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GEOLOGICAL SURVEY OF CANADA
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Exercise Coastal Response 2023: scenario earthquake and potential impacts

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2023

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Preface

This document provides a brief overview of the scenario earthquake and its projected impacts on Greater Vancouver, designed by staff with the national Geohazard Risk project at Natural Resources Canada (NRCan), for the Coastal Response emergency response exercise slated to be held in 2023 (CR23). This scenario also benefited greatly from contributions by co-authors and their colleagues at Defence Research and Development Canada, and at the University of Victoria's Department of Civil Engineering.

1 Introduction: Earthquakes in Canada

British Columbia is the most seismically active province in Canada (Figure 1), with roughly 3,000 earthquakes located in the province each year, and about 900 of those occurring in the southwest corner of the province – an area of high seismic risk due to the combination of earthquake hazard and the region's dense population and infrastructure.

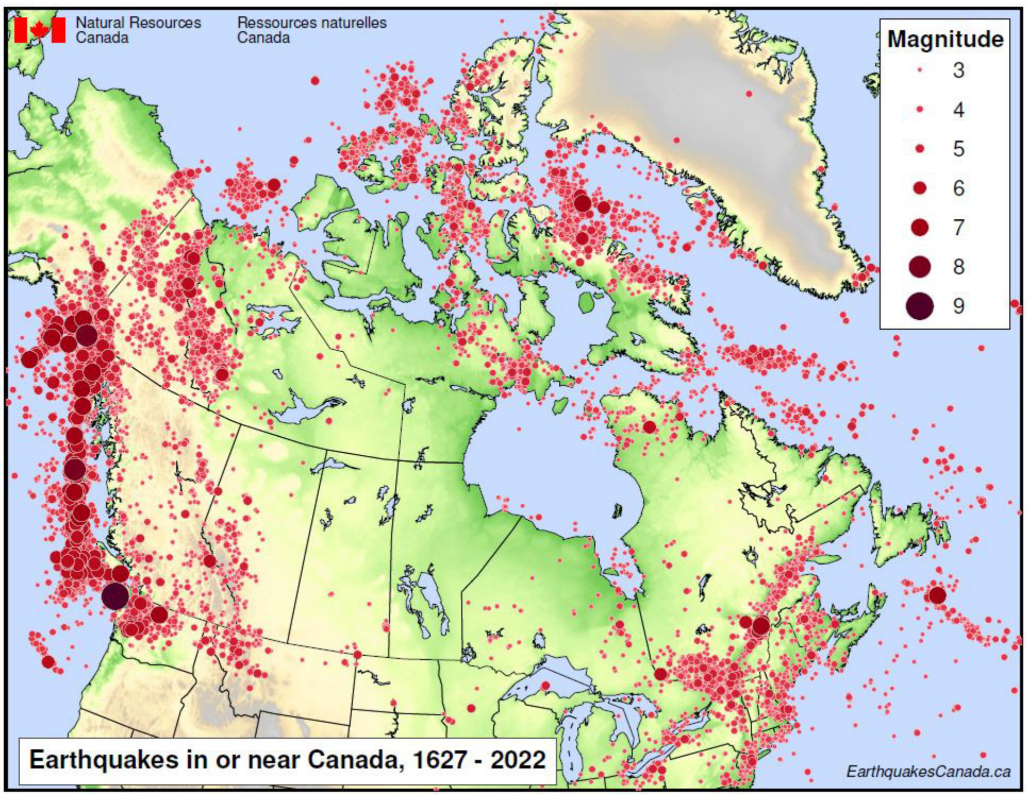

Figure 1. Historical earthquake catalogue for Canada: as earthquakes tend to occur repeatedly in same location, the high volume of activity is difficult to discern on this map. Roughly 3,000 earthquakes every year in BC; approximately 900 a year occur in the Vancouver Island Region

The earthquake data gathered by NRCan inform the seismic provisions within the National Building Code of Canada (Figure 2; National Research Council, 2020), along with other measures towards hazard mitigation in Canadian communities.

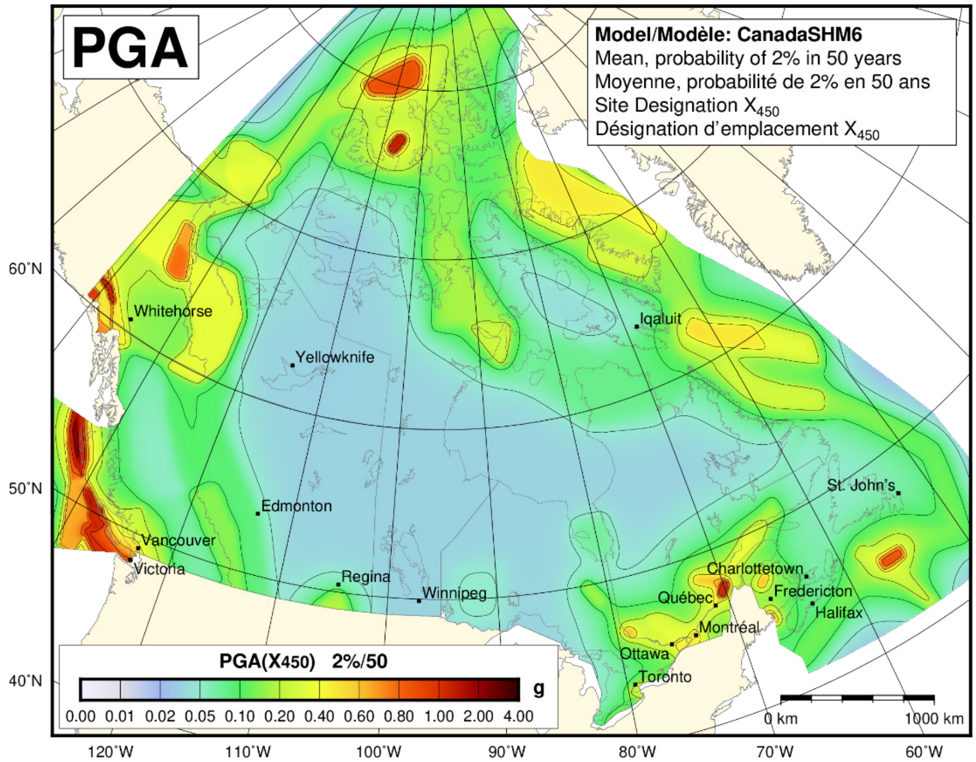

Figure 2. 2020 National Seismic Hazard Map of Peak Ground Acceleration, based on a probability of exceedance of 2% in 50 years. The west coast of British Columbia is clearly the region of the country with the greatest hazard from earthquakes (National Research Council, 2020).

2 Disclaimer

Estimates of earthquake impacts are produced using loss estimation modelling software and are based on current scientific, engineering, and geographical knowledge. There are uncertainties inherent in any loss estimation technique (Deelstra & Bristow, 2020), related to inaccuracies in modelling parameters including: the specifics of the earthquake rupture, expected ground shaking, the exposure database, behaviour of buildings relative to generic building taxonomies, and calculation of losses as a result of shaking damage. As such, actual losses following a real earthquake event may differ from the modelled event. Although this scenario earthquake would have impacts beyond Greater Vancouver, the focus of the exercise is Greater Vancouver. Results presented in this document are preliminary and only for the portrayed earthquake scenario and are not necessarily applicable to other earthquakes. They are also based on a representative inventory of buildings rather than the exact building stock. These results should therefore not be used for structural mitigation planning.

3 *OpenQuake* and *HAZUS* Risk Modelling Software

NRCan uses Global Earthquake Model's *OpenQuake* software to model the potential impacts of a scenario earthquake on the human environment (Global Earthquake Model, 2020). As inputs, the fault rupture model takes into account site conditions (geological; Turner, *et al*., 1998), hypocentral location and extent of rupture, rupture type, and the behaviour of seismic waves as they propagate away from the source, i.e., how the waves attenuate, or weaken, over distance, through the use of Ground Motion Prediction Equations (Allen & Wald, 2009).

Incorporating information concerning the fragility and vulnerability of structures enables *OpenQuake* to produce estimates of impacts including building damage, lifeline disruptions, injuries and fatalities, displaced population, and business interruption. Additionally, incorporation of physical and socioeconomic vulnerabilities, mentioned below, allows users to consider differential and potentially inequitable distributions of impacts.

Outside of the scope of this exercise, but of interest, the *OpenQuake* tool also allows for the “virtual retrofitting” of high-risk structures, with the aim of performing a cost benefit analysis of retrofitting against various scenario earthquakes.

Additionally, the United States Federal Emergency Management Agency’s (FEMA) program, *HAZUS,* is employed to model effects on a selection of linear structures, such as power lines, water mains, and sewage pipes.

4 Physical Exposure

In order to model the impacts on a settled environment, it is important to have reliable data on the built environment. NRCan combined Census data (Statistics Canada, 2016) with land use classification and satellite imagery to portray the settled areas of BC (Figure 3).

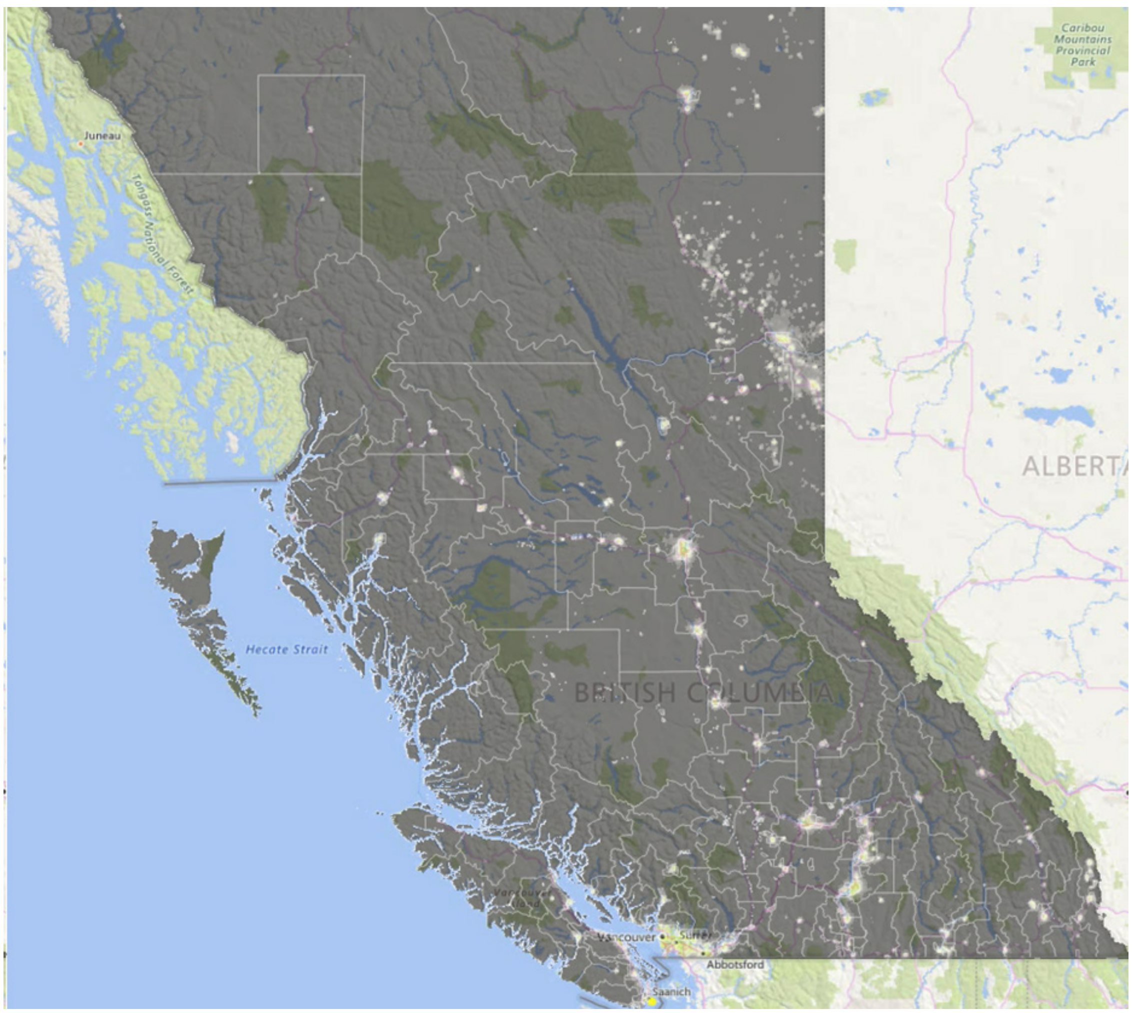

Figure 3. Settled areas (white/translucent) within BC, according to 2011 Census data (Statistics Canada, 2011).

For each settled area, a database was developed, comprised of building attributes including construction type and vintage (such as single-family-dwellings, older masonry buildings and modern high-rises) - elements which inform the seismic resistance of the structures (Figure 4). In addition, a database containing details of “linear structures” such as water mains, sewage lines, electrical lines, and gas mains, was also compiled for the region.

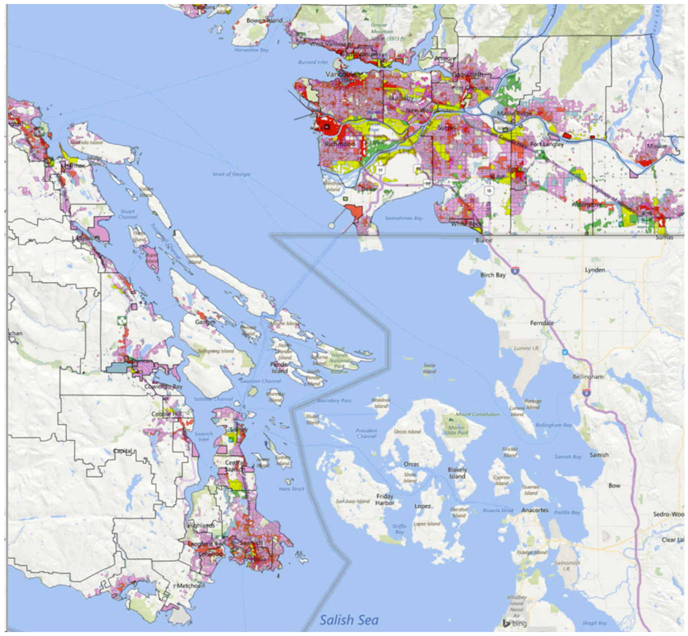

Figure 4. Neighbourhood level building typologies.

5 Socioeconomic Vulnerabilities

The people who would be exposed to the earthquake and its associated hazards were considered, including their distribution at different times: during business hours, during typical commuting hours, and at night (Figure 5). Location (and hence construction) holds considerable influence over the relative safety of the individual.

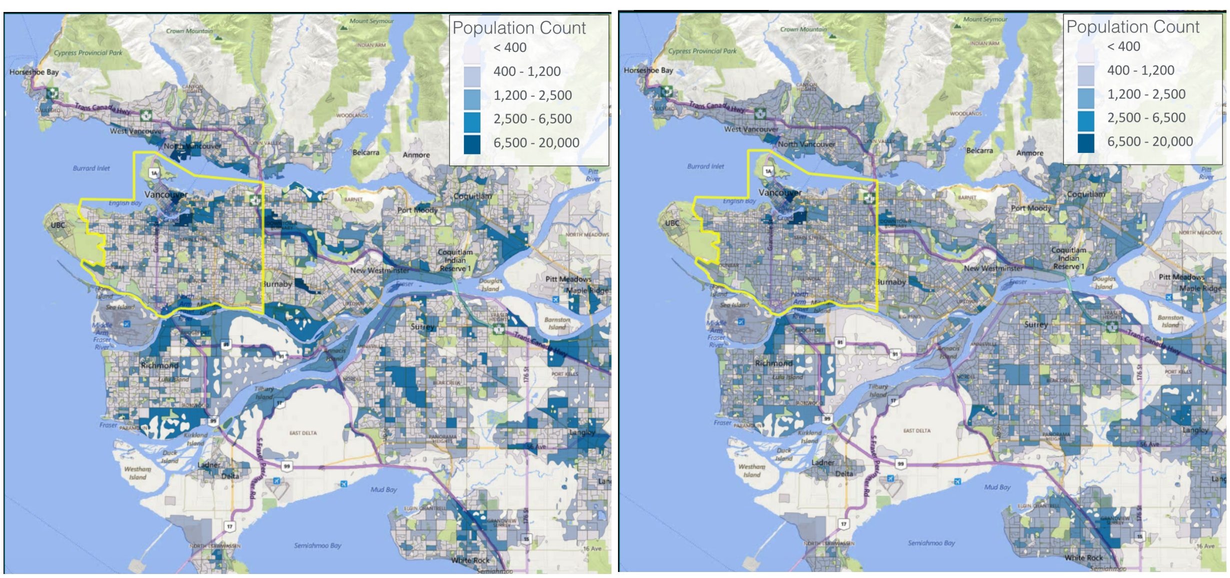

Figure 5. Population density in Greater Vancouver in the day, left, and at night, right (based on Statistics Canada, 2011); yellow outline is the Metro Vancouver area.

Following an earthquake, people will have varying needs and face different challenges. In order to enhance recovery, the NRCan team has developed a neighbourhood vulnerability archetype map to determine the needs and requirements of different populations (Figure 6), such as age, low-income, new immigrant (who may not have developed a social network and who may not yet speak English fluently), and other potentially marginalized populations (Journeay, *et al*., 2022).

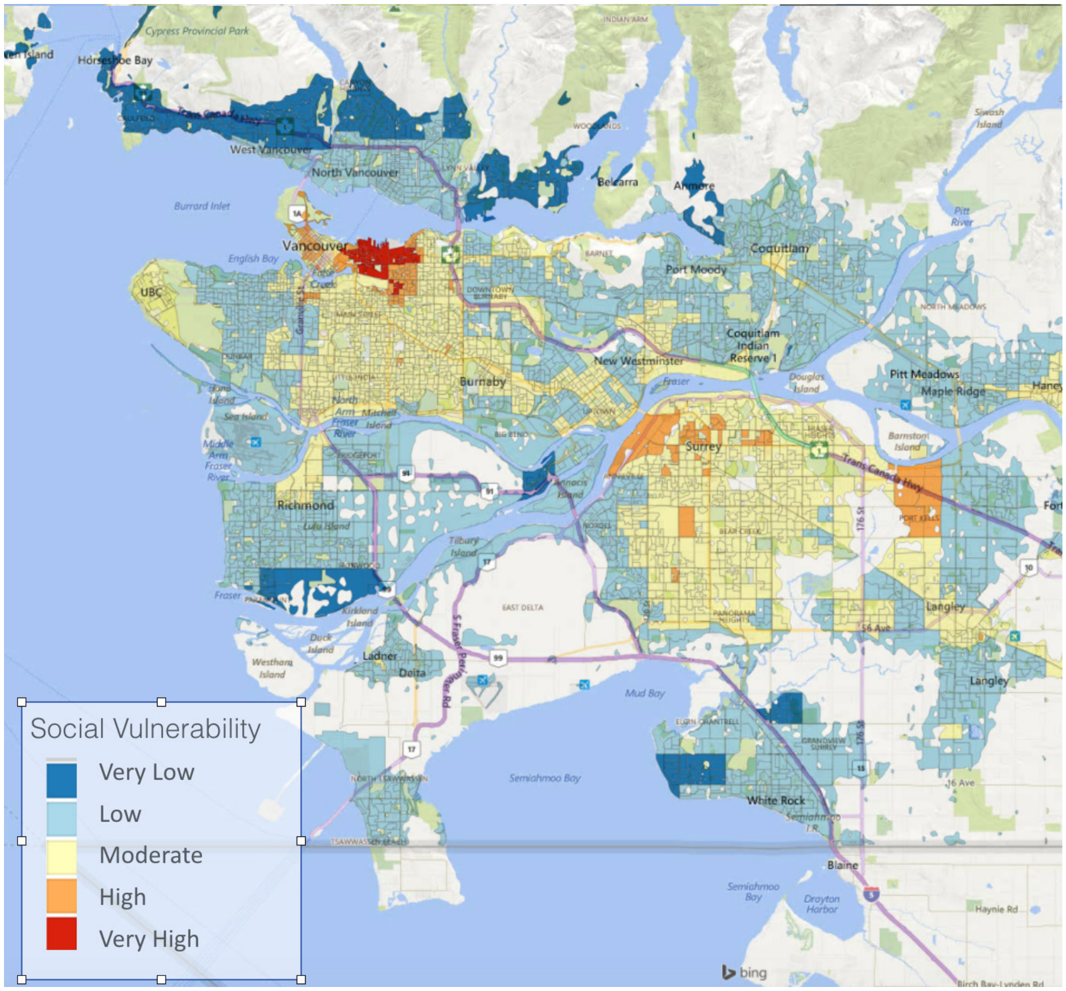

Figure 6. Social vulnerability in Greater Vancouver; note the concentration of vulnerable populations in the Downtown East Side where few will have the resources to be resilient to a natural disaster situation.

6 Scenario Earthquake: M6.8 In-slab

Note: Since earlier versions of this document, published prior to July 2021, the fault rupture for this event was updated and the ground motion and impact models were re-run. While there are some reductions, the overall level and extent of impacts remains consistent.

Southwestern British Columbia lies at the northern end of the Cascadia Subduction Zone, where the oceanic Juan de Fuca Plate pushes under the continental North American Plate, on which Canadian communities sit (Figure 7). The largest earthquakes in the world occur along subduction zones: megathrust events with the added hazard of tsunami. Megathrust earthquakes occur along a subduction zone infrequently (often hundreds of years apart), but the significant stresses along these compressional boundaries result in concentrations of earthquakes, some large, to occur within the two neighbouring plates. In our region, earthquakes occur daily, although the vast majority are too small to be felt. Historically, sizeable earthquakes (some over magnitude 7) have occurred within the North American Plate, and others (near magnitude 7) have occurred within the subducting Juan de Fuca Plate (Cassidy, *et al*., 2010). While few of these events occurred in recent decades, in the first half on the twentieth century, numerous events around magnitude 7 struck the region, and will do so again.

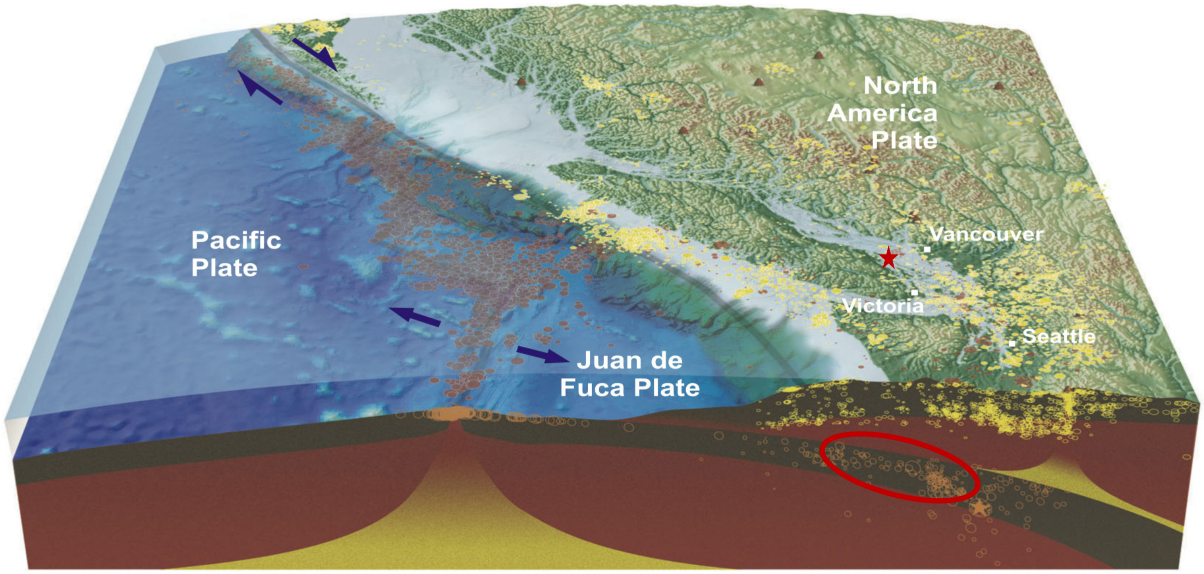

Figure 7. Cartoon showing the three-dimensional tectonics of southwestern British Columbia, where the Juan de Fuca plate pushes under the North American Plate along the Cascadia Subduction Zone. The area of the scenario earthquake, within the Juan de Fuca Plate, is indicated with a red ellipse, and its epicentre (the surface projection of the quake) with a red star.

There were several types of potentially damaging earthquakes considered as scenario earthquakes for CR23, including a moderate "crustal" earthquake, shallow within the North American Plate and close to the infrastructure of Vancouver, and the most dramatic, a megathrust earthquake along the Cascadia Subduction Zone. A moderately strong earthquake within the subducting Juan de Fuca Plate (an "in-slab" earthquake), just off Greater Vancouver provided, however, the level and extent of damage, human displacement, and impacts to critical infrastructure desired by the exercise planners.

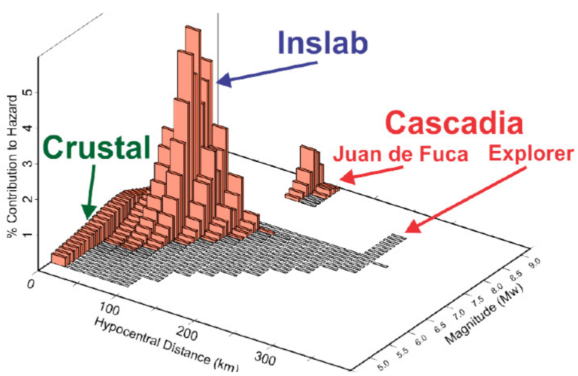

Figure 8. Deaggregation plot, showing probability of shaking at different distances and magnitudes, with respect to the City of Vancouver (Halchuk, et al.*, 2019).*

This magnitude 6.8 in-slab earthquake is especially realistic because a statistical analysis of historic events in the region suggests this is a relatively likely event to occur (Figure 8). The earthquake would be similar to the Nisqually earthquake that struck near Olympia, WA in 2001 (Kimura, *et al*., 2001; United States Geological Survey, 2001), most notably in terms of its magnitude, depth, and proximity to a metropolitan region. Recently, the Nisqually event was investigated by Hobbs, *et al*. (2020) as a "ground truth" model of the *OpenQuake* software, comparing modelled and actual impacts, to establish the validity of this modelling software in estimating the impacts of such an event.

NRCan's mock Earthquake Report and web page for the scenario event are included as Appendices I and II, and show the magnitude 6.8 earthquake occurred at 6:16am on Wednesday, 05th February, with its hypocentre at 49.10 latitude, -123.20 longitude, and 63 km depth. A computer-generated located is calculated for any significant earthquake in Canada (magnitude greater than 4 and with sufficient quality of data for the location and magnitude to be reliably estimated). This is automatically posted to the Earthquakes Canada website and to the @CanadaQuakes Twitter feed within ~1.5 minutes of being detected. The Seismologist-on-Call confirms the location and details, then sends an Earthquake Report (Appendix I) and updates the information on the website (including map and other information, as shown in Appendix II), usually within 10 minutes. The modelled strength of shaking (ground motion) is shown in the map of Peak Ground Acceleration

(PGA; Figure 9). Estimates of Modified Mercalli Intensity (MMI; Wood & Neumann, 1931) are shown in the map's legend. People would feel the shaking from this earthquake for approximately 1¼ minutes.

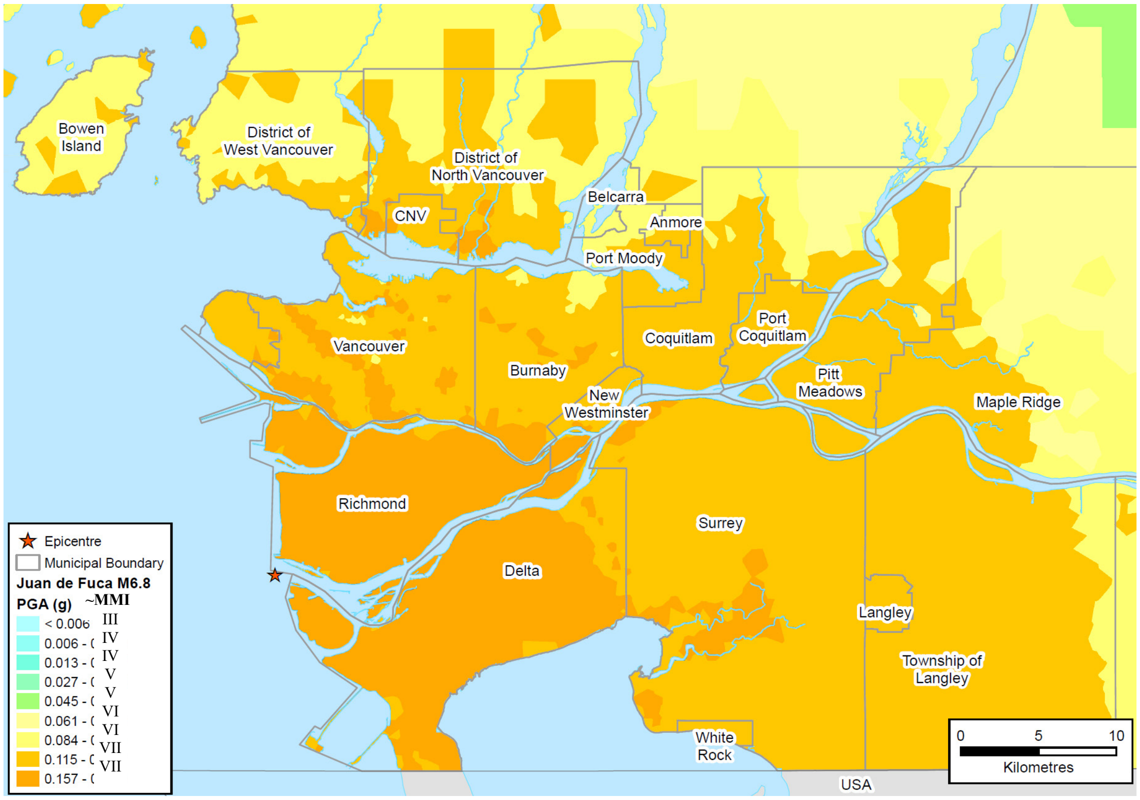

Figure 9. Average Peak Ground Acceleration (PGA), based on multiple Ground Motion Prediction Equations (Abrahamson, et al.*, 2016; Atkinson & Boore, 2003; Zhao,* et al.*, 2006) and site conditions, with approximations of Modified Mercalli Intensities (MMI).*

7 Secondary Hazards

Site Amplification

Generally, seismic waves propagating from an earthquake amplify when they pass from bedrock into soft soils, as is shown in the cartoon image, below. As there are varying compositions and thicknesses of sediment in the Greater Vancouver area, site conditions have to be taken into consideration when determining the strength of shaking from an earthquake. This can be challenging as the various wave frequencies act differently in different soil conditions and thicknesses; for example, some areas of thick, soft sediments in the Frazer River Delta may de-amplify some high-frequency waves, but amplify long-period waves.

Amplification can also occur on hilltops (through complimentary interference of seismic waves) and in geographic basins, such as that which lies under the Strait of Georgia. In the case of the latter phenomenon, the basin acts similarly to an amphitheatre in the amplification of seismic waves. In this case, the amplification is most pronounced where the basin is thickest and at its edges. Unfortunately, basin effects cannot be included in our modelling efforts at this time. Estimates of shaking in the Georgia Basin under Metro Vancouver are, therefore, likely underestimated.

Liquefaction

Another hazard associated with soft soils is liquefaction: a phenomenon in which the ground becomes temporarily liquefied, similar to quicksand, when subjected to earthquake shaking. The severity of liquefaction depends on the variability of sediment grain size, fluid saturation, and frequency of seismic waves. The construction above or within liquefied soils may no longer be supported properly, leading to tilting or even partially sunken structures, uneven and damaged roadways, and unsupported on- and off-ramps (Figure 10).

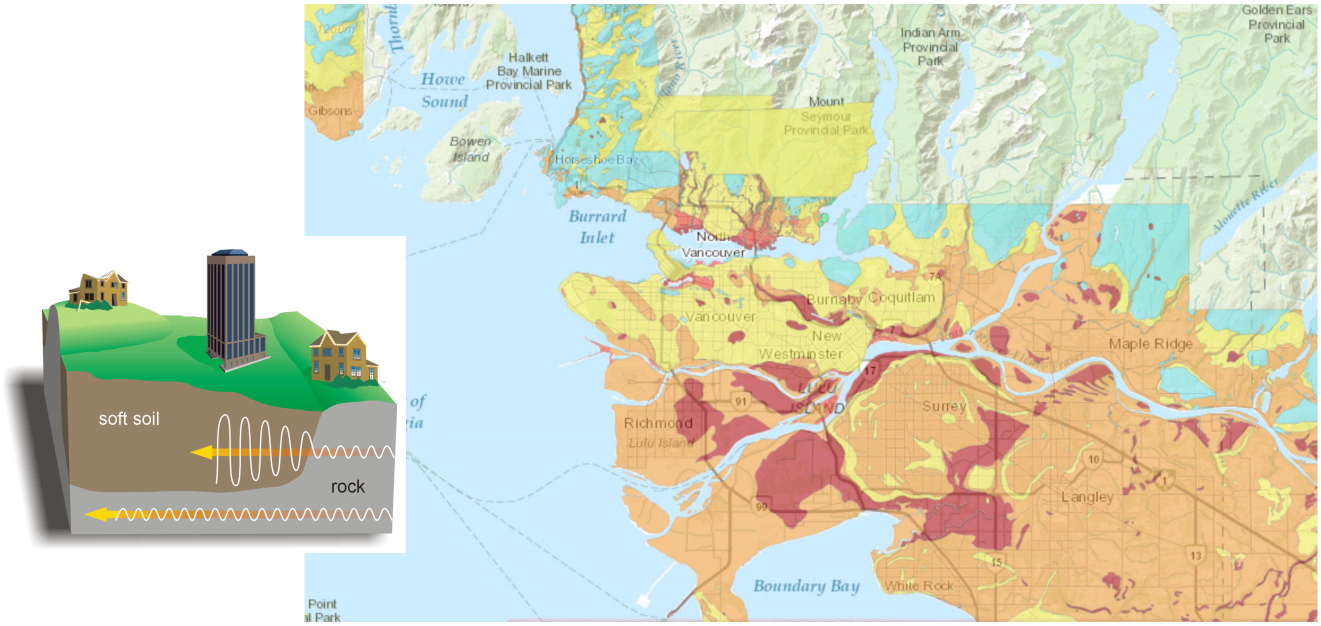

Figure 10. Soil conditions with likelihood of liquefaction in Greater Vancouver (higher likelihood in darker, warmer colours: orange to red); the most liquefiable soils are in the river delta. Inset shows cartoon of seismic waves amplifying as they pass from bedrock into soft soils.

Landslides & Subsidence

In hilly areas exposed to heavy precipitation, landslides are particularly common after strong earthquakes (Keefer, 2002). The 2012 magnitude 7.8 Haida Gwaii earthquake triggered innumerable landslides on the archipelago (Barth, *et al.*, 2020). The scenario earthquake presented herein would similarly be expected to cause landslides along vulnerable slopes. Landslides can bury and damage infrastructure and buildings and take lives. In addition, landslide material can dam and block rivers resulting in outburst flooding.

As mentioned earlier, this earthquake shares several similarities with the Nisqually earthquake in 2001. As with that event, there were numerous instances of slumping, which primarily damaged roadways, caused failures of waterfronts, and disturbed gardens. In coastal areas, this can lead to flooding (see below), particularly in low-lying areas and especially at high tide.

Flooding

Intense ground shaking can damage vulnerable dyke and dam structures causing flooding in low-lying areas. The lower mainland has nearly 700 kilometres of dyke structures. Of these, none is built to the National Building Code (National Research Council, 2020) standards to withstand a 1-in-2,500 year event. A recent study conducted by the Province of British Columbia highlights 25 dike structures in the Lower Mainland that are highly vulnerable (Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019). The majority of highly vulnerable dykes identified in the report are located in the Fraser Valley region. Of concern are a number of sea dikes located in Richmond and Tsawwassen First Nation that could pose a threat to the neighbouring regions.

Fire

Broken gas lines and power lines can lead to fires that, in turn, can be exacerbated when nearby fire hydrants, water lines, and fire stations are damaged to the point of being rendered inoperable. With widespread breaks to water mains and pipes, there will be a significant reduction in pressure to pump water. Multi-storey residential, commercial, and industrial buildings that rely on sprinkler systems to extinguish fires may be challenged in slowing down and extinguishing resident fires. This is of great concern if the structure houses toxic substances that could release poisonous plumes and threaten nearby residents' health.

Tsunami and Surface Rupture

While tsunamis are common with other types of earthquakes, they are uncommon with the character of the scenario earthquake presented within this document, so will not be considered here. It should be noted, however, that it is not uncommon for strong earthquakes to cause coastal landslides into waterbodies, or underwater landslides, which can in turn trigger localized tsunami.

Additionally, land displacement from a fault rupturing at the surface and causing offsets are common with very shallow earthquakes within the continental crust. As the scenario earthquake occurs at considerable depth, surface offsets are not expected in this scenario.

8 Modelled Impacts from Scenario Earthquake and Associated Hazards

An overview of the various impacts to buildings, people, and other concerns in Greater Vancouver are outlined below. While earthquake impact modelling has not been performed on a building-by-building or detailed, individual infrastructure basis, we are able to provide a reasonably instructive description of what would be likely to occur as a result of the scenario earthquake. An overview of impacts, for municipalities with more than 24 displaced people, is presented in Table 1 (Appendix III).

Building Damage

Neighbourhood estimations of damage were based on the estimated levels of shaking from the scenario earthquake and the exposed construction. The maps below (Figures 11, 12, and 13) show the number of buildings expected to be damaged, by municipality, using Applied Technology Council's 'tagging' system (Applied Technology Council, 1989): 'Green Tagged' means the building has sustained slight or moderate damage but is habitable without restrictions, 'Yellow Tagged' means the building has sustained extensive damage but is habitable with spatial or temporal restrictions, and 'Red Tagged' means the building has sustained complete damage or has collapsed entirely. In the latter case, the building is deemed by inspectors to be uninhabitable under any circumstance.

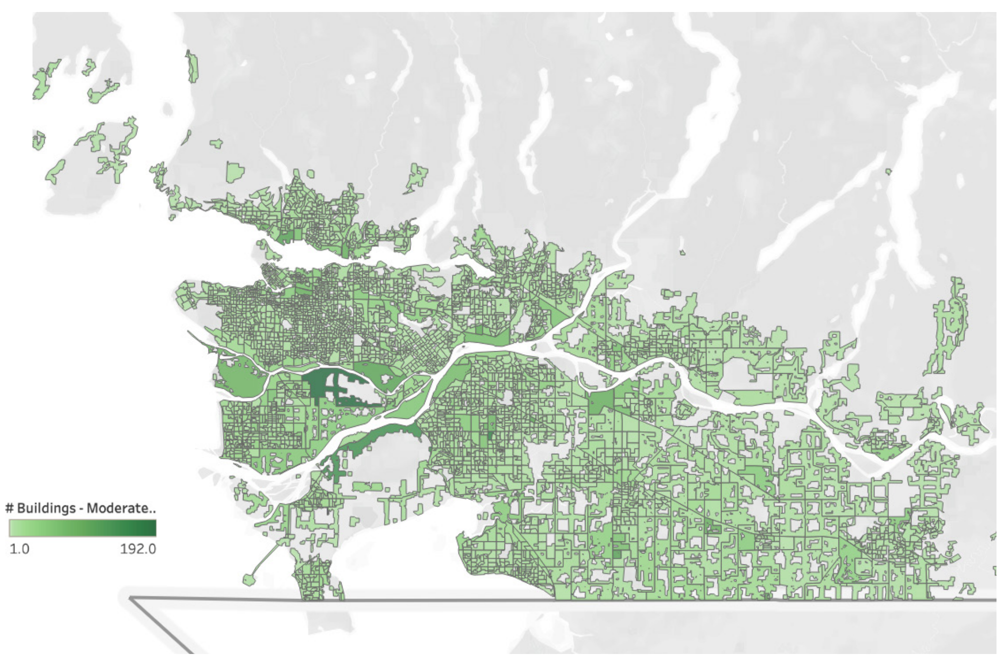

Figure 11. Modelled fully habitable (Green Tag) buildings, for the scenario, M6.8 in-slab earthquake.

Focussing on extensive to complete building damage, which would render the structure at least partially uninhabitable and/or out of service, the maps highlight those areas most likely to contain concentrations of badly damaged buildings.

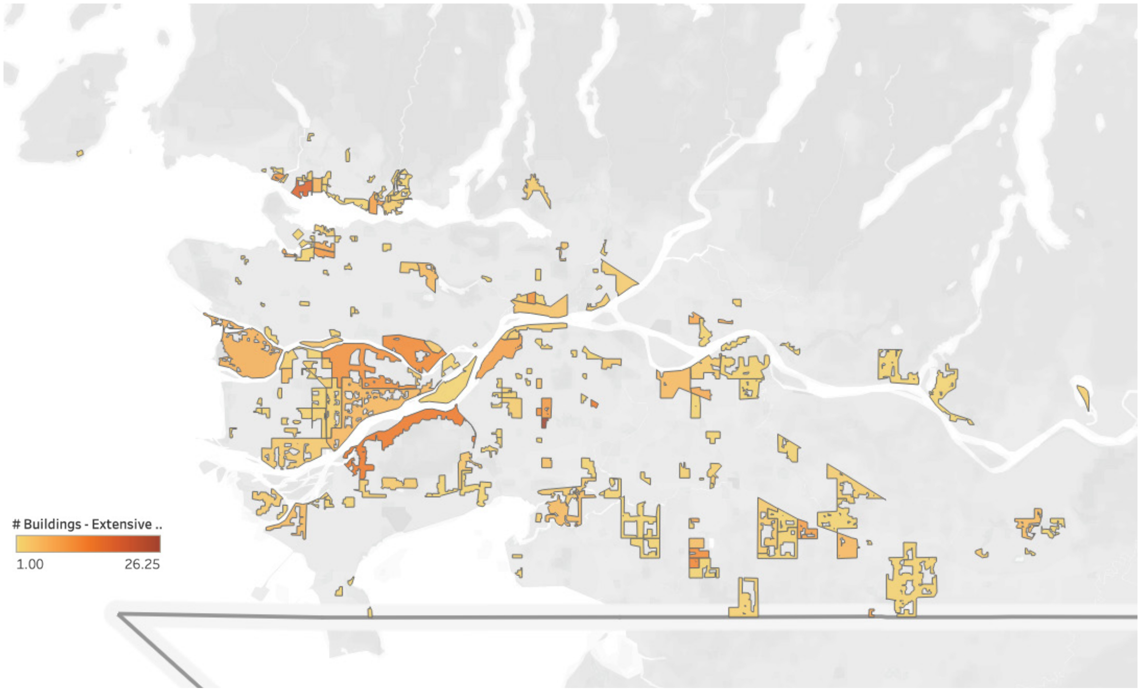

Figure 12. Modelled partially habitable (Yellow Tag) buildings, for the scenario, in-slab earthquake.

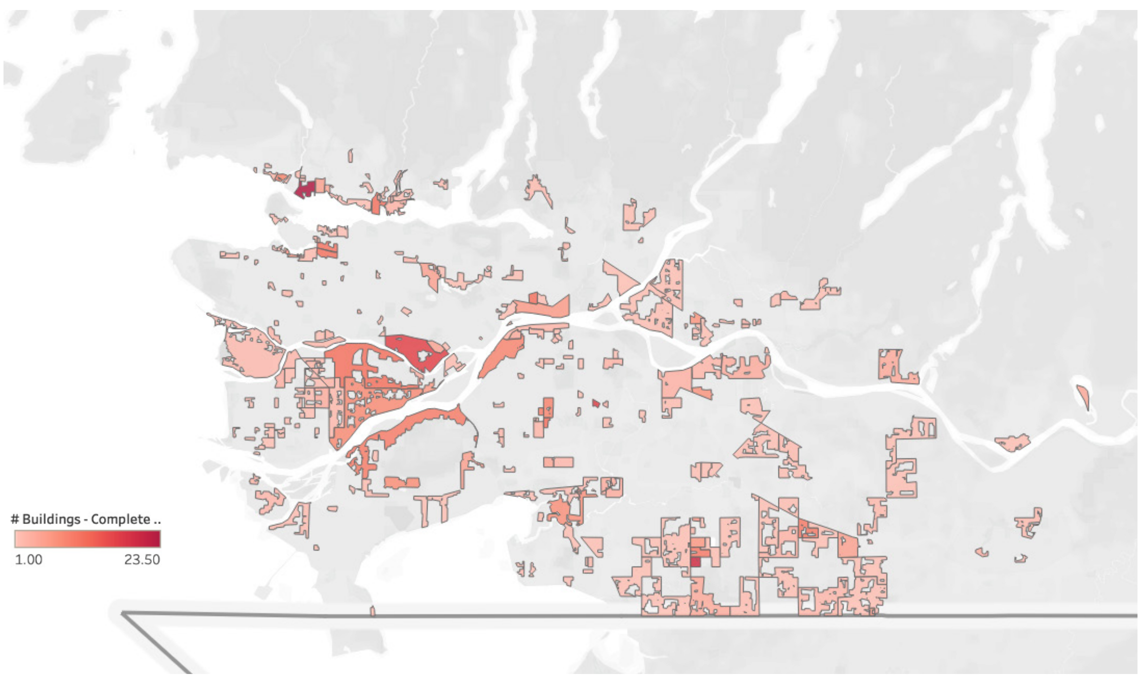

Figure 13. Modelled uninhabitable (Red Tag) buildings, for the scenario, in-slab earthquake.

Injuries

Modelling of the magnitude 6.8 event estimates that, as a direct result of the earthquake's damage, 2,813 people are injured (Figure 14), with 648 people requiring hospitalization (Figure 15), and 158 fatalities are anticipated (Figure 16). Please see Appendix III for more details.

This event is modelled to have occurred at 9:10 am local time, when most people are at work or school, and therefore in generally more vulnerable buildings (due to style and construction). This timing results in a considerably high number of fatalities and injuries than had the earthquake occurred in the middle of the night, when most people would be at home, due to most houses being of wood frame construction and the lack of residential masonry or steel buildings.

Maps of injuries and fatalities, below, are naturally linked with both the map of population density and those of building damage, presented above.

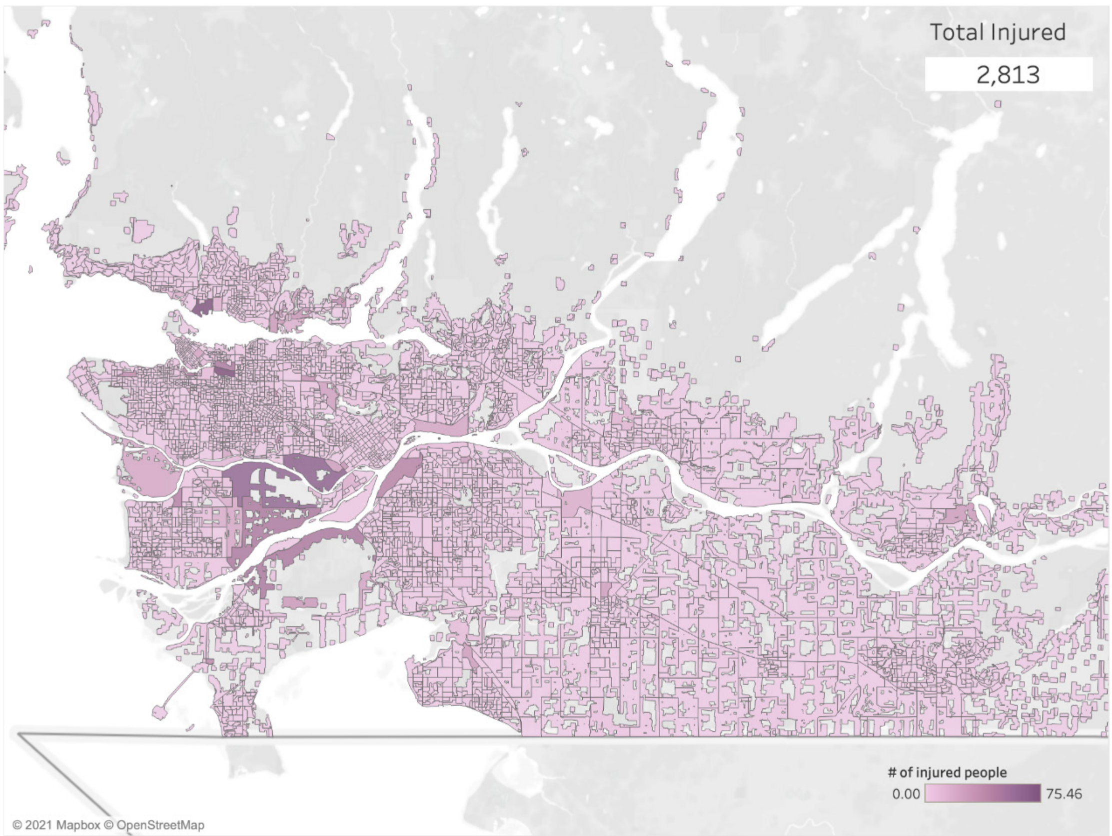

Figure 14. Map showing concentrations of all injured people, modelled from the scenario earthquake.

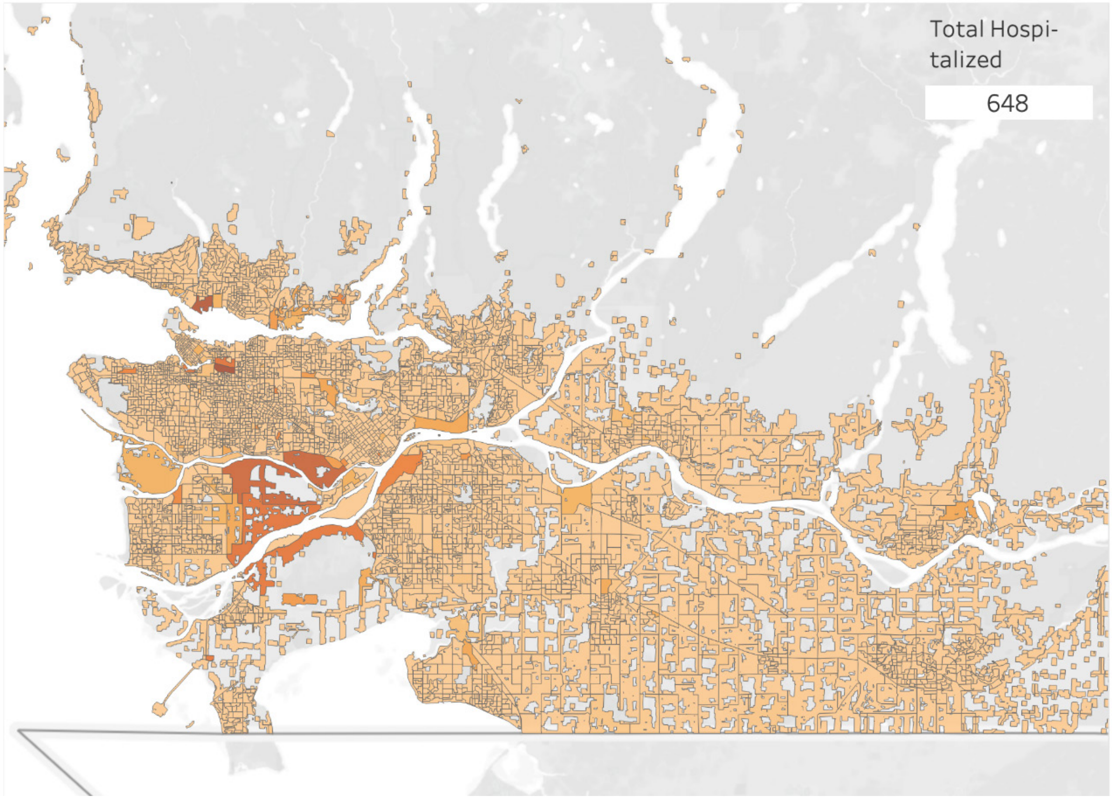

Figure 15. Map of modelled injuries requiring hospitalization, for the scenario earthquake.

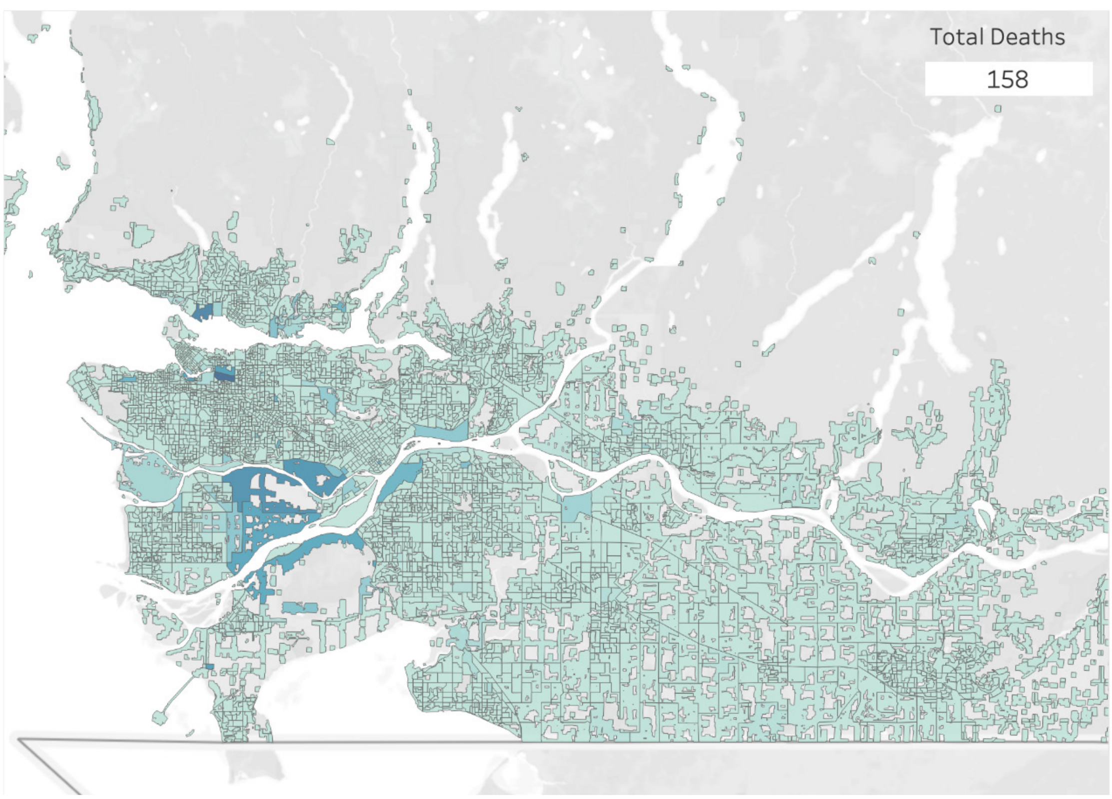

Figure 16. Map of modelled fatalities, based on the scenario earthquake.

Displaced Population

Based on damage level to different types of residential housing and the expected time for recovery of that building to a habitable state, it is possible to determine the impact to people's lives and how long they may be displaced. It is estimated that over 233,000 people will suffer some level of damage to their homes, which may result in significant displacement if they are unable to shelter in place while awaiting a formal damage assessment. Likely, many people with only slight or moderate damage will stay in their houses. For buildings with appreciable damage, it is estimated that over 30,000 people will be displaced for at least one month after the earthquake (Figure 17).

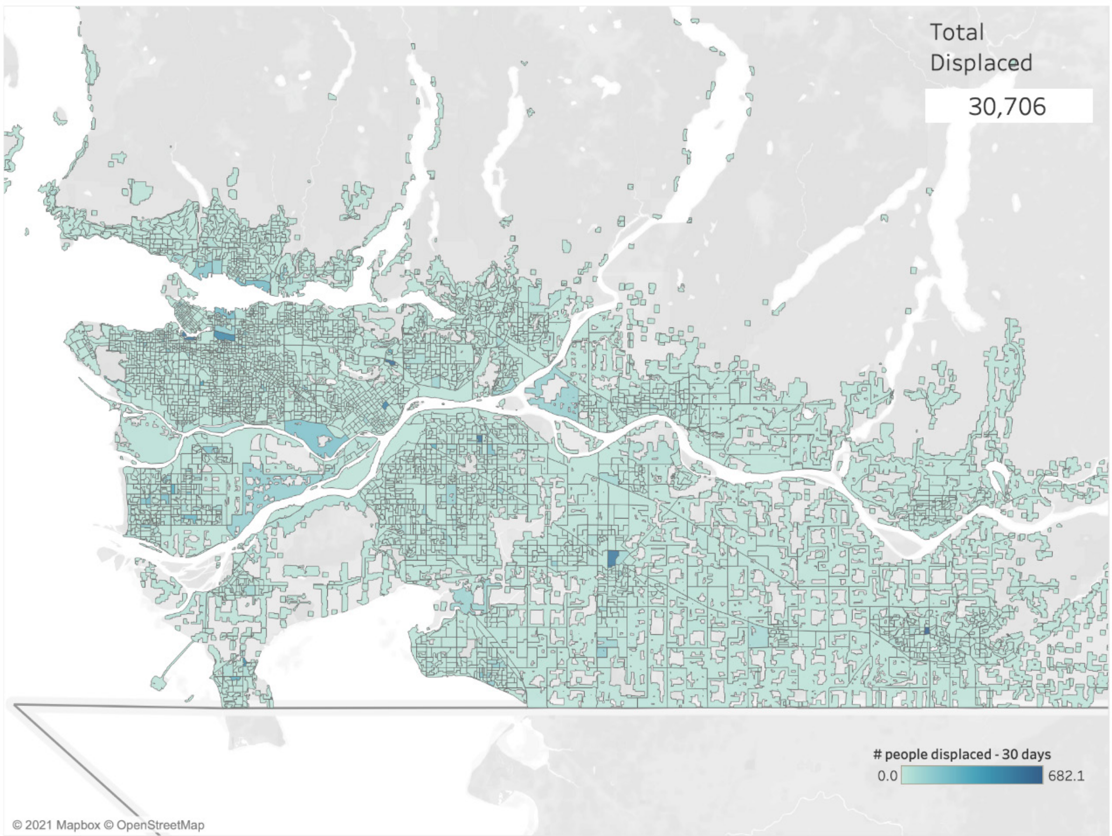

Figure 17. Map of people modelled to be displaced from their homes for at least 30 days. The number of people displaced for ninety days or longer are similarly distributed throughout the region.

Debris Generation

It is estimated that damage to buildings will create over 2.5 million U.S. tons (over 2 billion kilograms) of debris across Greater Vancouver (Figure 18). Using FEMA conversions of 2 cubic yards per tonne of construction/demolition debris (FEMA, 2010), and an average dump truck capacity of 12 cubic yards, we estimate that this volume of debris would require approximately 420,000 dump truck loads for removal. This does not account for damage to linear infrastructure such as roads or airport runways. Vancouver alone bears about a quarter of this burden, requiring over 100,000 dump truck loads to remove building debris from property and roadways.

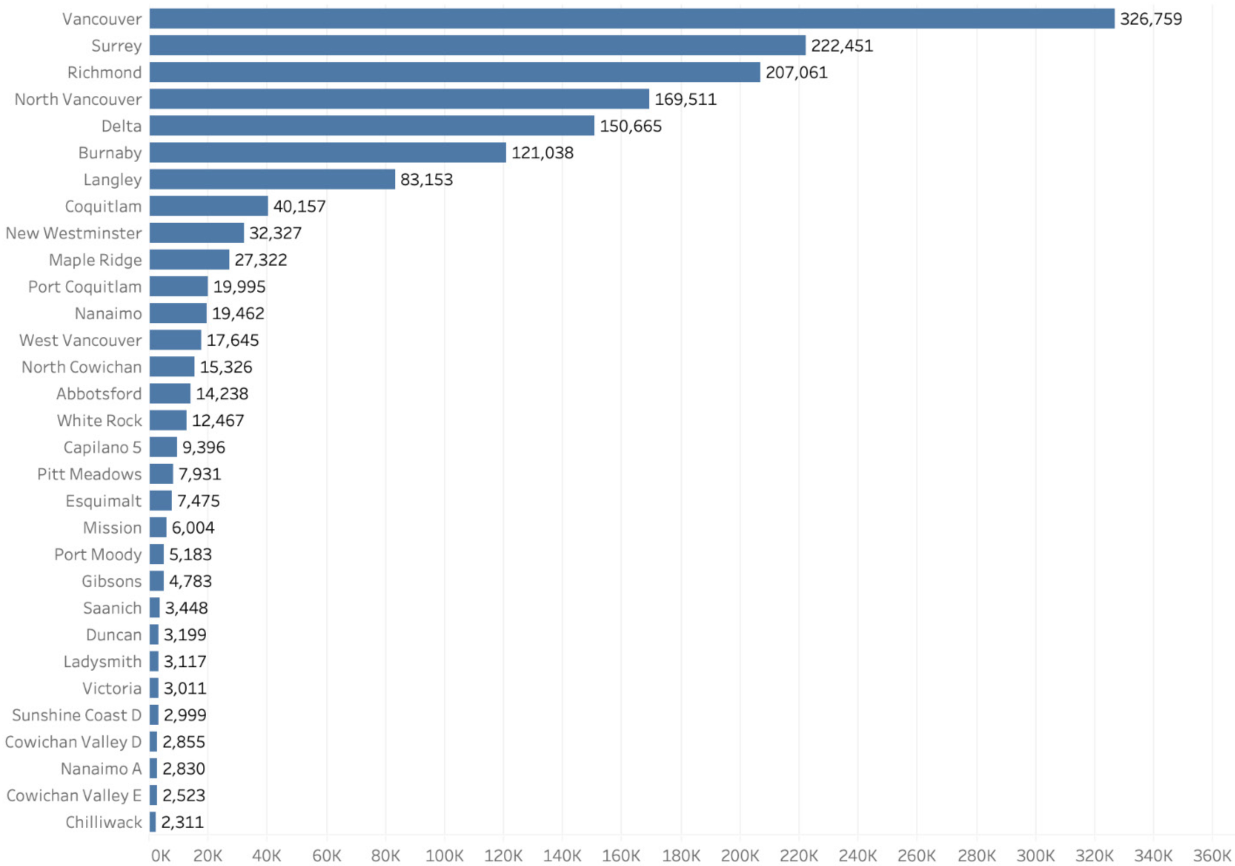

Figure 18. Modelled debris (in tonnes) generated by the scenario earthquake's impact on the built environment.

Damage to Critical Infrastructure

Given that modelling of disruptions to critical infrastructure (CI) systems has not fully been carried out, the narrative section below is intended to provide background information on potential impacts to this sector. Impacts to CI are defined according to the ten critical infrastructures defined by Public Safety Canada (Figure 19).

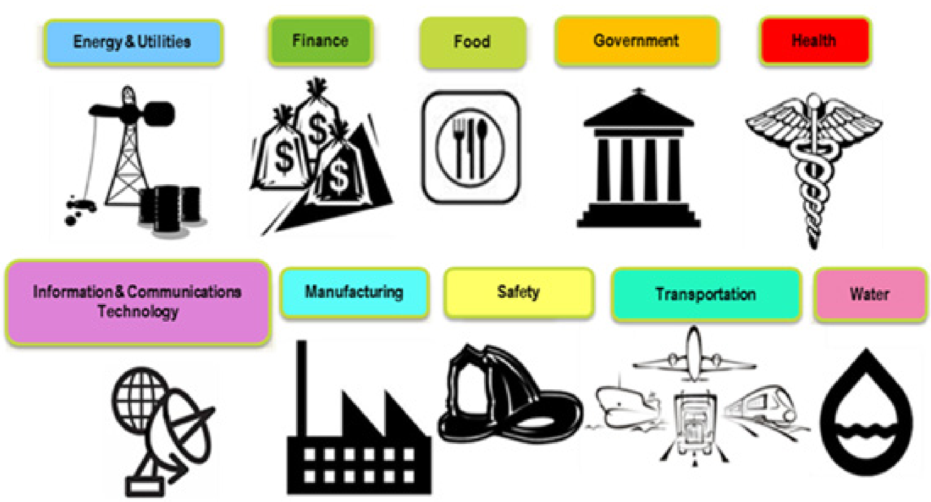

Figure 19. Critical infrastructure sectors (Public Safety Canada 2009).

Energy, Water & Other Utilities

Strong, high frequency ground motions during an earthquake are likely to cause liquefaction of soils, especially those that are water-saturated. Liquefaction commonly causes disruption to utilities such as electricity, water, sewage, natural gas, and Internet services due to the ground on and in which these utilities lie becoming disturbed and shifting. Outages can last days to weeks in the wake of events similar to the CR23 earthquake.

Fuel

Gas stations may become unserviceable as underground fuel storage tanks are displaced and become unsafe. While immediately after an earthquake fuel may not be a concern as most response organizations maintain full tanks in their vehicles and/or an on-site supply, oil and gas begins to become scarce after a few days. Damage to the Burnaby Mountain Tank Farm area, plus an increased reliance on diesel fuel for backup generators, would lead to shortages. Additionally, breaches to natural gas lines can cause outages and a small number of fires.

Electricity

Throughout the lower mainland region, disruptions to electrical services are likely to have widespread and long-term impacts on the continuity of services and people's health and well-being. Of serious concern is the potential failure of the 500 kV transmission line that would cause widespread outages. Part of this system traverses an area of high liquefaction hazard, in the municipalities of Surrey and White Rock. Transmission towers located in these types of soils could buckle, causing outages to power systems and hazards to isolated communities "downstream" of affected transmission lines.

Sewage

As the sewage treatment plant in southern Richmond is out of commission due to earthquake damage, removal of waste will be a priority for the health and safety of populations in the area. Following the Christchurch earthquake in 2012, thousands of portable toilets were needed in the city (Wareham & Bourke, 2013).

Water

Similarly, water supply has been disrupted as water mains and lines crack and leak, resulting in low pressure and possible loss of water flow entirely (Figure 20). This is of concern for lower mainland communities located far from the critical drinking water reservoirs (Capilano, Coquitlam and Seymour reservoirs). Communities with access to bottled drinking water will be able to withstand short-term crises. Lack of water supply will rapidly become a significant issue in the short-term recovery phase. Alternative sources such as wells and ponds will have become temporarily murky, as the earthquake has disturbed the sediments surrounding the waterbody. Additionally, concerns over possible contamination from sewage and other hazardous waste results in a boil water advisory for the region. Water and wastewater repair crews may be busy with assessments/inspections and opening or closing valves to conserve water in towers or prevent loss in certain areas in the community.

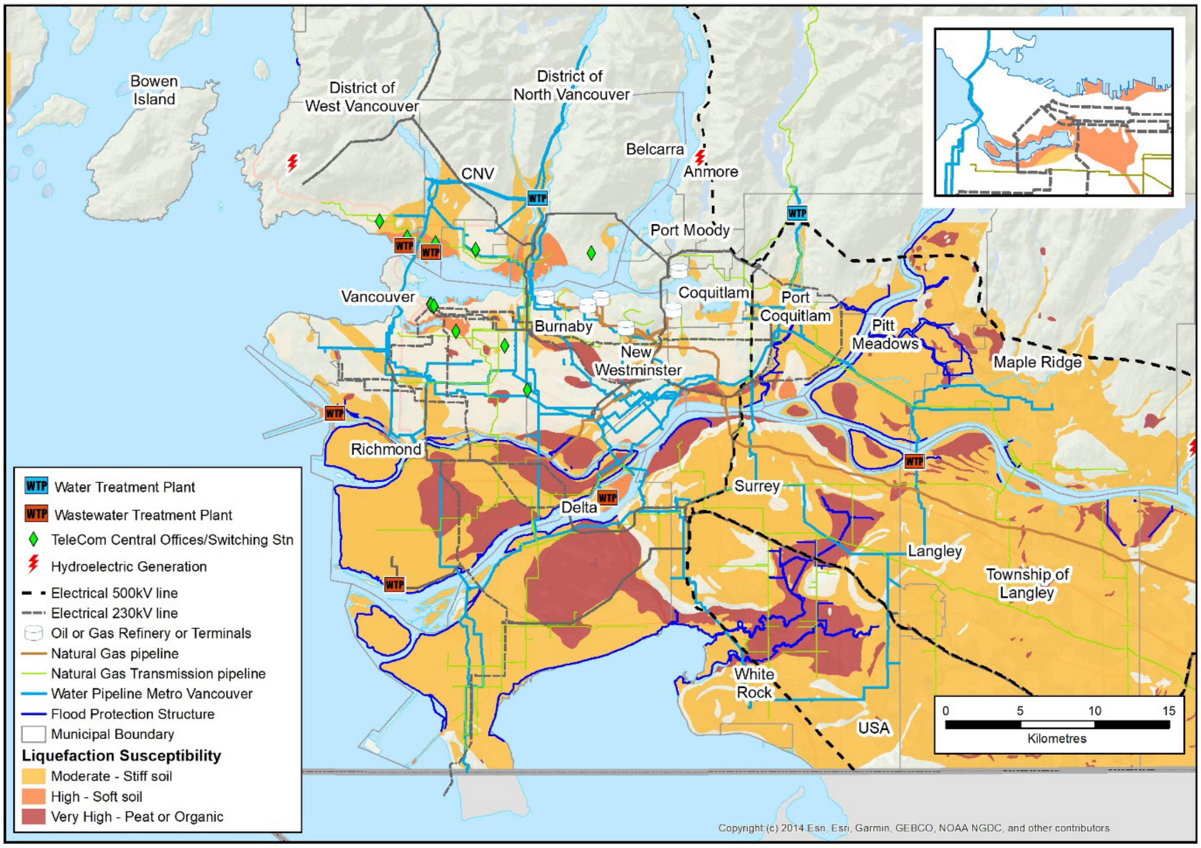

Figure 20. Major utilities infrastructure overlaid on map of relative liquefaction hazard. Inset shows relative liquefaction for the downtown area of Vancouver.

Health

Damage to major medical facilities is varied across the region. Many hospitals have been seismically upgraded, but those hospitals that have not yet been modernized could suffer structural damages resulting in the closure of facilities and movement of patients and staff to other locations. Many of the hospitals in the lower mainland are known to be at capacity already. With injuries resulting from the earthquake, there would be a need to find care for "new patients." In some cases, the hospital may be sound structurally from the earthquake, but if the electrical, water and/or sanitary services are impacted, this could result in the closure.

Extensive damage to St Paul's hospital has occurred. It is close to the earthquake's epicentre so subject to strong shaking, and it is relatively old, with many sections constructed before seismic provisions were included in the National Building Code. Lion's Gate, UBC and Richmond hospitals are also likely to sustain some damage, although, providing utilities are still available, many sections of the buildings should be operational.

It is possible that there will be damage and data loss, disrupting centralized data services for regional health services. Disruptions to medical lab services are also anticipated.

Safety

Emergency response personnel (fire, police, ambulance, and search and rescue) will be overwhelmed with demand, and with stress and fatigue taking their toll. Damage to emergency response routes and an overwhelming demand would delay response actions (Figure 21).

Multiple types of inspection services are overwhelmed, not simply for the inspection of homes for habitability, but for the priority structures: bridges, hospitals, etc. Disruptions to professional services required for recovery of lifeline utilities (engineering, environmental, etc.) are also anticipated.

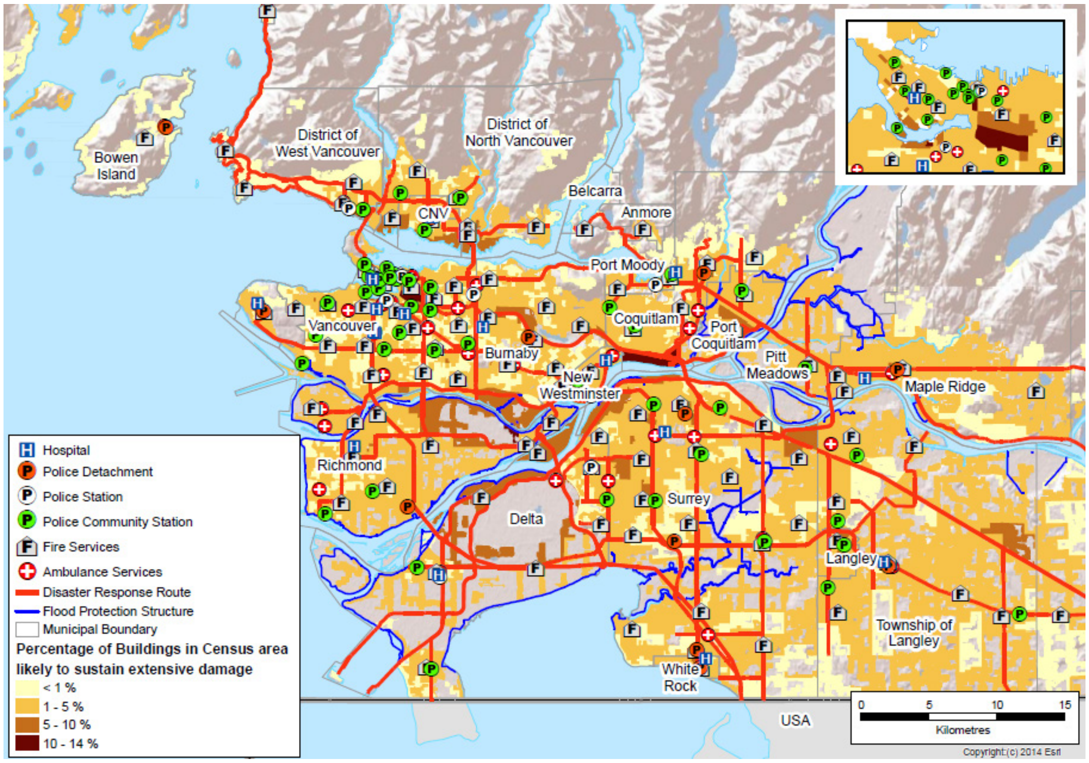

Figure 21. Some critical infrastructure and level of anticipated damage based on the scenario earthquake.

Transportation

The lower mainland's geography means that travel in and around the region is reliant on a network of roads, bridges, and rail services. Many routes will be unable to withstand intense shaking and/or liquefaction; damage to these will disrupt the movement of people, goods, and services across the region (Figure 22). Of immediate concern is the movement of emergency responders around the area during search and rescue activities, and the transportation of injured to medical care centres. Some specific examples of disruptions to transportation are outlined below.

Roadways and Bridges

This scenario earthquake has caused landslides to cascade onto sections of the Sea-to-Sky Highway, cutting off that transportation route to Whistler and other communities in the area. Liquefaction has affected the north end of the George Massey Tunnel, making it impassable. On- and off-ramps to the south end of the Alex Fraser Bridge have collapsed. Many bridges will require inspection. Some roadways in the Fraser River Delta will also be damaged due to liquefaction and lateral spreading, rendering them at least partially impassable to vehicles. Failure of a section of the dyke in southeastern Richmond (between No.s 4 and 5 Road) will cause some roadways to be flooded, although generally confined to an area of farmland and industry, including minor flooding of the southern region of the Ironwood complex. None of the main routes will be impacted.

While there will often be alternative routes, trial-and-error attempts to reach a destination (until clear road systems are understood) could delay emergency services and expend more fuel.

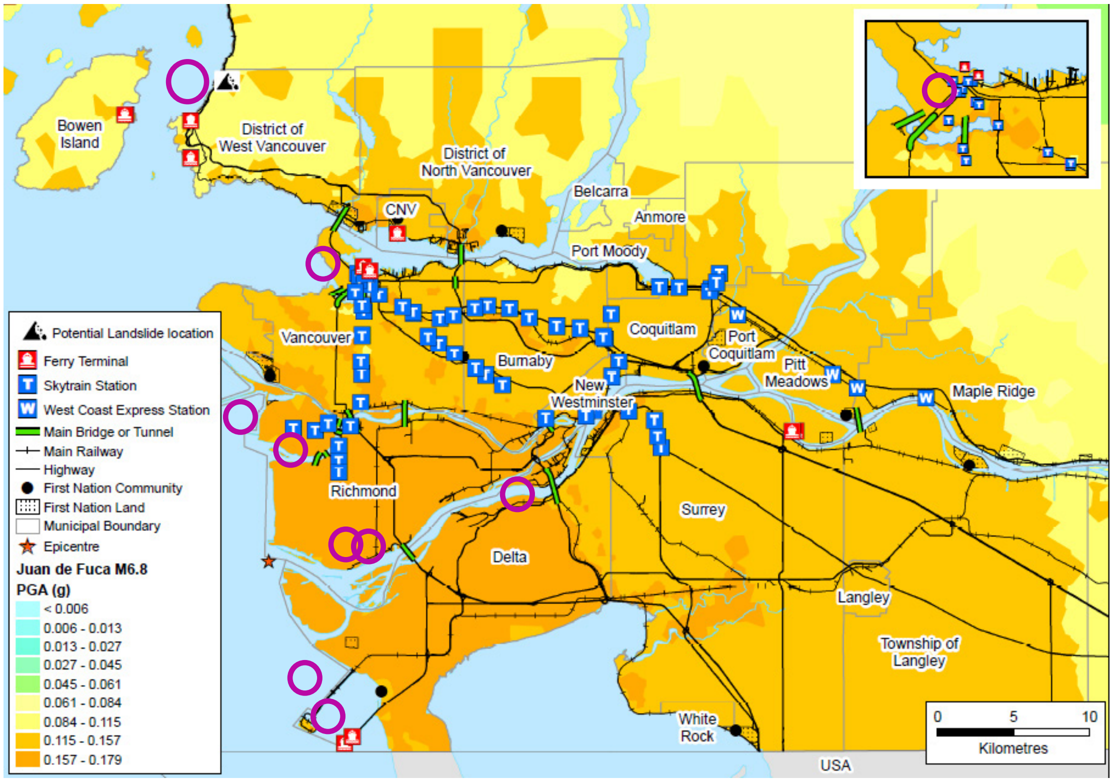

Figure 22. Map showing (with warm colours) the strength of shaking (peak ground acceleration) in the Greater Vancouver region, along with landslide (icon on the Sea-to-Sky Highway), and major transportation routes. Major disruptions to traffic are encircled in purple. Inset shows impacts in Metro Vancouver.

Marine Ports & Traffic

The Tsawwassen and Delta Port causeways have been damaged, and possible impacts to port infrastructure such as BC Ferry's terminals and Sea Bus terminals could prove challenging for ferries to dock safely, which might strand passengers; inspection will be needed. These impacts may have compounding effects if there are disruptions to the transport of goods needed for survival (food, bottled water, aid supplies, and temporary shelter). Long-term disruption of the Port of Vancouver is anticipated.

Shifting sediments at the bottom of the Fraser River is unlikely to be an impediment to barges, but may impede larger vessels. Additionally, vessels may avoid marine routes under bridges until those bridges have been inspected and deemed safe.

Rail Lines & Mass Transit

Due to liquefaction in areas of elevated portions of SkyTrain, inspection is required. Additionally, the loss of electricity will disrupt much of the public transit system.

Rail line disruption would primarily be due to bridge and causeway damage, restricting communications to/from the ports to other parts of North America. There is, however, also the possibility of damaged rail lines along areas of liquefiable sediments, especially along riverbanks. As such the rail line leading into the Port of Vancouver and Delta Port have both been disturbed. Furthermore, a spill at the Vancouver Railyard might necessitate the evacuation of Fire Hall #1 and City Hall, along with all of Olympic Village, Mt Pleasant, and parts of Grandview Woodland, assuming a symmetric region around the rail yard with a radius of City Hall-to-rail yard distance. This increases the number of displaced people from those projected strictly through scenario earthquake models. Finally, the rail line along the Sea-to-Sky corridor has been affected by the landslides along this route.

Airport

Specific to Vancouver International Airport, as a result of liquefaction, Dinsmore Bridge onto Lulu Island is impassable, the north runway is damaged beyond short-term repair, and the south runway needs minor repairs. The tower and older sections of the airport's buildings may have suffered moderate damage. In the immediate aftermath of the earthquake, planes are unable to safely land or take off. While the South Terminal remains operable, nearby slumping and dike breaches along the southern bank of Lulu Island have affected Sea Island Hovercraft SAR to the west.

Given the abundance of fuel stored in the area, there is also the potential of environmental contamination. Abbotsford Airport is undamaged and functional.

Information and Communications Technology

Damages to facilities where switching stations are located are likely to cause intermittent interruptions to information and communications technology (ICT) services. It is crucial to consider to what degree operations of other utilities are vulnerable to disruption of telecommunications (e.g., relatively independent networks highly dependent on data passing through a common facility may be damaged or disrupted by other means). As an example, a fire at the Cathedral Substation disrupted multiple internet services in 2008 (Paul Chouinard, *personal communications*, 2020). Landline and wireless telephone networks are typically overloaded in the aftermath of earthquakes, as they would be with the scenario event, providing intermittent service. The ability to text, however, has proven relatively reliable. Response organizations may also rely on satellite and radio communications.

Food

The lower mainland acquires much of its food, and in particular fruit and produce from south of the border, but disruptions to transportation routes will hinder the flow of these supplies. The supply of foodstuffs around the lower mainland to various neighbourhoods will similarly be hampered. Furthermore, perishable foods requiring refrigeration will likely be dependent on back-up generators.

Manufacturing

Although the lower mainland has few industrial facilities, impacts to manufacturing facilities that employ hazardous materials or produce hazardous waste could result in the need to evacuate local residents and businesses quickly. For instance, if a chlorine plant were impacted and resulted in the release of hazardous gases, this would require the rapid evacuation of the immediate and downwind communities.

Disruptions to supply chains, utilities and externally contracted services could affect an industrial facility's capacity to recover.

Government

As with the private sector, business continuity plans for all levels of government will be tested by the various impacts from this earthquake. In particular, regional entities will be contending with their own obstacles to operations while attempting to provide services needed during the event's response phase.

Finance

Banking sector is immediately impacted as some branches are damaged and/or do not have the electricity and Internet service to continue business.

9 Aftershock

Aftershocks are extremely common in the wake of large earthquakes and, while the vast majority are too small to be felt, they can often be nearly as strong as the main event. Unfortunately, it is not currently possible to model effects of an earthquake on an already damaged environment. NRCan does have considerable anecdotal knowledge, however, of what occurs in the wake of aftershocks similar to that modelled for the CR23 scenario. **Please note** that in-slab earthquakes, such as that modelled for the CR23 scenario earthquake, are rarely followed by aftershocks, so this would be considered an atypical event.

Early in the morning, four days after the M6.8 earthquake (main shock), a magnitude 5.7 aftershock occurs, with moderate-to-strong local shaking lasting less than a minute (Figure 23). The aftershock is located just northeast of the main shock (49.11, -123.19) at a similar depth, but substantially weaker in strength. Again, no tsunami occurs.

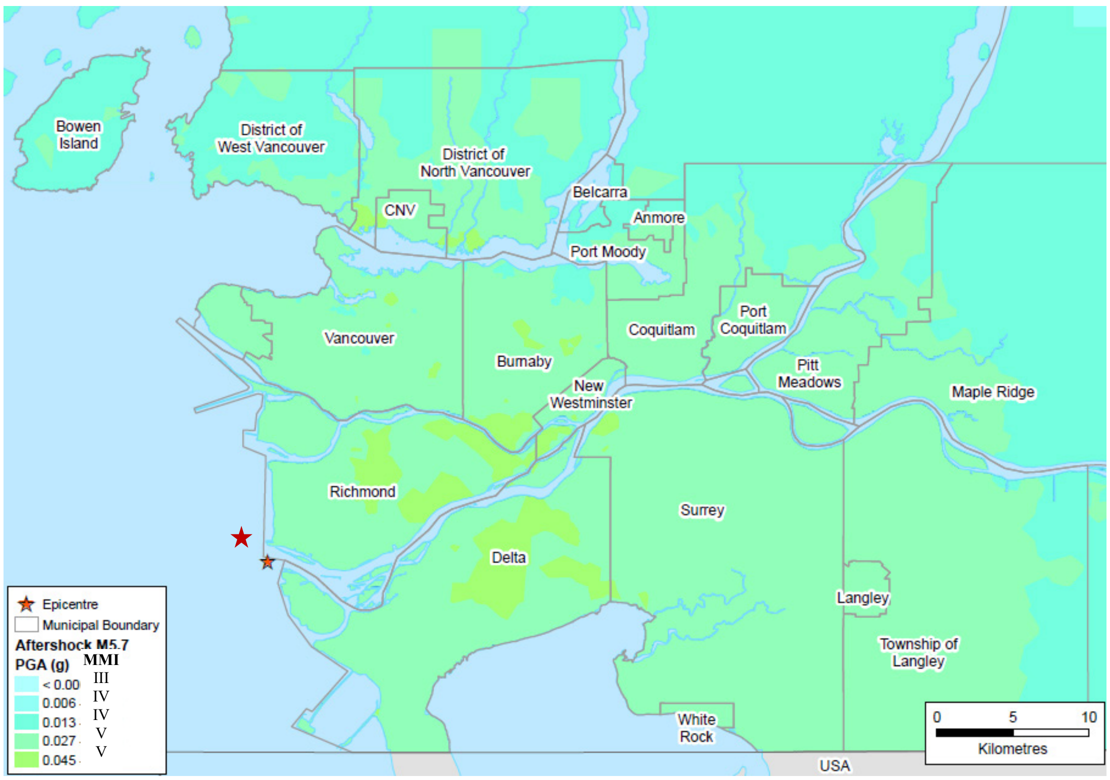

Figure 23. Shaking (peak ground accelerations) for the M5.7 aftershock, showing much lower levels of shaking intensity than for the main shock.

As this is a relatively moderately sized earthquake and at substantial depth, no damage is expected, except to especially vulnerable (previously badly damaged) buildings. Re-inspection will be required for numerous structures, particularly critical infrastructure. The region is still in response mode and Search and Rescue efforts may need to be temporarily halted. Additionally, the event is likely to trigger elevated levels of stress and, possibly, panic and PTSD in an already agitated population.

Buildings badly damaged by the main earthquake will have been evacuated and cordoned off from access, and no potentially harmful structural damage is anticipated in populated buildings during the M5.7 event. Only minor injuries might therefore be expected from the aftershock, and no fatalities.

10 Further Details & Conclusions

It should be noted that the vast majority of buildings in Vancouver were built before seismic provisions within the national, provincial, and municipal building codes were at modern standards for seismic safety (Kakoty, *et al.*, 2021). For example, approximately one third (34%) of all buildings in Metro Vancouver were constructed prior to the mid 1970s. Greater Vancouver has ageing, vulnerable infrastructure in several areas. Additionally, although southwestern BC suffered several strong, damaging earthquakes in the first half of the 20th century, there have been no strong earthquakes in the region since 1946. Despite all of this, the scenario earthquake presented here, and the other earthquakes anticipated for the region, do not represent the apocalyptic situation many people envision.

While relatively weak earthquakes occur far more frequently than large, highly impactful events, the likelihood of a strong, damaging earthquake in our region remains relatively high (a 20% chance in 50 years for Greater Vancouver), and it is the responsibility of all in this region to prepare for such earthquakes and their risks. Given the complexities and interdependencies of systems in today's society, cascading impacts to critical infrastructure systems will amplify impacts to the region.

In addition to constructing to building code standards and other resilience and preparedness measures, Natural Resources Canada is developing an Earthquake Early Warning system for moderate-to-high risk regions of Canada (see Appendix IV). This will provide valuable seconds for people and systems to take protective measures, and hence reduce the impacts of major earthquakes in our country (Bird, *et al*., 2023).

References

Abrahamson N., N. Gregor, and K. Addo (2016) BC Hydro ground motion prediction equations for subduction earthquakes. **Earthquake Spectra**, **32**:23-44. https://doi.org/10.1193/051712EQS188MR

Atkinson G.M. and D.M. Boore (2003). Empirical ground-motion relations for subduction-zone earthquakes and their application to Cascadia and other regions. *Bulletin of the Seismological Society of America*, **93**: 1703–1729. https://doi.org/10.1785/0120020156

Allen, Trevor I., and David J. Wald. 2009. *Ground-Motion Modeling Techniques for Use in Global ShakeMap—A Critique of Insrumental Ground-Motion Prediction Equations, Peak Ground Motion to Macroseismic Intensity Conversions, and Macroseismic Intensity Predictions in Different Tectonic Settings.* United States Geological Survey Open-File Report, United States Department of the Interior. https://pubs.usgs.gov/of/2009/1047/pdf/OF09-1047.pdf.

Applied Technology Council (1989) ATC-20: Procedures for Post-earthquake Safety Evaluation of Buildings. https://store.atcouncil.org/

Barth, S., M. Geertsema, A.R. Bevington, A.L. Bird, J.J. Clague, T. Millard, P.T. Bobrowsky, A. Hasler and H. Liu (2020). Landslide response to the 27 October 2012 earthquake (MW 7.8), southern Haida Gwaii, British Columbia, Canada, *Landslides* **17**: 517–526. https://doi.org/10.1007/s10346-019-01292-7

Bird, A.L., H.C.J. Seywerd, S. Crane, J. Adams, and D.A. McCormack (2023). "National Earthquake Early Warning System Will Mitigate Impacts of Earthquakes to Critical Infrastructure in Canada", *Infrastructure Resilience Risk Reporter*, **1.13:** 3-10. https://carleton.ca/irrg/wp-content/uploads/VOL-1-ISSUE-13-Final-Version.pdf.

Cassidy, J.F., Rogers, G.C., Lamontagne, M., Halchuk, S., and Adams, G. (2010). Canada's earthquakes: 'the Good, the Bad, and the Ugly', *Geoscience Canada*, **37**: 1-16, https://journals.lib.unb.ca/index.php/GC/article/view/15300.

Deelstra, A. & D. Bristow (2020). Characterizing Uncertainty in City-Wide Disaster Recovery through Geospatial Multi-Lifeline Restoration Modeling of Earthquake Impact in the District of North Vancouver, *International Journal of Disaster Risk Science*. **11:** 807–820 https://doi.org/10.1007/s13753-020-00323-5

Federal Emergency Management Agency, Department of Homeland Security (2010): *Debris Estimating Field Guide. FEMA Report 329*, https://www.fema.gov/sites/default/files/2020-07/fema_329_debris-estimating_field-guide_9-1-2010.pdf.

Global Earthquake Model, 2020: *OpenQuake*, https://www.globalquakemodel.org/openquake.

Halchuk, S., J. Adams, M. Kolaj, & T. Allen (2019) Deaggregation of NBCC 2015 Seismic Hazard for Selected Canadian Cities, *12th Canadian Conference on Earthquake Engineering, Quebec City*.

Hobbs, T.E., M. Journeay, J.Z.K Yip, & A. Rao (2022) Benchmarking Scenario Performance in the First Generation Canadian Seismic Risk Assessment. *American Geophysical Union, iPosterSessons* https://d197for5662m48.cloudfront.net/documents/publicationstatus/118861/preprint_pdf/6289dbf158e9ff0f9f31f6b00b57960d.pdf.

Journeay, M., J.Z.K. Yip, C.L. Wagner, P. LeSueur, & T. Hobbs (2022), Social vulnerability to natural hazards in Canada: an overview of methods and findings, *Geological Survey of Canada,* Open File Report **8902**.

Kakoty, P., S.M. Dyaga, & C. Molina Hutt (2021) Impacts of simulatedM9 Cascadia Subduction Zone earthquakes considering amplifications due to the Georgia sedimentary basin on reinforced concrete shear wall buildings, *Earthquake Engineering and Structural Dynamics*, **50:** 237–256, https://doi.org/10.1002/eqe.3361

Keefer, D.K. Investigating Landslides Caused by Earthquakes – A Historical Review. *Surveys in Geophysics* **23**, 473–510 (2002). https://doi.org/10.1023/A:1021274710840

Kimura, Y., H. Tagawa, D. Lehman, & G.A. Macrae (2001). Report of Damage to Building Structures Caused by the Nisqually Earthquake in 2001, *Bulletin of the Seismological Society of America*, **94**: 1143-1158, https://doi.org/10.3130/aijt.7.373

Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019: *BC Dike Consequence Classification Study,* https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/dike-management#dike_conseq.

National Research Council, 2020: *National Building Code of Canada*, https://www.nationalcodes.ca/eng/index.html.

Public Safety Canada, 2009: *National Strategy for Critical Infrastructure*, *https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/srtg-crtcl-nfrstrctr/index-en.aspx.*

Public Safety Canada: *National Public Alerting System*, https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/mrgnc-prprdnss/ntnl-pblc-lrtng-sstm-en.aspx.

Statistics Canada, 2011: *Census of Population Program,* https://www12.statcan.gc.ca/census-recensement/2011/rt-td/index-eng.cfm?TABID=4.

Statistics Canada, 2016: *2016 Census,* https://www12.statcan.gc.ca/census-recensement/2016/rt-td/index-eng.cfm?TABID=4.

Turner, R.J.W., J.J. Clague, B.J. Groulx, & J.M. Journeay (1998) GeoMap Vancouver: Geological Map of the Vancouver Metropolitan Area, *Geological Survey of Canada*, Open File 3511: https://www.cgenarchive.org/vancouver-geomap.html.

United Nations Office for Disaster Risk Reduction, 2015: *Sendai Framework for Disaster Risk Reduction 2015-2030*, https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.

United States Geological Survey, 2001: *Nisqually Earthquake*, https://earthquake.usgs.gov/earthquakes/eventpage/uw10530748/executive.

Wareham, D.G. & M. Bourke (2013) The 2010–2011 Canterbury earthquakes: impact on the liquid waste management system of Christchurch, New Zealand, *Civil Engineering and Environmental Systems*, **30.1:** 1-14, https://doi.org/10.1080/10286608.2012.709507

Wood, H.O. & F. Neumann (1931) Modified Mercalli Intensity Scale of 1931, *Bulletin of the Seismological Society of America*, **21:** 277-283.

Zhao J.X., J. Zhang, A. Asano, Y. Ohno, T. Oouchi, T. Takahashi, H. Ogawa, K. Irikura, H. Thio, P.G. Somerville, Y. Fukushima, and Y. Fukushima (2006). Attenuation relations of strong ground motion in Japan using site classification based on predominant period. *Bulletin of the Seismological Society of America*, **96**: 898–913. https://doi.org/10.1785/0120050122

Further Reading

Natural Resources Canada: *Earthquakes Canada*: https://www.earthquakescanada.nrcan.gc.ca/index-en.php.

Insurance Bureau of Canada with AIR Worldwide, 2013: *Study of Impact and the Insurance and Economic Cost of a Major Earthquake in British Columbia and Ontario/Québec*, http://assets.ibc.ca/Documents/Studies/IBC-EQ-Study-Full.pdf.

Appendix I: "Earthquake Report" for Scenario Earthquake

EXERCISE EXERCISE EXERCISE

From: Earthquake Info / Info Seisme (NRCAN/RNCAN) [mailto:EarthquakeInfo@nrcan.gc.ca]
Sent: Wednesday, February 05, 2020 06:30 AM
To …
Cc: Earthquake Info / Info Seisme (NRCAN/RNCAN) <nrcan.earthquakeinfo-infoseisme.rncan@canada.ca>; nrcan.flms.mchisit.rncan@canada.ca
Subject: Earthquake Report

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EARTHQUAKE REPORT

NATURAL RESOURCES CANADA
GEOLOGICAL SURVEY OF CANADA

OTTAWA, ON, K1A 0Y3	SIDNEY, BC, V8L 4B2
Tel: 613-995-5548	Tel: 250-363-6500
Fax: 613-992-8836	Fax: 250-363-6565

DATE: Wednesday, 05 February 2020

TIME: 06:16 PST

PRELIMINARY MAGNITUDE: 6.8

LOCATION: 49.10 North, 123.20 West (12 km NW of Tsawwassen, BC)

ADDITIONAL INFORMATION:

THIS IS A SYSTEM TEST. THIS IS NOT AN EARTHQUAKE ALERT.
Serious damage reported in Greater Vancouver.
Strongly felt in most areas of southwestern BC.
No tsunami expected.
Strong aftershocks are possible.

Prepared by: Honn Kao

Web: http://www.earthquakescanada.nrcan.gc.ca | Twitter: @CanadaQuakes

EXERCISE EXERCISE EXERCISE

Appendix II: “Web Page” for Scenario Earthquake

EXERCISE EXERCISE EXERCISE

Government of Canada | Gouvernement du Canada

Canada.ca | Services | Departments | Français

Natural Resources Canada

Canada

Search

Energy | Mining/Materials | Forests | Earth Sciences | Hazards | Explosives | The North | Climate Change

Home → Hazards → Natural Hazards → Earthquakes Canada → Earthquake Details (2020-01-24)

(2020-02-05)

- **Earthquakes Canada**
- Recent Earthquakes
- Historic Events
- Earthquake Hazard
- Be Prepared!
- Stations and Data
  - Upgrades to the Network
- General Information
- Products / Research
- Earthquake Resources
  - Earthquake Search
  - Hazard Calculator
  - Station Book
  - Seismogram viewer
  - Waveform Data
  - External Links
- Contact EqCan

Earthquake Details (2020-02-05)

Wednesday February 05, 2020

Earthquake details | Nearby locations | Regional seismicity | Regional seismograph stations | Did you feel the earthquake? | Other recent earthquake reports

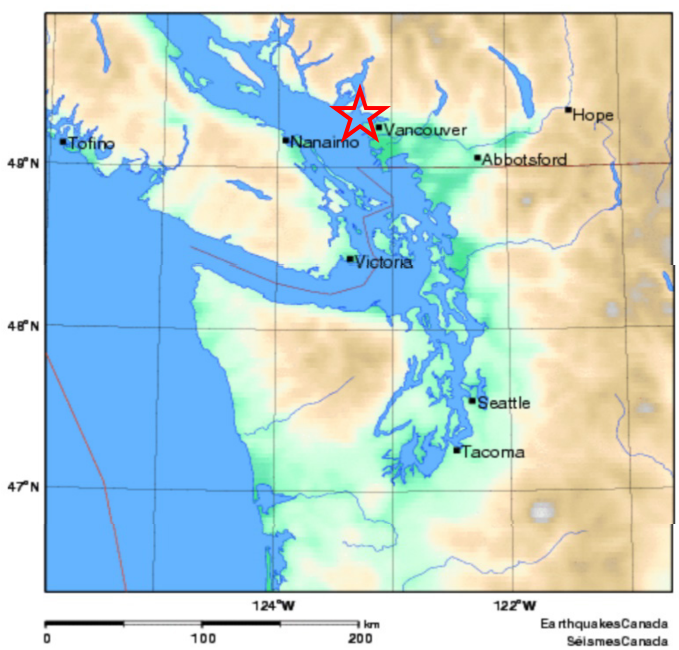
Local Time:	06:16:00 PST
Magnitude:	6.8 Mw
Latitude:	49.10 North
Longitude:	123.20 West
Depth:	63 km
UT Date and Time:	2020/02/05 14:16:00 UT

Did you feel it?

Fill out our questionnaire.

THIS IS A SYSTEM TEST. THIS IS NOT AN EARTHQUAKE ALERT.

Approximate Location of Earthquake: Serious damage reported in Greater Vancouver. Strongly felt in most areas of southwestern BC. No tsunami expected. Strong aftershocks are possible.



Appendix III: Summary of modelled impacts for Scenario Event

Table 1. Summary of modelled impacts for municipalities with more than 24 displaced people.

	First Aid	Noncritical Hospital	Critical Hospital	Fatalities + Entrapments	30 Day Displacement	Red Tag Buildings	Yellow Tag Buildings	Green Tag Buildings
Vancouver	536	145	21	41	8,028	92	121	5,598
Surrey	270	69	10	19	4,526	148	163	4,963
Richmond	303	82	12	24	4,323	87	98	3,535
Langley	86	21	2	4	2,045	106	102	1,893
Burnaby	171	44	6	11	1,735	38	36	1,579
North Vancouver	255	69	9	18	1,662	63	77	1,642
Delta	168	47	8	15	1,443	47	64	2,108
New Westminster	90	27	4	8	1,014	10	9	493
Abbotsford	14	1	0	0	900	9	16	615
White Rock	7	1	0	0	606	2	7	323
Maple Ridge	37	10	2	3	543	23	20	699
Coquitlam	37	9	2	3	492	24	25	826
Port Coquitlam	15	3	0	1	364	5	13	533
North Cowichan	9	2	0	0	354	21	24	371
Nanaimo	17	3	0	1	247	21	31	731
Greater Vancouver A	2	0	0	0	222	0	2	54
Ladysmith	1	0	0	0	189	12	12	165
Pitt Meadows	11	3	1	1	185	11	9	245
Gibsons	3	1	0	0	180	1	3	107
Musqueam 2	0	0	0	0	175	0	0	35
Capilano 5	18	4	1	1	144	11	12	131
Esquimalt	4	1	0	0	133	2	1	43
Central Saanich	1	0	0	0	118	0	1	45
Port Moody	3	0	0	0	99	0	4	205
Nanaimo A	2	1	0	0	97	15	8	143
West Vancouver	30	8	1	2	76	6	8	342
Chilliwack	2	0	0	0	76	4	6	164
New Songhees 1A	0	0	0	0	49	2	5	73
Sechelt	1	0	0	0	45	12	11	153
Lakahahmen 11	0	0	0	0	35	3	4	21
Matsqui 4	0	0	0	0	30	8	8	91
Sunshine Coast D	2	1	0	0	29	5	5	84
Nanaimo River	0	0	0	0	26	1	2	5
Cowichan Valley D	2	1	0	0	24	4	8	73

Appendix IV: Earthquake Early Warning

Earthquake Early Warning (EEW) is the rapid detection of earthquakes, real-time estimation of the shaking hazard, and notification of expected shaking (Figure 24).

Earthquakes release energy that travels through the Earth as seismic waves. Seismic sensors detect the first energy to radiate from an earthquake, the P-wave, which rarely causes damage. The sensors transmit this information to data centres where the earthquake's location and magnitude, and the expected ground shaking across the region are rapidly calculated by specialized software and an alert is disseminated. This method can provide warning before the arrival of secondary S-waves, which bring the strong shaking that can cause most of the damage.

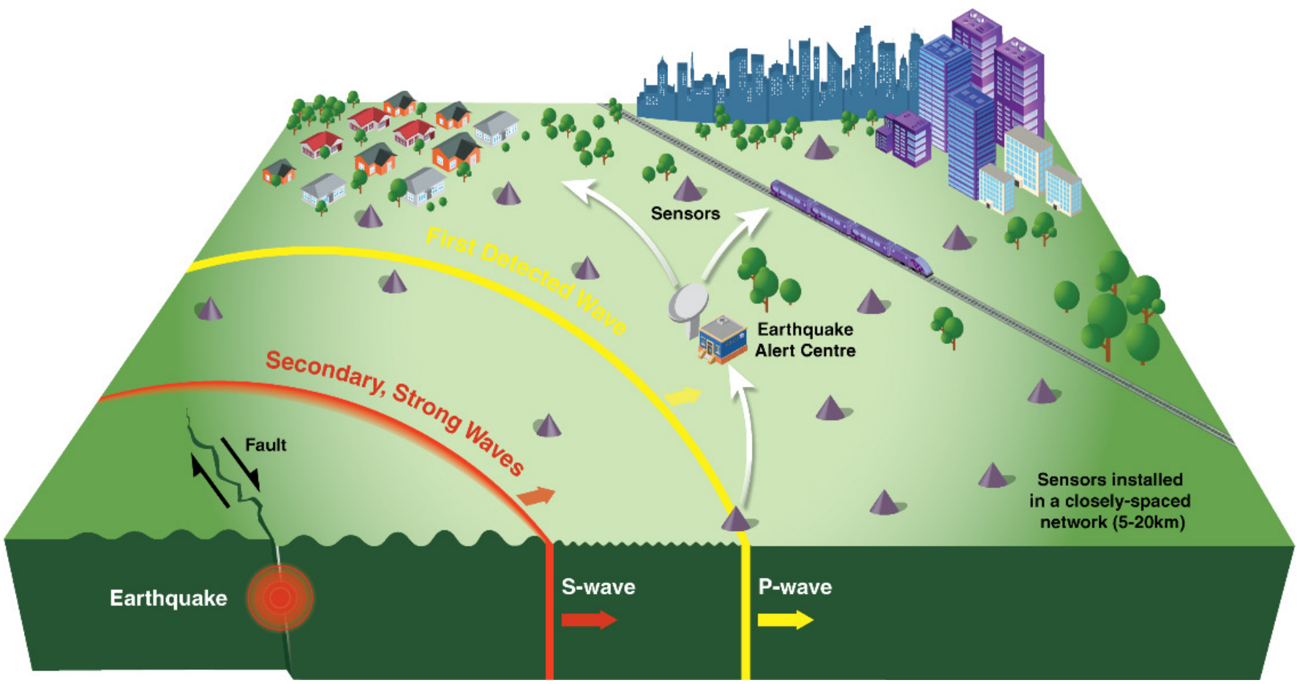


Figure 24. Earthquake Early Warning (EEW) is the rapid detection of an earthquake, rapid estimation of the shaking hazard, and alerting of imminent shaking.

Warning times range from a few seconds to tens of seconds depending on distance from the earthquake location. The further one is away from the epicentre, the more warning time. Unfortunately, areas very close to an earthquake's epicentre may not receive an alert before the arrival of strong shaking.

As part of the Emergency Management Strategy for Canada launched in 2019, the federal government funded Natural Resources Canada to develop an EEW system. EEW is being established for areas of both moderate to high seismic hazard and moderate to high concentrations of population and infrastructure, primarily western British Columbia, eastern Ontario, and southern Quebec. The United States Geological Survey EEW software has been adopted by Canada to facilitate sharing data between the countries, which will ensure earthquakes close to the Canada-United States border are managed as effectively as those that occur well within each country's own EEW network.

EEW notifications will be sent to the public via the National Public Alerting System (Public Safety Canada) to advise that strong shaking is likely and imminent, and that they should protect themselves. Critical Infrastructure operators, Government Operations Centres, and other industrial facilities will receive EEW messages that could trigger automated protective actions specific to their operations (Bird, *et al*., 2023). The EEW system will therefore help to reduce injuries, deaths, and property losses by allowing time to enact certain precautions (Figure 25).

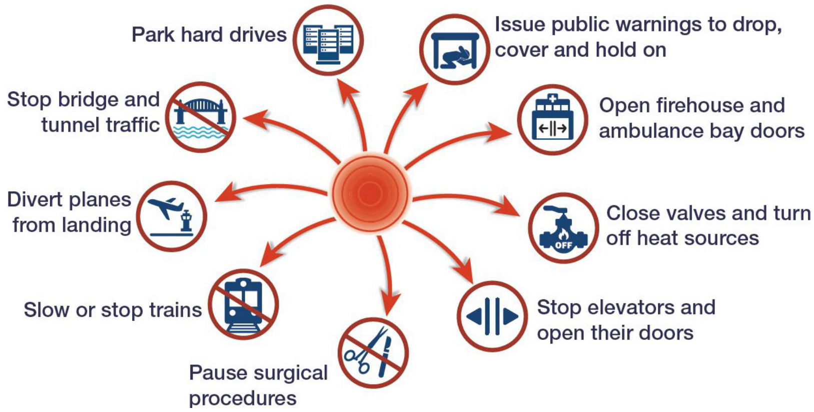


Figure 25. Selection of protective actions that can be taken with the few seconds' notice provided by an EEW system.

The Canadian EEW system in Canada will become operational in 2024. . The system will contribute to the country's resiliency from seismic hazards, as part of Canada's commitment to the recommendations outlined within the Sendai Framework for Disaster Risk Reduction (United Nations Office for Disaster Risk Reduction, 2015).