1.03
Total	**30,753**		**787**		**192**		**17**		**0**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	25,828	83.99	502	63.86	54	28.05	3	18.73	0	0.05
Steel	565	1.84	22	2.76	9	4.87	1	6.92	0	5.39
Concrete	683	2.22	26	3.31	7	3.80	1	3.10	0	0.60
Precast	497	1.62	23	2.91	15	7.67	3	16.35	0	6.59
RM	1,171	3.81	39	4.92	21	11.19	3	18.01	0	1.21
URM	253	0.82	22	2.85	10	5.38	2	11.03	0	52.94
MH	1,755	5.71	153	19.39	75	39.04	4	25.85	0	33.21
Total	**30,753**		**787**		**192**		**17**		**0**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_WNW 6.9 valued at 15.77 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.04	0.91	0.02	0.08	1.05
	Capital-Related	0.00	0.02	0.72	0.01	0.01	0.76
	Rental	0.11	0.29	0.73	0.01	0.03	1.17
	Relocation	0.36	0.28	0.96	0.04	0.16	1.80
	Subtotal	**0.47**	**0.62**	**3.33**	**0.09**	**0.28**	**4.79**
Capital Stock Losses							
	Structural	0.75	0.40	1.11	0.10	0.13	2.49
	Non_Structural	3.21	1.38	1.66	0.17	0.28	6.70
	Content	0.71	0.22	0.62	0.10	0.11	1.76
	Inventory	0.00	0.00	0.01	0.02	0.00	0.04
	Subtotal	**4.67**	**2.00**	**3.40**	**0.39**	**0.53**	**10.98**
	Total	**5.14**	**2.62**	**6.73**	**0.47**	**0.81**	**15.77**

AS08_S1-6.5

Hazus estimates from the AS08_S1 - 6.5. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	20	0.07	1	0.09	0	0.16	0	0.26	0	0.27
Commercial	2,160	6.97	80	12.67	31	22.42	4	39.63	0	66.14
Education	56	0.18	2	0.24	1	0.40	0	0.60	0	0.90
Government	47	0.15	1	0.23	0	0.36	0	0.48	0	0.78
Industrial	270	0.87	10	1.51	4	2.90	1	4.99	0	4.44
Other Residential	4,934	15.93	188	29.86	63	45.25	3	27.78	0	25.85
Religion	96	0.31	3	0.43	1	0.67	0	0.92	0	1.62
Single Family	23,387	75.51	346	54.97	39	27.84	3	25.35	0	0.00
Total	**30,970**		**629**		**139**		**11**		**0**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	25,965	83.84	386	61.36	35	25.29	2	17.78	0	0.00
Steel	569	1.84	19	3.03	8	5.75	1	8.74	0	3.99
Concrete	686	2.21	24	3.86	6	4.67	0	3.83	0	0.12
Precast	500	1.61	22	3.44	14	9.80	2	21.68	0	10.49
RM	1,178	3.80	35	5.61	19	13.45	2	21.31	0	0.00
URM	255	0.82	21	3.42	10	7.00	2	15.01	0	85.40
MH	1,818	5.87	121	19.29	47	34.03	1	11.65	0	0.00
Total	**30,970**		**629**		**139**		**11**		**0**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_S1 - 6.5 valued at 12.9 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.03	0.83	0.02	0.07	0.94
	Capital-Related	0.00	0.01	0.64	0.01	0.01	0.67
	Rental	0.07	0.25	0.67	0.01	0.03	1.03
	Relocation	0.24	0.22	0.88	0.04	0.12	1.50
	Subtotal	**0.31**	**0.51**	**3.03**	**0.07**	**0.22**	**4.15**
Capital Stock Losses							
	Structural	0.53	0.33	1.01	0.08	0.11	2.06
	Non_Structural	2.21	1.16	1.52	0.14	0.22	5.26
	Content	0.46	0.18	0.58	0.09	0.09	1.40
	Inventory	0.00	0.00	0.01	0.02	0.00	0.03
	Subtotal	**3.20**	**1.67**	**3.13**	**0.33**	**0.43**	**8.76**
	Total	**3.52**	**2.18**	**6.15**	**0.40**	**0.65**	**12.90**

AS08_S1-6.7

Hazus estimates from the AS08_S1 6.7. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	20	0.06	1	0.08	0	0.14	0	0.24	0	0.27
Commercial	2,090	6.88	123	11.17	53	20.51	9	36.90	0	57.11
Education	54	0.18	2	0.22	1	0.39	0	0.58	0	0.87
Government	46	0.15	2	0.21	1	0.35	0	0.47	0	0.76
Industrial	261	0.86	15	1.34	7	2.69	1	4.68	0	4.97
Other Residential	4,772	15.72	297	26.91	112	43.15	7	29.39	0	34.48
Religion	94	0.31	4	0.39	2	0.65	0	0.89	0	1.54
Single Family	23,026	75.84	658	59.67	84	32.11	6	26.84	0	0.00
Total	**30,363**		**1,102**		**260**		**23**		**1**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	25,565	84.20	738	66.92	80	30.93	5	20.02	0	0.00
Steel	549	1.81	31	2.79	15	5.79	2	8.72	0	8.95
Concrete	665	2.19	38	3.48	12	4.80	1	4.22	0	1.29
Precast	479	1.58	31	2.85	22	8.50	5	19.78	0	9.21
RM	1,146	3.78	52	4.74	31	12.07	5	20.48	0	0.00
URM	239	0.79	30	2.70	15	5.76	3	13.02	0	67.95
MH	1,718	5.66	182	16.52	84	32.15	3	13.76	0	12.58
Total	**30,363**		**1,102**		**260**		**23**		**1**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_S1 6.7 valued at 25.66 million dollars. With 46% of the total losses are from residential buildings.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.06	1.50	0.03	0.12	1.71
	Capital-Related	0.00	0.03	1.16	0.02	0.01	1.22
	Rental	0.16	0.46	1.17	0.01	0.05	1.85
	Relocation	0.52	0.40	1.56	0.07	0.23	2.78
	Subtotal	**0.67**	**0.95**	**5.39**	**0.13**	**0.41**	**7.55**
Capital Stock Losses							
	Structural	1.07	0.59	1.76	0.15	0.21	3.78
	Non_Structural	4.70	2.37	3.11	0.31	0.46	10.94
	Content	1.10	0.44	1.37	0.20	0.21	3.32
	Inventory	0.00	0.00	0.03	0.05	0.00	0.08
	Subtotal	**6.86**	**3.39**	**6.28**	**0.70**	**0.88**	**18.12**
	Total	**7.53**	**4.34**	**11.66**	**0.83**	**1.29**	**25.66**

AS08_S1-6.9

Hazus estimates from the AS08_S1 - 6.9. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	19	0.06	1	0.07	1	0.13	0	0.23	0	0.27
Commercial	1,991	6.76	180	10.10	88	18.78	16	33.93	1	52.86
Education	52	0.18	4	0.21	2	0.37	0	0.56	0	0.86
Government	44	0.15	4	0.20	2	0.35	0	0.49	0	0.82
Industrial	248	0.84	22	1.23	12	2.53	2	4.44	0	5.12
Other Residential	4,541	15.42	437	24.52	194	41.38	15	33.15	0	37.46
Religion	90	0.31	7	0.37	3	0.63	0	0.88	0	1.50
Single Family	22,465	76.28	1,129	63.31	168	35.82	12	26.33	0	1.11
Total	**29,450**		**1,783**		**468**		**46**		**1**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	24,937	84.68	1272	71.35	169	36.13	9	20.48	0	0.02
Steel	516	1.75	48	2.70	29	6.18	5	9.91	0	12.24
Concrete	632	2.15	58	3.27	24	5.06	2	5.04	0	3.64
Precast	453	1.54	43	2.38	34	7.22	8	17.54	0	9.19
RM	1,106	3.75	71	4.01	49	10.44	9	18.72	0	2.35
URM	222	0.76	38	2.13	21	4.58	5	10.76	1	55.81
MH	1,584	5.38	253	14.16	142	30.39	8	17.57	0	16.76
Total	**29,450**		**1,783**		**468**		**46**		**1**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_S1 6.9 valued at 47.89 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.11	2.65	0.06	0.20	3.02
	Capital-Related	0.00	0.05	2.04	0.03	0.02	2.15
	Rental	0.30	0.83	1.97	0.03	0.09	3.22
	Relocation	1.03	0.73	2.70	0.12	0.43	5.01
	Subtotal	**1.33**	**1.73**	**9.36**	**0.23**	**0.74**	**13.40**
Capital Stock Losses							
	Structural	1.97	1.04	2.99	0.26	0.37	6.64
	Non_Structural	8.99	4.49	5.90	0.59	0.87	20.85
	Content	2.33	0.91	2.80	0.39	0.43	6.85
	Inventory	0.00	0.00	0.06	0.09	0.00	0.15
	Subtotal	**13.29**	**6.45**	**11.76**	**1.33**	**1.66**	**34.49**
	Total	**14.62**	**8.17**	**21.12**	**1.57**	**2.41**	**47.89**

AS08_S2-6.5

Hazus estimates from the AS08_S2 - 6.5. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	20	0.07	1	0.10	0	0.17	0	0.30	0	0.28
Commercial	2,175	6.99	70	13.56	26	23.47	4	42.09	0	65.78
Education	56	0.18	1	0.26	0	0.42	0	0.63	0	0.90
Government	47	0.15	1	0.24	0	0.36	0	0.48	0	0.70
Industrial	272	0.87	8	1.61	3	3.00	0	5.22	0	3.81
Other Residential	4,973	15.99	161	31.14	51	45.66	2	27.37	0	26.97
Religion	97	0.31	2	0.45	1	0.69	0	0.96	0	1.57
Single Family	23,470	75.44	272	52.63	29	26.22	2	22.96	0	0.00
Total	**31,111**		**517**		**112**		**9**		**0**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	26,057	83.76	303	58.66	26	23.26	1	14.91	0	0.00
Steel	573	1.84	17	3.21	7	5.85	1	9.02	0	0.49
Concrete	690	2.22	21	4.05	5	4.64	0	3.83	0	0.00
Precast	504	1.62	19	3.75	12	10.39	2	23.10	0	7.58
RM	1,186	3.81	31	6.01	16	13.92	2	22.00	0	0.00
URM	258	0.83	20	3.77	8	7.54	1	16.17	0	91.93
MH	1,842	5.92	106	20.55	39	34.42	1	10.97	0	0.00
Total	**31,111**		**517**		**112**		**9**		**0**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_S2 - 6.5 valued at 10.02 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.03	0.67	0.01	0.05	0.77
	Capital-Related	0.00	0.01	0.52	0.01	0.01	0.55
	Rental	0.06	0.20	0.56	0.01	0.02	0.84
	Relocation	0.18	0.17	0.72	0.03	0.10	1.20
	Subtotal	**0.23**	**0.41**	**2.47**	**0.06**	**0.18**	**3.36**
Capital Stock Losses							
	Structural	0.41	0.26	0.83	0.07	0.09	1.66
	Non_Structural	1.68	0.89	1.16	0.10	0.17	4.00
	Content	0.32	0.13	0.40	0.06	0.06	0.98
	Inventory	0.00	0.00	0.01	0.01	0.00	0.02
	Subtotal	**2.41**	**1.28**	**2.40**	**0.25**	**0.33**	**6.67**
	Total	**2.64**	**1.70**	**4.87**	**0.31**	**0.51**	**10.02**

AS08_S2-6.7

Hazus estimates from the AS08_S2 - 6.7. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	20	0.06	1	0.09	0	0.16	0	0.27	0	0.32
Commercial	2,114	6.91	109	11.83	45	21.53	7	38.44	0	62.14
Education	55	0.18	2	0.23	1	0.40	0	0.59	0	0.91
Government	46	0.15	2	0.22	1	0.35	0	0.46	0	0.77
Industrial	264	0.86	13	1.41	6	2.79	1	4.81	0	4.96
Other Residential	4,834	15.80	257	27.90	92	43.66	5	28.42	0	29.28
Religion	95	0.31	4	0.41	1	0.66	0	0.91	0	1.61
Single Family	23,173	75.73	532	57.91	64	30.44	5	26.09	0	0.00
Total	**30,601**		**919**		**211**		**18**		**0**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	25,727	84.07	597	64.89	61	28.76	3	18.95	0	0.00
Steel	557	1.82	27	2.90	12	5.81	2	8.69	0	7.80
Concrete	673	2.20	33	3.62	10	4.78	1	4.06	0	1.34
Precast	486	1.59	28	3.07	19	9.08	4	20.78	0	9.64
RM	1,158	3.78	46	5.06	27	12.67	4	20.95	0	0.00
URM	244	0.80	27	2.96	13	6.26	3	13.92	0	75.41
MH	1,756	5.74	161	17.49	69	32.62	2	12.66	0	5.81
Total	**30,601**		**919**		**211**		**18**		**0**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_S2 - 6.7 valued at 20.20 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.05	1.22	0.03	0.09	1.39
	Capital-Related	0.00	0.02	0.95	0.02	0.01	1.00
	Rental	0.12	0.37	0.97	0.01	0.04	1.51
	Relocation	0.39	0.32	1.28	0.06	0.19	2.24
	Subtotal	**0.52**	**0.77**	**4.42**	**0.11**	**0.33**	**6.14**
Capital Stock Losses							
	Structural	0.85	0.48	1.45	0.12	0.17	3.07
	Non_Structural	3.63	1.84	2.43	0.24	0.36	8.49
	Content	0.80	0.32	1.01	0.15	0.16	2.44
	Inventory	0.00	0.00	0.02	0.03	0.00	0.06
	Subtotal	**5.28**	**2.64**	**4.91**	**0.54**	**0.69**	**14.06**
	Total	**5.79**	**3.41**	**9.33**	**0.65**	**1.02**	**20.20**

AS08_S2-6.9

Hazus estimates from the AS08_S2 - 6.9. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	19	0.06	1	0.08	1	0.15	0	0.26	0	0.33
Commercial	2,028	6.80	159	10.56	74	19.67	13	35.71	1	56.08
Education	53	0.18	3	0.22	1	0.39	0	0.57	0	0.90
Government	44	0.15	3	0.20	1	0.35	0	0.47	0	0.77
Industrial	253	0.85	19	1.27	10	2.61	2	4.55	0	5.19
Other Residential	4,636	15.55	382	25.32	158	41.76	11	31.16	0	35.06
Religion	91	0.31	6	0.38	2	0.64	0	0.90	0	1.55
Single Family	22,699	76.11	935	61.96	130	34.44	9	26.38	0	0.13
Total	**29,825**		**1,509**		**378**		**36**		**1**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	25,200	84.49	1052	69.72	129	34.19	7	20.05	0	0.00
Steel	529	1.77	42	2.77	23	6.09	3	9.41	0	11.79
Concrete	646	2.16	51	3.35	19	4.99	2	4.73	0	2.33
Precast	463	1.55	39	2.56	29	7.77	7	18.71	0	9.39
RM	1,121	3.76	65	4.28	42	11.13	7	19.69	0	0.26
URM	228	0.77	35	2.34	19	5.05	4	11.80	1	62.62
MH	1,639	5.50	226	14.97	117	30.78	6	15.61	0	13.61
Total	**29,825**		**1,509**		**378**		**36**		**1**	

*Note:

RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_S2 - 6.9 valued at 37.87 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.09	2.14	0.05	0.16	2.44
	Capital-Related	0.00	0.04	1.66	0.03	0.02	1.74
	Rental	0.24	0.67	1.62	0.02	0.07	2.61
	Relocation	0.80	0.58	2.19	0.09	0.34	4.01
	Subtotal	**1.04**	**1.38**	**7.61**	**0.19**	**0.59**	**10.80**
Capital Stock Losses							
	Structural	1.58	0.84	2.45	0.21	0.30	5.38
	Non_Structural	7.08	3.53	4.63	0.46	0.68	16.37
	Content	1.75	0.69	2.13	0.30	0.32	5.19
	Inventory	0.00	0.00	0.05	0.07	0.00	0.12
	Subtotal	**10.40**	**5.06**	**9.25**	**1.05**	**1.30**	**27.06**
	Total	**11.44**	**6.44**	**16.86**	**1.24**	**1.89**	**37.87**

AS08_K - 5

Hazus estimates from the AS08_K - 5. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	20	0.06	1	0.08	0	0.15	0	0.27	0	0.33
Commercial	2,102	6.90	110	10.68	53	21.02	10	39.67	0	60.44
Education	55	0.18	2	0.22	1	0.39	0	0.61	0	0.83
Government	46	0.15	2	0.22	1	0.41	0	0.62	0	0.95
Industrial	267	0.88	11	1.04	5	2.16	1	3.84	0	3.58
Other Residential	4,849	15.93	241	23.47	92	36.36	6	25.52	0	25.75
Religion	94	0.31	4	0.41	2	0.67	0	0.95	0	1.36
Single Family	23,012	75.59	656	63.88	98	38.84	7	28.52	0	6.77
Total	**30,443**		**1,028**		**252**		**25**		**1**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	25,546	83.91	737	71.74	99	39.19	6	23.37	0	6.19
Steel	565	1.85	21	2.06	10	4.04	1	5.45	0	3.89
Concrete	672	2.21	32	3.14	11	4.44	1	4.10	0	1.75
Precast	484	1.59	28	2.69	21	8.32	5	19.78	0	10.04
RM	1,153	3.79	46	4.51	30	11.90	5	20.66	0	3.12
URM	242	0.79	27	2.65	15	5.84	3	13.32	1	65.51
MH	1,782	5.85	136	13.22	66	26.27	3	13.31	0	9.50
Total	**30,443**		**1,028**		**252**		**25**		**1**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_K - 5 valued at 45.78 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	0.07	1.62	0.02	0.13	1.84
	Capital-Related	0.00	0.03	1.26	0.01	0.01	1.31
	Rental	0.18	0.40	1.21	0.01	0.05	1.84
	Relocation	0.60	0.33	1.64	0.06	0.23	2.86
	Subtotal	**0.78**	**0.82**	**5.72**	**0.11**	**0.42**	**7.86**
Capital Stock Losses							
	Structural	1.15	0.48	1.80	0.12	0.24	3.79
	Non_Structural	8.56	3.97	7.53	0.75	1.09	21.89
	Content	3.92	1.30	5.35	0.59	0.83	11.99
	Inventory	0.00	0.00	0.10	0.13	0.02	0.25
	Subtotal	**13.63**	**5.75**	**14.78**	**1.60**	**2.17**	**37.93**
	Total	**14.41**	**6.57**	**20.50**	**1.71**	**2.60**	**45.78**

AS08_K - 6.5

Hazus estimates from the AS08_K - 6.5. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	11	0.06	4	0.05	4	0.10	2	0.18	0	0.29
Commercial	1,056	5.54	428	5.81	502	12.30	240	22.32	50	31.89
Education	31	0.16	10	0.14	11	0.28	5	0.47	1	0.60
Government	25	0.13	8	0.11	10	0.25	5	0.47	1	0.66
Industrial	136	0.71	51	0.69	62	1.53	29	2.71	6	3.67
Other Residential	2,657	13.93	1,148	15.59	965	23.66	356	33.13	61	39.05
Religion	50	0.26	19	0.25	20	0.50	9	0.85	2	1.06
Single Family	15,108	79.21	5,698	77.36	2,504	61.38	429	39.88	36	22.78
Total	**19,074**		**7,365**		**4,079**		**1,075**		**156**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	16,672	87.41	6466	87.79	2,791	68.43	423	39.36	36	22.83
Steel	265	1.39	92	1.25	149	3.65	74	6.88	17	11.06
Concrete	333	1.75	139	1.89	165	4.04	69	6.41	11	6.76
Precast	224	1.17	75	1.02	131	3.20	91	8.47	17	10.63
RM	635	3.33	166	2.25	263	6.46	155	14.43	15	9.92
URM	103	0.54	59	0.81	68	1.67	39	3.61	19	11.99
MH	842	4.41	368	4.99	512	12.56	224	20.82	42	26.80
Total	**19,074**		**7,365**		**4,079**		**1,075**		**156**	

*Note:

RM	Reinforced Masonry
URM	Unreinforced Masonry
MH	Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_K - 6.5 valued at 625.57 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	1.64	29.88	0.51	2.14	34.16
	Capital-Related	0.00	0.71	22.92	0.31	0.24	24.17
	Rental	5.09	9.52	17.58	0.21	1.01	33.41
	Relocation	19.28	7.63	26.15	0.91	4.92	58.89
	Subtotal	**24.37**	**19.49**	**96.54**	**1.93**	**8.31**	**150.64**
Capital Stock Losses							
	Structural	26.07	10.66	30.92	2.46	4.84	74.94
	Non_Structural	126.70	59.97	79.93	7.09	11.97	285.67
	Content	43.92	15.61	41.26	5.01	6.50	112.31
	Inventory	0.00	0.00	0.78	1.12	0.12	2.01
	Subtotal	**196.69**	**86.24**	**152.89**	**15.68**	**23.42**	**474.93**
	Total	**221.06**	**105.73**	**249.43**	**17.62**	**31.73**	**625.57**

AS08_K - 6.7

Hazus estimates from the AS08_K - 6.7. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	10	0.06	4	0.05	4	0.09	2	0.17	1	0.27
Commercial	898	5.21	427	5.38	564	11.60	307	21.29	79	30.79
Education	27	0.15	10	0.13	13	0.26	7	0.46	2	0.60
Government	22	0.13	8	0.10	11	0.23	6	0.45	2	0.65
Industrial	114	0.66	51	0.64	71	1.46	38	2.67	10	3.79
Other Residential	2,339	13.56	1,191	15.00	1,084	22.27	472	32.77	103	39.85
Religion	44	0.25	19	0.24	23	0.47	12	0.82	3	1.05
Single Family	13,793	79.98	6,231	78.46	3,095	63.61	596	41.36	59	23.00
Total	**17,245**		**7,942**		**4,865**		**1,440**		**257**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	15,198	88.13	7066	88.98	3,467	71.26	598	41.52	59	22.87
Steel	218	1.26	88	1.11	164	3.37	98	6.82	29	11.38
Concrete	281	1.63	138	1.74	186	3.83	93	6.46	19	7.22
Precast	187	1.09	73	0.91	140	2.87	111	7.72	27	10.38
RM	550	3.19	166	2.08	293	6.02	199	13.82	27	10.63
URM	87	0.50	57	0.72	72	1.48	46	3.18	26	9.96
MH	724	4.20	354	4.46	543	11.17	295	20.48	71	27.55
Total	**17,245**		**7,942**		**4,865**		**1,440**		**257**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_K – 6.7 valued at 795.63 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	2.15	38.45	0.69	2.75	44.02
	Capital-Related	0.00	0.92	29.59	0.42	0.31	31.25
	Rental	6.60	12.42	22.18	0.27	1.30	42.78
	Relocation	25.00	9.83	33.03	1.17	6.35	75.38
	Subtotal	**31.60**	**25.32**	**123.25**	**2.55**	**10.72**	**193.43**
Capital Stock Losses							
	Structural	33.51	13.95	40.34	3.35	6.33	97.49
	Non_Structural	157.36	76.47	104.86	9.64	15.76	364.08
	Content	52.16	19.11	51.89	6.69	8.14	137.99
	Inventory	0.00	0.00	0.99	1.51	0.14	2.64
	Subtotal	**243.03**	**109.53**	**198.08**	**21.18**	**30.38**	**602.20**
	Total	**274.63**	**134.86**	**321.32**	**23.72**	**41.10**	**795.63**

AS08_K - 6.9

Hazus estimates from the AS08_K - 6.9. Damage details are shown below.

Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	9	0.05	4	0.05	5	0.09	3	0.16	1	0.26
Commercial	776	4.89	418	5.03	607	11.11	363	20.77	111	30.42
Education	24	0.15	10	0.12	14	0.25	8	0.46	2	0.61
Government	19	0.12	8	0.09	12	0.22	8	0.44	2	0.65
Industrial	97	0.61	50	0.60	77	1.40	46	2.65	14	3.88
Other Residential	2,099	13.24	1,211	14.56	1,163	21.31	568	32.45	147	40.27
Religion	39	0.24	19	0.22	25	0.45	14	0.82	4	1.06
Single Family	12,798	80.69	6,596	79.32	3,557	65.17	739	42.26	83	22.86
Total	**15,861**		**8,315**		**5,459**		**1,750**		**365**	

building damage by building type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	14,085	88.81	7472	89.86	3,998	73.24	750	42.86	82	22.51
Steel	183	1.15	83	0.99	171	3.13	118	6.77	42	11.64
Concrete	240	1.52	134	1.61	200	3.67	114	6.52	28	7.64
Precast	160	1.01	69	0.83	144	2.64	127	7.25	37	10.25
RM	483	3.04	162	1.95	312	5.72	236	13.51	41	11.33
URM	75	0.47	55	0.66	74	1.36	51	2.92	32	8.82
MH	635	4.00	340	4.09	558	10.23	353	20.17	101	27.82
Total	**15,861**		**8,315**		**5,459**		**1,750**		**365**	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Building damage costs

The software predicts total economic losses from AS08_K - 6.9 valued at 946.94 million dollars.

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	2.61	46.28	0.85	3.29	53.04
	Capital-Related	0.00	1.12	35.75	0.52	0.38	37.77
	Rental	7.86	15.02	26.31	0.33	1.57	51.09
	Relocation	29.77	11.75	39.14	1.40	7.66	89.72
	Subtotal	**37.63**	**30.51**	**147.48**	**3.11**	**12.90**	**231.63**
Capital Stock Losses							
	Structural	39.81	16.93	49.15	4.21	7.71	117.81
	Non_Structural	182.47	91.16	128.83	12.21	19.42	434.09
	Content	58.39	22.04	61.72	8.35	9.67	160.16
	Inventory	0.00	0.00	1.19	1.90	0.17	3.26
	Subtotal	**280.67**	**130.13**	**240.89**	**26.67**	**36.96**	**715.31**
	Total	**318.30**	**160.64**	**388.37**	**29.77**	**49.86**	**946.94**

APPENDIX D

Pre-Code damage results for likely scenario (AS08_K -5)

Building Damage Count for Pre Code Seismic Design Level

April 04, 2017

	# of Buildings					
	None	Slight	Moderate	Extensive	Complete	Total
British Columbia						
Thompson-Nicola						
Wood	413	21	2	0	0	436
Steel	496	20	10	1	0	527
Concrete	451	25	9	1	0	487
Precast	365	23	18	4	0	410
Reinforced Masonry	919	40	26	5	0	990
Unreinforced Masonry	242	27	15	3	1	288
Manufactured Home	1,005	98	49	2	0	1,153
Total	**3,891**	**254**	**129**	**17**	**1**	**4,291**
Region Total	**3,891**	**254**	**129**	**17**	**1**	**4,291**

Low-Code damage results for likely scenario (AS08_K -5)

Building Damage Count for Low Seismic Design Level

April 04, 2017

	# of Buildings					
	None	Slight	Moderate	Extensive	Complete	Total
British Columbia						
Thompson-Nicola						
Wood	25,132	716	97	6	0	25,951
Steel	69	1	0	0	0	70
Concrete	221	7	2	0	0	230
Precast	119	4	3	1	0	127
Reinforced Masonry	234	7	4	0	0	245
Manufactured Home	777	38	18	1	0	834
Total	**26,552**	**774**	**123**	**9**	**0**	**27,458**
Region Total	**26,552**	**774**	**123**	**9**	**0**	**27,458**