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UNDERSTANDING MODELLED EARTHQUAKE RISKS FOR BRITISH COLUMBIA - LIMITATIONS AND OPPORTUNITIES

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ABSTRACT: Modelling seismic risk at a regional scale presents both opportunities and challenges for the risk modeller and risk decision maker. The assessment of seismic risk for southwestern British Columbia was analyzed using the Canadian version of Hazus-MH, a best practices loss estimation tool developed by the US Federal Emergency Management Agency. The Geohazard Risk Project within Natural Resources Canada's Public Safety Geoscience program is tasked to implement tools for assessment of earthquake risk at regional scales. As part of the recent British Columbia earthquake preparedness consultation report, Emergency Management British Columbia and partners were recommended to develop a strategy for enhanced province wide hazard and risk and vulnerability assessment. This paper explores some of the inputs and outputs in modelling two hypothetical earthquake scenarios located in close proximity to the Metro Vancouver area and the Greater Victoria area. Lessons learned from this assessment provide an initial view of hazard and risk outputs and highlight opportunities to build on these findings.

1. Introduction

"British Columbia is not adequately prepared for a catastrophic earthquake" (OAGBC, 2014). These are the conclusions of a recent audit on Emergency Management British Columbia (EMBC). Emergency Management British Columbia (EMBC) is responsible for leading the management of provincial level emergencies and disasters and supporting other authorities within their areas of jurisdiction. As such, EMBC has made a commitment to British Columbians to develop a comprehensive earthquake plan. The BC Earthquake Immediate Response Plan (IRP) is the first component of this comprehensive plan and sets the conditions for the subsequent planning efforts: sustained response and recovery. This paper explores the assessment of the two earthquake scenarios using the loss modelling software Hazus-MH.

Hazus-MH is a geospatial modelling tool developed by the United States Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences. The software supports models for estimating physical, social and economic losses from earthquakes, floods and hurricanes. In the United States, Hazus is used to support risk assessments of regional and local mitigation plans and policies, emergency preparedness and response and recovery planning. In 2011, Natural Resources

Canada and FEMA signed a collaboration agreement to adapt Hazus for use in Canada. Hazus-MH Canada is freely available from www.hazuscanada.ca and operates on esri's ArcGIS platform. The Canadian version of Hazus supports modelling assessments for impacts to people and the built environment from earthquake and flood events.

The Public Safety Geoscience Program at Natural Resources Canada (NRCan) is responsible for ensuring Canadians are protected from natural hazards such as earthquakes, by providing information and products to other levels of government. The NRCan Risk Project recently completed a five-year Project to validate and demonstrate the use of Hazus Canada to plan and prepare for earthquake risks in a mid-sized Canadian urban community (Journeay et al., 2015). As part of a new five-year research project, the Risk Project has been tasked to implement tools for the assessment of earthquake risk at a regional/Provincial scale and work closely with partners to understand how an assessment can inform decision making. The NRCan risk team was approached by EMBC to assist in modelling earthquake risks for two catastrophic earthquake scenarios; a scenario in close proximity to the Greater Victoria area and a scenario in close proximity to Metro Vancouver. This paper will provide a first assessment of impacts and consequences from these two earthquake scenarios and share lessons learned to build upon the assessments.

2. Seismic Risk Assessment

The Pacific coast is the most earthquake-prone region in Canada. Approximately 3500 earthquakes are recorded in this region in a year (www.earthquakecanada.ca). Although few earthquakes are felt, large earthquakes have been recorded. Two "catastrophic" earthquake scenarios are modelled that impact the most densely populated regions of British Columbia. Catastrophic earthquakes are defined as extremely rare, but capable of a high number of fatalities and injuries and extensive damage to buildings and infrastructure (Russ, 2014). The recommendation to model a catastrophic earthquake came from EMBC. EMBC recently visited Christchurch, New Zealand following the 2010-2011 earthquake sequence and were advised, "that if you are prepared for the worst case earthquake scenario, you can be prepared for any earthquake".

A shallow crustal earthquake in close proximity to densely populated regions of southwestern British Columbia, could cause significant damage to urban areas. These types of earthquakes appear to be localized on faults close to the earth's surface (Hyndman et al., 2003).

2.1 Earthquake Scenarios

The earthquake hazard scenarios were modelled using the USGS ShakeMap software (Wald *et al.*, 2005). Faults used for these scenarios were modelled as arbitrary earthquake sources that would produce catastrophic impacts and would assist in conceptualizing and preparing detailed emergency management plans for the province. The scenarios are credible shake scenarios based on the knowledge of regional tectonic structures. If these events were to occur, they would be exceedingly rare. The examples selected in the study approach worst-case scenarios, and, as such, present the most challenging hazard to plan for, respond to and recover from. For both scenarios, the calculated shaking intensities were modified to include soil site amplification estimated using the standard ShakeMap topographic gradient-based V_{S30} model using 30 arcsec SRTM data (Wald and Allen, 2007; Allen and Wald, 2009).

2.2.1 Scenario 1: M7.3 Greater Vancouver

The Vancouver scenario (Figure 1a) was modelled as a shallow crustal event of magnitude 7.3. The magnitude was chosen based on the largest historical shallow earthquake in southwestern British Columbia, the M7.3 Vancouver Island earthquake in 1946. This scenario represents the maximum likely magnitude that could occur for this type of earthquake in the region. Using the recurrence parameters as proposed for the 2015 National Building Code (NBC) of Canada for the source area in which Vancouver is located (VICM; Halchuk *et al*., 2014), a shallow crustal earthquake of M7.3 might be expected approximately every 90,000 years within any 100 × 100 km area.

The size of the fault was determined from equations that relate earthquake magnitude to fault area and represents a "blind thrust fault", where the shallowest edge of the fault (northern edge) is buried beneath 1.5 km of sediment in the Georgia Basin. The fault dips from the northern edge at an angle of 30 degrees to a depth of 22 km at the southern edge with its orientation (or strike) being subparallel to Vancouver's North Shore Mountains. Ground shaking was calculated for the scenario using equations that relate the earthquake's magnitude and the fault-to-site distance to a ground-shaking intensity. The Akkar and Bommer (2007) ground-motion model (GMM) was used to estimate the ground-motion intensity measures used by Hazus-MH for loss assessment. The macroseismic intensity maps were produced through combining the Akkar and Bommer (2007) GMM with the Worden et al. (2012) intensity conversion equation.

2.2.2. Scenario 2: M7.0 Greater Victoria

The Victoria scenario (Fig. 1b) is based on the Leech River fault, a thrust fault that crosses the southern tip of Vancouver Island. Undisturbed glacial deposits show that this fault has not been active in the last 10,000 years. Based on the geometry of this structure, it is expected that M 7.0 is the largest magnitude earthquake that could occur on the fault-segment. Using the recurrence parameters as proposed for the 2015 NBC for the source area in which Victoria is located (PGT; Halchuk *et al*., 2014), a shallow crustal earthquake of M7.0 might be expected approximately every 6,000 years within any 100 × 100 km area. The same ground-motion models as used for the Vancouver example are also used in the Victoria scenario. Liquefaction hazards are included in estimating losses for the Victoria scenario and are based on the Monahan, 2001 map.

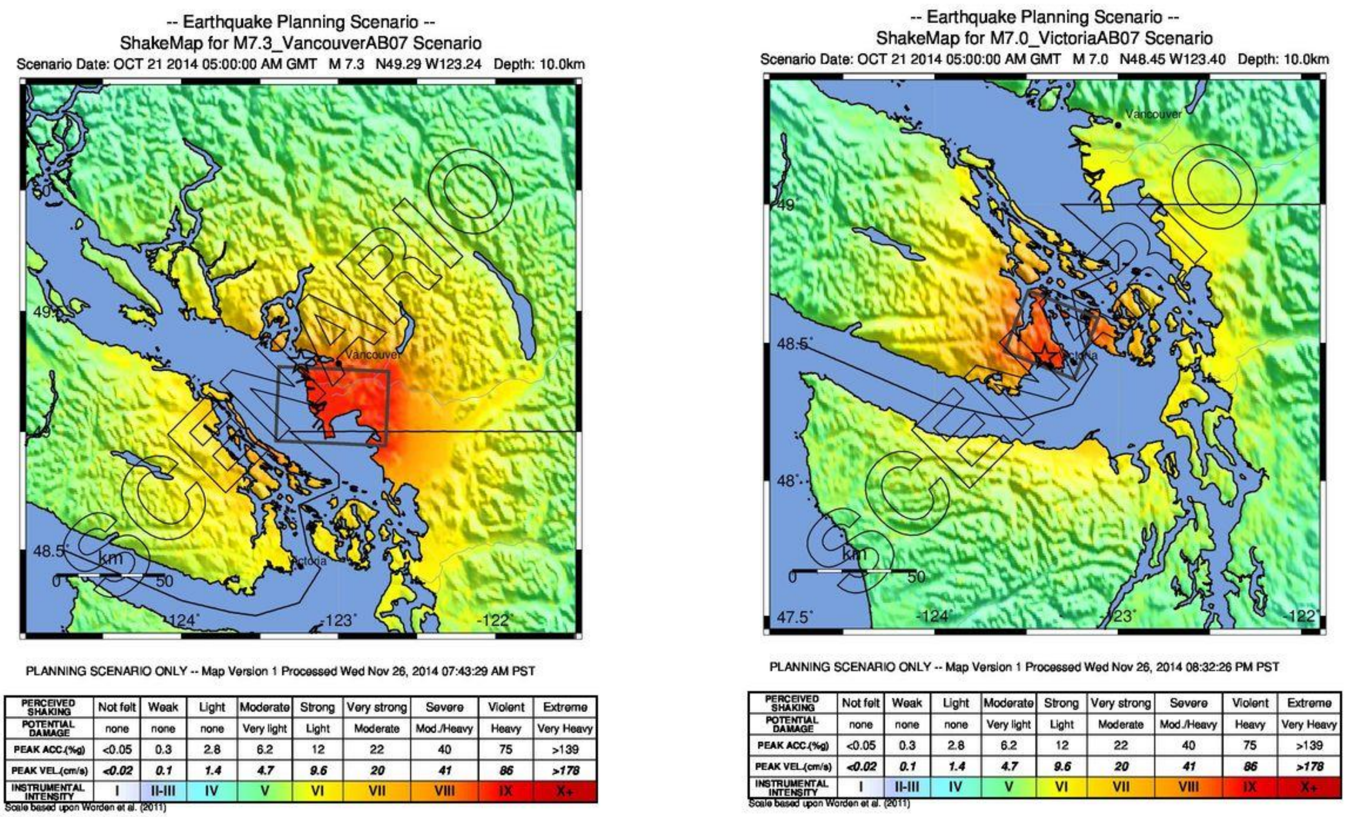

Fig. 1 – Planning scenario, shallow crustal earthquake events a) M 7.3 near Vancouver, British Columbia b) M 7.0 near Victoria, British Columbia

3. Exposure and Vulnerability

3.1 Exposure Assessment

The geographic area for the assessment was selected based on the location of specific assets in the region that are of interest to EMBC for emergency planning purposes. For this reason, the study region area extends from Courtenay, British Columbia on Vancouver Island. It includes the community of Whistler in the Northern part of the study area and is bounded in the east by the town of Hope and stretches to the Canada/U.S. border (Figure 1).

Asset information for the study area is based on datasets included in Hazus Canada. These datasets were developed using National Household Survey data from Census Canada (Statistics Canada, 2011) aggregated to census dissemination areas. Dissemination areas are the smallest geographical areas for which detailed Canadian census data is released. Aggregated information on business, commercial and industrial buildings contained in Hazus Canada are derived from datasets acquired by Dun and Bradstreet in 2013.

There are approximately 780,000 buildings in the study region (Figure 2), of which 90% are residential, 8% are commercial and 2% are industrial and other occupancy types. Of the total calculated floor area, 74% accounts for residential buildings, 20% for commercial buildings, 4% for industrial buildings and the remaining percentage for other building occupancies. There are nearly 3.5 million people who live in the region, 2.3 million people are in the Metro Vancouver area 350,000 in the Victoria Regional District and 145,000 in the Nanaimo Regional District. Datasets for essential facilities and critical transportation facilities were provided by GeoBC.

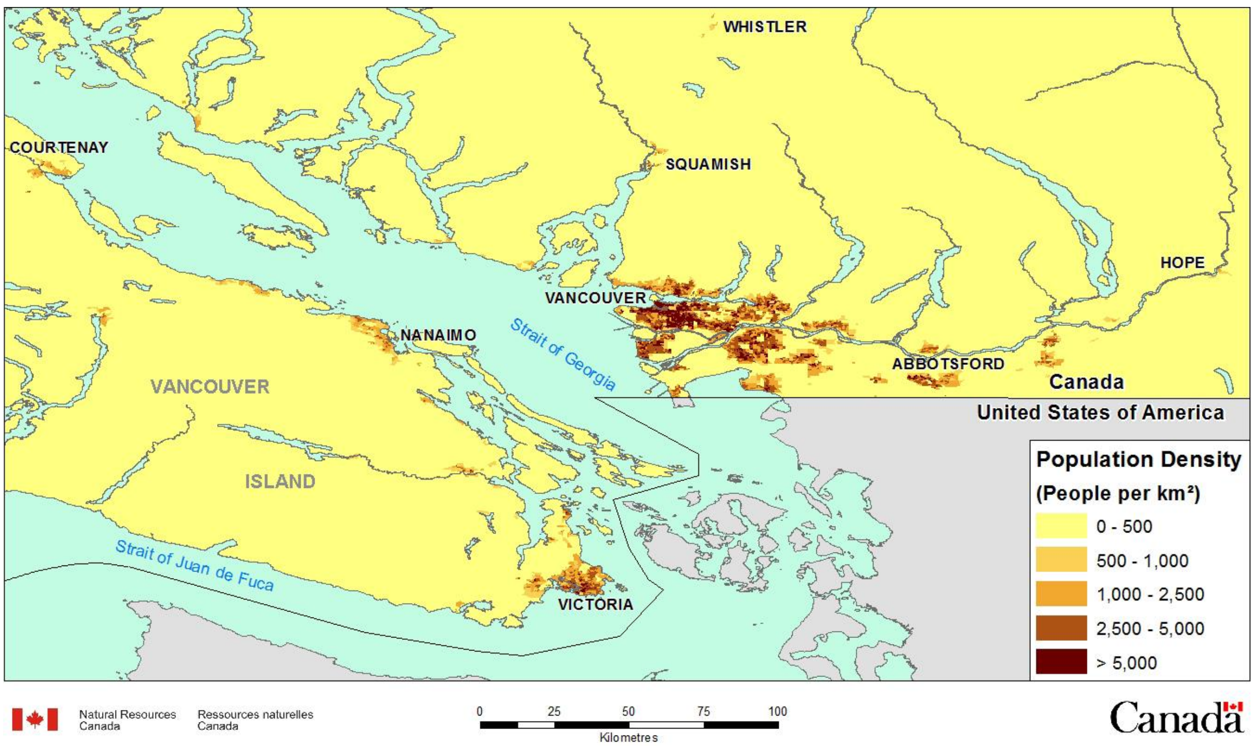

Fig. 2 – Study region map highlights population distribution of the 3.5 million people in the area.

3.2 Vulnerability

Hazus-MH assess the vulnerability of people, buildings and infrastructure for a given hazard scenario. Structures of similar building type are assigned a suite of unique fragility functions that determine the probability of exceeding a damage state for a given ground-shaking intensity. Details of the hazard/vulnerability analysis are well documented in the Hazus-MH technical manual (FEMA, 2012).

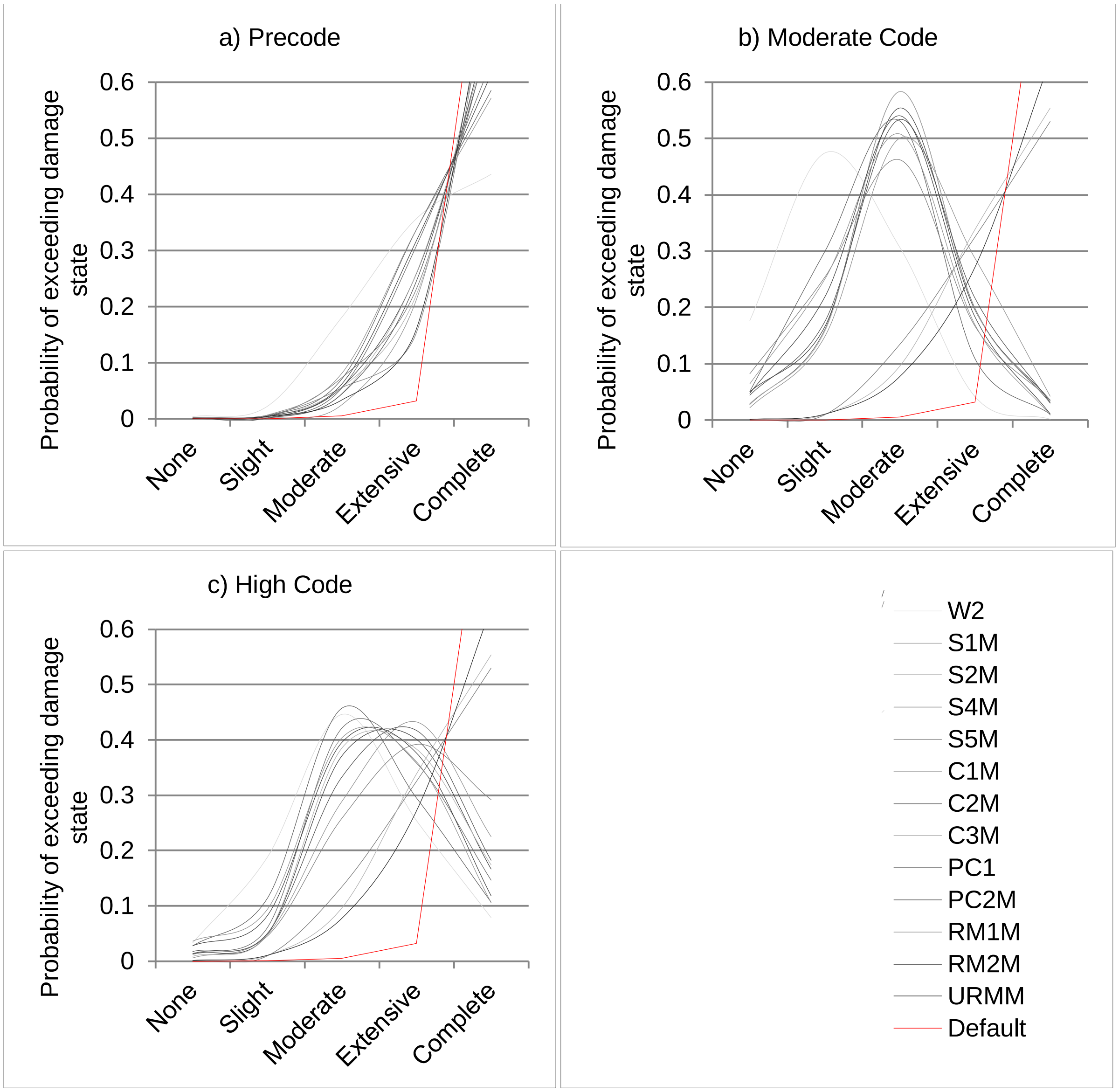

Fig. 3 – Probability of exceeding a damage state using Hazus fragility curves for a moderate sized structure given a PGA value of 0.56g, PGV value of 34 cm/sec, Sa 0.3 sec of 1.48g and Sa 1.0 sec of 0.84g for a) precode b) moderate code c) High Code. Note, the Hazus default curve (red line) is identical for all three design codes

Impacts to Essential Facilities and Transportation facilities are important for emergency planning at the regional scale. GeoBC provided basic building information for these facilities. Because information was not available on the building construction type, analysis of these structures were assessed using the default building type in Hazus. Results from this analysis indicated that ground shaking would have serious impacts to all of these essential facilities. Given the understanding that many of the essential facilities in the region are built to higher design code, this result is misleading. To understand the impacts of analyzing a building using a default building type as opposed to a specific building classification, a single structure was analyzed with Hazus for three different seismic design codes and fourteen different building construction types (Figure 3). When a building is analyzed as a default Hazus building type the probability of exceeding an extensive to complete damage state is very likely. Given these findings, EMBC and partners are currently connecting with stakeholders to acquire more detailed building construction information so that impacts and consequences of essential facilities and transportation facilities can be more appropriately modelled.

4. Impacts and Consequences

The two earthquake scenarios model very significant catastrophic impacts to British Columbia (Table 2). For the Vancouver scenario nearly 46% of structures in the study region are anticipated to suffer at least moderate structural damage. Moderately damage structures exceed the yield point of a building but do not compromise the structural integrity. Extensive damage impacts the load bearing structure beyond repair and complete damage estimates the likelihood of complete failure and potential collapse. Further studies for this assessment would improve an understanding as to what seismic design level structures in British Columbia are built to. Unreinforced masonry, concrete and older wood frame structures not built to modern seismic design codes are likely to suffer more serious damage. Non-structural impacts are not modelled in this assessment and would cause additional losses.

Table 2 – Estimated losses for Vancouver and Victoria shallow crustal earthquake scenarios.

Scenario	Estimated Building with Extensive Damage	Estimated Buildings with Complete Damage	Estimated Injury rate (people)	Estimated Fatality rate (people)	Estimated Short Term Shelter Needs	Estimated Debris (million tons)
Vancouver	18%	12%	52/1000	4/1000	4%	36
Victoria	18%	11%	52/1000	4/1000	4%	6

Injuries will greatly exceed fatalities and overwhelm first responders and medical facilities (Figures 4 and 5). Medical facilities close to the epicentre may receive the most damage, especially structures located in areas prone to liquefaction and not built to modern seismic design. Small blue boxes on the maps indicate the location of hospitals. The most significant impacts are anticipated for the downtown and densely populated areas of Vancouver and Victoria, especially where there are older more vulnerable structures not built to modern day seismic codes.

The maps highlight the directional impact from the median ground-motion intensity field. A different earthquake scenario would show a different pattern of impacts and consequences. Modelling the probabilistic hazard of all known earthquakes would help to address some of the spatial patterns anticipated from other earthquake scenarios. Alternatively, evaluating the losses for each scenario using multiple realisations of spatially correlated ground-motion fields could, at the very least, provide a sense of the uncertainty in the median loss estimates for each4/1000 scenario (e.g., Jayaram and Baker, 2009).

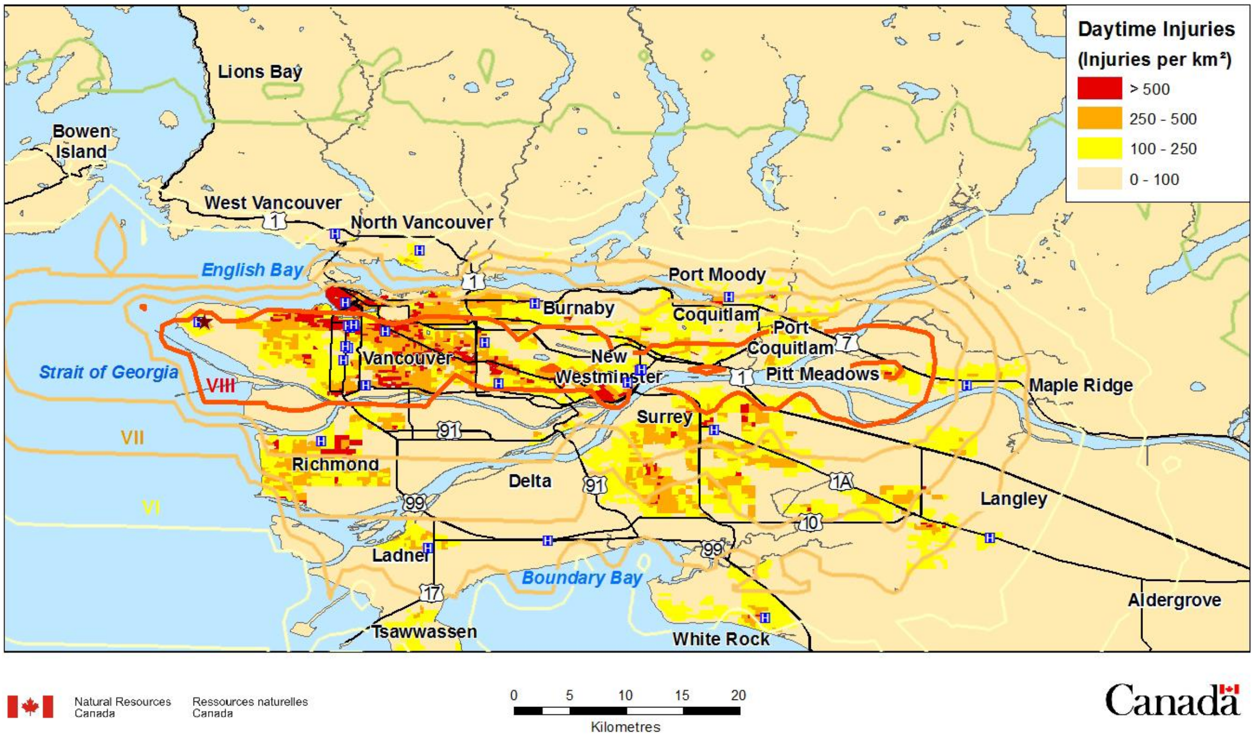

Fig. 4 – Daytime injuries for hypothetical Vancouver magnitude 7.3 scenario.

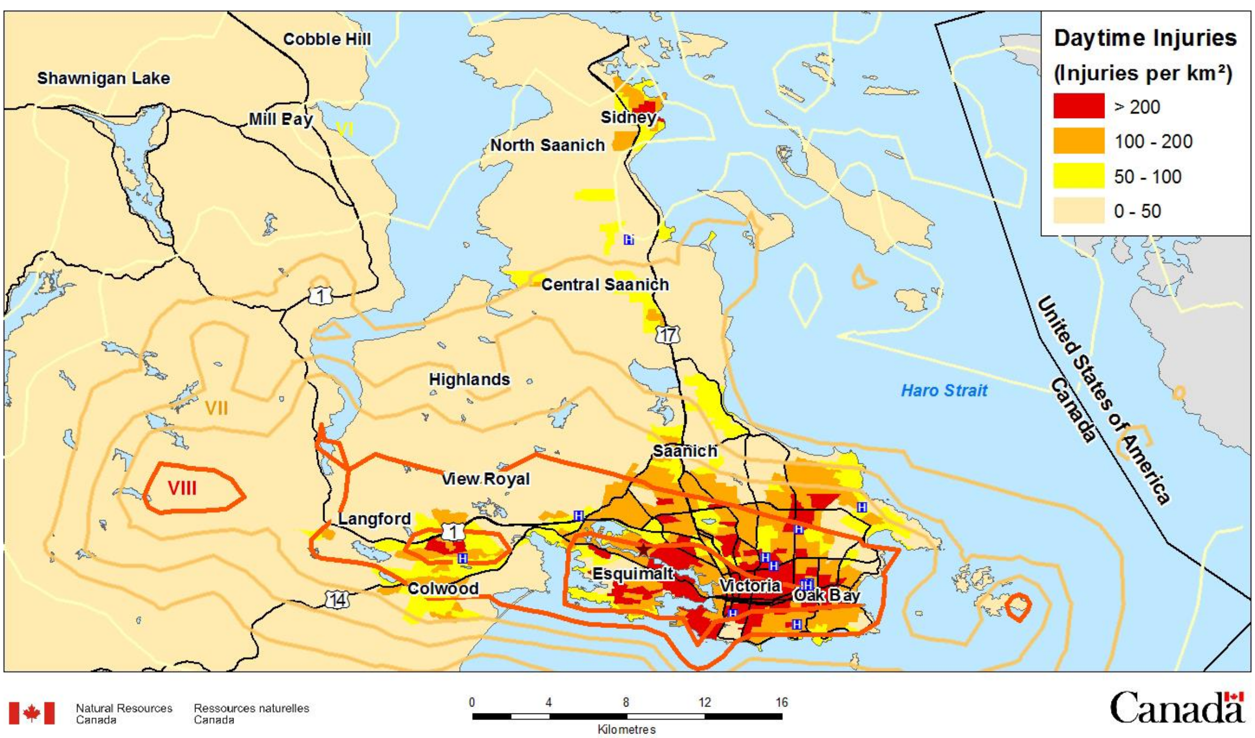

Fig. 5 – Daytime injuries for hypothetical Victoria magnitude 7.0 scenario.

5. Conclusions and Outlook

As a first order assessment of risks for two catastrophic earthquake scenarios in southwestern British Columbia, this paper provides insights into some of the potential impacts and consequences that this region would experience. Modelled losses will challenge Emergency Management British Columbia to plan for, respond to and recover from such events.

Permanent ground deformation and secondary induced hazards have been shown to have significant impacts on risk assessment results and can effectively highlight hotspots of concern. Future modelling should take into account a detailed site amplification map to examine the impacts of the geotechnical, geological, 2D and 3D modelling methods that includes shallow structure and fundamental site period (Cassidy et al., 2010) to include regional basin effects, soil site amplification, liquefaction, landslide, and tsunami impacts. Regional basin effects can both dampen and amplify the shaking intensity up to a factor of 10 (Molnar, 2014), which will significantly alter the risk assessment outputs.

The default inventory included in Hazus Canada is based on 2011 Statistics Canada datasets, which is collected every four years. The latest census collection was based on the National Household Survey. This survey is a voluntary survey introduced for the first time in Canada to replace the long form census questionnaire, which was a mandatory survey for all Canadians. The collected information provides data on demographics, social and economic characteristics of Canadians and their dwellings. Provincial assessors collect more detailed parcel-level data for residential buildings and some essential facilities - information on building construction, year built, number of storeys and building floor area that would support a more risk accurate analysis. At the time of this assessment, parcel data was not available. Future risk modelling assessments will build upon the current knowledge using building specific data where available. A building level analysis of essential facilities can be assessed using the Advanced Engineering Building Module (AEBM) within Hazus. This can be an effective method in assessing the impacts for a specific building type that may be more vulnerable to earthquakes. For example a wood building with weak cripple walls would perform poorly compared to a typical wood frame structure. The NRCan Risk Project is in the process of developing a new loss-modelling tool (Smirinoff et al., 2015). Its methodology is similar to that implemented in Hazus, but will improve upon the non-structural loss calculations and will be used in future regional risk assessments.

To take into account any known earthquake hazard, future modelling will examine probabilistic seismic hazards using the Global Earthquake Model's, OpenQuake tool, an open-source international application that assess probabilistic earthquake risk and calculates cost-benefit analysis for risk transfer and retrofit upgrade analysis (Pagani *et al.*, 2014).

Earthquakes cannot be predicted but a detailed risk assessment can help to anticipate and plan for what might happen and reduce potential impacts and suffering from a catastrophic earthquake.

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