Calibration of Seismic Risk Analyses through Reanalysis of Historical Earthquakes

- An Application of Hazus-MH2.1 Canada

By

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Abstract

More than half of Canada's population lives in areas endangered by earthquake hazard. Urban centers such as Vancouver, Montreal, Quebec City lie in these regions of significant seismic hazard. Although many studies on seismic loss comparison between estimated and observed damage using HazUS have been conducted for US earthquakes (e.g. 1994 Northridge earthquake and 2014 Napa Valley earthquake), little has been done in the Canadian context. In order to calibrate the seismic loss software HazCan (a version of HazUS adapted to Canadian context), a comparative study is carried out using data collected after the M5.8 1944 Cornwall and the M6.0 1988 Saguenay earthquakes, which occurred in Eastern Canada.

Following the HazCan methodology, the default regional dataset is updated for each earthquake analysis. It includes the collection of 1) demographic data adjusted from census and default database 2) building inventory at the year of the event and 3) local soil conditions to account for eventual site amplification. The lack of seismic records requires testing of several ground motion prediction equations for both earthquake events.

Direct damage on residential buildings, economic losses and casualty estimates are compared with the calculated ones from HazCan. Specific parameters are chosen as the "metrics" for comparison of each type of damage and loss values, and the choice of the parameters is largely influenced by the quality and availability of the observed data.

The results indicate that HazCAN tends to over predict the damage and loss within a short epicentral distance, approximately less than 30-km. The degree of overestimation is greatly dependent on the accuracy of the ground motion prediction. Overall, the soil amplification effect calculated from HazCAN matches the observed trend of damage distribution. Unreinforced masonry buildings prove to have the worst performance among all construction types. HazCAN also overpredicts the number of buildings with complete damage state by a significant amount. Some recommendations are provided to improve the HazCAN estimation for future research.

Résumé

Plus de la moitié de la population du Canada vit dans des régions menacées par le séisme. Des centres urbains comme Vancouver, Montréal et Québec se trouvent dans ces régions à risque sismique important. Bien que de nombreuses études sur la comparaison des pertes sismiques entre les dommages estimés et observés à l'aide de HazUS aient été menées pour les tremblements de terre aux États-Unis (e.g. le séisme du Northridge en 1994 et le séisme du Napa Valley en 2014), peu a été fait dans le contexte canadien. Afin d'étalonner le logiciel de perte sismique HazCan (une version de HazUS adaptée au contexte canadien), une étude comparative est réalisée à partir des données recueillies après les séismes du M5.4 1944 Cornwall et du M6.0 1988 Saguenay, survenus dans l'Est du Canada.

Conformément à la méthodologie HazCan, l'ensemble de données régionales par défaut est mis à jour pour chaque analyse sismique. Il comprend la collecte de 1) des données démographiques ajustées à partir du recensement et de la base de données par défaut 2) de l'inventaire des bâtiments à l'année de l'événement et 3) des conditions locales du sol pour tenir compte d'une éventuelle amplification du site. Le manque d'enregistrements sismiques nécessite de tester plusieurs équations de prévision du mouvement du sol pour les deux événements sismiques.

Les dommages directs sur les bâtiments résidentiels, les pertes économiques et les estimations des pertes sont comparés à ceux calculés par HazCan. Des paramètres spécifiques sont choisis comme ‘métriques’ pour comparer chaque type de valeurs de dommages et de pertes, et le choix des paramètres est largement influencé par la qualité et la disponibilité des données observées.

Les résultats indiquent que HazCAN a tendance à surestimer les dommages et les pertes sur une courte distance épicentrale, environ moins de 30 km. Le degré de surestimation dépend fortement de la précision de la prédiction du mouvement du sol. Dans l'ensemble, l'effet d'amplification du sol calculé à partir de HazCAN correspond à la tendance observée de la distribution des dommages. Les bâtiments en maçonnerie non renforcée s'avèrent avoir les pires performances parmi tous les types de construction. HazCAN a également surestimé le nombre de bâtiments avec un état de dommages complet d'un montant significatif. Certaines recommandations sont fournies pour améliorer l'estimation de HazCAN pour de futures recherches.

Acknowledgement

I would like to extend my profound gratitude to Prof. Luc E. Chouinard and Dr. Philippe Rosset for their continuous guidance throughout this project. Their constructive advice has been enlightening. Their kindness and caring towards my physical well-being are extremely helpful.

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Chapter 1: Introduction

1.1 Background

In North America, earthquake loss estimation began in 1972 with the study for the San Francisco Bay Area (Algermissen et al. (1972) done by the National Oceanic and Atmospheric Agency (NOAA). It was followed by over thirty major regional earthquake loss studies (National Institute of Building Sciences, 1994). However, because of methodology, assumptions, and approaches of the studies differed, none of these loss estimation methodologies have been applicable nation-wide. In 1992, the Federal Emergency Management Agency (FEMA) and National Institute of Building Sciences (NIBS) initiated a project to develop a national standardized methodology. The standardized loss estimation methodology was completed in 1997 and implemented in the software package (HazUS) which operates in conjunction with a geographic information system (GIS). The first release of the software was for the estimation of earthquake risks, and a multi-hazard version called Hazus-MH was released in 2004 (FEMA, 2004; Schneider Philip & Schauer Barbara, 2006). Hazus-MH has been applied in many case studies domestically within the United States (HazUS) for loss estimation and to perform sensitivity analyses. Loss estimation examples include the case study for the Salt Lake County, Utah by Moffatt and Cova (2010) and the study on a blind-thrust earthquake in Los Angeles, California (Field et al., 2005). Examples of sensitivity analyses with HazUS are those of Remo and Pinter (2012) and Neighbors et al. (2013).

Hazus Canada (HazCAN) has been adapted from HazUS since 2011 as an effective tool for seismic risk assessment and loss estimation (Hastings & Journeay, 2011). Although many studies on seismic loss comparison between estimated and observed damage using HazUS have been conducted for US earthquakes, little has been done in the Canadian context. One example from the US is the study conducted by Kircher et al. (2006), in which a comparison of estimated and actual damage and loss due to the 1994 Northridge earthquake was discussed. In the paper, the large study region used to estimate losses included 1,652 census tracts of Los Angeles County, and 743 census tracts of affected areas of neighboring counties. Default building inventory and population data was updated. ShakeMap data and ground motion data from instrumental records were used for comparison purpose. It was found from several key results that the maximum and mean ShakeMap data provided bounding values of observed damage and loss except for the casualties and the serious injuries, with the former overpredicted (by a factor of about 2) and the latter underpredicted (by a factor of 2). The ground motion data developed from instrumental records provided reasonably accurate and modestly conservative estimates. Another example is a validation assessment of the 2008 Mt. Carmel, Illinois earthquake by Remo and Pinter (2012), which revealed that HazUS overpredicted observed damages by 68% to 221% depending on the model parameters used.

Several risk assessment studies based on deaggregation of the seismic hazard defined by the National Building Code have been carried out in Canada during the past few years, such as the study for Downtown Ottawa (Ploeger, 2009), the District of North Vancouver (Journeay et al., 2015), Quebec City (Abo El Ezz et al., 2015) and Montreal Island (Yu et al., 2016). However, a calibration of estimated damage and loss using HazCan has never been done

In this thesis, a comparative study is performed with HazCan using data collected after the M5.8 1944 Cornwall and the M6.0 1988 Saguenay earthquakes, which occurred in Eastern Canada. The 1944 Cornwall earthquake study is presented in Chapter 2. Beginning with earthquake introduction, the chapter is further divided into four sections in a logical order of HazCAN modelling and analysis; they are: data collection and processing, validation of the ground motion prediction equations, damage and loss calculation, and discussion. The 1988 Saguenay earthquake comparative analysis presented in Chapter 3 follows the same procedures as described above. Lastly, the overall conclusions and recommendations achieved from both earthquake analyses are provided in Chapter 4.

1.2 HazCAN methodology

The framework of the HazCAN methodology is illustrated in Figure 1. The outputs of the risk assessment are based on three modules of data: 1) the seismic hazards, 2) the inventory database and 3) the damage functions. In the HazCAN analysis, damage and losses are estimated at three levels of details. The first level only uses default inventory and parameter data; the second level of estimation is achieved by improving inventories and parameters with user-supplied data; the third level incorporates information from third-party studies (FEMA, 2003b). The analyses of the historical earthquakes performed in this research are done at the second level.

First, an inventory database is updated based on the building and demographics information at the time of the earthquake event. All data collected and processed for this study are provided in Table 1. Second, ground shaking hazards are defined considering several perspectives: earthquake source parameters, attenuation relationships and local soil conditions. Due to the lack of ground motion records (specially for the Cornwall earthquake), the calculation of ground motions using several attenuation relationships are compared with the observed ground shaking. For the vulnerability module, fragility curves or damage functions are provided for each type of the structures. These functions are the HazCAN default models. Last, damage and loss are estimated and several parameters from the risk outputs are selected and compared with the observed records.

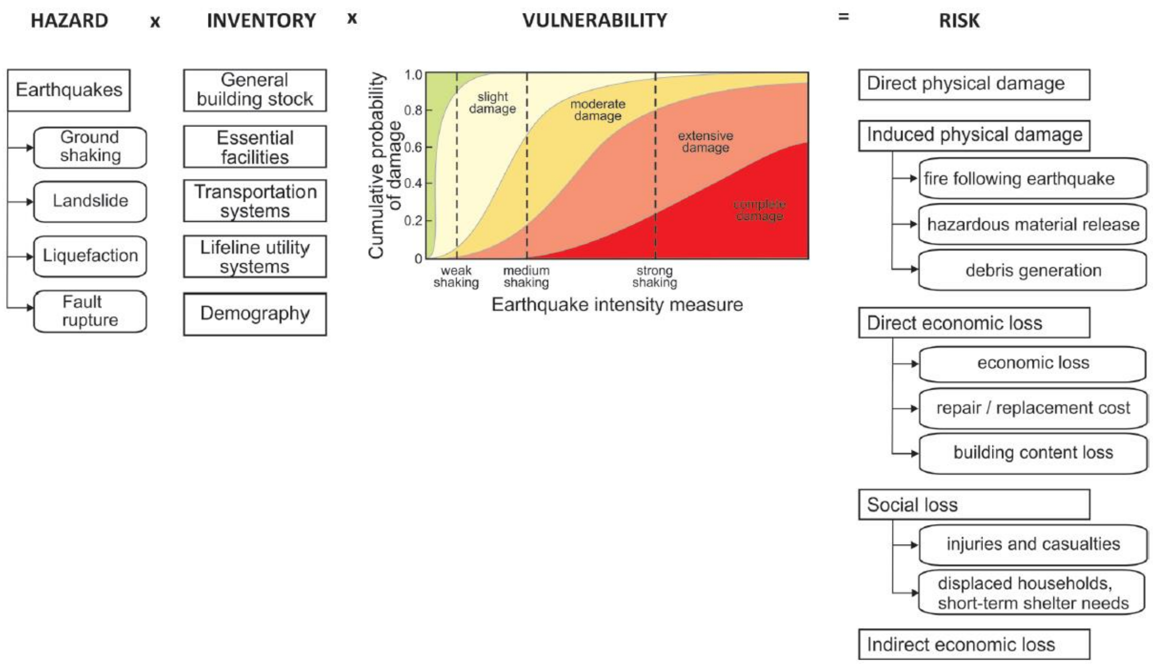


Figure 1: Schematic presentation of considered hazards and inventory databases, damage functions , and risk outputs in the Hazus earthquake model (Nastev, 2013).

Table 1: Summary of data collected for the 1944 Cornwall and 1988 Saguenay earthquake studies.

	Data Category	Type/Description	Source/Reference
1944 Cornwall Earthquake	Demographics	Population	1941 Census of Canada Vol.2 Table 2
		Age groups	1941 Census of Canada Vol.2 Table 22
		Principal origins	1941 Census of Canada Vol.2 Table 32
		Average rent	1941 Census of Canada Vol.5 Table 13
		Total households	1941 Census of Canada Vol.5 Table 4
		Average households income	1941 Census of Canada Vol.9 Table 19
		Average value of dwellings	1941 Census of Canada Vol.9 Table 23
	Building Inventory	Year of units build	1941 Census of Canada Vol. 9 Table 8
		Construction type (exterior material)	1941 Census of Canada Vol.9 Table 2
		Occupancy type	1941 Census of Canada Vol.5 Table 4
	PESH	Soil classification map	Dundas 1952, Stormont 1954, Glengarry 1957 (Ontario Soil Survey), Regional VS30 model for the St. Lawrence Lowlands
1988 Saguenay Earthquake	Demographics	Population Age groups Principal oringins Average rent Total households Average households income Average value of dwellings	Adjusted from 2006 HazCAN Database
	Building Inventory	Year of units build Occupancy type Construction type	
	PESH	Soil classification map	Saguenay microzonation map Quebec city microzonation map

1.3 Objectives

The objective of this research is to compare the damage and loss between the observed and the calculated by HazCAN for the 1944 Cornwall earthquake and the 1988 Saguenay earthquake. Specific damage and loss parameters regarding building damage, economic loss in monetary terms, and casualties should be selected as the "metrics" for comparison and to obtain both qualitative and quantitative results. The effect of the choice of attenuation relationships used for calculating predicted ground motion should be studied, and the local site amplification effect should be considered when studying the trend and distribution of the damage and loss.

Chapter 2: 1944 Cornwall comparative analysis

2.0 Earthquake introduction

The 1944 Cornwall earthquake (Mw=5.8) M_w5.8occurred on September 5 at 12:38:45am Eastern time. The hypocenter is estimated at 20km depth and the epicenter is located midway between Cornwall, Ontario and Massena, New York (Figure 2). The maximum Modified Mercalli intensity (MMI) is VII and the extent of the zone is an approximate 50-km radius from the epicenter. The isoseismals on intensity map are elongated in a northeast-southwest direction along the St. Lawrence River.

2.1 Data collection and processing

2.1.1 Study region and census tracts

A first step in HazCAN modelling is to define a study region. The current version of HazCAN permits users to create study regions based on Statistics Canada 2006 census boundaries and data. In this study, census subdivisions of Stormont-Dundas-Glengarry cover the major part of the affected areas. The census subdivisions contain 8 census tracts, and they represent the basic unit of the study for input and output data (Figure 2). Table 2 lists the codes denoting the townships, the City of Cornwall and the Akwesasne First Nations reserve. The study area is located on a flat delta southeast to the City of Ottawa between the St. Lawrence and Ottawa Rivers. Its location lies within the extent of the old Champlain Sea with marine clay as the most prominent soil deposit.

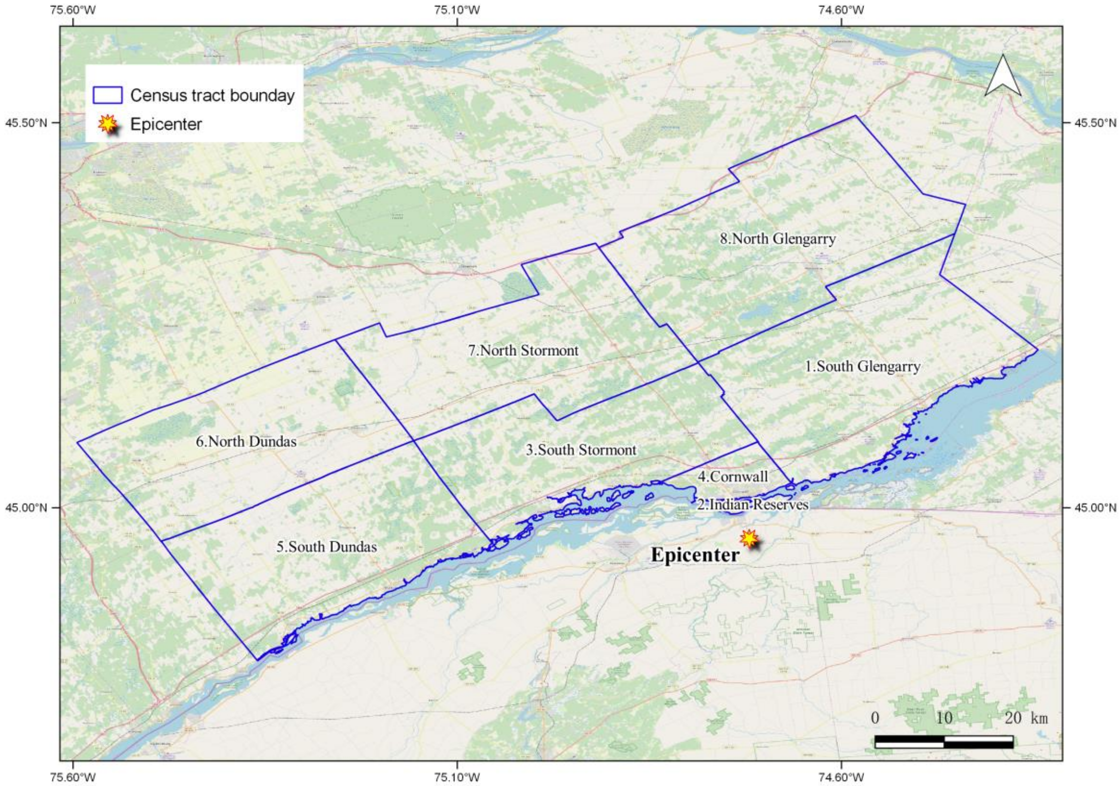


Figure 2: Division of the study area in census tract for the 1944 Cornwall earthquake study.

Table 2: Codes and names of the census tracts as shown in Figure 2 (TP: Township, CY: City).

Code	Name	Code	Name
1	South Glengarry, TP	5	South Dundas, TP
2	Indian Reserves	6	North Dundas, TP
3	South Stormont, TP	7	North Stormont, TP
4	Cornwall, CY	8	North Glengarry, TP

2.1.2 Demographics

For reanalyzing the 1944 earthquake, demographic data is obtained from the 1941 Census of Canada (Government of Canada, 1941). The geographic units are based on individual townships under the county of Stormont, Dundas and Glengarry in 1941. Figure 3 shows the townships locations in relation to the default census tract boundaries and the population of each township in

1941. At the time, the total population in the study region was 75,847 with Cornwall City having the highest population of 30,151. This population data is grouped based on census tract boundary to obtain an updated distribution profile for use in HazCAN. Most of other demographics data such as the total number of households, the population by age groups and the population by origins, etc. can be grouped similarly based on the geographic locations (Table 3 and Figure 4). The Cornwall census tract (CT#4) has the highest population with around 40% of the total population, and the Indian Reserves (CT#2) has the lowest population percentage (0.6%). For the items that were not collected in 1941, for instance the total population in residence during day or night, data are calculated based on the proportion of the population in 1941 compared to the population in the 2006 database.

Beside population data, dwelling unit count based on ownership type and year of construction are also required in the demographics input section in HazCAN. In addition, some monetary related items such as monthly rent, average household income and average value of dwellings are required as well to complete the demographics input for analysis. Table 3 and 4 list the items and data collected from 1941 census for demographics section input in HazCAN. For data that cannot be directly obtained from the census due to difference in geographical unit resolution, for example, unit count based on ownership type (owner/renter) is only available by county as a total. A proportional calculation based on total population is performed to obtain the required information for each census tract.

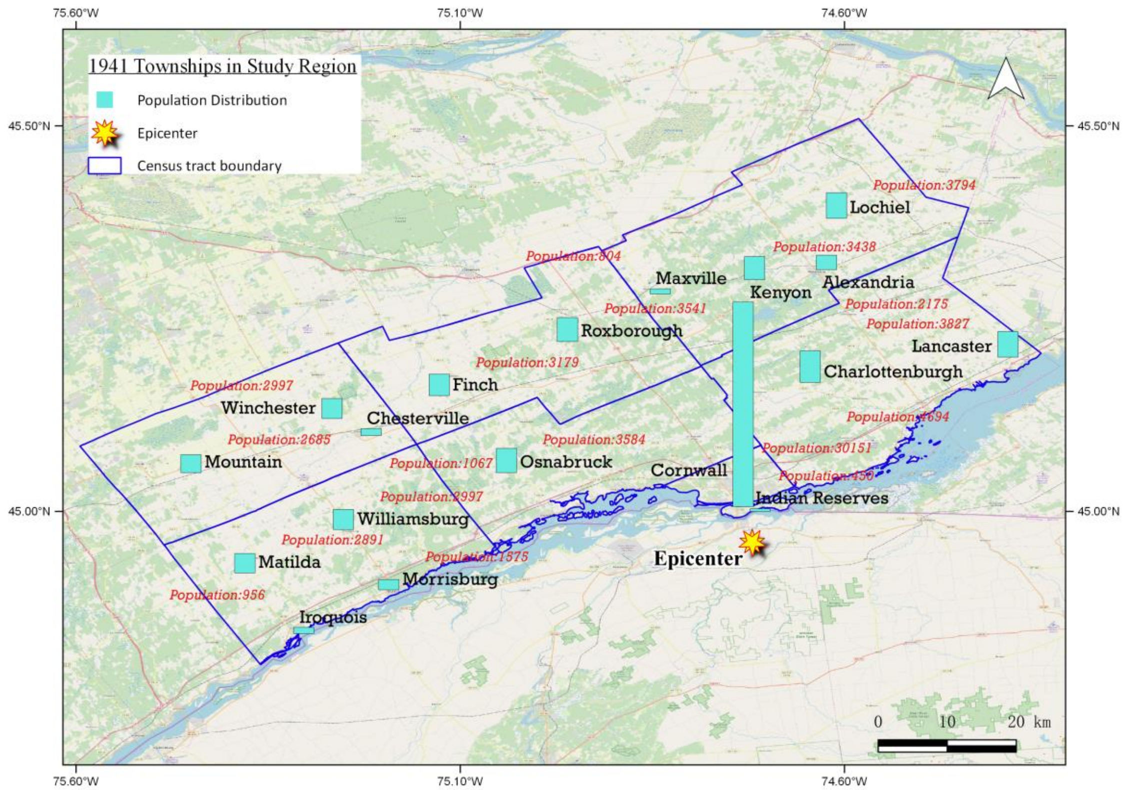


Figure 3: Population of the city and townships in the Cornwall earthquake study region in 1941. The population is listed in red italic font for each township.

Table 3: Demographics data by census code for the 1944 Cornwall earthquake study. Categories include total population, population by sex and age groups, population by origins, and total number of households. CT code are the ones in Table 2.

CT Code	TOTAL POP	Tot male	Tot female	M less 16	F less 16	M 16to65	F 16to65	M over65	F over65	Asian	Native	Black	White	others	Tot households
1	8,521	4,482	4,039	1,400	1,344	2,678	2,257	404	437	0	0	6	8,515	0	1,941
2	450	227	223	74	74	138	134	15	15	0	441	0	5	4	100
3	3,584	1,810	1,774	592	586	1,100	1,069	119	119	1	1	0	3,582	0	795
4	30,151	15,228	14,923	4,976	4,933	9,250	8,990	1,002	1,001	101	24	15	29,981	30	6,690
5	8,419	4,351	4,068	1,163	1,123	2,729	2,470	460	475	31	2	0	8,385	1	2,168
6	7,791	4,027	3,764	1,076	1,040	2,526	2,285	425	439	12	1	0	7,778	0	2,006
7	6,720	3,394	3,326	1,109	1,099	2,062	2,004	223	223	1	0	3	6,718	0	1,491
8	10,211	5,372	4,839	1,678	1,611	3,209	2,705	484	524	15	0	10	10,186	0	2,325
Total	75,847	38,891	36,956	12,067	11,810	23,691	21,914	3,132	3,232	161	469	34	75,150	35	17,516
Source: 1941 Census Volume and Table Number	*V2 T10*	*V2 T22*								*V2 T32*					*V5 T4*

Note. Data used to calculate the demographics information for each census tract from Statistics Canada (Government of Canada, 1941). Specific volume and table number from which the data is extracted indicated in the last row of the table. Volume 2: Population by local subdivisions. Volume 5: Dwellings, households and families.

Table 4: Other data in HazCAN demographics input section for the 1944 Cornwall earthquake study including owner/renter-occupied single/multiple unit counts, dwelling built median years, units year built, average monthly rent, average household annual income, and average value of owner-occupied dwellings.

CT Code	Owner ocup single unit	Owner ocup mult	Renter ocup sing	Renter ocup mult	Median years	Units built before 40s	Units built after 40s	Avg rent ($)	Average houseold income <10k = total household	Avg value of owner occupied dwellings ($)
1	1,224	112	527	48	1933	1,533	487	8	Ontario average annual earning per head = $1453	2712
2	36	17	30	15	1933	84	16	21		2712
3	284	137	242	117	1933	635	162	21		2712
4	2,391	1,155	2,033	982	1936	5,153	1,548	21		2712
5	1,295	201	546	85	1933	1,687	536	14		2712
6	1,199	186	505	78	1933	1,561	496	14		2712
7	533	257	453	219	1933	1,134	360	21		2712
8	1,467	134	632	58	1933	1,818	577	8		2712
Source: 1941 Census Volume and Table Number	*V5 T4*				*V9 T8b*			*V5*	*V9 T19*	*V9 T23*

Note. *Data used to calculate the information for each census tract from Statistics Canada (Government of Canada, 1941). Specific volume and table number from which the data is extracted indicated in the last row of the table. Volume 5: Dwellings, households and families. Volume 9: Housing.*

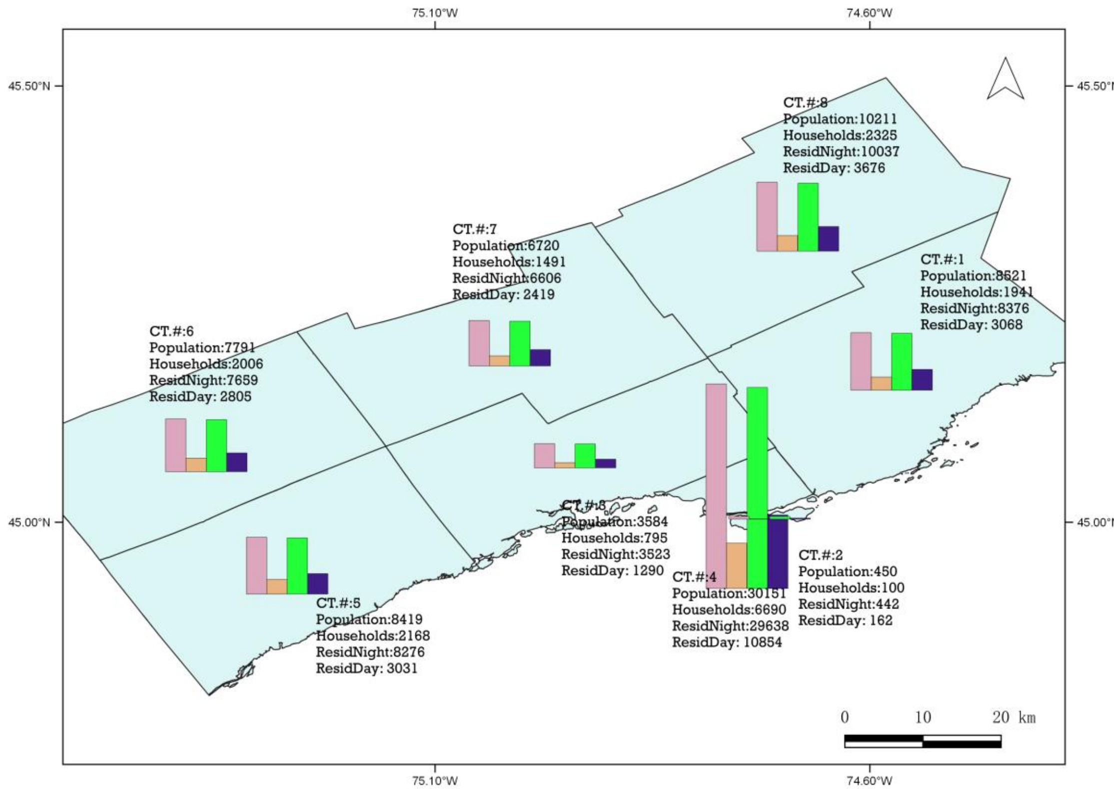


Figure 4: Demographic data by census tract in 1941. The total population, households, residents during day and night are based on 1941 census data.

2.1.3 Building inventory

Information is also extracted and processed according to the 1941 Census of Canada to assess parameters related to the building vulnerability with a focus on residential building stock inventory. A similar methodology as for demographics data is used to prepare the updated dataset. In the 1941 census, 4 types of dwelling units were surveyed: (1) single-family, (2) semi-detached, (3) apartment and (4) rowhouse. After data processing, the number of dwelling units under each category are prepared for each census tract in the study region. They are converted subsequently to HazCAN occupancy types following the rules indicated in Table 5. In addition to the occupancy types, building square footage, building exposure and content exposure in dollar values are also important parameters related to the building vulnerability. To obtain the square footage values, a multiplication was performed of the number of units in each occupancy class by a value of the average square footage for that type of unit. Table C.5 in the HazUS-MH 2.1 Canada User and Technical Manual Earthquake Module (Ulmi et al., 2014) provides a list of average square footages per RES building occupancies. Table 6 lists the average square footage per unit for the occupancy classes that were used by this study. To generate residential building exposure cost data, Replacement Means Square Foot Costs (RS.Means) are needed to multiply with the square footage of the building and the exposure content values are 50% of the building exposure values. Equations used for 2006 dataset exposure calculation are provided in the HazUS-MH 2.1 Canada User and Technical Manual as below:

$$Building\ Exposure\ (Thousands\ of\ \$) = square\ footage \times \frac{RSMeans\ Cost\ for\ 2006}{1000}$$

(Eq. 1)

$$Content\ Exposure\ (Thousands\ of\ \$) = 0.5 \times square\ footage\ \times \frac{RSMeans\ Cost\ for\ 2006}{1000}$$

(Eq. 2)

The RS.Means costs for 2006 for each occupancy types are found in HazCAN software package: around $90 for RES1 and $80 for RES3. For this study, the RS.Means costs for 1944 are estimated to be $7.46 and $6.63 for RES1 and RES3 respectively, taking into consideration of national inflation using inflation calculator (Bank of Canada). Subsequently, the building exposure data can be calculated following equations 1 and 2. Table 7 and Table 8 summarize the building inventory parameters that are developed so far for this study.

Table 5: Conversion from Statistics Canada classifications to HazCAN occupancy codes.

Census Canada Classification (Estimated Range of Number of Units)		Hazus Occupancy Code (Number of Units)	Average Number of Units per Building Class	Conversion from Census units to Hazus Buildings
Single-detached house (1)	100%	RES1 (1)	1	Units / 1
Other single attached (1)	100%			
Movable dwelling (1)	100%	RES2 (1)	1	Units / 1
Semi-detached house (2)	100%	RES3A (2)	2	Units / 2
Apartment, duplex (2)	100%			
Rowhouse (3~10)	30%	RES3B (3-4)	3.5	Units / 3.5
	70%	RES3C (5-9)	7	Units / 7

Source: HazUS-MH 2.1 Canada User and Technical Manual Earthquake Module (Ulmi et al., 2014)

Table 6: Occupancy Class square footages used in HazCAN for the 1944 Cornwall earthquake study.

Occupancy Class	Description	Average Square Footage per Unit
RES1	Single Family Dwelling	2000
RES2	Manufactured Housing	1000
RES3A	Multi Family Dwelling – Duplex	1500
RES3B	Multi Family Dwelling – Triplex/Quads	1200
RES3C	Multi Family Dwelling – 5-9 units	900

Source: HazUS-MH 2.1 Canada User and Technical Manual Earthquake Module (Ulmi et al., 2014).

Table 7: Building distribution by HazCAN occupancy types converted from Statistics Canada classification for the 1944 Cornwall earthquake study.

	Statistics Canada Classification				Building count by occupancy type					Unit count by occupancy type				
CT Code	Single	Semi-detached	Appartment	Row	RES1	RES2	RES3A	RES3B	RES3C	RES1	RES2	RES3A	RES3B	RES3C
1	1,877	57	50	6	1,877	0	53	1	1	1,877	0	107	2	4
2	78	11	11	0	78	0	11	0	0	78	0	22	0	0
3	622	87	87	3	622	0	87	0	0	622	0	174	1	2
4	4,292	1,020	1,147	117	4,292	0	1,084	10	12	4,292	0	2,167	35	82
5	1,973	106	117	6	1,973	0	111	1	1	1,973	0	223	2	4
6	1,836	91	100	5	1,836	0	96	0	1	1,836	0	191	2	4
7	1,139	171	175	8	1,139	0	173	1	1	1,139	0	346	2	5
8	2,153	99	108	13	2,153	0	104	1	1	2,153	0	207	4	9

Note. Data for dwellings under Statistics Canada classification compiled from Statistics Canada 1941 census volume 5 table 4 (Government of Canada, 1941).

Table 8: Building vulnerability parameters including square footage, building exposure, and content exposure in dollar values for the 1944 Cornwall earthquake study.

	Square footage (thous. sqft)					Building exposure (thous.$)					Content exposure (thous.$)				
CT Code	RES1	RES2	RES3A	RES3B	RES3C	RES1	RES2	RES3A	RES3B	RES3C	RES1	RES2	RES3A	RES3B	RES3C
1	3,754	0	160	2	4	28,003	0	1,064	14	25	14,001	0	532	7	12
2	156	0	33	0	0	1,164	0	218	1	1	582	0	109	0	1
3	1,243	0	261	1	2	9,273	0	1,733	6	11	4,637	0	866	3	6
4	8,584	0	3,251	42	74	64,037	0	21,555	280	490	32,019	0	10,778	140	245
5	3,946	0	334	2	4	29,440	0	2,217	14	25	14,720	0	1,109	7	13
6	3,671	0	287	2	3	27,386	0	1,900	12	21	13,693	0	950	6	10
7	2,278	0	520	3	5	16,994	0	3,445	18	32	8,497	0	1,723	9	16
8	4,307	0	311	5	8	32,127	0	2,059	31	55	16,063	0	1,029	16	27

Furthermore, construction types and design code level are also important aspects to consider for building vulnerability. In 1941 census Volume 9 Table 2 (Government of Canada, 1941), principal exterior material usage percentage can be found for Ontario province (Table 9). In order to obtain the HazCAN construction building type from the principal exterior material, some assumptions are made because the survey was done on the provincial level of statistics and there was no detailed description about the construction materials. In total, 4 construction types are assumed in HazCAN: (1) W1, (2) URML, (3) S3 and (4) S5L, where W1 includes structures with wood and stucco exterior material, URML includes structures with brick and stone exterior material, S3 and S5L each represents 50% of the structures in the "other type of exterior material" category. According to the modeling building type definition in Hazus-MH User's Manual (FEMA, 2003b), W1 represents wood and light frame structural building with area less than 5,000 square ft; URML represents low-rise structural building with unreinforced masonry bearing walls; S3 represents steel light frame building; S5L represents low-rise structural building with steel frame and unreinforced masonry infill walls. The assumption of the steel structure type has limited impact considering the low number of buildings in these categories. With above assumptions, a distribution by construction type for the different census tracts is calculated combining the information given in Table 9 for rural and urban locations as well as by population groups. This distribution is presented in Figure 5.

Table 9: Ontario building exterior material usage percentage by land types and population groups from 1941 census of Canada (Government of Canada, 1941).

Ontario	Rural	Urban	Population groups				
Exterior Material (%)	Average	Average	<1000	1000-4999	5000-14999	15000-29999	>30000
Brick	28.6	59.2	30.1	32.0	50.2	44.4	73.6
Wood	57.7	27.6	56.6	51.9	33.4	39.1	15.4
Stucco	5.1	8.5	5.0	8.7	10.8	9.1	8.0
Stone	2.9	1.3	1.7	1.9	1.7	2.4	0.8
Other	5.9	3.4	6.6	5.5	3.9	5.0	2.2

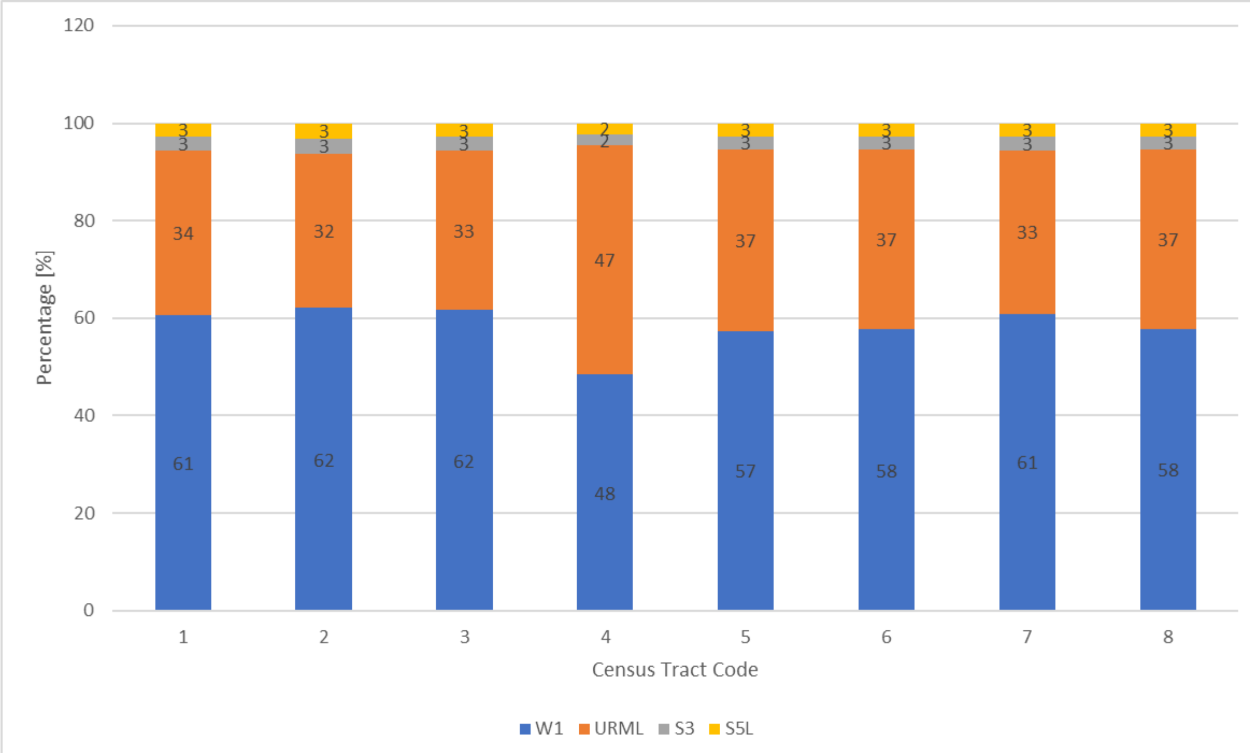


Figure 5: Distribution of building by construction type calculated for each census tract for the 1944 Cornwall earthquake study.

The type of a building is a function of its construction year, number of storey and occupancy type (Roquet, 1998; Smith & Coull, 1991). HazCAN calculates building stock by construction types based on its distribution within each occupancy type (e.g. RES1, RES2). Due to lack of information, it is assumed that the percentage distribution developed in Figure 5 serves as the mapping scheme for all included occupancy types (RES1, RES2, RES3A/3B/3C). As an example, for CT#4 the new construction type distribution in RES1 is 48% in wood structures, 5% in steel structures and 47% in masonry structures. Compared to the default mapping scheme in 2006 which has 86% structures in wood and 14% in masonry, there is considerably more percentage of masonry structures in RES1. According to a study on Montreal building construction type by Yu et al. (2016), a number of buildings constructed before 1940s' with wood frame structures behave like unreinforced masonry structures due to sharing walls with adjacent buildings, and the wood frame construction started to get popular starting in the 1940s, when the structural type distribution shows a significant change. Assuming that the construction techniques in Cornwall are similar to the Montreal area, therefore, an increase of 33% of masonry structures in RES1 for the 1944 Cornwall earthquake is reasonable and the assumption of using Figure 4 as the mapping scheme for this study is justifiable.

Figures 6 and 7 display the building distribution by occupancy and construction types, respectively, for the census tracts in the study region. Some observations can be made from these two distributions: 1) RES1 takes up the majority percentage in all CTs; 2) CT#4 has noticeably higher RES3 type of building than other CTs; 3) CT#4 has considerably higher percentage of unreinforced masonry structures than other CTs. This distribution is reasonable considering that CT#4 is mainly the region of Cornwall City, resulting in more variety of occupancy types and older construction types.

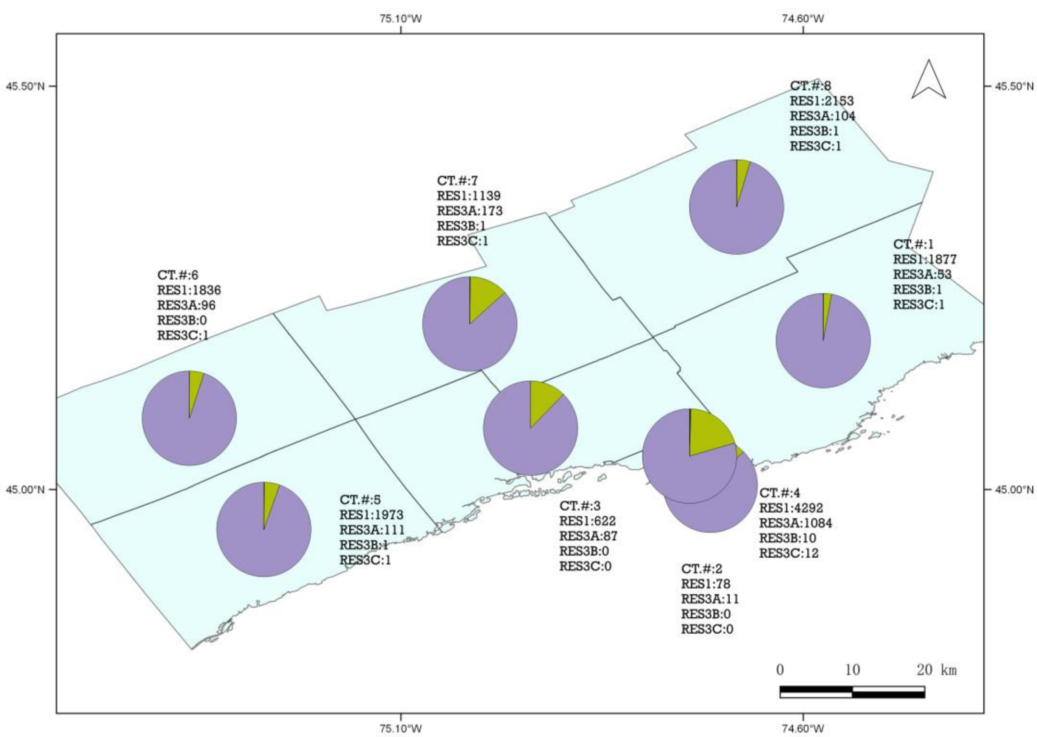


Figure 6: Building distribution by occupancy types for the 1944 Cornwall earthquake study.

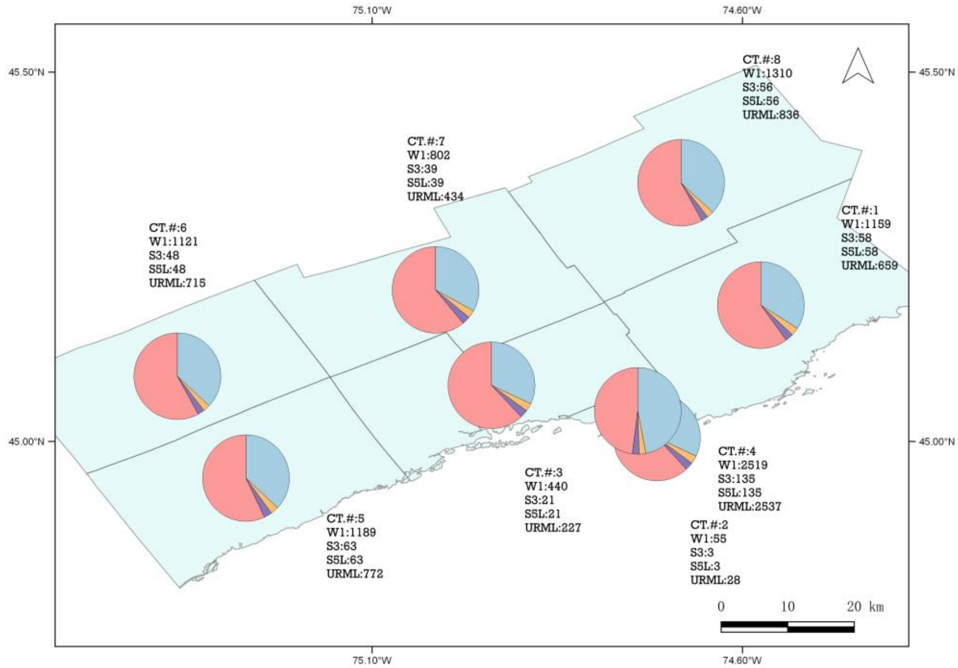


Figure 7: Building distribution by construction types for the 1944 Cornwall earthquake study.

Occupancy mapping in HazCAN does not isolate age of the building as a variable; instead, the overall design level (High, Moderate, Low, and re-code) is considered when assigning a mapping scheme. The choice of design levels is directly related to the selection of capacity and fragility curves used to calculate the building damage. Older areas of construction, not conforming to modern standards, should be modeled using a lower level of seismic design. For the assignment of building design levels, it is suggested in the HazUS-MH 2.1 Canada User and Technical Manual Earthquake Module (Ulmi et al., 2014) that when the actual seismic design level to which a building had been constructed is not known, the seismic design level could be assigned for the building based on year of construction and building type. Following the guidelines indicated in Table 10, Pre-Code design level is assigned to all building types for the 1944 Cornwall earthquake study. Pre-Code refers to buildings that are not seismically designed according to the technical manual. This assignment is also supported by a study on the evolution of seismic design provisions for

Canada (Mitchell et al., 2010) where it demonstrated that the first National Building Code (NBC) containing seismic design provisions was published in 1941.

Table 10: Guidelines for selection of seismic design levels for typical buildings based on year of construction and building type.

	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)

Source: Hazus-MH 2.1 Canada User and Technical Manual Earthquake Module (Ulmi et al., 2014).

2.1.4 Potential Earth Science Hazard (PESH)

The estimate of the seismic hazard is a primary step for any seismic risk analysis. The earthquake-related hazards considered by HazCAN in evaluating casualties, damages and resultant losses are collectively referred to as potential earth science hazards (PESH). It analyses two main categories of hazards in terms of intensity and distribution: ground motion, and ground failure (e.g., liquefaction, landslide and surface fault rupture). The ground failure hazards are not considered in this calibration study.

Ground motion is defined by several parameters: 1) spectral acceleration at 0.3 and 1s period (Sa0.3 and Sa1.0 respectively), 2) peak ground acceleration (PGA) and 3) peak ground velocity (PGV). The spatial distribution of ground motion for the 1944 event is determined using the deterministic approach, where the ground motion demands are calculated for the specified earthquake source (Table 11).

Table 11: 1944 Cornwall earthquake source parameters.

Date	Longitude (°W)	Latitude (°N)	Depth (km)	Magnitude (Mw)
	-74.72	44.96	20	5.8

Four attenuation functions are tested which are calibrated for Eastern USA and are supplied by HazCAN (Table 12). Two of them (noted CEUS, for Central and Eastern US) are a weighted combination of several ground motion prediction equations (see Hazus manual for more details).

Table 12: List of attenuation relations tested for ground motion estimation.

Attenuation Relationships	**ID**
Atkinson & Boore (2006)	AB06
Central & East US (CEUS 2008)	CEUS08
CEUS, Charleston 2008	CEUSC08
Tavakoli & Pezeshk (2005)	TP05

Moreover, in addition to the earthquake source characteristics and the attenuation functions, soil characteristics also play an important role in predicting ground shaking and ground failure of a site. One of the most important soil characters is its shear-wave velocity Vs V_s. Due to energy conservation laws, the amplitude of the ground motion is negatively related to the shear wave velocity of the soil layer. The shear wave velocity is smaller in softer layers close to the surface, and the soil amplification is maximized when the seismic wave frequency equals to the fundamental soil frequency f_0. Equation 3 shows the relationship between the fundamental soil frequency f_0, the soil thickness H and the shear wave velocity Vs (Dobry et al., 1976).

$$\frac{1}{f_0} = \frac{4H}{V_s} f_0 = Vs / 4H \quad \text{(Eq.3)}$$

The equation indicates that the fundamental frequency decreases with increasing thickness of soil deposits and with decreasing shear wave velocities. Since earthquake frequencies of engineering interest are typically lower than 20 Hz (Rathje et al., 1998), thick and soft soil layers tend to amplify the ground motion to a greater extent. Therefore, site amplification due to soft deposits needs to be accounted for in the calculation of ground shaking at the site surface. HazCAN follows the National Earthquake Hazard Reduction Program (NEHRP) site classification scheme (FEMA, 2009) which uses the average shear-wave velocity of the top 30 meters of soil deposit (V_{s30}) to determine the site class (Table 13).

Table 13: Site classification scheme, from NEHRP (1997).

Site Class	Site Class Description	Shear Wave Velocity (m/sec) Minimum	Maximum
A	**HARD ROCK** Eastern United States sites only	1500	
B	**ROCK**	760	1500
C	**VERY DENSE SOIL AND SOFT ROCK** Untrained shear strength $u_s \geq 2000$ psf ($u_s \geq 100$ kPa) or $N \geq 50$ blows/ft	360	760
D	**STIFF SOILS** Stiff soil with undrained shear strength 1000 psf $\leq u_s \leq 2000$ psf (50 kPa $\leq u_s \leq$ 100 kPa) or $15 \leq N \leq 50$ blows/ft	180	360
E	**SOFT SOILS** Profile with more than 10 ft (3 m) of soft clay defined as soil with plasticity index PI > 20, moisture content *w* > 40% and undrained shear strength $u_s < 1000$ psf (50 kPa) (N < 15 blows/ft)		180
F	**SOILS REQUIRING SITE SPECIFIC EVALUATIONS** **1. Soils vulnerable to potential failure or collapse under seismic loading:** e.g. liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. **2. Peats and/or highly organic clays** (10 ft (3 m) or thicker layer) **3. Very high plasticity clays:** (25 ft (8 m) or thicker layer with plasticity index >75) **4. Very thick soft/medium stiff clays:** (120 ft (36 m) or thicker layer)		

The study performed by Nastev et al. (2016) on regional V_{s30} model for the St. Lawrence Lowlands, Eastern Canada produced a detailed site classification map covering most of the study regions (Figure 8). It is found from Figure 8 that the main site classification information in census tracts are site class B and C depending on the location of the population settlements (Figure 9). Since this study region in HazCAN has relatively low resolution in terms of geographical unit level, a conservative assignment of class C soil is assigned to all the census tracts that are covered by the site classification map. An estimate of the site class is needed for the CT#5 South Dundas census tract that has no site classification information. A surficial soil survey conducted by the Dominion Department of Agriculture, Ottawa in 1951 (Government of Canada, 2012) is used as shown in Figure 10. Although this map describes the soil condition for the first meter mainly for agricultural purpose, due to lack of detailed V_{s30} measurements, it is assumed to be used as rough indicators and estimates of the underlying soil characteristics. The map shows that soils with code: Ml, Mrl and Grs are major types of deposit to investigate. Ml and Grs are described as medium to heavy textured till soil material with stony surface, and Mrl represents heavy textured till with moderately stony surface as indicated in the legend in Figure 11. A representative value of V_{s30}=385m/s $V_s = 385\ (m/s)$for glacial and sub-glacial sediments (till) is suggested in the study by Nastev et al. (2016). Therefore, an estimate of a site class C is also assigned to the CT#5. This means that the 1944 Cornwall earthquake study region has a uniform site class C distribution and there is no need for supplying user-defined site map to HazCAN.

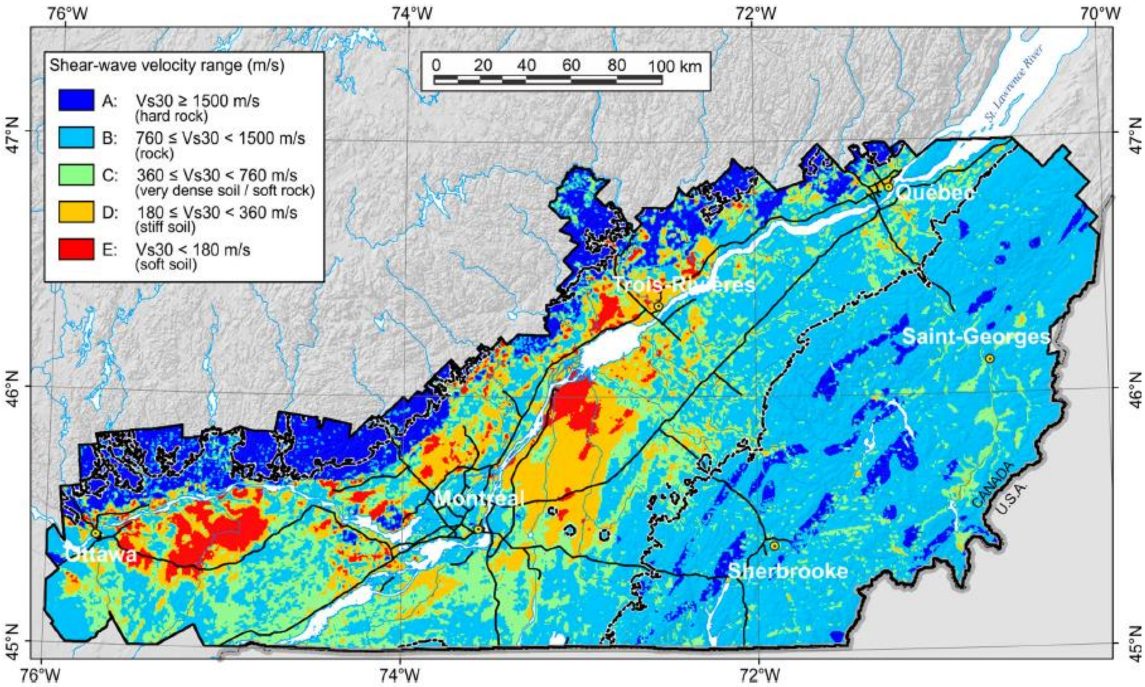


Figure 8: Site classification for seismic site response from the regional model developed by Nastev et al. (2016).

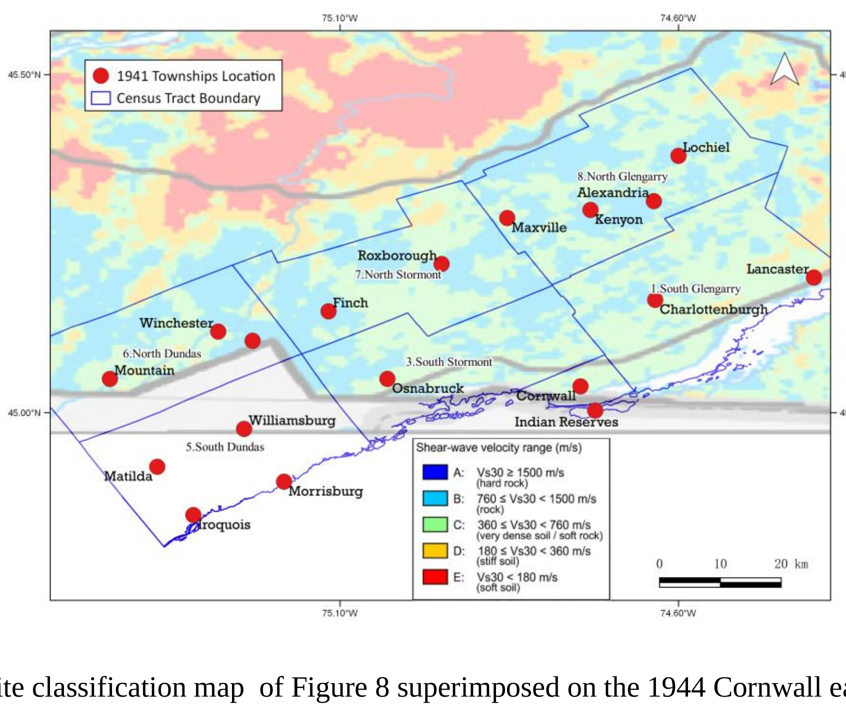


Figure 9: Site classification map of Figure 8 superimposed on the 1944 Cornwall earthquake study region.

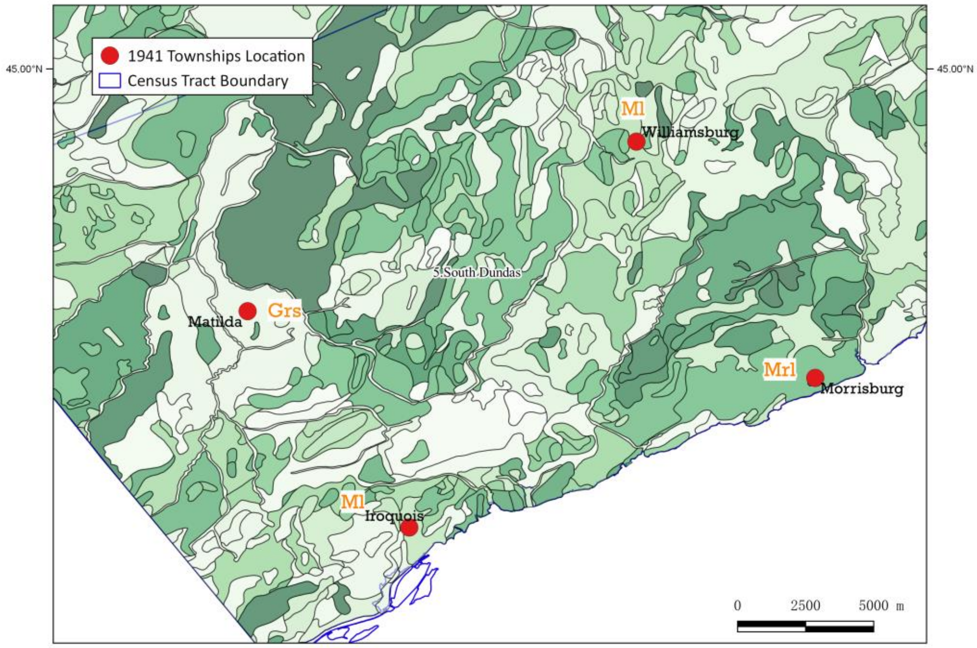


Figure 10: 1951 Soil survey map of Dundas County, Ontario (Government of Canada, 2012). The different gradient of green infills represent different types of soil deposits. Three soil deposit codes Grs, Ml & Mrl colored in orange are representative deposit types under major population settlements. Grs and Ml are medium textured till material and Mrl represents heavy textured till soil material.

SOIL MATERIALS	MEDIUM TEXTURED TILL			HEAVY TEXTURED TILL		
NATURAL DRAINAGE	Good	Imperfect	Poor	Good	Imperfect	Poor
SERIES	GRENVILLE	MATILDA	LYONS	WOLFORD	MORRISBURG	OSNABRUCK
TYPE, SYMBOL, ACREAGE	loam Gl 18,600 loam shallow phase Gl-s 2,000 loam bouldery Gl-b •500 sandy loam Grs 1,800	loam Ml 14,400	loam Ll 1,500	clay loam Wl 9,400	clay loam Mrl 30,900	clay loam Obcl 9,500
COLOUR						
TOPOGRAPHY	Undulating to rolling.	Gently undulating to slightly depressional.	Usually depressional.	Gently undulating to rolling.	Gently undulating to level.	Level to depressional.
SURFACE STONINESS	Moderately stony to bouldery.	Moderately stony.	Moderately stony.	Moderately stony; occasionally bouldery.	Moderately stony.	Moderately stony.
SURFACE REACTION	About neutral.	About neutral.	Neutral to slightly alkaline.	Neutral to slightly alkaline.	Alkaline.	Alkaline.
GREAT SOIL GROUP	Brown Forest.	Brown Forest.	Dark Grey Gleisolic.	Brown Forest.	Brown Forest.	Dark Grey Gleisolic.
PROFILE DESCRIPTION OF CULTIVATED SOIL	6 inches of dark brown loam underlain by reddish brown loam underlain by dark brown loam over greyish brown calcareous till.	6 inches of very dark brown loam underlain by greyish brown loam slightly mottled over greyish brown loam highly mottled underlain by greyish brown calcareous till.	6-8 inches of black loam underlain by greyish brown highly mottled calcareous till.	6 inches of greyish brown clay loam underlain by light brown clay loam over greyish brown clay loam till.	6 inches of very dark grey clay loam underlain by mottled greyish brown calcareous till; lower horizons poorly defined.	6-8 inches of very dark grey clay loam underlain by grey, hightly mottled, clay loam till.
MAIN FERTILITY NEEDS	ORGANIC MATTER PHOSPHORUS POTASH	Organic Matter PHOSPHORUS POTASH	Organic Matter PHOSPHORUS POTASH	Organic Matter PHOSPHORUS Potash	Organic Matter PHOSPHORUS Potash	PHOSPHORUS Potash

Figure 11: Legend from 1951 soil survey map of Dundas County, Ontario (Government of Canada, 2012).

2.2 Validation of the ground motion prediction equations

Before calculating the earthquake damage, observed and calculated ground motions are compared for the four attenuation functions. For the Cornwall earthquake, intensity is chosen as the parameter of comparison since there are no ground motion records at the time of the event. The observations of damage in terms of Modified Mercally Intensity (MMI) are used to draw the isoseismal map (Natural Resources Canada, 2019) which is superimposed onto the study region (Figure 12). Individual MMI values are determined from damage observation reports (Bruneau & Lamontagne, 1994; Hodgson, 1945) and added to the map of the Figure 12. These values confirm the intensity VII in the center of the city of Cornwall.

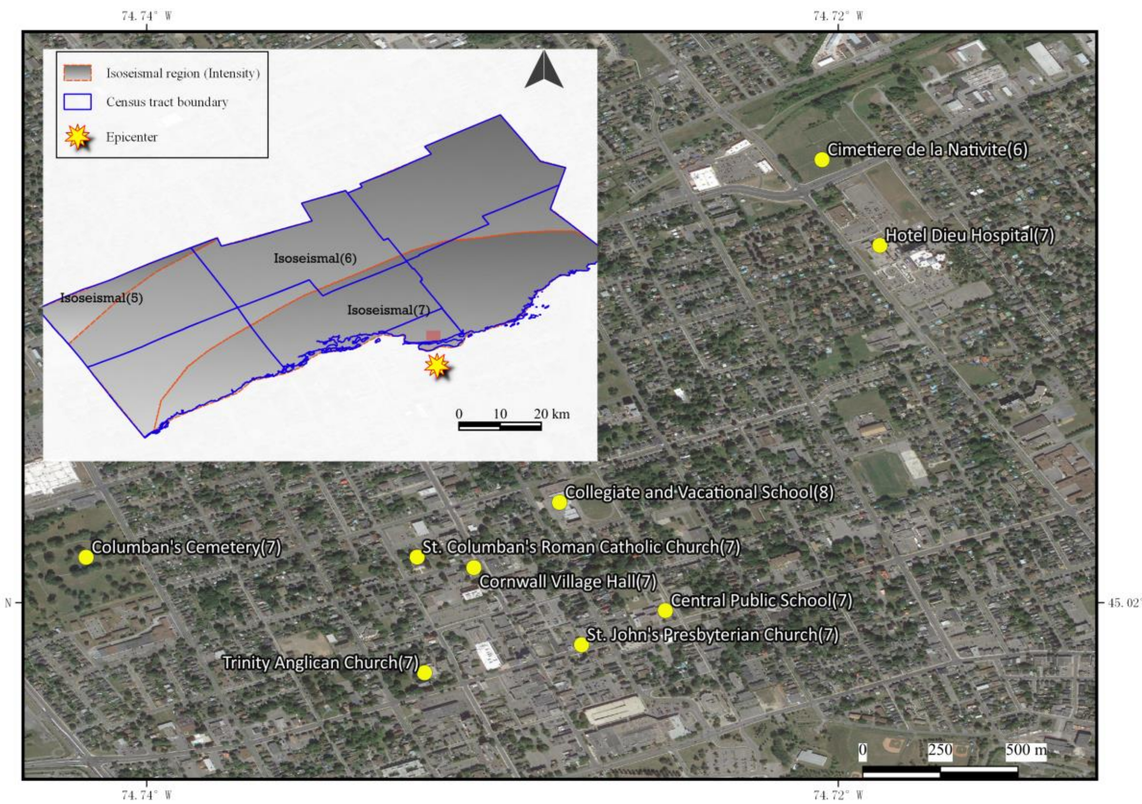


Figure 12: Intensity distribution (MMI) in the investigated area. Individual estimates of intensity from reports are localized in the inset map indicated by yellow dots with names and intensities into parentheses.

The ground motion parameters (Sa0.3, Sa1.0, PGA and PGV) calculated by HazCAN using 4 different attenuation relationships of Table 12 are shown in Table 14.

Table 14: Ground motion parameters calculated from AB06, CEUS08, CEUSC08 and TP05.

AB06	**CT#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Distance (km)	29.7	7.7	27.3	9.1	61	74	42.4	43.4
	Sa0.3(g)	0.466	1.873	0.519	1.873	0.187	0.157	0.296	0.288
	Sa1.0(g)	0.296	1.093	0.328	1.093	0.125	0.106	0.193	0.188
	PGA(g)	0.164	1.12	0.191	1.12	0.047	0.037	0.088	0.085
	PGV(in/s)	11.112	40.997	12.293	40.997	4.691	3.978	7.255	7.056
CEUS08	**CT#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Distance (km)	29.7	7.7	27.3	9.1	61	74	42.4	43.4
	Sa0.3(g)	0.198	0.785	0.22	0.766	0.088	0.073	0.137	0.133
	Sa1.0(g)	0.097	0.354	0.107	0.349	0.043	0.037	0.066	0.064
	PGA(g)	0.115	0.637	0.131	0.612	0.044	0.034	0.077	0.074
	PGV(in/s)	3.628	13.282	4.004	13.103	1.621	1.378	2.478	2.414
CEUSC08	**CT#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Distance (km)	29.7	7.7	27.3	9.1	61	74	42.4	43.4
	Sa0.3(g)	0.174	0.66	0.192	0.643	0.078	0.063	0.121	0.117
	Sa1.0(g)	0.08	0.29	0.089	0.285	0.036	0.03	0.055	0.054
	PGA(g)	0.103	0.533	0.116	0.512	0.041	0.031	0.069	0.067
	PGV(in/s)	3.013	10.862	3.321	10.706	1.348	1.14	2.065	2.012
TP05	**CT#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Distance (km)	29.7	7.7	27.3	9.1	61	74	42.4	43.4
	Sa0.3(g)	0.109	0.551	0.133	0.487	0.069	0.057	0.097	0.095
	Sa1.0(g)	0.048	0.142	0.051	0.129	0.019	0.016	0.024	0.024
	PGA(g)	0.156	0.777	0.183	0.671	0.061	0.046	0.1	0.097
	PGV(in/s)	1.45	5.343	1.504	4.834	0.697	0.599	0.909	0.895

The calculated parameter values are then converted to intensity values in order to be compared with the reported intensity values. For that purpose, the two conversion equations of Wald et al. (1999) for PGA and PGV for earthquakes with intensity greater than V are used:

$$I_{mm} = 3.66 \log (PGA) - 1.66 \qquad (\sigma = 1.08) \qquad (Eq. 4)$$

$$I_{mm} = 3.47 \log (PGV) + 2.35 \qquad (\sigma = 0.98) \qquad (Eq. 5)$$

The two equations are used for each of the attenuation relationships and the average intensity is calculated, as well as the standard deviation. Figure 13 shows the aggregated curves of the intensity versus distance to the epicenter for all the tested attenuation relationships. It can be found that AB06 produces the highest ground motion estimation, and TP05 produces the lowest among the four. CEUS08 and CEUSC08 yields very similar results with CEUS08 estimating slightly higher.

For the observed intensities, the isoseismal regions in Figure 12 are used to determine the approximate intensity values. As HazCAN computes ground motion demand at the centroid of a census tract (FEMA, 2003a), the observed intensity at the same location is considered for each census tract. Intensity observations are shown in Figure 13 by crosses. Among the four predictions, AB06 performs the best in predicting locations further than 30-km from the epicenter, whereas the other three attenuation relationships tend to underestimate the intensity within this range. However, for areas that are very close to the epicenter (< 10 km), all attenuation relationships overestimate the intensities by a minimum of 8% (TP05) to a maximum of 35% (AB06) the observed intensity.

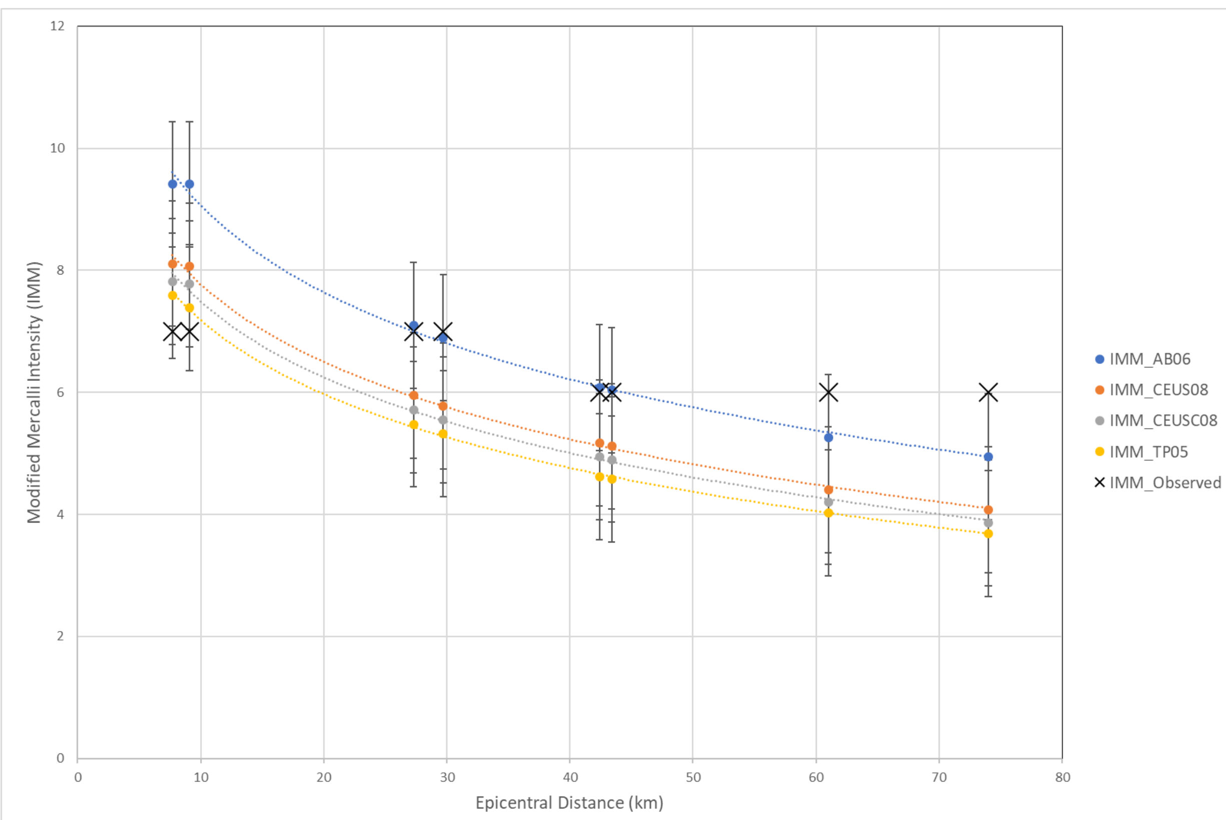


Figure 13: Comparison of calculated and observed Intensities. Observed intensity values in the 8 census tracts are indicated by crosses. Standard deviations of intensity converted from PGA/PGV estimates using the 4 GMPEs are indicated by vertical bars.

The PGA calculated from AB06 is 1.12g for census tract #2 and #4. It is about 4 times the estimated value (0.374g) specified in the 2015 National Building Code of Canada (NBCC) for a 2%/50 years probability. The checking of PGA values verifies that for this earthquake study AB06 appears to overestimate the ground motion parameters by a significant amount (35% at intensity scale and 224% at PGA scale) at short epicentral distance (<10 km). Considering that CT#4 with epicentral distance of 9.1 km are the zones with the majority of building stock and have documented damage and loss observations for comparison, the TP05 attenuation relationship will be selected for the damage and loss calculation in the next chapter as it produces the closest estimation to the observed ground motion.

2.3 Damage and loss calculation

In this section, HazCAN damage and loss estimations for the 1944 earthquake event are generated and used to compare with the observation records.

A limited amount of damage and loss date are available due to the old time of the event and most of the reports are general and descriptive in nature. The recorded damage was not specific to building construction type or damage state. The main observations reported by Hodgson, E.A (1945) and Nottis, G.N (1996) are stated below:

(i) There were around 3081 buildings in the Cornwall municipality with an estimate of an average of $200 damage to each.

(ii) The estimate of the total property damage in the Massena and Cornwall area was between $1.75 and $2.0 million in 1944 dollars; the total rough estimates for Cornwall alone was between $0.75 and $1.0 million with the maximum for putting things back into the same condition as before the earthquake and the minimum for the money that would actually be spent in recovering the damage.

(iii) Residential building damage was primarily non-structural. Around 3000 chimneys in Cornwall lost bricks, collapsed down to roof lines, or peeled away from homes, of which 2000 were badly damaged and need to be repair. At least 1 two-family residence in Cornwall had to be demolished. Most of residences suffered from damage to interior ceiling and wall plaster.

(iv) Several minor injuries were reported. However, none of those injuries were treated at the Cornwall or Massena hospitals.

All these observations describe only the damage that occurred in the Cornwall municipality (CT#4). There are a lack of reports for other regions. Therefore, HazCAN damage and loss estimations for CT#4 are analyzed and compared with the observed values. From the ground motion validation results in the previous section, all attenuation functions used overpredict the ground motion by different factors for the CT#4 with epicentral distance around 10 km. Among these, TP05 has the closest agreement with observations. As a result, it is reasonable to begin with the analysis using TP05 alone instead of an average of all attenuation functions for this specific census tract.

The following types of damage and losses are used for comparing estimated and observed earthquake consequences:

1) Direct damage – total number of damaged buildings by damage state;
2) Economic loss – direct economic losses to residential buildings;
3) Social loss – number of casualties at night time 2 a.m.

The choice of these parameters as the "metrics" for comparison of damage and loss values is influenced largely by the quality and availability (or lack thereof) of observed data. Observations (i) to (iv) are used to generate statistical data to be compared with the calculated losses. The total number of damaged buildings 3081 (category i) and at least 1 residence had to be demolished which would correspond to the complete damage state (category iii) are used. For the direct economic losses to buildings, an upper bound estimate of $1.0 million is considered since the replacement cost is remarkably higher than the actual loss in cash value, which is the lower estimate ($0.6~$0.75 million). Observation (iv) corresponds to casualty severity level 1 defined by injuries requiring basic medical aid without requiring hospitalization (FEMA, 2003b); a value of 10 is assumed. Observation (v) cannot be compared with or reflected by the HazCAN results for this study theoretically, because it describes the damage distribution related to soil amplification inside Cornwall city (CT#4), the smallest geographical unit to which a single soil class C was assigned. Table 15 summarizes the HazCAN calculation results for the selected parameters and corresponding observations. Figure 14 shows specifically the number of damaged buildings by damage state and construction type, as well as the construction type percentage within the damage state. Results for other census tracts are included in Appendix A for reference.

Table 15: Comparison of damage and losses estimated using TP05 attenuation function with observations for the 1944 Cornwall earthquake for CT#4.

	HazCAN-TP05 Results for CT#4											**Observations**
	(1) Building Damage											
	None		**Slight**		**Moderate**		**Extensive**		**Complete**		**Total**	
	Count	*(%)*	*Count*	*(%)*	*Count*	*(%)*	*Count*	*(%)*	*Count*	*(%)*	**damaged**	*Around 3081 buildings damaged; At least 1 complete damaged;*
W1	1,505	54.9	717	52.5	323	34.9	42	14.4	4	5.6	1,086	
S3	54	2.0	24	1.8	37	4.0	19	6.5	1	1.4	81	
S5L	72	2.6	31	2.3	24	2.6	7	2.4	0	0.0	62	
URML	1,112	40.5	593	43.4	542	58.5	224	76.7	66	93.0	1,425	
Total	2,743		1,365		926		292		71		2,654	

	(2) Direct Economic Losses to Buildings (dollars in thousands)			
	Structural Damage	**Non-Structural Damage**	**Total building damage**	*Primarily non-structure in nature; Total property loss $1 million*
	$241.6	$2,202.8	$2,444.4	

	(3) Casualty Estimates @ 2 a.m.					
	Severity 1	**Severity 2**	**Severity 3**	**Severity 4**	**Total casualties**	
Wood	15	2	0	0		*Several Severity 1 injuries (assume 10)*
Steel	1	0	0	0		
Masonry	44	10	1	3		
Total	60	12	1	3	76	

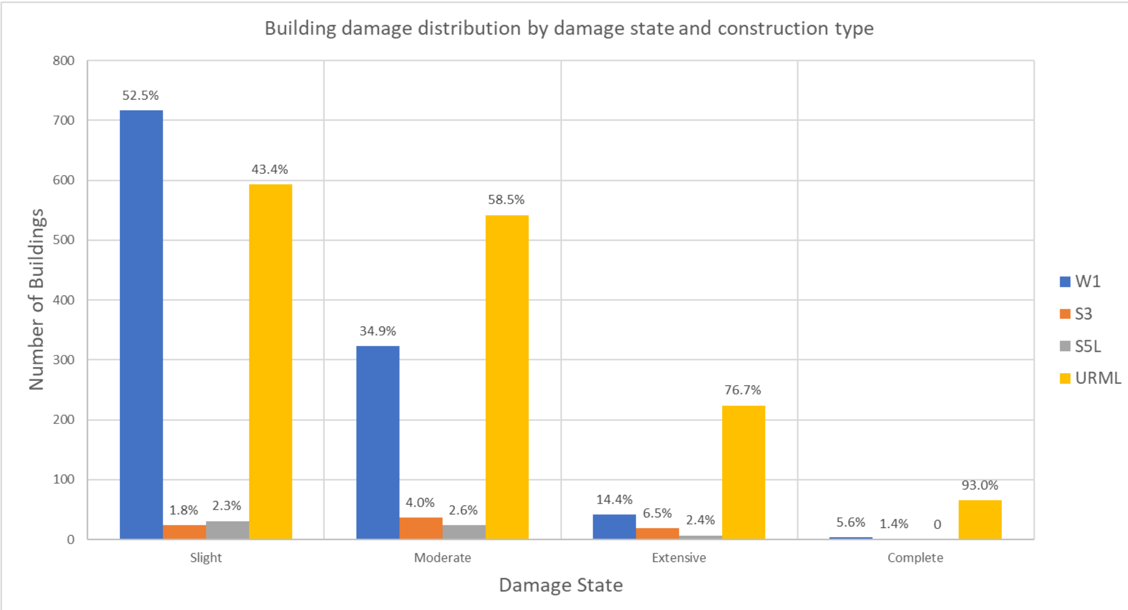


Figure 14: Distribution of damaged buildings by damage state and construction type for CT#4 in the 1944 Cornwall earthquake study. The percentage by construction type is given at the top of the columns.

2.4 Discussion

For direct damage, HazCAN estimates that around 2654 buildings in total were damaged in CT#4 during the earthquake. This estimation is lower than the observation, which is 3081, by a factor of 13.9%. This difference of 427 buildings is reasonable because the observed damage includes other occupancy types than residential (commercial, education, industrial, etc.). It was not possible to distinguish the different occupancy types in the damage reports.

The percentage of damage for unreinforced masonry buildings (URML) increases with the damage state (Figure 14). This result shows that the fragility curves used for unreinforced masonry structures perform poorly which is relevant with the observation of (Lefebvre, 2004) for this type of building in Quebec city.

The percentages of damage for steel light frame structures (S3 and S5L) are higher for moderate and extensive damage states than for slight and complete damage state. This is a specificity of the HazCan fragility curves for these types.

Although the estimate of total number of damaged buildings is close to the observation, the numbers for complete state damage differ. HazCan estimates 71 collapsed buildings, mainly URML type, whereas only 1 (or few more) needed to be demolished after the earthquake according to the reports. This implies a potential shift of damage building distribution towards the complete end. The shift of damage state could also be related to the cumulative probability distribution in the fragility curves for a given structure type (steepness of a fragility curve). Further investigation needs to be done to account for this result.

The total calculated building damage loss is $2,444.4 thousands , around $241.6 thousands for structural damage and $2,202.8 thousands from non-structural damage. The reported value is estimated around $1,000 thousands, mainly non-structural damage, which is 2.2 time less than the calculation. The overestimation by HazCan is related to the high number of URML extended and complete damaged buildings. .

The Cornwall earthquake occurred at 12:38 a.m. Eastern time, therefore causality estimates at 2 a.m. is used for social loss comparison. The estimation for total casualties is 76, out of which 60 casualties are in Severity level 1. This is a significant over-estimation compared to the reported number and level of injuries, approximately less than 10 people. It could be partly due to an incomplete survey, when some minor injuries were not reported by people and more particularly, this is also related to the over-prediction of collapsed buildings mentioned above. As previously discussed, the TP05 attenuation function is used in this analysis since all other attenuation functions produce even higher ground motion estimation than observations. However, it should not be ignored that the TP05 still over predicts by a factor of 8% (intensity scale) at the step of calculating ground motion parameters when comparing the final damage and losses.

The overall over-estimation of HazCAN for this study is resulted from several aspects:

1) assumptions made for categorizing building construction types from census data could affect the accuracy and quality of the inventory, since it is based on the percentage of total building numbers instead of a function related to construction type, number of storey and occupancy type
2) it could bring notable uncertainties when census data is not collected in the same geographical unit as in HazCAN where proportional calculation was performed to obtain the demographics and building information
3) although the TP05 attenuation relationship used for comparison produces the closest ground motion estimation, it still over estimates the intensity by 8%, thus the calculated damage and loss is on the conservative side for the investigated area (epicentral distance<10 km)
4) possible difference in damage functions (capacity and fragility curves) between local structures and the HazCAN models.

Chapter 3. 1988 Saguenay earthquake comparative analysis

3.0 Earthquake parameters

The 1988 Saguenay earthquake, of magnitude M_w=5.9, occurred on November 25 at 6:46:04 pm Eastern time. The main shock hypocenter is at 28-km depth, which is deeper than 95% of all other earthquakes recorded in eastern Canada (Lamontage et al., 1990). The epicenter is located on the southern shore of the Saguenay River about 35 km south of Chicoutimi, Quebec (Figure 15). This location is in a relatively aseismic region about 75 km north of the outer boundary of the Charlevoix-Kamouraska seismic zone.

3.1 Data collection and processing

3.1.1 Study region and division in census tracts

The maximum Modified Mercalli intensity (MMI) is around VII to VIII in the Chicoutimi-Jonquiere-La Baie area, and was felt strongly by most people within a 500 km radius around the epicenter (Cajka and Drysdale, 1996). A circular zone with a radius of 200km around the epicenter is selected in order to compare the calculated building damage and loss with the statistics provided by Paultre et al. (1993). The census subdivisions within the study region are shown in Figure 15. They follow the census tracts according to the 2006 Census Canada geographical boundaries. Twenty census subdivisions are selected to cover the investigated area corresponding to 411 census tracts. The list of census subdivisions for the region is provided in Appendix B. Few census tracts on the north side of the Saguenay River are not included as they are unpopulated areas.

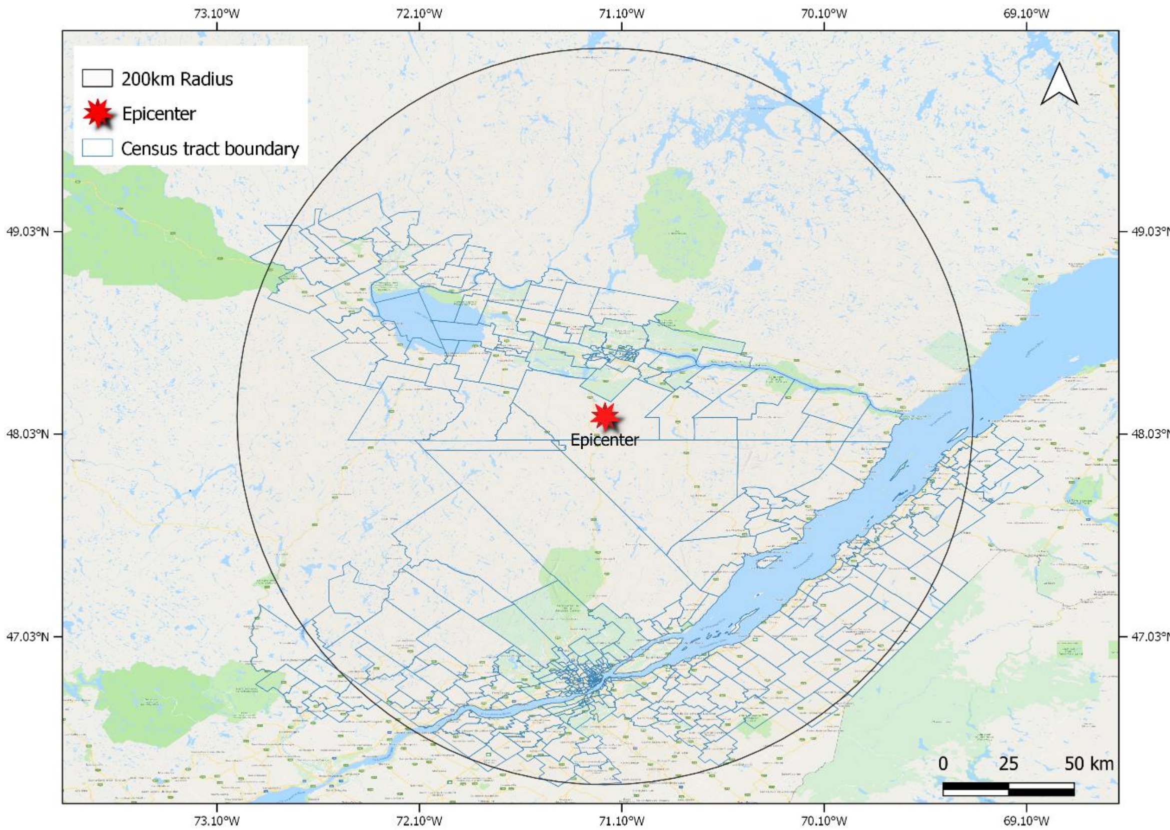


Figure 15: 1988 Saguenay earthquake study region. Limits of the census tract are shown in light blue within the circular zone of 200km radius around the epicenter (red star)

3.1.2 Population and building inventories

HazCAN uses occupancy mapping schemes to describe the aggregated building stock by occupancy and construction types. Building construction type inventory is derived from an occupancy mapping scheme, which mean that the primary data used is the distribution of buildings into occupancy types. The default occupancy mapping schemes in HazCAN are adapted for each province or territory from a comparable neighboring US state as indicated in the Hazus-MH 2.1 user and technical manual (FEMA, 2003a, 2003b). Massachusetts is the state used for occupancy mapping scheme proxy for Quebec province as shown in Table 16.

Table 16: Quebec default occupancy mapping scheme for selected occupancy types in HazCAN.

Occupancy	Wood (%)	Concrete (%)	Steel (%)	Masonry (%)	Manufacture Housing (%)
RES1	99	0	0	1	0
RES2	0	0	0	0	100
RES3A	62	4	3	31	0
RES3B	62	4	3	31	0
RES3C	62	4	3	31	0
RES3D	62	4	3	31	0

For the 1988 Saguenay earthquake, the most accurate data describing population and building inventory should come from the 1986 Canada census; however, as there are large discrepancies between the geographical division of census units in 1986 and 2006: expansion of the census subdivision and addition of the census tract, it is impracticable to update the database according to the 1986 census. Thus, the building inventory by occupancy type and demographics data for the Saguenay earthquake analysis are obtained by adjusting the information from the 2006 database.

The number of units built before the date of the earthquake is approximated by subtracting the number of units built from 1990 to 1998 and the number of units built after 1998 from the 2006 statistic. The histogram of the Figure 16 shows the variations in the number of units by periods of construction.

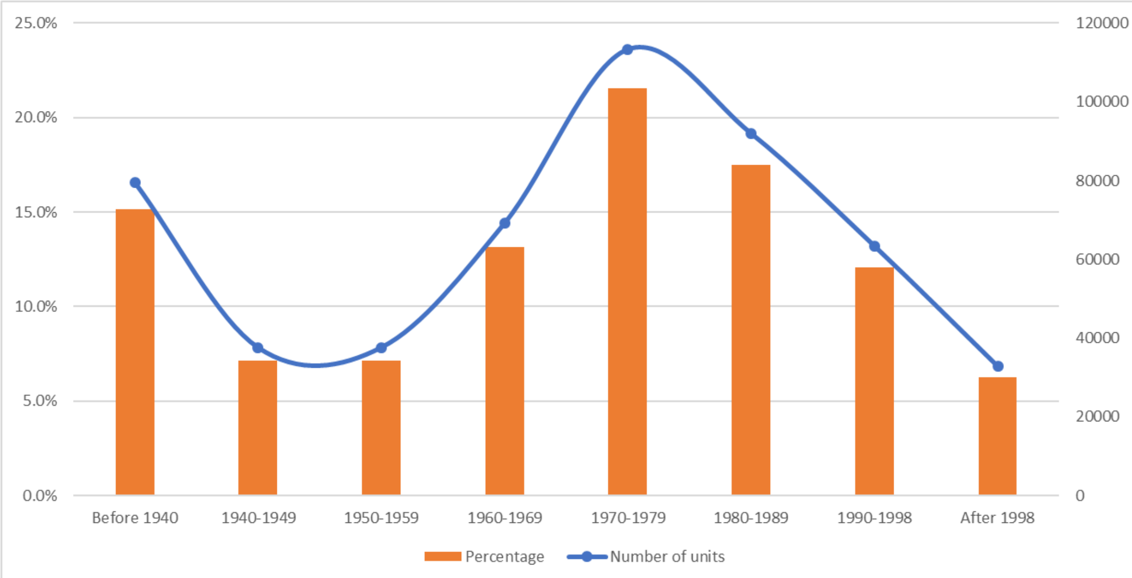


Figure 16: Distribution of units by periods of construction as in the 2006 census. Orange bars are the percentage of the total units and blue dots the numbers.

The rest of the demographics data such as population, total in residential property during day and night, number of households can then be calculated by multiplying the ratio of the number of units built before the date of the earthquake to the total number of units in the 2006. The number of buildings by occupancy type is obtained by calculating the ratio of the number of units in each occupancy type to the total number of units in 2006. An adjusted number of units is then obtained by multiplying the occupancy type ratio with the total change in units count and then subtracting the total change in units count calculated from each occupancy type in 2006. The study concerns residential buildings and among them RES3E and RES3F are excluded from the updated inventory because these two occupancy codes represent mainly apartments and buildings that have five or more storeys. Considering that these two types of residence are of very low percentage, it is assumed that all residential buildings in this analysis are low rise with less than five storeys. Lastly a conversion from unit counts to building counts is done following the conversion rules given in Table 4. The 1988 adjusted population and an aggregated number of buildings for Quebec City subdivision and Saguenay City subdivision are displayed in Figure 17. A comparison between the

2006 and the adjusted number of buildings in each occupancy type for these two subdivisions can be found in Figure 18. A complete list for all the census tract is provided in Appendix B.

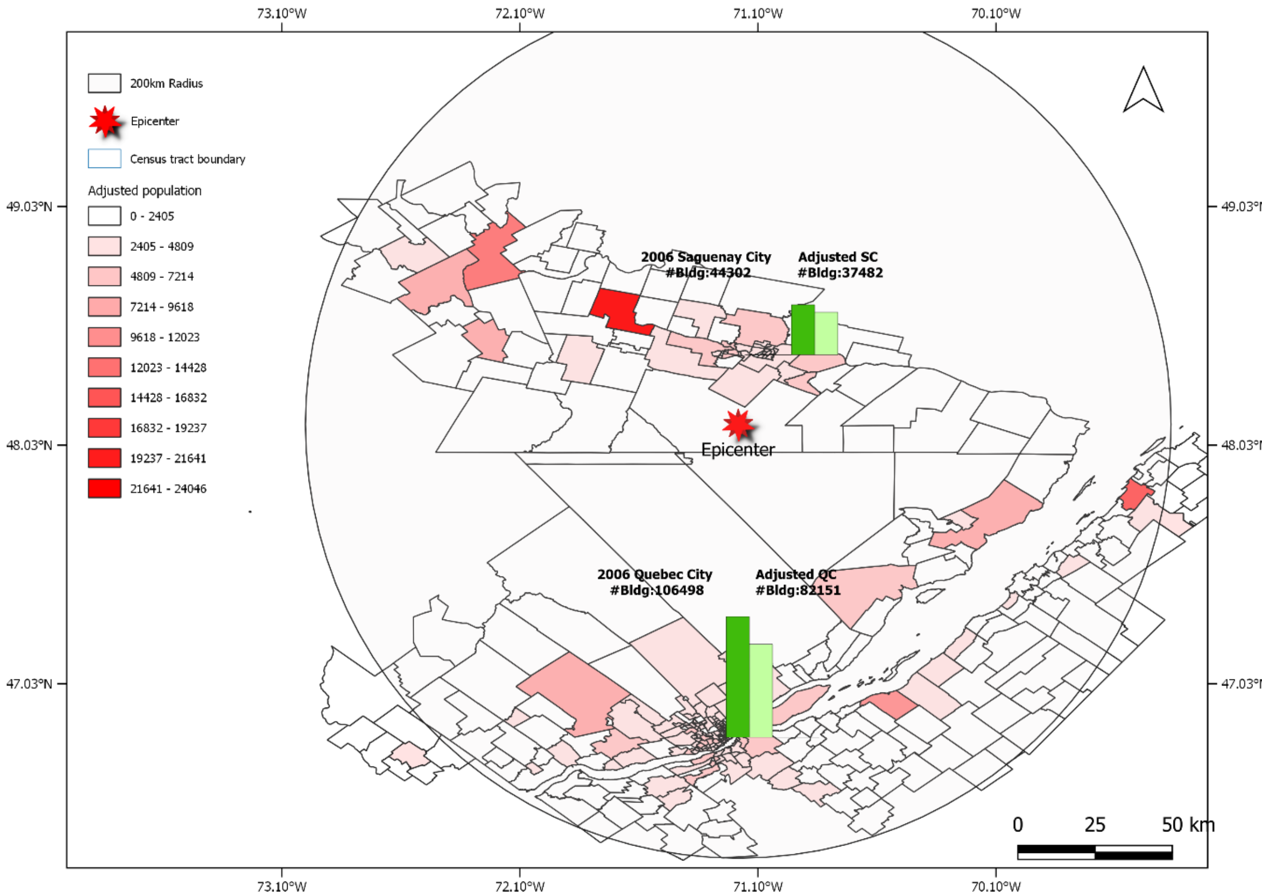
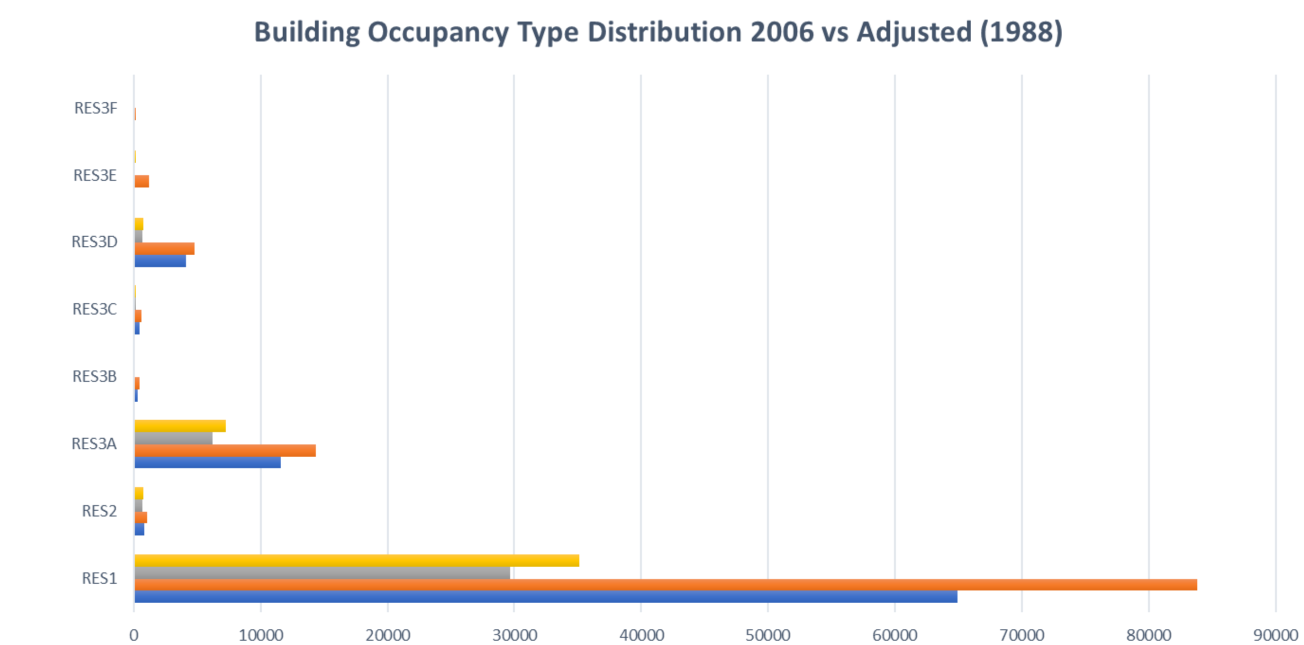


Figure 17: Population distribution by census tract adjusted for 1988. Green bars give the total number of buildings for Quebec City and Saguenay City regions in 2006 census and the adjusted number for 1988.



	RES1	RES2	RES3A	RES3B	RES3C	RES3D	RES3E	RES3F
2006 SC	35145	740	7221	110	168	751	158	9
Adjusted SC	29700	652	6232	99	149	650		
2006 QC	83805	1065	14372	441	604	4822	1222	167
Adjusted QC	64903	795	11585	321	445	4102		

Figure 18: Comparison of the distribution of building occupancy types for 2006 census and adjusted values in 1988. Cases of the Saguenay City subdivision (SC) and Quebec City subdivision (QC) .

Furthermore, other building inventory information including square footage, building exposure in dollar value, content exposure in dollar value are computed similarly and updated according to the procedures described in Section 2.1.3. A national inflation rate of 53.1% (Bank of Canada) for the period between year 1988 and 2006 is used to reduce the dollar value when computing monetary related parameters.

3.1.3 Potential Earth Science Hazard (PESH)

The source parameters used for the 1988 Saguenay earthquake analysis are listed in Table 17. Two GMPEs are tested for this study, namely AB06 and CEUS08, as they provide better ground motion estimation for a wider epicentral distance range (>30-km) from previous study.

Table 17: Source parameters of the 1988 Saguenay earthquake.

Date	Longitude (°W)	Latitude (°N)	Depth (km)	Magnitude (Mw)
	-71.18	48.12	28	5.9

Foulon et al. (2017) and Leboeuf et al. (2013) have developed site microzonation maps for the Saguenay and Quebe City areas using the V_{s30} parameter (left maps of Figure 19). The V_{s30} data are used to generate site maps at the scale of the census tracts in HazCAN. Since the resolution of the site microzonation maps and the census tracts in HazCAN is different, the urbanized areas within the census tracts have been identified using satellite images to assign the main soil type. The resulting soil maps for these regions are displayed on the right side in Figure 19.

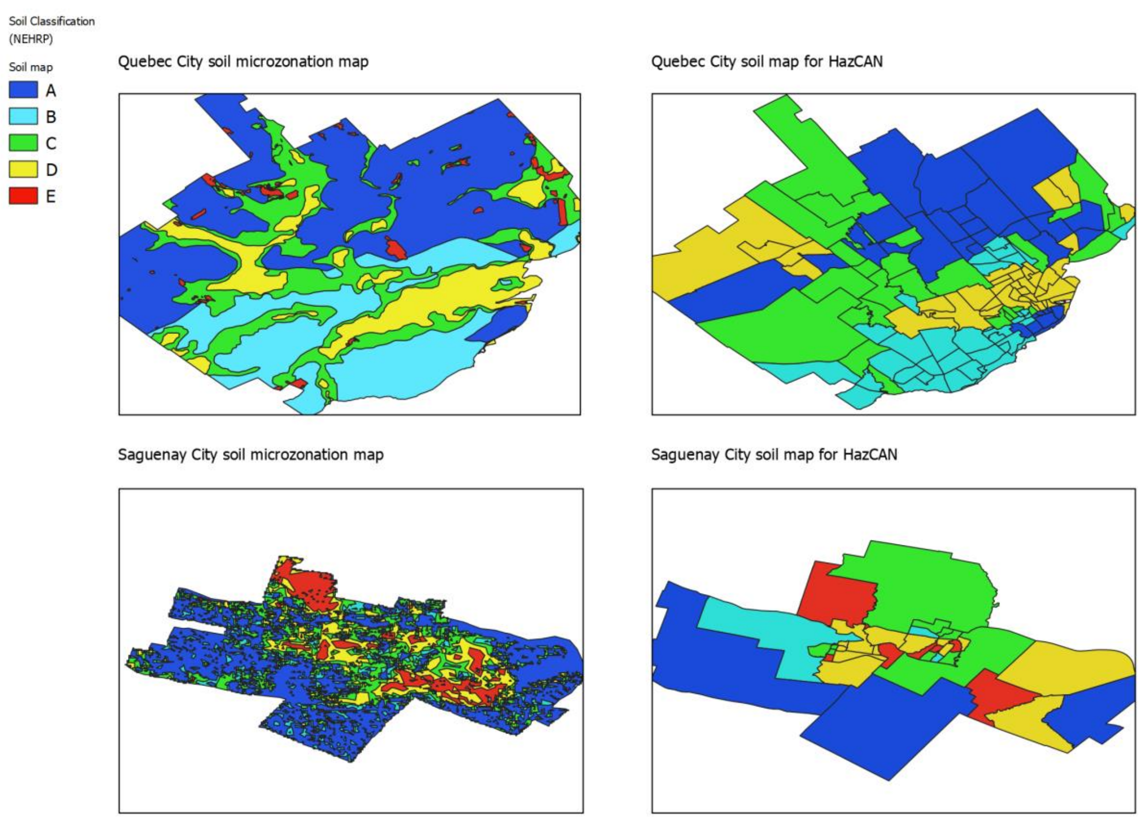


Figure 19: Soil classes microzonation of the Quebec City (Leboeuf et al., 2013) and Saguenay City (Foulon, 2017). The right maps are the corresponding soil maps generated at the census tract scales using the information on urbanized areas.

For areas without available microzonation information, site class distribution is derived from observations in terms of soil deposits given by by Paultre, P et al.(1993) and in terms of V_{s30} by Nastev et al. (2016) (Figure 20). For example, Baie-St-Paul region has confirmed alluvium soft soil deposit from a seismograph site report (Munro & Weichert, 1989) and hence, a type D soil class is assigned specifically to the corresponding census tract. The map of Figure 21 shows the finalized soil map at the census tract scale for the entire study region.

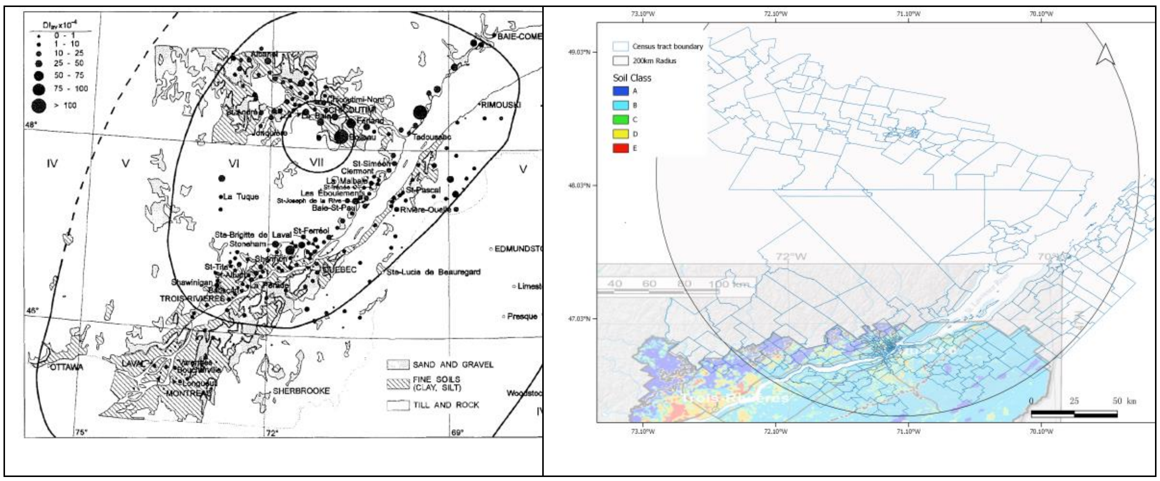


Figure 20: Site class distribution used to generate soil maps for other areas without microzonation maps: (right) in terms of soil types by Paultre et al. (1993), (b) in terms of V_{s30} by Nastev et al. (2016) superimposed onto the study region.

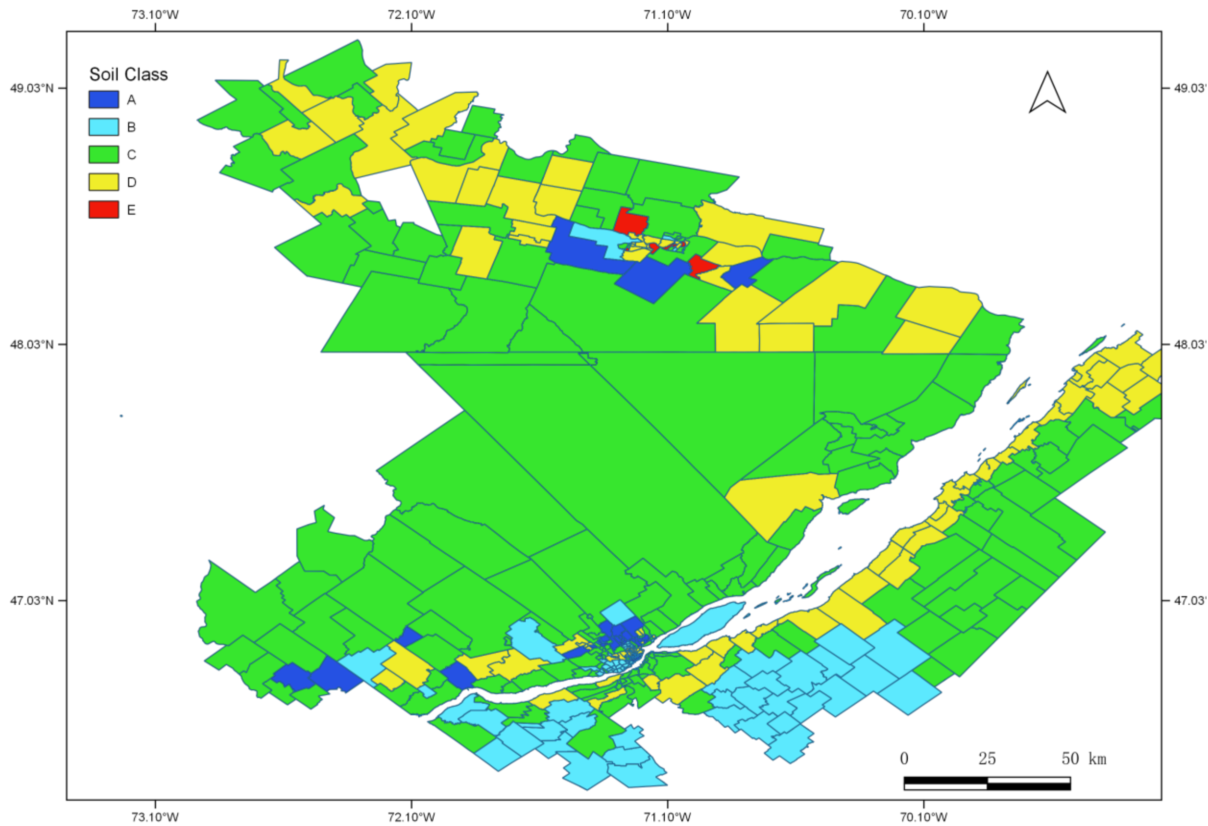


Figure 21: Soil map at the scale of census tract for the entire study region.

3.2 Validation of the ground motion prediction equations

The Peak Ground Acceleration (PGA) and the intensity in Modified Mercalli scale (MMI) are used as parameters for the validation of the ground motion equations. The calculated PGA and MMI using different attenuation relationships from HazCAN are compared with the recorded PGA and intensity values.

The recorded PGA data are obtained from the Eastern Canada Strong Motion Seismograph Network from Geological Survey of Canada (Munro & Weichert, 1989). A total of 11 stations in the province of Quebec have triggered during the Saguenay earthquake, among which 8 stations are located on the north shore of the Saint Lawrence River and 3 stations on the south shore (Table

18). The coordinates of each station are provided and used to calculate their epicentral distance. The sites are shown in Figure 22.

Table 18: List of accelerometer stations around the epicenter which recorded the Saguenay earthquake. PGA are given in g (g=9.81 m/s^2).

Station	Distance (km)	PGA (g)	Coordinates		Location
			Latitude	Longitude	
Chicoutimi-Nord	43.2	0.131	48.49	-71.01	North Shore
St-Andre	63.6	0.156	48.33	-71.99	
Les Eboulements	90.4	0.125	47.55	-70.33	
Baie-St-Paul	91.0	0.174	47.44	-70.51	
La Malbaie	93.0	0.124	47.66	-70.15	
Tadoussac	109.2	0.027	48.14	-69.72	
St-Ferreol	113.8	0.121	47.13	-70.83	
Quebec	149.3	0.051	46.78	-71.28	
Ste-Lucie-de-Beauregard	176.8	0.023	46.74	-70.02	South Shore
Riviere-Ouelle	114.4	0.057	47.48	-70.00	
St-Pascal	122.7	0.056	47.53	-69.81	

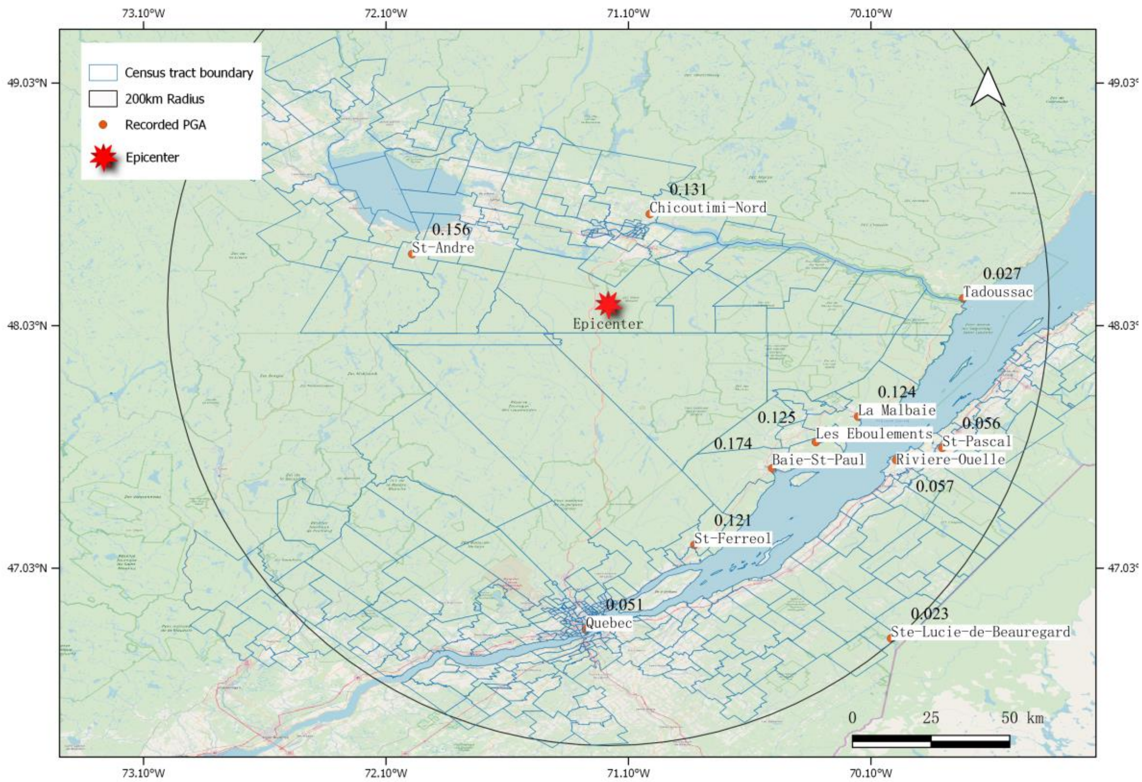


Figure 22: Seismic network around the epicenter. PGA value is given in g (g=9.81 m/s^2).

The Geological Survey of Canada recorded the observations in terms of MMI which originally came from 2400 questionnaires after the earthquake with an estimated respond rate to be around 75% of the affected population (Cajka & Drysdale, 1996). MMI higher than III are extracted from the report.

The graph of Figure 23 plots the recorded PGA values (black triangles) and calculated values at the centroid of each census tract using AB06 (circles) and CEUS08 (squares). The color of the symbols indicates the class of soil chosen.

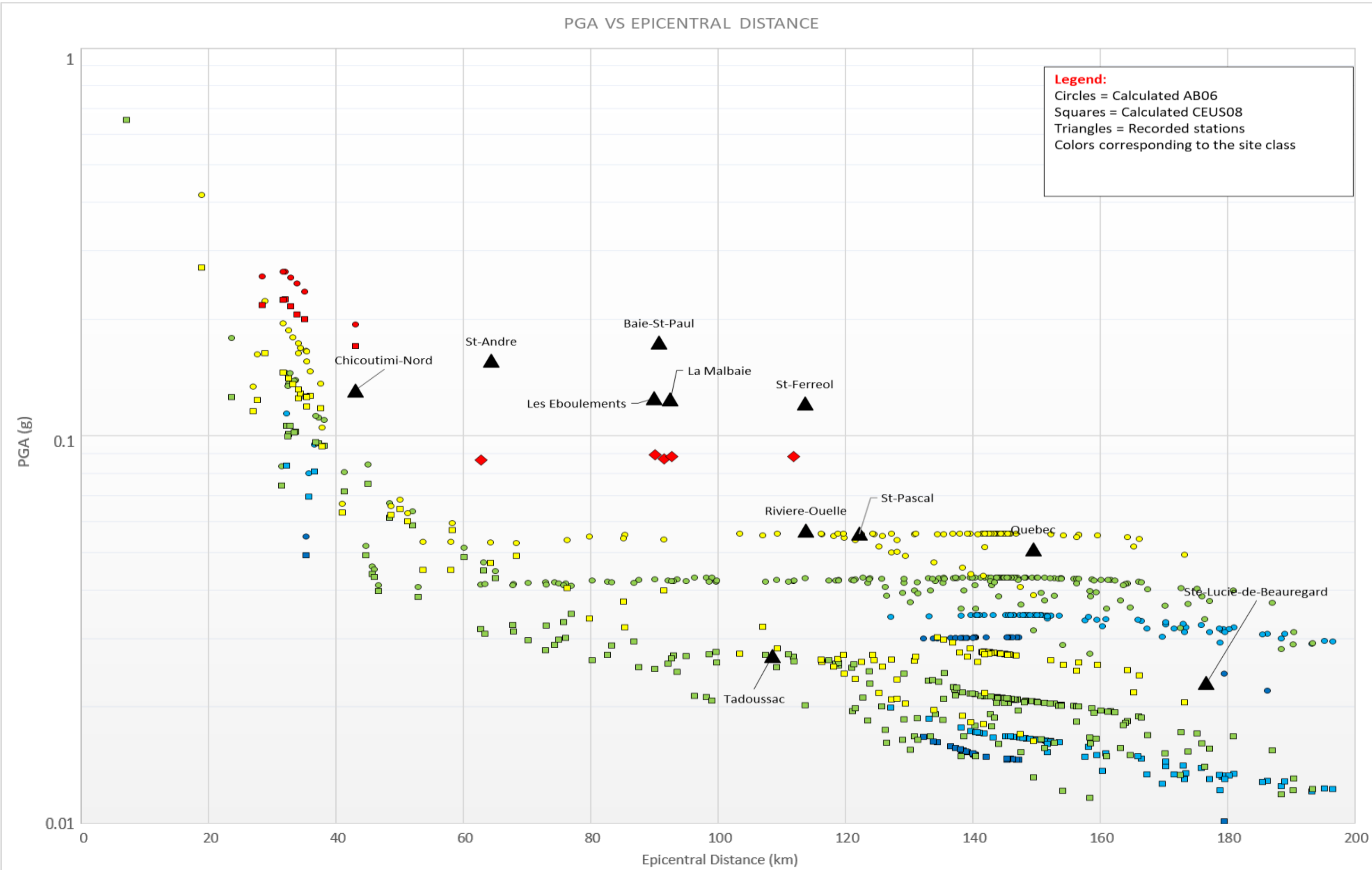


Figure 23: Observed versus calculated PGA for the Saguenay earthquakes. Black triangles are the recorded PGA at the stations given in Table 17. Circles and squares are the calculated PGA using AB06 and CEUS08, respectively, at each center of census tract. Diamonds are the worst-case soil class for stations between 60 to 120 km. Color of the symbols indicates the site class given for each census tract.

Some observations and conclusions can be drawn from the Figure 23:

1. At similar epicentral distances, PGA on site class D is higher than on site class C for both attenuation relationships by an average factor of 30%. Similar trends for other site classes are observed, This shows that the rule of softer soil amplifying more ground motion is reflected by the HazCAN analysis.
2. The PGA recorded on the north shore are generally 4 times higher than the ones on the south shore and there is a sudden decrease of PGA values at around 120-km. According to several authors, this drop is due to the large focal depth of the earthquake and the difference in geological context between the Grenville Province and the Appalachian of which the boundary largely coincides with the St. Lawrence River (Boore & Atkinson, 1992; Somerville et al., 1990). The difference in crustal structure between these provinces has been shown to cause corresponding differences in wave propagation and ground motion attenuation characteristics (Barker, 1988). The station Baie-St-Paul recorded the highest PGA among all the stations partly due to its location on alluvium soil (Cajka & Drysdale, 1996).
3. The AB06 produces higher PGA values than the CEUS08 within the study extent, and this difference increases up from 60 km distance. In general, the AB06 better fits the recorded PGA than the CEUS08. The exception of lower PGA recorded at Tadoussac station could be explained by the variation of waveform characteristics due to unilateral fault propagation, radiation pattern and source directivity (Haddon, 1992) which are not fully captured by the AB06 relation.
4. PGA values observed between 60 and 120 km are 2 times higher than the calculated ones by AB06. The estimates are still under predicted by an average factor of 35% in the worst-case site class E (red diamonds in Figure 23). Atkinson and Boore (2006) mentioned the high-frequency contents of the Saguenay earthquake which are not well defined in AB06

relation and under predicts high frequency amplitude data for M5.5 (±0.5) up to 100km. For the closest station Chicoutimi-Nord, the difference is not as large because PGA are controlled by direct shear waves at close distance (Atkinson & Boore, 2006).

The calculated intensity at each census tract is derived from the calculated PGA using the conversion equations developed by Wald et al. (1999) (Eq.4 & 5 in Section 2.2). Figure 24 plots the estimated MMI derived from observations (blue triangles) and calculated values at each center of census tract using AB06 (orange circles) and CEUS08 (grey circles) relationships. MMI's values are grouped within each 10km interval in order to calculate average and standard deviation. The AB06 estimation produces a closer intensity trend to the observations than CEUS08 which underestimates by an average factor of 17%. Intensity values are underestimated of 0.5 unit by AB06 for distances from 60 to 90km, which is consistent with the PGA observations. Intensity at close distance of the epicentre (less than 20km) were not reported to make any comparison.

Therefore, based on the comparison between predictions and observations of PGA and MMI, AB06 is selected to perform damage and loss analysis in HazCAN.

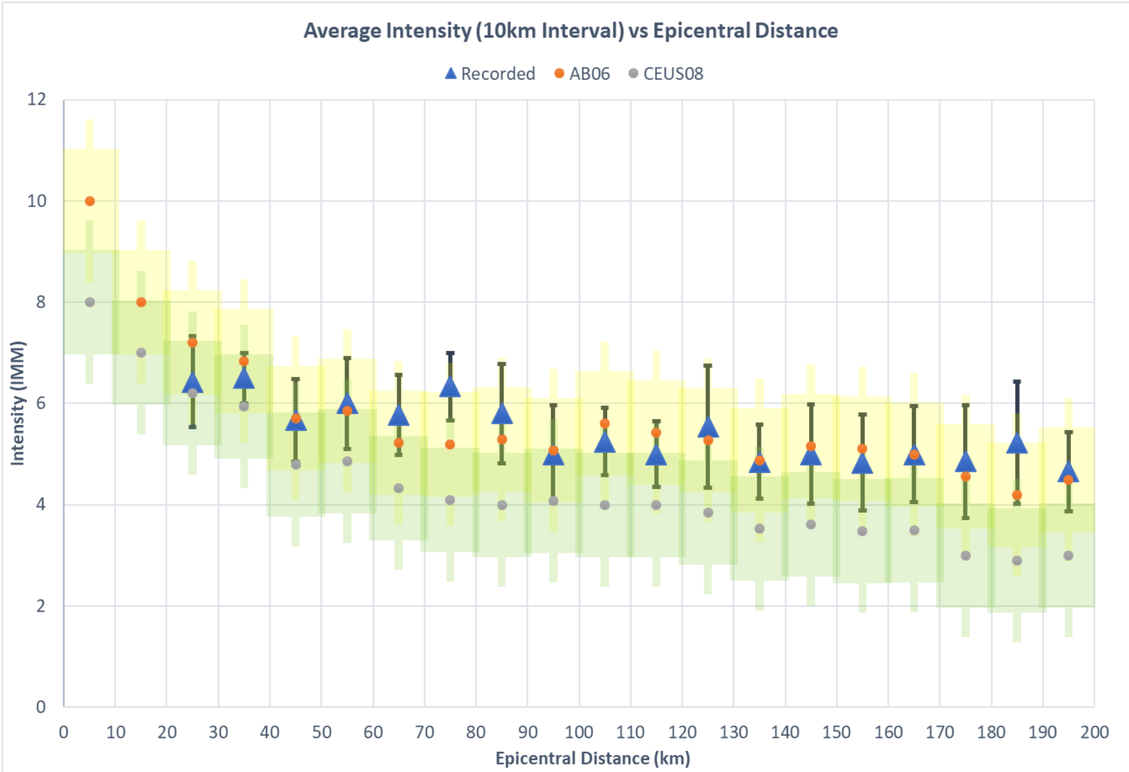


Figure 24: Observed versus calculated MMI for the Saguenay earthquake. Blue triangles are the reported MMI with standard deviation indicated by solid black bars. Orange and grey circles are the converted MMI from AB06 and CEUS08, respectively, with light yellow and green bars representing standard deviation.

3.3 Damage and loss calculation

In this section, AB06 is selected to calculate damage and loss estimates with HazCan for the 1988 Saguenay earthquake and results are compare with the damage reports.

The observed damage and loss statistics are mainly from the work done by Devic et al. (1990) and Paultre et al. (1993). Several of their observations and statistics are stated below:

(i) There are in total 1927 files of reported damages o buildings submitted under the compensation program sponsored by the Ministère de la Sécurité du Québec. Not all damages due to the earthquake were reported, because the compensation level was based on the repair cost. According to Table 1 in the paper by Paultre et al. (1993), a total of 1183 claims were received for houses of less than 2 storeys and apartment buildings of more than 2 storeys with a total amount of damage of C$ 6,202K. The graph of figure 5 in the paper displays the distribution of the number of claims with respect to epicentral distance (see Figure 25). The number of claims decreases with distance, except for a peak in the city of Quebec (at distance from 100 to 150 km). Claims collected within 200-km distance add up to 1047 cases. They are used to compare with the calculated number of damaged buildings for this study. A total loss of Can$ 5.5 million is calculated for the 1047 claims by proportion.

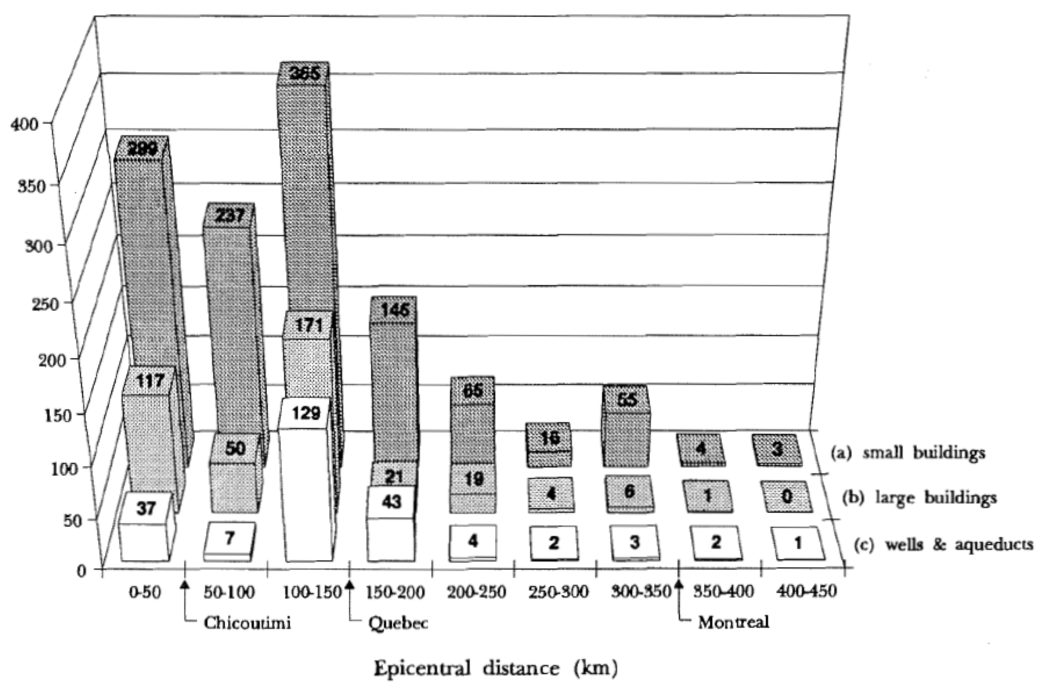


Figure 25: Distribution of the number of claims with respect to epicentral distance (a) for damaged houses and apartment buildings with two storeys or less, (b) for damaged churches, public services buildings, and apartment buildings of more than two storeys, (c) for damaged wells and aqueducts. From Paultre et al. (1993).

(ii) The types of damage most frequently encountered in the claims are: 1) cracked or pushed-in concrete-block basement walls; 2) large cracks in unreinforced masonry walls; 3) large cracks at the corners of openings, and at the junction of two walls or of wall and ceiling; 4) large damage concentrated in free-standing chimney parts. Table 4 in the work of Paultre et al. (1993) provides a damaged building percentage by type of damage and component, in which it is seen that the most type of structural damage for small buildings are foundation and chimney damage and the most type of non-structural damage are damage on exterior walls. Although the above observed damage could fall in the range of moderate to complete damage state based on the description in Hazus technical manual (FEMA, 2003a), considering that there was a compensation threshold for the reported claims, it is assumed that the claimed damage corresponds to the extensive to complete damage state.

Soil conditions played an important role in the geographical distribution of damage due to amplification of the ground motions induced by soft soil layers. Few damage occurred to structures built on bedrock or till since 95%of the reported cases are located on soft soil deposits; 53% on clay, 24% on multilayer soil profiles, and 18% on sand. In both papers, a parameter used to evaluate geographic distribution of damage is the damaged house density, defined as $d_h = n_{dh}/n$

$$d_h = n_{dh}/n$$

where n_{dh} is the number of damaged houses in a municipality and n is the total number of houses in that municipality. This parameter will be calculated for each census tract to compare with the observed damaged house density distribution provided in the Appendix 5 of the paper of Devic et al. (1990). The paper also provides a list of municipalities with individual damage greater than 80% in the Appendix (see Table 19). This damage percentage is calculated by the cost of repair divided by the value of building. There are 13 structures in total. They are assumed to have suffered complete level of damage and are compared with the number of buildings with complete damage state from the calculation.

Table 19: List of municipalities with damage percentage > 80% for the Saguenay earthquake study (from Devic et al., 1990).

Municipality	**Epicentral Distance (km)**	**Damage Percentage (%)**
Baie St-Paul	92	98
Beauport	140	100
St-Eusebe	182	86
Ferland et Boileau	27	100
Jonquiere	33	82.7
	33	83.8
La Baie	33	85.5
	33	82.2
Lac Kenogami	27	100
Latteriere	22	100
	22	83.5
Ste-Jeanne D'Arc	118	97.9
St-Felix D'Otis	45	88.4

Three types of damage and loss are calculated:

1) Direct damage – total number of damaged buildings by damage state;
   - distribution of the number of damaged buildings with respect to epicentral distance
   - geographical distribution of the damaged house density d_h d_h
2) Economic loss – direct economic losses to residential buildings;
3) Social loss – number of casualties at commute time 5 p.m.

The damage distribution comparison is investigated in more detail to study the site amplification effects generated from HazCAN computation. Casualties at 5 p.m is used since the earthquake event occurred at around 6:46 p.m. Table 20 provides a summary of the key data estimated by HazCAN using AB06 attenuation relationship and the corresponding observations. The number of damaged buildings is counted by general construction type and by damage state. Figure 26 displays the percentage of damaged buildings by construction type within each damage state from Table 20. The calculated number of damaged buildings (extensive and complete states) are plotted in Figure 27 with respect to the epicentral distance and compared with the distribution of number of claims in Figure 25.

The damaged house density $\mathrm{d_h}d_h$ is calculated for each census tract (number of damaged buildings with extensive and complete damage divided by the total number of buildings). Independent of the size of the census tract, it can be used as a better parameter to study the regional soil amplification effect. A geographical distribution of $\mathrm{d_h}d_h$ is displayed in Figure 28 and the comparison between the calculated and observed values is shown in Figure 29.

Table 20: Summary and comparison of damage and losses estimated using AB06 attenuation function for the 1988 Saguenay earthquake.

HazCAN-AB06 Results for the Sagunenay Earthquake — **Observations**

(1) Building Damage

	None Count	None (%)	Slight Count	Slight (%)	Moderate Count	Moderate (%)	Extensive Count	Extensive (%)	Complete Count	Complete (%)	Extensive+ Complete	Total damaged	Observations
Wood	212,059	94.4	20,059	91.1	4,764	75.7	492	45.1	31	12.8	523	25,346	*Total claims: 1047 Around 13 buildings with complete damage (damage percentage>80%).*
Steel	754	0.3	84	0.4	100	1.6	50	4.6	28	11.6	78	262	
Concrete	967	0.4	104	0.5	113	1.8	69	6.3	14	5.8	83	300	
RM	2,570	1.1	127	0.6	183	2.9	124	11.4	43	17.8	167	477	
URML	6,999	3.1	1,469	6.7	1,014	16.1	317	29.0	117	48.3	434	2,917	
MH	1,195	0.5	169	0.8	116	1.8	40	3.7	9	3.7	49	334	
Total	224,544		22,012		6,290		1,092		242		1,334	29,636	

(2) Direct Economic Losses to Buildings (dollars in thousands)

Structural Damage	Non-Structural Damage	Total building damage	Observations
$16,812	$84,825	$101,637	*Total amount: 5.5 million*

(3) Casualty Estimates @ 5 p.m.

	Severity 1	Severity 2	Severity 3	Severity 4	Total casualties	Observations
Wood	2	0	0	0		*Zero reported injuries*
Steel	0	0	0	0		
Masonry	2	0	0	0		
Total	4	0	0	0	4	

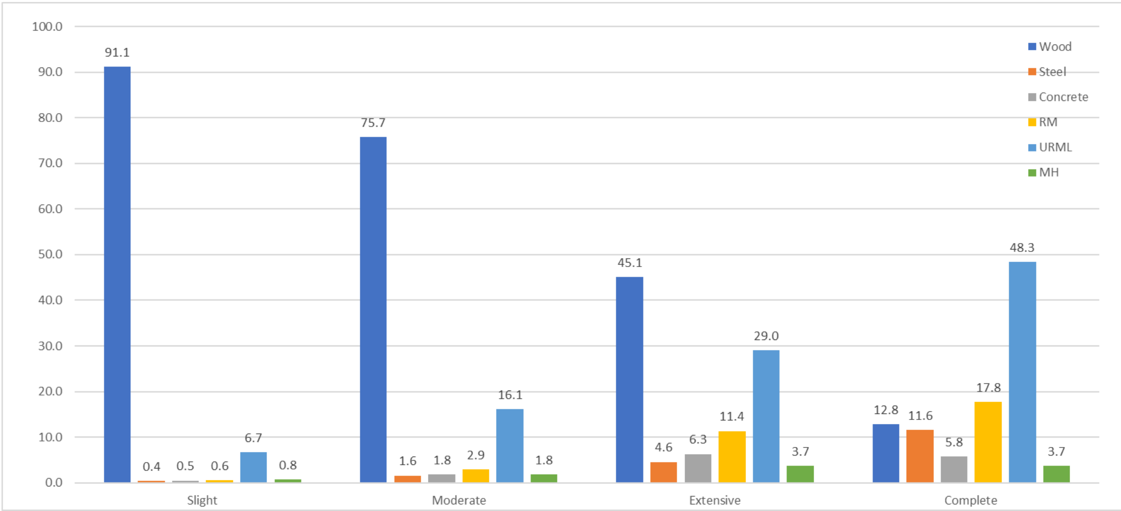


Figure 26: Distribution of damaged building by damage state and construction type in the 1988 Saguenay earthquake study.

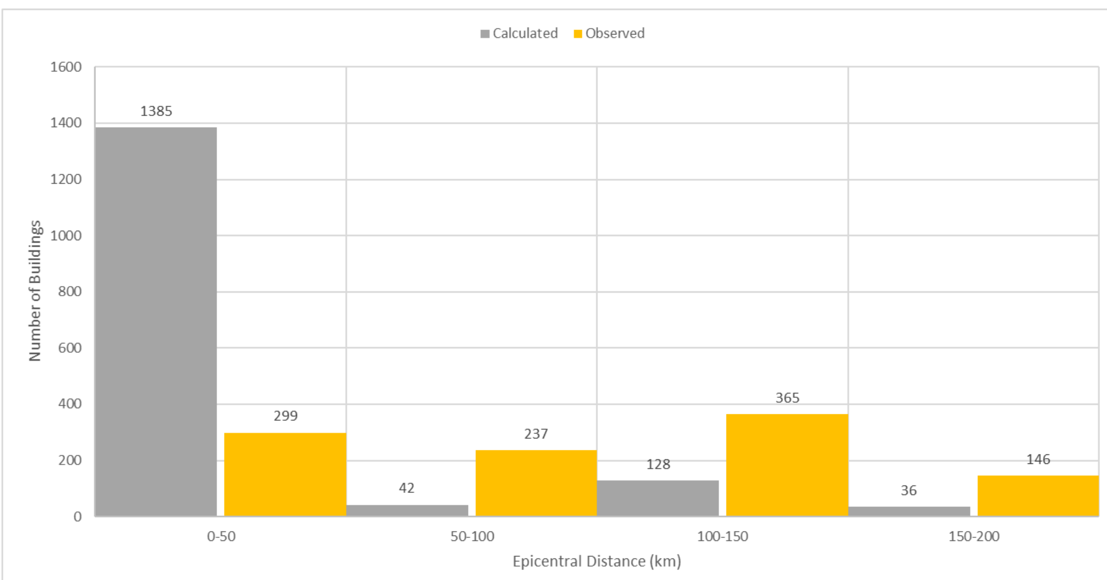


Figure 27: Comparison between the calculated number of damaged buildings and the observed number of claims with respect to the epicentral distance. Extensive and complete damage are here considered.

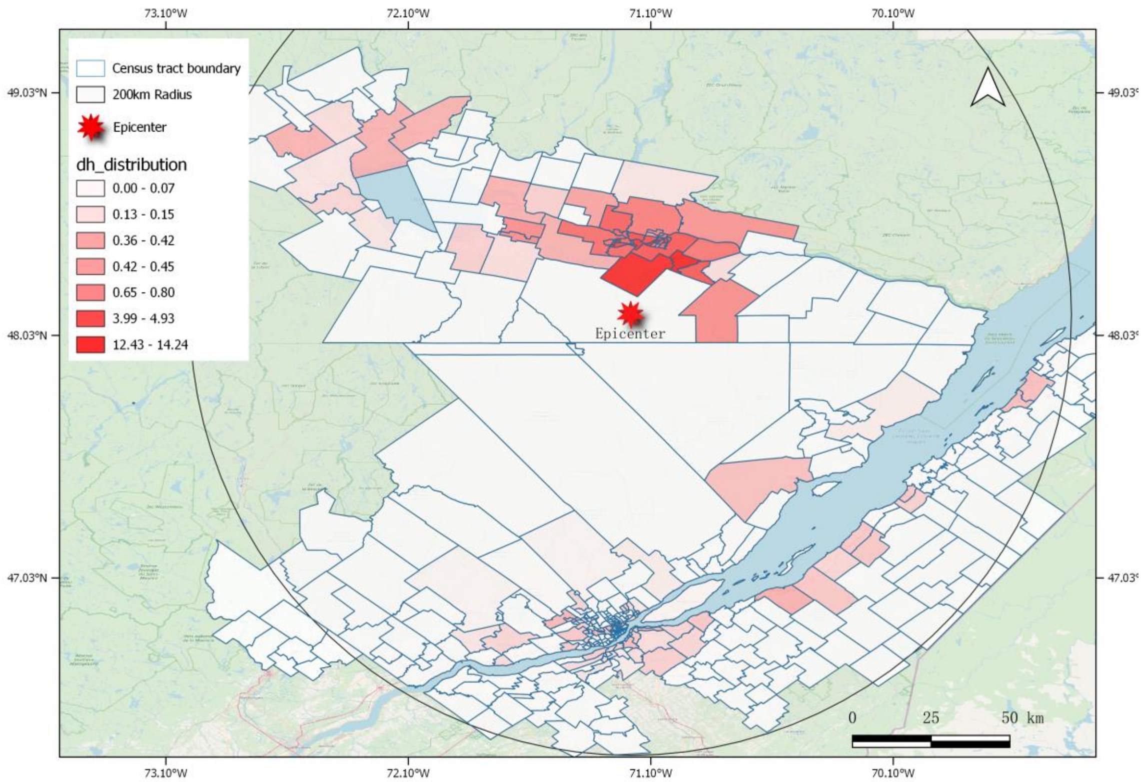


Figure 28: Distribution of the damaged house density d_h(d_h),. The damage index the number of damaged buildings with extensive and complete damage divided by the total number of buildings for each census tract.

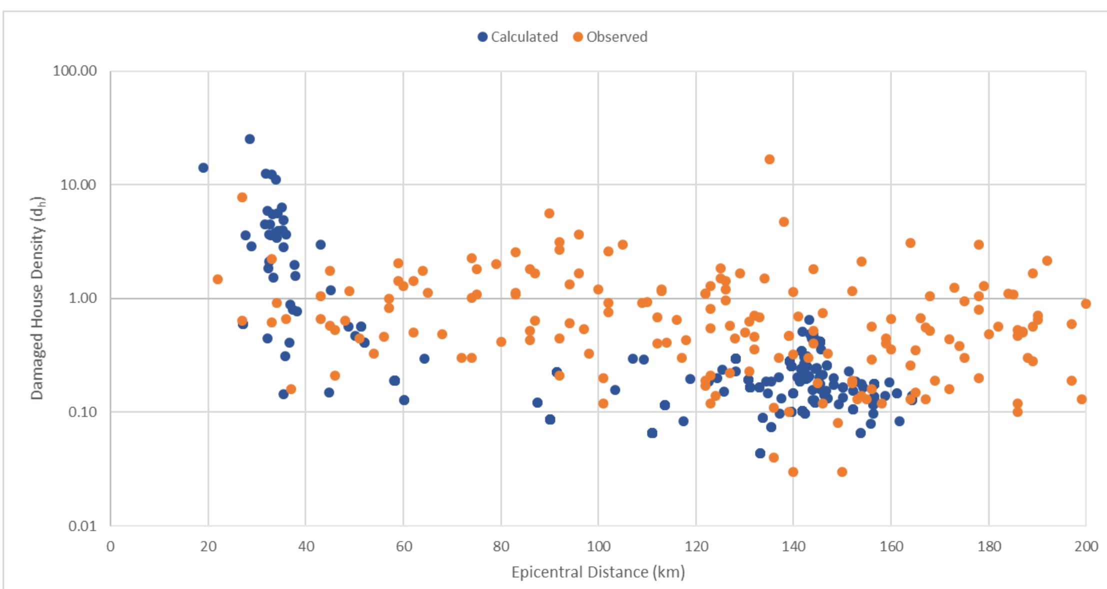


Figure 29: Comparison between the calculated and observed damaged house density (d_h) with respect to the epicentral distance. Data for the observed d_h from Devic et al. (1990)

3.4 Discussion

HazCAN estimates that in total 29636 buildings experience levels of damage from slight to complete; among them 1334 buildings are in the extensive and complete damage state and 6290 buildings are moderately damaged. If we assumed that the compensation threshold of the reported claims corresponds to the above extensive and complete damage states, the 1047 claims reported within 200-km is close to the 1334 calculated number. The low overestimation by a factor of 27%. could be partly explained by an incomplete survey, the geographical difference between the HazCAN study region and the surveyed area, and more importantly, by the selected attenuation relationship.

The calculated number of damaged buildings is around 3.5 times more than observed (Figures 22 and 26), the difference is mainly due to the overestimation of PGA from AB06 for epicentral distance less than 50-km. For distance greater than 50-km, although the trend matches, the calculation substantially under estimates the damaged buildings by an average of 74%. This is partly explained by the Figure 22 that AB06 under predicts the ground motion for a range between 60-km and 100-km due to high frequency content of the earthquake source. However, even with the worst soil class assigned, the ground motion is still under predicted; therefore, the other possible reason is lacking high quality soil maps for regions other than the Quebec City and Saguenay City, so the amplification effect by soft soil deposits is not fully reflected for those regions. The number of completely damaged buildings is estimated to be 242. Like the Cornwall earthquake analysis, this estimation is significantly greater than the observed which is around 13 cases. This is explainable since from previous findings more damaged buildings are calculated than observed within 50-km, among which many buildings are supposed to be in complete damage state for such short epicentral distance. The overestimation of the completely damaged buildings could also indicate a potential shift of the damage state distribution to a more severe end.

Figure 26 shows the damaged building percentage by construction type for each damage state. It shows a similar result as for the Cornwall earthquake study, where the percentage of the damaged unreinforced masonry structures increases as damage state goes to a more severe level, opposite to the wood structures. This confirms the poor performance of the unreinforced masonry structures during an earthquake event.

A total direct economic loss of Can$101.6 million is calculated including structural and non-structural damage in all damage states. It corresponds to an average loss of 3428 dollars per damaged building. On the other hand, the observed economic loss for the 1047 claims is around 5.5 million, which gives an average loss of 5253 dollars per building. As if the number of buildings with complete damage is over predicted, the calculated average loss by building is still lower than the observed one by 35%. This is because large amount of loss due to slight or part of moderate damage which is not included in the documented loss outweighs the loss due to overestimation of the complete damage.

The calculated losses due to structural damage is around 20% of the non-structural one which agrees with the observation that most of the building damage was non-structural. This result cannot be compared quantitatively.

HazCAN calculates that around 4 people undergo injuries of severity level 1. No reports of injuries during the earthquake are documented. This estimate is then reasonable considering the large extent of the study region and that the earthquake occurred at the commuting time during the day.

The calculated and reported damaged house density $\mathrm{d_h}$$d_h$ distribution are compared in Figures 28 and 29. Figure 28 shows that values of $\mathrm{d_h}$$d_h$ are not decreasing evenly with distance. For example, they are greaterd_h in the Quebec City, Baie-St-Paul and some regions on the South Shore where a softer soil class was assigned. The comparison of $\mathrm{d_h}$$d_h$ displayed in Figure 29 reveals that the difference is closely related to the ground motion calculation (Figure 23): an overestimation within short distance range (<50-km), a significant underestimation between 60-km and 120-km, and a slight underestimation between 120-km and 160-km. Therefore, it can be concluded that the accuracy of the damage distribution estimation is greatly dependent on the selection of the attenuation relationship and the quality of the available soil maps. The estimation results are more accurate if the attenuation relationship can better accommodate the effect of the special earthquake motion characteristics such as source radiation with high frequency energy.

Chapter 4. Conclusions and recommendations

Re-analysis of the 1944 Cornwall and 1988 Saguenay earthquake using HazCAN are performed in this study. Following the HazCan methodology, the default regional dataset is updated for each earthquake analysis in order to adapt the collection of 1) demographic data 2) building inventory and 3) local soil conditions to account for eventual site amplification. Several attenuation relationships are tested and validated against the observed ground motion parameters. Comparisons between the observed and calculated damage and losses are investigated from three perspectives: building damage, direct economic loss, and casualty estimates.

4.1 Conclusions

At this stage, some conclusions can be made:

1. HazCAN tends to overestimate the building damage within a short epicentral distance, approximately less than 30-km. The overestimation is reflected by the calculated total number of damaged buildings and the calculated damaged buildings with complete damage state. The degree of overestimation is greatly dependent on the over-prediction of the selected attenuation relationship within that distance range.
2. Overall, the soil amplification effect calculated from HazCAN matches the observed trend of damage distribution. The quality and availability of the soil maps largely influence the building damage estimates. Lack of identification of the soft soil classes can result in a remarkable under-estimation of the damaged buildings.
3. Independent of the occupancy mapping scheme, most of the completely damaged buildings come from the URML type. Unreinforced masonry structures prove to perform the worst among all included construction types under earthquake forces.
4. HazCAN overestimates the direct economic loss and casualties for both earthquakes. Apart from the overestimation of the building damage, which is the dominant reason, other

possible causes could be incomplete surveys, inaccurate dollar value conversion, and geographic unit difference between the surveyed area and study region.

5. For the building damage, there is a possible shift of damage state distribution to the severe end. This could be related to the construction type mapping scheme if more unreinforced masonry structures are modeled than the actual number. Another hypothesis is that the shift is due to the difference between the actual fragility curves and the modeled fragility curves for a certain type of structure, since the steepness of fragility curves can affect the percentage of each damage state for a given building spectral response.

4.2 Recommendations

Some recommendations to potentially improve the HazCAN estimation for future research are listed below:

1. For the potential earth science hazard (PESH), the analysis in this study does not include the effect from ground failure hazards. Susceptibility maps for the three types of ground failure: liquefaction, land sliding and surface fault rupture can be developed to calculate the site-specific estimates of peak ground deformation based on regional data.
2. This study analyses the earthquake damage and loss with a focus on the residential building stock, and therefore, the estimation is only a portion of the total damage caused by the earthquakes. Future calibration studies can cover the damage comparison for other general occupancy types such as commercial, industrial and government buildings. Comparisons on essential facilities, transportation lifelines and utility lifelines can be included as well. It is also suggested to use a relatively new technology in HazCAN of the advanced engineering building module (AEBM) to assess losses for an individual building or group of specific structures based on their seismic engineering characteristics.

3. It can be worthwhile to study and modify the default capacity and fragility curves (damage functions) for site-specific construction types. This could help verify whether the shift in damage state distribution is related to the embedded damage function (or to what extent).
4. More investigations and adjustments could be done to attenuation relationships to account for the over-estimation of the ground motion within short epicentral distance.

Appendix A: 1944 Cornwall earthquake HazCAN outputs for all census tracts (TP05)

Table A-1 Damaged building count by construction type and damage state.

Construction Type	CT#	1	2	3	4	5	6	7	8
W1	None	1,156	30	438	1,505	1,169	1,108	777	1,271
	Slight	43	16	22	717	17	11	22	34
	Moderate	7	8	1	323	2	1	3	4
	Extensive	0	1	0	42	0	0	0	0
	Complete	0	0	0	4	0	0	0	0
S3	None	57	1	21	54	60	47	37	53
	Slight	8	0	2	24	2	1	2	2
	Moderate	3	1	0	37	1	0	1	1
	Extensive	0	0	0	19	0	0	0	0
	Complete	0	0	0	1	0	0	0	0
S5L	None	58	1	21	72	61	47	38	54
	Slight	8	1	3	31	2	1	2	2
	Moderate	2	1	0	24	0	0	0	0
	Extensive	0	0	0	7	0	0	0	0
	Complete	0	0	0	0	0	0	0	0
URML	None	646	11	223	1,112	727	683	394	762
	Slight	64	7	28	593	32	23	27	50
	Moderate	39	7	13	542	12	8	11	21
	Extensive	0	3	0	224	2	1	2	3
	Complete	0	1	0	66	0	0	0	0
Total		2,091	89	772	5,397	2,087	1,931	1,316	2,257
Total damaged		174	46	69	2,654	70	46	70	117
Dmg %		8.3%	51.7%	8.9%	49.2%	3.4%	2.4%	5.3%	5.2%

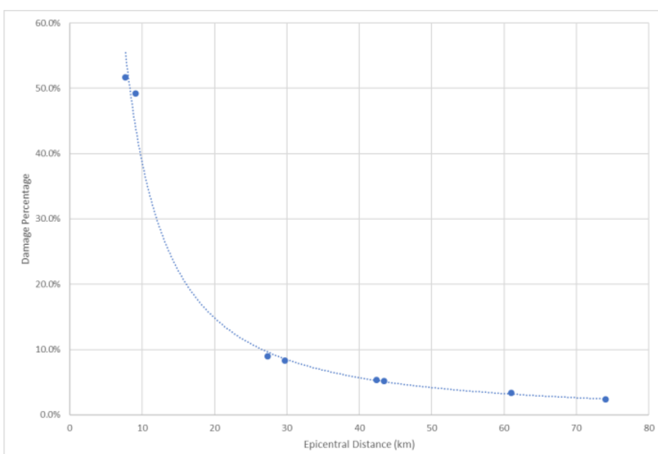


Figure A-1: Damaged building percentage distribution over the range of epicentral distance.

Table A-2: Direct economic loss.

CT#	1	2	3	4	5	6	7	8
Structural Damage (thous. $)	$4.7	$6.2	$1.1	$241.6	$2.2	$1.3	$2.8	$4.5
Non-Structural Damage (thous. $)	$24.3	$53.4	$8.0	$2,202.8	$7.8	$4.4	$14.9	$21.8
Building Damage (thous. $)	$29.2	$59.6	$9.6	$2,444.4	$10.0	$5.6	$17.7	$26.3
Content Damage (thous. $)	$9.7	$31.5	$3.2	$1,239.2	$2.2	$0.9	$5.9	$8.7
Inventory Loss (thous. $)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Relocation Cost (thous. $)	$28.6	$58.3	$9.5	$2,297.3	$12.1	$6.5	$17.0	$26.6
Income Loss (thous. $)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Rental Income Loss (thous. $)	$10.2	$22.0	$3.4	$1,045.9	$4.5	$2.5	$7.8	$9.5
Wage Loss (thous. $)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Total Loss (thous. $)	$87.4	$171.4	$29.4	$7,026.7	$28.8	$15.5	$48.4	$71.0

Table A-3: Casualty estimates by general building type.

	CT#	1	2	3	4	5	6	7	8
	Severity								
Wood	1	0	0	0	15	0	0	0	0
	2	0	0	0	2	0	0	0	0
	3	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0
Steel	1	0	0	0	1	0	0	0	0
	2	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0
Masonry	1	0	1	0	44	0	0	1	1
	2	0	0	0	10	0	0	0	0
	3	0	0	0	1	0	0	0	0
	4	0	0	0	3	0	0	0	0

Appendix B: 1988 Saguenay earthquake building inventory inputs

Table B-1: Census subdivision code listing for the study region.

Rivière-du-Loup,QC	240120
Kamouraska,QC	240140
Charlevoix-Est,QC	240150
Charlevoix,QC	240160
L'Islet,QC	240170
Montmagny,QC	240180
Bellechasse,QC	240190
L'Île-d'Orléans,QC	240200
La Côte-de-Beaupré,QC	240210
La Jacques-Cartier,QC	240220
Québec,QC	240230
Lévis,QC	240250
Lotbinière,QC	240330
Portneuf,QC	240340
Mékinac,QC	240350
La Tuque,QC	240900
Le Domaine-du-Roy,QC	240910
Maria-Chapdelaine,QC	240920
Lac-Saint-Jean-Est,QC	240900
Le Saguenay-et-son-Fjord,QC	240940

Table B-2: Adjusted 1988 building distribution by occupancy type.

Tract	RES1	RES2	RES3A	RES3B	RES3C	RES3D	Total
24012002010	459	9	20	0	0	1	489
24012002015	917	0	45	0	1	5	968
24012002020	264	4	8	0	0	0	277
24012002025	96	5	5	0	0	0	105
24012002030	310	0	8	0	1	1	320
24012002035	150	5	3	0	0	0	158
24012002043	526	0	13	0	0	3	542
24012002045	20	0	0	0	0	0	20
24012002055	307	0	25	0	2	4	337
24012002060	209	0	4	0	0	1	214
24012002065	278	0	15	0	2	2	297
24012002072	2,902	32	414	11	19	119	3,497
24012002080	350	59	13	0	1	1	424
24012002802	0	0	0	0	0	0	0
24012002804	0	0	0	0	0	0	0
24014004005	413	4	4	0	0	1	423
24014004010	186	0	3	0	0	0	188
24014004018	970	5	92	1	1	11	1,080
24014004025	260	4	16	0	0	0	280
24014004030	145	0	3	0	0	0	148
24014004035	469	9	30	0	1	5	514
24014004040	158	4	8	0	0	2	171
24014004045	88	0	7	0	0	0	94
24014004050	237	5	3	0	0	1	245
24014004055	167	4	2	0	0	0	174
24014004060	270	5	23	0	0	2	300
24014004065	339	9	11	0	0	0	360
24014004070	476	4	25	0	0	2	507
24014004075	285	10	11	0	1	0	307
24014004080	201	0	4	0	0	0	206
24014004085	849	23	104	3	6	30	1,015
24014004090	503	17	14	0	1	0	535
24014004902	0	0	0	0	0	0	0
24014004904	0	0	0	0	0	0	0
24015005005	257	0	9	0	0	0	266
24015005013	2,037	46	212	3	4	28	2,331
24015005025	87	0	57	0	0	0	143
24015005030	288	21	26	0	0	0	336
24015005035	638	56	99	0	0	10	804
24015005058	330	17	34	0	1	1	383
24015005065	81	0	3	0	0	0	83
24015005902	40	0	0	0	0	0	40

24015005904	45	5	0	0	0	0	50
24016006005	162	0	14	0	0	0	176
24016006013	1,502	16	231	2	3	17	1,771
24016006023	419	4	29	0	0	0	452
24016006048	406	0	16	0	0	1	423
24016006050	296	17	19	0	0	2	333
24016006055	400	4	54	0	0	0	458
24016006902	0	0	0	0	0	0	0
24017007005	135	0	3	0	0	0	138
24017007010	720	17	58	0	0	6	801
24017007015	210	0	0	0	0	0	210
24017007020	180	0	3	0	0	0	183
24017007025	151	9	3	0	0	0	163
24017007030	546	4	33	0	2	4	588
24017007035	218	0	0	0	0	2	220
24017007040	202	0	4	0	1	0	208
24017007045	310	5	8	0	0	1	324
24017007055	499	14	7	0	0	1	521
24017007060	233	5	5	0	0	1	243
24017007065	305	5	19	0	0	2	330
24017007070	911	9	77	0	3	8	1,008
24017007078	1,138	4	67	0	1	6	1,217
24018008015	305	0	9	3	3	1	320
24018008020	131	0	5	0	0	0	135
24018008025	217	5	9	0	0	0	231
24018008030	294	4	7	0	0	1	306
24018008035	155	5	0	0	0	0	160
24018008040	175	0	3	0	0	0	178
24018008045	923	9	54	0	2	3	990
24018008050	2,370	0	390	4	9	52	2,826
24018008055	322	0	10	0	0	0	332
24018008060	409	0	20	2	2	3	436
24018008065	353	0	22	0	1	2	378
24018008070	65	5	0	0	0	0	70
24019009005	257	4	5	0	0	2	268
24019009010	292	5	0	0	0	2	299
24019009015	125	0	0	0	0	0	125
24019009020	448	0	14	0	0	1	463
24019009025	394	12	2	0	0	3	410
24019009030	538	5	33	0	0	5	580
24019009037	557	9	17	0	0	3	586
24019009045	290	0	0	0	0	0	290
24019009050	364	4	7	0	0	1	376
24019009055	819	17	59	2	3	7	906

24019009062	790	26	54	1	3	5	878
24019009070	238	0	4	0	0	1	243
24019009075	566	19	18	0	0	3	605
24019009082	727	27	25	0	0	2	781
24019009090	173	11	7	0	0	1	192
24019009097	623	4	20	0	1	2	650
24019009110	486	4	24	0	1	0	516
24019009117	317	4	16	0	0	1	338
24019070000	602	4	17	0	0	2	625
24019090000	1,029	0	50	1	2	6	1,088
24020054000	2,172	9	107	0	3	6	2,297
24021001005	424	0	42	0	0	1	467
24021001010	698	0	54	0	1	2	755
24021001015	0	0	0	0	0	0	0
24021001020	345	0	35	0	0	1	381
24021001025	646	17	92	1	2	10	768
24021001030	542	36	119	0	1	11	708
24021001902	0	0	0	0	0	0	0
24021001904	0	0	0	0	0	0	0
24021050000	1,050	0	56	0	1	4	1,110
24021051000	720	51	81	0	0	4	856
24021053000	838	291	66	0	1	5	1,201
24022002902	0	0	0	0	0	0	0
24022019000	482	11	44	0	0	0	537
24022020000	1,455	21	27	5	6	1	1,515
24022021002	97	0	27	0	0	0	124
24022037000	1,400	0	9	0	0	0	1,409
24022052000	976	0	38	0	0	1	1,016
24022060500	1,529	150	41	2	3	2	1,726
24022061000	608	18	38	20	25	3	712
24023000101	98	0	67	0	0	41	206
24023000102	260	0	108	0	0	48	417
24023000200	211	0	79	0	0	29	319
24023000300	121	0	53	1	5	99	279
24023000400	44	0	34	0	1	12	91
24023000500	48	0	45	0	0	68	161
24023000600	42	0	41	9	10	79	181
24023000700	57	0	121	0	0	38	215
24023000800	34	0	60	0	0	32	126
24023000900	84	0	104	0	0	41	229
24023001000	48	0	145	2	2	48	245
24023001100	51	0	94	0	1	33	179
24023001200	85	0	100	0	0	38	223
24023001300	86	0	96	0	0	23	204

24023001400	28	0	6	0	1	47	81
24023001500	31	0	14	0	1	40	85
24023001600	38	0	20	0	3	63	123
24023001700	0	0	0	0	1	2	3
24023001800	10	0	3	0	0	32	45
24023001900	43	0	3	0	0	72	118
24023002000	51	0	3	0	0	66	119
24023002100	17	0	13	0	0	33	63
24023002200	29	4	16	2	3	40	94
24023002300	5	0	0	0	0	13	18
24023002400	0	0	4	0	0	13	17
24023002500	0	0	0	0	0	11	11
24023002600	128	0	185	2	3	79	396
24023002700	28	5	27	0	0	39	98
24023002800	34	0	44	0	0	38	116
24023002900	17	0	27	0	0	44	88
24023003000	33	0	121	2	3	64	222
24023003100	48	0	118	0	0	44	211
24023003200	3	0	3	3	3	13	24
24023003301	79	0	63	0	1	66	209
24023003302	300	0	115	0	0	61	476
24023003400	194	0	108	0	0	85	387
24023003500	46	0	68	0	0	45	159
24023003600	238	0	158	0	0	93	489
24023003700	140	0	107	6	8	61	322
24023003801	69	0	71	6	8	46	199
24023003802	157	0	127	0	0	45	329
24023003901	1,137	0	379	4	5	28	1,553
24023003902	543	0	63	0	1	66	672
24023004001	848	0	112	8	11	15	994
24023004002	185	0	173	21	26	66	470
24023004101	602	0	174	9	11	32	828
24023004102	460	0	81	3	4	14	562
24023004103	299	4	19	0	0	0	322
24023004104	1,056	0	170	10	11	28	1,274
24023004105	796	0	140	12	14	13	975
24023004106	724	0	94	2	3	1	823
24023004107	641	0	65	3	4	19	731
24023010000	247	0	59	10	13	4	333
24023010100	1,202	0	66	4	6	8	1,286
24023010200	268	0	64	0	1	17	349
24023010300	478	0	74	2	3	14	572
24023011000	1,062	0	78	1	1	13	1,156
24023011100	991	0	74	0	0	26	1,091

24023011201	410	0	76	6	8	35	536
24023011202	382	0	37	0	0	72	492
24023011301	301	0	54	9	11	49	424
24023011302	862	0	114	13	15	37	1,042
24023011400	570	0	52	10	11	70	712
24023011500	270	0	54	5	6	35	370
24023011600	255	0	57	0	0	106	418
24023011700	688	0	88	0	0	78	854
24023011800	851	0	41	6	7	94	999
24023011902	990	286	212	4	5	6	1,502
24023011903	1,048	12	130	11	14	8	1,222
24023011904	578	15	94	1	4	1	692
24023012001	783	0	145	6	9	9	951
24023012002	1,085	0	81	7	9	20	1,201
24023012003	1,017	0	124	2	6	2	1,151
24023014001	1,316	6	90	3	4	2	1,421
24023014002	640	8	124	0	0	38	810
24023014003	1,098	4	175	1	1	15	1,294
24023016001	867	0	121	0	0	43	1,032
24023016002	864	4	133	0	0	25	1,026
24023016003	940	0	118	0	2	11	1,071
24023017003	770	4	128	0	0	4	906
24023017004	448	0	47	4	4	2	504
24023017005	714	0	83	2	4	29	832
24023017006	866	0	101	0	0	6	972
24023017007	664	0	55	8	11	9	746
24023021001	811	189	33	1	1	1	1,034
24023021002	1,121	8	90	0	0	3	1,223
24023022001	1,042	0	182	12	15	6	1,257
24023022002	1,084	172	164	0	2	4	1,427
24023023001	789	0	175	12	15	3	994
24023023002	635	31	71	0	1	2	740
24023024001	767	0	109	16	20	24	936
24023024002	238	0	50	5	7	37	337
24023026001	73	0	160	0	1	49	283
24023026002	68	0	107	1	1	62	239
24023026003	228	0	110	12	14	50	413
24023027001	253	0	127	0	0	64	445
24023027002	302	0	109	4	5	103	522
24023027101	1,047	0	53	0	0	15	1,116
24023027102	835	0	76	0	0	23	933
24023027200	226	0	68	0	1	10	305
24023027301	335	0	56	0	0	55	447
24023027302	672	5	53	20	25	1	775

24023027303	1,040	0	107	0	0	8	1,155
24023027304	945	0	68	2	2	33	1,051
24023028001	992	0	93	0	1	16	1,102
24023028002	1,102	0	104	2	3	25	1,236
24023028003	962	0	139	0	1	27	1,129
24023029001	399	0	74	2	2	12	489
24023029002	640	0	102	2	4	27	774
24023030000	341	0	37	0	0	2	380
24023031000	127	0	135	0	0	30	291
24023031101	274	0	148	1	1	75	501
24023031102	324	5	77	0	0	41	446
24023032001	1,061	0	228	0	1	69	1,359
24023032002	950	5	152	0	0	33	1,140
24023032003	529	0	112	8	10	7	665
24023032004	673	0	89	0	0	24	787
24023032005	725	0	48	0	1	2	775
24023032007	859	0	72	0	1	2	934
24023032008	687	0	61	0	0	0	749
24023033000	179	0	171	1	5	34	389
24023034001	400	0	75	1	2	14	492
24023034002	565	0	171	0	0	26	761
24023034003	1,254	0	98	0	0	5	1,357
24023036001	1,392	20	184	1	2	6	1,605
24023036002	976	0	97	0	0	3	1,076
24023060001	1,463	0	49	1	1	8	1,522
24023060003	659	0	31	0	0	2	693
24023060004	1,014	9	81	7	7	8	1,125
24025080001	1,010	103	89	0	1	18	1,220
24025080002	999	0	92	8	11	23	1,134
24025080100	546	0	207	0	2	32	786
24025080200	598	23	149	0	2	7	778
24025081000	564	5	153	1	3	37	762
24025081100	943	4	115	16	21	56	1,155
24025081200	351	0	180	0	2	34	567
24025082001	697	0	114	11	14	22	857
24025082002	597	143	105	1	2	22	870
24025082500	1,329	48	86	3	3	13	1,481
24025083001	915	0	138	0	2	27	1,081
24025083002	469	84	111	6	7	40	717
24025083501	1,164	36	48	4	4	18	1,274
24025083503	1,122	10	64	1	1	6	1,203
24025083504	686	0	45	1	1	5	738
24025083505	868	0	32	0	0	3	903
24025084001	774	14	176	3	4	53	1,024

24025084002	560	0	155	5	6	26	752
24025084501	1,421	31	95	1	1	13	1,562
24025084502	278	15	13	0	0	1	307
24025084602	1,245	0	103	0	1	7	1,356
24025084603	316	26	23	0	0	0	364
24025084604	1,235	0	191	1	1	10	1,437
24025085001	1,612	9	65	0	1	13	1,699
24025085002	437	0	34	0	0	8	479
24033003007	276	8	9	0	0	0	293
24033003017	365	4	11	0	0	1	382
24033003025	319	0	13	0	1	0	333
24033003030	284	4	3	0	0	1	291
24033003035	530	25	17	0	0	2	574
24033003040	290	0	4	0	0	2	296
24033003045	740	0	53	0	1	7	801
24033003052	340	0	22	1	2	2	366
24033003060	433	27	49	0	1	7	517
24033003065	269	0	7	0	0	1	277
24033003070	295	0	7	0	0	1	302
24033003080	355	14	10	0	2	2	383
24033003085	211	0	2	0	0	0	214
24033003090	1,050	11	58	0	1	9	1,130
24033003095	468	0	13	0	1	1	482
24033003102	581	4	48	0	0	8	640
24033003115	315	5	12	0	0	2	333
24033003123	215	5	3	0	0	0	223
24034004007	946	0	42	0	0	1	989
24034004017	1,637	11	150	0	1	7	1,807
24034004025	1,196	0	226	0	2	18	1,442
24034004030	793	4	35	0	1	3	836
24034004038	801	4	43	0	0	3	851
24034004048	924	18	84	0	1	4	1,031
24034004058	562	13	30	1	1	4	610
24034004060	96	0	3	0	0	0	98
24034004065	723	4	90	0	1	4	822
24034004078	488	5	36	0	1	4	534
24034004085	115	5	0	0	0	0	120
24034004090	484	0	22	0	1	1	508
24034004097	391	13	19	0	0	0	423
24034004105	186	4	0	0	0	0	190
24034004115	355	0	12	0	0	1	367
24034004120	142	0	2	0	0	0	144
24034004128	2,438	37	219	2	2	16	2,713
24034004135	221	0	12	0	0	0	233

24034004902	0	0	0	0	0	0	0
24034004904	0	0	0	0	0	0	0
24034004906	0	0	0	0	0	0	0
24035005005	346	10	18	0	0	0	373
24035005010	411	0	24	0	0	2	437
24035005015	310	9	13	2	3	0	335
24035005020	288	0	7	0	0	1	296
24035005027	1,129	9	122	3	3	9	1,275
24035005035	462	0	12	0	0	0	474
24035005040	141	0	5	0	1	0	147
24035005045	120	0	0	0	0	0	120
24035005050	796	9	50	2	3	4	864
24035005055	132	3	0	0	0	0	135
24035005902	0	0	0	0	0	0	0
24090000801	0	0	0	0	0	0	0
24090000804	111	0	5	0	0	0	116
24091001005	365	4	30	0	1	3	403
24091001010	138	4	7	0	0	0	149
24091001015	159	4	12	0	0	2	177
24091001020	388	0	53	0	0	2	443
24091001025	1,959	154	308	4	5	57	2,487
24091001030	254	4	7	0	0	1	267
24091001035	560	23	47	1	1	4	636
24091001042	2,102	215	223	2	5	32	2,578
24091001050	420	32	22	0	0	3	477
24091001802	276	13	18	2	3	1	313
24092002005	121	0	7	0	0	0	129
24092002010	169	0	11	0	0	0	180
24092002015	288	33	21	0	0	1	343
24092002022	2,791	116	426	5	7	68	3,413
24092002030	642	0	19	1	2	2	665
24092002040	866	52	97	1	2	6	1,024
24092002045	236	0	11	0	0	0	246
24092002050	145	5	5	0	0	0	155
24092002055	366	18	16	0	0	1	402
24092002060	75	0	0	0	0	0	75
24092002065	139	8	13	0	0	1	161
24092002070	115	0	0	0	0	0	115
24093003005	269	4	40	0	0	3	317
24093003012	930	8	111	2	3	7	1,060
24093003020	598	8	58	1	1	3	669
24093003025	293	14	40	1	1	3	352
24093003030	434	28	68	0	1	5	536
24093003035	479	8	28	1	1	1	517

24093003042	5,102	68	1,082	13	19	122	6,407
24093003045	467	4	54	0	0	1	526
24093003055	317	15	17	0	0	0	349
24093003060	150	0	13	0	0	0	163
24093003065	468	0	40	1	1	2	511
24093003070	225	4	11	0	0	0	240
24093003075	210	0	25	1	2	1	237
24093003080	200	4	15	0	0	1	220
24093003902	0	0	0	0	0	0	0
24093003904	0	0	0	0	0	0	0
24093003906	0	0	0	0	0	0	0
24093003908	0	0	0	0	0	0	0
24094000100	779	23	252	0	1	17	1,073
24094000201	559	0	82	11	15	14	681
24094000202	484	0	135	3	4	34	661
24094000301	810	4	137	2	3	14	969
24094000302	569	0	93	2	3	8	675
24094000400	452	0	117	1	1	48	619
24094000500	394	5	210	7	9	32	656
24094000600	114	0	128	0	0	45	287
24094000700	180	0	138	2	3	17	339
24094000800	822	0	255	11	12	18	1,117
24094004205	200	0	45	1	1	0	247
24094004210	289	4	27	0	0	2	322
24094004215	129	4	6	0	0	1	139
24094004220	163	0	7	0	1	0	171
24094004225	291	0	14	0	0	1	306
24094004230	108	0	9	0	0	0	117
24094004245	732	0	52	0	1	2	787
24094004250	246	0	25	0	0	0	271
24094004255	842	75	59	2	3	3	983
24094004260	148	0	11	0	0	0	160
24094004926	0	0	0	0	0	0	0
24094004928	0	0	0	0	0	0	0
24094010000	1,001	0	115	0	0	7	1,122
24094010100	780	0	252	9	12	24	1,077
24094010200	600	0	167	3	4	8	781
24094010300	1,175	0	206	1	2	17	1,400
24094010400	1,557	0	282	5	6	14	1,865
24094010500	363	0	228	1	3	31	625
24094010600	512	0	260	3	6	24	804
24094010702	680	71	151	4	6	12	923
24094010703	1,146	4	249	2	7	35	1,442
24094010704	219	0	30	0	0	2	251

24094010800	164	0	130	1	3	33	330
24094010900	147	0	138	1	2	25	312
24094011000	1,023	0	184	0	1	27	1,235
24094011102	914	4	55	0	0	1	973
24094012001	696	4	37	0	1	1	738
24094012002	1,503	124	220	0	2	6	1,855
24094013000	1,006	0	177	9	10	13	1,215
24094013100	912	0	115	1	1	13	1,041
24094013200	877	0	116	0	2	7	1,001
24094013300	649	0	123	0	1	14	787
24094014000	847	83	134	2	3	4	1,073
24094015000	1,063	31	123	1	1	5	1,223
24094016000	1,018	4	337	6	10	28	1,403
24094016100	365	185	123	8	9	7	697
24094016200	1,029	4	322	2	3	32	1,392
24094016300	579	0	109	1	2	6	695
24094016400	565	22	49	0	0	3	639

Table B-3: Adjusted 1988 building distribution by construction type.

Tract	W1	C1L	C2L	S2L	RM1L	RM2L	URML	MH	Total
24012002010	467	0	0	1	1	1	9	9	489
24012002015	940	1	1	2	3	2	20	0	968
24012002020	267	0	0	0	0	0	4	4	277
24012002025	98	0	0	0	0	0	2	5	105
24012002030	313	0	0	0	1	0	5	0	320
24012002035	150	0	0	0	0	0	2	5	158
24012002043	531	0	0	0	1	1	9	0	542
24012002045	20	0	0	0	0	0	0	0	20
24012002055	323	1	1	1	2	1	10	0	337
24012002060	210	0	0	0	0	0	3	0	214
24012002065	287	0	0	1	1	1	7	0	297
24012002072	3,222	11	11	17	30	23	151	32	3,497
24012002080	355	0	0	0	1	1	7	59	424
24012002802	0	0	0	0	0	0	0	0	0
24012002804	0	0	0	0	0	0	0	0	0
24014004005	412	0	0	0	0	0	5	4	423
24014004010	185	0	0	0	0	0	2	0	188
24014004018	1,026	2	2	3	6	4	33	5	1,080
24014004025	267	0	0	0	1	1	6	4	280
24014004030	145	0	0	0	0	0	2	0	148
24014004035	487	1	1	1	2	1	13	9	514
24014004040	162	0	0	0	0	0	4	4	171

24014004045	91	0	0	0	0	0	2	0	94
24014004050	237	0	0	0	0	0	3	5	245
24014004055	167	0	0	0	0	0	2	4	174
24014004060	283	1	1	1	1	1	8	5	300
24014004065	343	0	0	0	1	0	6	9	360
24014004070	487	1	1	1	1	1	10	4	507
24014004075	290	0	0	0	1	0	5	10	307
24014004080	202	0	0	0	0	0	3	0	206
24014004085	929	3	3	4	8	6	40	23	1,015
24014004090	507	0	0	0	1	1	8	17	535
24014004902	0	0	0	0	0	0	0	0	0
24014004904	0	0	0	0	0	0	0	0	0
24015005005	260	0	0	0	0	0	5	0	266
24015005013	2,170	5	5	7	13	10	74	46	2,331
24015005025	121	1	1	2	3	2	13	0	143
24015005030	302	1	1	1	1	1	9	21	336
24015005035	700	2	2	3	6	4	30	56	804
24015005058	349	1	1	1	2	1	11	17	383
24015005065	81	0	0	0	0	0	1	0	83
24015005902	40	0	0	0	0	0	0	0	40
24015005904	45	0	0	0	0	0	0	5	50
24016006005	169	0	0	0	1	1	5	0	176
24016006013	1,644	5	5	8	13	10	70	16	1,771
24016006023	433	1	1	1	2	1	10	4	452
24016006048	412	0	0	1	1	1	8	0	423
24016006050	306	0	0	1	1	1	7	17	333
24016006055	430	1	1	2	3	2	16	4	458
24016006902	0	0	0	0	0	0	0	0	0
24017007005	136	0	0	0	0	0	2	0	138
24017007010	753	1	1	2	3	3	21	17	801
24017007015	208	0	0	0	0	0	2	0	210
24017007020	180	0	0	0	0	0	2	0	183
24017007025	151	0	0	0	0	0	2	9	163
24017007030	564	1	1	1	2	2	14	4	588
24017007035	217	0	0	0	0	0	3	0	220
24017007040	204	0	0	0	0	0	3	0	208
24017007045	312	0	0	0	0	0	5	5	324
24017007055	499	0	0	0	0	0	7	14	521
24017007060	234	0	0	0	0	0	4	5	243
24017007065	314	0	0	1	1	1	8	5	330
24017007070	956	2	2	3	5	4	28	9	1,008
24017007078	1,173	1	1	2	4	3	28	4	1,217
24018008015	311	0	0	0	1	1	6	0	320
24018008020	132	0	0	0	0	0	2	0	135

24018008025	220	0	0	0	0	0	4	5	231
24018008030	296	0	0	0	0	0	5	4	306
24018008035	153	0	0	0	0	0	2	5	160
24018008040	175	0	0	0	0	0	2	0	178
24018008045	950	1	1	2	3	2	22	9	990
24018008050	2,629	9	9	14	24	18	123	0	2,826
24018008055	325	0	0	0	1	0	5	0	332
24018008060	422	1	1	1	1	1	10	0	436
24018008065	365	0	0	1	1	1	9	0	378
24018008070	64	0	0	0	0	0	1	5	70
24019009005	258	0	0	0	0	0	4	4	268
24019009010	290	0	0	0	0	0	3	5	299
24019009015	124	0	0	0	0	0	1	0	125
24019009020	452	0	0	0	1	1	8	0	463
24019009025	393	0	0	0	0	0	5	12	410
24019009030	556	1	1	1	2	2	14	5	580
24019009037	564	0	0	1	1	1	10	9	586
24019009045	287	0	0	0	0	0	3	0	290
24019009050	365	0	0	0	0	0	5	4	376
24019009055	854	1	1	2	4	3	23	17	906
24019009062	820	1	1	2	3	3	21	26	878
24019009070	239	0	0	0	0	0	4	0	243
24019009075	573	0	0	1	1	1	10	19	605
24019009082	737	1	1	1	1	1	13	27	781
24019009090	176	0	0	0	0	0	3	11	192
24019009097	631	0	0	1	1	1	11	4	650
24019009110	497	1	1	1	1	1	10	4	516
24019009117	324	0	0	0	1	1	7	4	338
24019070000	608	0	0	1	1	1	10	4	625
24019090000	1,055	1	1	2	3	2	23	0	1,088
24020054000	2,222	2	2	3	6	5	47	9	2,297
24021001005	446	1	1	1	2	2	14	0	467
24021001010	727	1	1	2	3	2	19	0	755
24021001015	0	0	0	0	0	0	0	0	0
24021001020	364	1	1	1	2	1	11	0	381
24021001025	705	2	2	3	6	4	29	17	768
24021001030	617	3	3	4	7	5	34	36	708
24021001902	0	0	0	0	0	0	0	0	0
24021001904	0	0	0	0	0	0	0	0	0
24021050000	1,077	1	1	2	3	2	24	0	1,110
24021051000	766	2	2	3	5	3	26	51	856
24021053000	874	1	1	2	4	3	24	291	1,201
24022002902	0	0	0	0	0	0	0	0	0
24022019000	504	1	1	1	2	2	14	11	537

24022020000	1,465	1	1	1	2	2	23	21	1,515
24022021002	113	1	1	1	1	1	7	0	124
24022037000	1,391	0	0	0	0	0	16	0	1,409
24022052000	991	1	1	1	2	2	18	0	1,016
24022060500	1,543	1	1	1	2	2	26	150	1,726
24022061000	656	2	2	3	5	3	25	18	712
24023000101	164	2	2	3	6	4	24	0	206
24023000102	354	3	3	5	8	6	37	0	417
24023000200	276	2	2	3	6	4	26	0	319
24023000300	218	3	3	5	8	6	35	0	279
24023000400	72	1	1	1	2	2	11	0	91
24023000500	118	2	2	3	6	5	25	0	161
24023000600	127	3	3	4	7	6	31	0	181
24023000700	154	3	3	5	8	6	35	0	215
24023000800	90	2	2	3	5	4	20	0	126
24023000900	173	3	3	4	8	6	32	0	229
24023001000	170	4	4	6	10	8	43	0	245
24023001100	130	3	3	4	7	5	28	0	179
24023001200	170	3	3	4	7	6	31	0	223
24023001300	158	2	2	4	6	5	27	0	204
24023001400	61	1	1	2	3	2	12	0	81
24023001500	64	1	1	2	3	2	12	0	85
24023001600	90	2	2	3	5	3	19	0	123
24023001700	2	0	0	0	0	0	1	0	3
24023001800	31	1	1	1	2	1	8	0	45
24023001900	89	1	1	2	4	3	17	0	118
24023002000	93	1	1	2	4	3	15	0	119
24023002100	45	1	1	1	2	2	10	0	63
24023002200	66	1	1	2	3	2	13	4	94
24023002300	13	0	0	0	1	1	3	0	18
24023002400	10	0	0	1	1	1	4	0	17
24023002500	7	0	0	0	1	0	2	0	11
24023002600	293	5	5	8	14	11	59	0	396
24023002700	68	1	1	2	3	3	15	5	98
24023002800	84	2	2	2	4	3	18	0	116
24023002900	61	1	1	2	4	3	16	0	88
24023003000	150	4	4	6	10	8	41	0	222
24023003100	149	3	3	5	9	7	36	0	211
24023003200	16	0	0	1	1	1	5	0	24
24023003301	159	3	3	4	7	5	29	0	209
24023003302	406	4	4	5	9	7	41	0	476
24023003400	312	4	4	6	10	8	44	0	387
24023003500	115	2	2	3	6	5	25	0	159
24023003600	391	5	5	8	13	10	57	0	489

24023003700	252	4	4	5	10	7	41	0	322
24023003801	149	3	3	4	7	5	29	0	199
24023003802	262	3	3	5	9	7	39	0	329
24023003901	1,383	8	8	12	22	17	102	0	1,553
24023003902	617	3	3	4	7	5	34	0	672
24023004001	930	3	3	4	8	6	40	0	994
24023004002	360	6	6	9	15	11	64	0	470
24023004101	736	5	5	7	12	9	55	0	828
24023004102	518	2	2	3	5	4	27	0	562
24023004103	308	0	0	1	1	1	7	4	322
24023004104	1,181	4	4	7	12	9	58	0	1,274
24023004105	899	4	4	5	9	7	47	0	975
24023004106	778	2	2	3	5	4	29	0	823
24023004107	690	2	2	3	5	4	26	0	731
24023010000	298	2	2	3	5	3	21	0	333
24023010100	1,242	2	2	3	4	3	30	0	1,286
24023010200	316	2	2	2	4	3	20	0	349
24023010300	532	2	2	3	5	4	25	0	572
24023011000	1,110	2	2	3	5	4	31	0	1,156
24023011100	1,043	2	2	3	5	4	32	0	1,091
24023011201	484	3	3	4	7	5	31	0	536
24023011202	446	2	2	3	6	4	28	0	492
24023011301	374	2	2	4	6	5	30	0	424
24023011302	965	4	4	5	9	7	48	0	1,042
24023011400	652	3	3	4	8	6	37	0	712
24023011500	329	2	2	3	5	4	24	0	370
24023011600	353	3	3	5	9	7	38	0	418
24023011700	784	3	3	5	9	7	43	0	854
24023011800	934	3	3	4	8	6	41	0	999
24023011902	1,121	5	5	7	12	9	59	286	1,502
24023011903	1,138	3	3	5	9	7	46	12	1,222
24023011904	633	2	2	3	5	4	27	15	692
24023012001	879	3	3	5	9	7	44	0	951
24023012002	1,146	2	2	3	6	5	36	0	1,201
24023012003	1,090	3	3	4	7	5	39	0	1,151
24023014001	1,364	2	2	3	5	4	35	6	1,421
24023014002	734	3	3	5	9	7	42	8	810
24023014003	1,206	4	4	6	10	8	53	4	1,294
24023016001	960	3	3	5	9	7	44	0	1,032
24023016002	953	3	3	5	8	6	43	4	1,026
24023016003	1,012	3	3	4	7	5	38	0	1,071
24023017003	844	3	3	4	7	5	36	4	906
24023017004	478	1	1	2	3	2	17	0	504
24023017005	780	2	2	4	6	5	33	0	832

24023017006	923	2	2	3	6	4	32	0	972
24023017007	708	2	2	2	4	3	24	0	746
24023021001	824	1	1	1	2	1	16	189	1,034
24023021002	1,168	2	2	3	5	4	31	8	1,223
24023022001	1,165	4	4	6	11	9	57	0	1,257
24023022002	1,179	3	3	5	9	7	48	172	1,427
24023023001	908	4	4	6	11	8	52	0	994
24023023002	675	1	1	2	4	3	22	31	740
24023024001	864	3	3	5	9	7	44	0	936
24023024002	297	2	2	3	5	4	24	0	337
24023026001	202	4	4	6	11	8	46	0	283
24023026002	173	3	3	5	9	7	38	0	239
24023026003	341	4	4	6	10	7	42	0	413
24023027001	370	4	4	6	10	8	44	0	445
24023027002	435	4	4	7	12	9	51	0	522
24023027101	1,079	1	1	2	4	3	25	0	1,116
24023027102	888	2	2	3	5	4	30	0	933
24023027200	273	2	2	2	4	3	19	0	305
24023027301	401	2	2	3	6	4	27	0	447
24023027302	726	2	2	3	5	4	28	5	775
24023027303	1,101	2	2	3	6	5	35	0	1,155
24023027304	1,001	2	2	3	6	4	32	0	1,051
24023028001	1,050	2	2	3	6	4	34	0	1,102
24023028002	1,174	3	3	4	7	5	40	0	1,236
24023028003	1,055	3	3	5	9	7	46	0	1,129
24023029001	450	2	2	3	5	4	24	0	489
24023029002	717	3	3	4	7	5	36	0	774
24023030000	362	1	1	1	2	2	12	0	380
24023031000	228	3	3	5	9	7	37	0	291
24023031101	412	5	5	7	12	9	52	0	501
24023031102	394	2	2	4	6	5	29	5	446
24023032001	1,235	6	6	9	16	12	75	0	1,359
24023032002	1,055	4	4	6	10	7	50	5	1,140
24023032003	608	3	3	4	7	5	35	0	665
24023032004	737	2	2	3	6	5	31	0	787
24023032005	749	1	1	2	3	2	18	0	775
24023032007	897	1	1	2	4	3	25	0	934
24023032008	718	1	1	2	3	3	20	0	749
24023033000	307	4	4	6	11	8	47	0	389
24023034001	453	2	2	3	5	4	24	0	492
24023034002	681	4	4	6	10	8	48	0	761
24023034003	1,305	2	2	3	5	4	35	0	1,357
24023036001	1,498	4	4	6	10	8	56	20	1,605
24023036002	1,028	2	2	3	5	4	31	0	1,076

24023060001	1,485	1	1	2	3	2	27	0	1,522
24023060003	673	1	1	1	2	1	14	0	693
24023060004	1,067	2	2	3	5	4	32	9	1,125
24025080001	1,067	2	2	3	6	4	34	103	1,220
24025080002	1,073	3	3	4	7	5	39	0	1,134
24025080100	689	5	5	7	13	10	58	0	786
24025080200	690	3	3	5	8	6	40	23	778
24025081000	678	4	4	6	10	8	48	5	762
24025081100	1,063	4	4	6	11	8	55	4	1,155
24025081200	482	4	4	6	11	9	50	0	567
24025082001	789	3	3	5	8	6	42	0	857
24025082002	672	3	3	4	7	5	34	143	870
24025082500	1,381	2	2	3	6	4	36	48	1,481
24025083001	1,009	3	3	5	9	7	45	0	1,081
24025083002	566	3	3	5	9	7	40	84	717
24025083501	1,198	1	1	2	4	3	28	36	1,274
24025083503	1,155	1	1	2	4	3	27	10	1,203
24025083504	711	1	1	2	3	2	18	0	738
24025083505	881	1	1	1	2	1	16	0	903
24025084001	913	5	5	7	12	10	59	14	1,024
24025084002	674	4	4	6	10	8	47	0	752
24025084501	1,475	2	2	3	6	4	38	31	1,562
24025084502	284	0	0	0	1	1	6	15	307
24025084602	1,302	2	2	3	6	4	37	0	1,356
24025084603	327	0	0	1	1	1	8	26	364
24025084604	1,348	4	4	6	11	8	56	0	1,437
24025085001	1,645	2	2	2	4	3	33	9	1,699
24025085002	459	1	1	1	2	2	14	0	479
24033003007	279	0	0	0	0	0	5	8	293
24033003017	369	0	0	0	1	0	6	4	382
24033003025	325	0	0	0	1	1	6	0	333
24033003030	283	0	0	0	0	0	4	4	291
24033003035	536	0	0	1	1	1	9	25	574
24033003040	291	0	0	0	0	0	4	0	296
24033003045	770	1	1	2	3	2	21	0	801
24033003052	353	1	1	1	1	1	9	0	366
24033003060	464	1	1	2	3	2	17	27	517
24033003065	272	0	0	0	0	0	4	0	277
24033003070	297	0	0	0	0	0	5	0	302
24033003080	360	0	0	0	1	1	7	14	383
24033003085	211	0	0	0	0	0	3	0	214
24033003090	1,082	1	1	2	4	3	25	11	1,130
24033003095	472	0	0	0	1	1	8	0	482
24033003102	609	1	1	2	3	2	18	4	640

24033003115	320	0	0	0	1	1	6	5	333
24033003123	215	0	0	0	0	0	3	5	223
24034004007	963	1	1	1	2	2	19	0	989
24034004017	1,719	3	3	5	8	6	51	11	1,807
24034004025	1,337	5	5	7	13	10	65	0	1,442
24034004030	809	1	1	1	2	2	16	4	836
24034004038	822	1	1	1	2	2	18	4	851
24034004048	970	2	2	3	5	4	29	18	1,031
24034004058	578	1	1	1	2	1	13	13	610
24034004060	96	0	0	0	0	0	2	0	98
24034004065	774	2	2	3	5	4	28	4	822
24034004078	508	1	1	1	2	2	14	5	534
24034004085	114	0	0	0	0	0	1	5	120
24034004090	494	0	0	1	1	1	10	0	508
24034004097	399	0	0	1	1	1	8	13	423
24034004105	184	0	0	0	0	0	2	4	190
24034004115	359	0	0	0	1	1	6	0	367
24034004120	142	0	0	0	0	0	2	0	144
24034004128	2,561	5	5	7	13	10	76	37	2,713
24034004135	226	0	0	0	1	0	5	0	233
24034004902	0	0	0	0	0	0	0	0	0
24034004904	0	0	0	0	0	0	0	0	0
24034004906	0	0	0	0	0	0	0	0	0
24035005005	354	0	0	1	1	1	7	10	373
24035005010	423	1	1	1	1	1	10	0	437
24035005015	317	0	0	1	1	1	7	9	335
24035005020	290	0	0	0	0	0	5	0	296
24035005027	1,203	3	3	4	7	6	41	9	1,275
24035005035	465	0	0	0	1	0	7	0	474
24035005040	143	0	0	0	0	0	3	0	147
24035005045	119	0	0	0	0	0	1	0	120
24035005050	825	1	1	2	3	2	21	9	864
24035005055	130	0	0	0	0	0	1	3	135
24035005902	0	0	0	0	0	0	0	0	0
24090000801	0	0	0	0	0	0	0	0	0
24090000804	113	0	0	0	0	0	2	0	116
24091001005	383	1	1	1	2	1	11	4	403
24091001010	141	0	0	0	0	0	3	4	149
24091001015	166	0	0	0	1	1	4	4	177
24091001020	418	1	1	2	3	2	16	0	443
24091001025	2,172	7	7	11	20	15	101	154	2,487
24091001030	257	0	0	0	0	0	4	4	267
24091001035	587	1	1	2	3	2	17	23	636
24091001042	2,243	5	5	8	14	11	78	215	2,578

24091001050	431	0	0	1	1	1	10	32	477
24091001802	288	0	0	1	1	1	8	13	313
24092002005	125	0	0	0	0	0	3	0	129
24092002010	174	0	0	0	1	0	4	0	180
24092002015	299	0	0	1	1	1	8	33	343
24092002022	3,076	10	10	15	27	20	138	116	3,413
24092002030	650	0	0	1	1	1	11	0	665
24092002040	923	2	2	3	6	4	32	52	1,024
24092002045	240	0	0	0	1	0	5	0	246
24092002050	147	0	0	0	0	0	3	5	155
24092002055	373	0	0	1	1	1	7	18	402
24092002060	74	0	0	0	0	0	1	0	75
24092002065	146	0	0	0	1	1	4	8	161
24092002070	114	0	0	0	0	0	1	0	115
24093003005	293	1	1	1	2	2	12	4	317
24093003012	996	2	2	4	6	5	36	8	1,060
24093003020	631	1	1	2	3	2	19	8	669
24093003025	318	1	1	1	2	2	13	14	352
24093003030	476	1	1	2	4	3	20	28	536
24093003035	493	1	1	1	2	1	11	8	517
24093003042	5,818	25	25	37	65	50	319	68	6,407
24093003045	496	1	1	2	3	2	17	4	526
24093003055	325	0	0	1	1	1	7	15	349
24093003060	156	0	0	0	1	1	4	0	163
24093003065	490	1	1	1	2	2	14	0	511
24093003070	229	0	0	0	1	0	5	4	240
24093003075	225	1	1	1	1	1	8	0	237
24093003080	208	0	0	0	1	1	5	4	220
24093003902	0	0	0	0	0	0	0	0	0
24093003904	0	0	0	0	0	0	0	0	0
24093003906	0	0	0	0	0	0	0	0	0
24093003908	0	0	0	0	0	0	0	0	0
24094000100	939	5	5	8	14	11	66	23	1,073
24094000201	629	2	2	4	6	5	32	0	681
24094000202	589	4	4	5	9	7	43	0	661
24094000301	898	3	3	5	8	6	42	4	969
24094000302	629	2	2	3	6	4	29	0	675
24094000400	551	3	3	5	9	7	41	0	619
24094000500	549	5	5	8	14	10	60	5	656
24094000600	220	3	3	5	9	7	39	0	287
24094000700	277	3	3	5	8	6	36	0	339
24094000800	997	6	6	9	16	12	72	0	1,117
24094004205	227	1	1	1	2	2	12	0	247
24094004210	304	1	1	1	2	1	9	4	322

24094004215	132	0	0	0	0	0	3	4	139
24094004220	166	0	0	0	0	0	3	0	171
24094004225	297	0	0	0	1	1	6	0	306
24094004230	113	0	0	0	0	0	3	0	117
24094004245	759	1	1	2	3	2	19	0	787
24094004250	259	1	1	1	1	1	8	0	271
24094004255	874	1	1	2	3	3	23	75	983
24094004260	154	0	0	0	1	0	4	0	160
24094004926	0	0	0	0	0	0	0	0	0
24094004928	0	0	0	0	0	0	0	0	0
24094010000	1,066	2	2	4	6	5	36	0	1,122
24094010100	956	6	6	9	16	12	72	0	1,077
24094010200	706	4	4	5	10	7	45	0	781
24094010300	1,303	5	5	7	12	9	61	0	1,400
24094010400	1,733	6	6	9	16	12	82	0	1,865
24094010500	522	5	5	8	14	11	61	0	625
24094010600	688	6	6	9	15	12	69	0	804
24094010702	780	3	3	5	9	7	44	71	923
24094010703	1,315	6	6	9	15	12	75	4	1,442
24094010704	237	1	1	1	2	1	9	0	251
24094010800	266	3	3	5	9	7	38	0	330
24094010900	248	3	3	5	9	7	37	0	312
24094011000	1,144	4	4	6	11	9	56	0	1,235
24094011102	939	1	1	2	3	2	21	4	973
24094012001	713	1	1	1	2	2	15	4	738
24094012002	1,629	5	5	7	12	9	64	124	1,855
24094013000	1,126	4	4	6	11	8	55	0	1,215
24094013100	983	3	3	4	7	5	37	0	1,041
24094013200	945	2	2	4	7	5	36	0	1,001
24094013300	728	3	3	4	7	6	36	0	787
24094014000	927	3	3	4	8	6	39	83	1,073
24094015000	1,132	3	3	4	7	5	39	31	1,223
24094016000	1,244	8	8	11	20	15	93	4	1,403
24094016100	452	3	3	4	8	6	36	185	697
24094016200	1,241	7	7	11	19	14	88	4	1,392
24094016300	645	2	2	3	6	5	31	0	695
24094016400	591	1	1	2	3	2	17	22	639

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