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2015

Canada

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2015

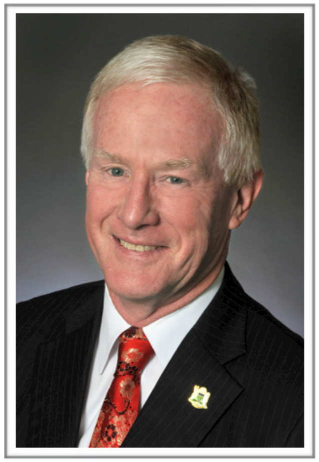
doi:10.4095/296256

This publication is available for free download through GEOSCAN (http://geoscan.nrcan.gc.ca/).

Recommended citation

Journeay, J.M., Dercole, F., Mason, D., Weston, M., Prieto, J.A., Wagner, C.L., Hastings, N.L., Chang, S.E., Lotze, A., and Ventura, C.E., 2015. A profile of earthquake risk for the District of North Vancouver, British Columbia; Geological Survey of Canada, Open File 7677, 223 p. doi:10.4095/296256

Publications in this series have not been edited; they are released as submitted by the author.



On behalf of the District of North Vancouver, I am pleased to introduce this innovative and meaningful study which takes a highly-detailed look at the earthquake risks and resiliency opportunities for our community.

It is important to fully understand the potential risks that we face as a community, and to put those risks into the context of our daily lives, before we commit resources towards risk reduction. This in-depth study provides a clear picture of what we can expect in the event of a major earthquake, and what we can do to prevent future losses and increase our resilience. It is our hope that this study, along with the associated community outreach program, will foster action in all levels of our community.

When the Ground Shakes is our plain language companion piece to the detailed technical study. It tells the story of three fictional, but typical, North Vancouverites and their experiences immediately following a major earthquake. The EQ Story Map is our interactive storytelling tool that uses images and GIS maps to highlight important components of the report.

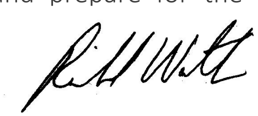
This is a call to action for our residents, our businesses and those of us in government, to be as prepared as we can for a major earthquake or other serious emergency.

The District is taking stock of municipally-owned assets, such as buildings, underground utilities and other infrastructure, and is borrowing best practices from around the world to strengthen these systems through mitigation. Seismic risk will be incorporated into our asset management program. We now know which areas of the municipality will be most severely impacted, and can plan to send our emergency response teams there first. And we can ensure that key facilities are hardened so that they will function as areas of refuge and reunification. We have been participating in exercises to practice how we work together in our Emergency Operations Centre to coordinate and prioritize response and recovery activities. Our new town centres present an opportunity to redevelop some older neighbourhoods, with structures currently quite vulnerable to earthquakes, to current standards for seismic safety.

If you are a business owner, we invite you to make use of the resources on the North Shore Emergency Management Office website aimed to increase business continuity and reduce economic losses. For some businesses, it may simply be a matter of restraining tall shelving and heavy objects, and backing up critical data off-site. For those in older, more vulnerable buildings, you may consider investing in seismic retrofits to protect your business and ensure that you can recover quickly with minimal disruption. We encourage businesses to work together with their supply chains and pool resources with neighbouring businesses to become resilient hubs.

And if you are a resident, please do educate yourself about possible hazards in your area, stock up on emergency supplies, prepare a family emergency plan and, perhaps most importantly, get to know your neighbours. You will be relying on each other for support until response agencies are able to get to you, which may take some time.

In the spirit of regional cooperation and as a United Nations Role Model City, we will openly share this study and the outcomes generated by it. We also invite the opportunity to learn from others who may have experienced a major earthquake and know first-hand what works and what doesn't. Our thanks to Natural Resources Canada and the University of British Columbia for this opportunity to partner with them on this ground-breaking work that has helped us better understand and prepare for the hazards and risks in our community.



Mayor Richard Walton - District of North Vancouver

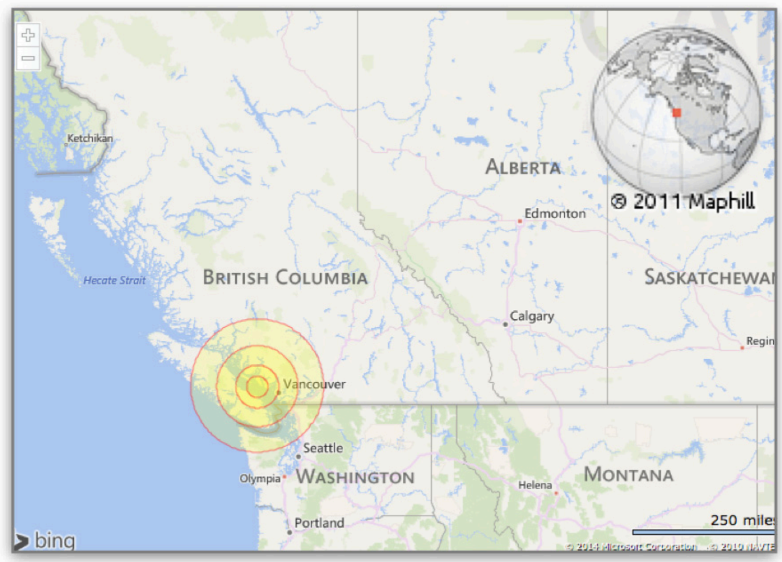
ABSTRACT

The societal costs of natural hazards are large and steadily increasing in Canada due to increased urban development, an aging infrastructure, and limited capacities to anticipate and plan for unexpected disasters. Lessons learned from recent disasters underscore the need for a comprehensive risk-based approach to land use planning and emergency management at all levels of government—one that utilizes available knowledge about the risk environment to inform actions that have a potential to minimize future disaster losses and increase the resilience of communities to the dynamic and uncertain forces of change.

We cannot predict or prevent earthquakes from happening. However, we do have the knowledge and capabilities to change the outcome of earthquake disasters through a combination of risk assessment and disaster resilience planning. Risk assessment is the process through which knowledge about a community and its exposure to natural hazards is used to anticipate the likely impacts and consequences of an unexpected event at some point in the future. Disaster resilience planning is focused on actions that can be taken in advance to balance policy trade offs for growth and development (opportunities) with risk reduction investments that have a potential to minimize future losses (liabilities) while increasing capabilities of a community to withstand, respond to and recover from unexpected disaster events (resilience).

This study provides a detailed assessment of earthquake risk for the District of North Vancouver – an urban municipality of approximately 83,000 people situated along the North Shore Mountains in southwestern British Columbia. It describes the probable impacts of a significant earthquake with greater clarity and detail than ever before, and develops both a methodology and target criteria to guide future risk reduction and disaster resilience planning activities through the lens of building performance, public safety, lifeline resilience and socioeconomic security. We examine cause-effect relationships and seismic risks for a plausible earthquake scenario in the Strait of Georgia (M7.3), and undertake a more general assessment of who and what are vulnerable to known earthquake hazards in the region using probabilistic ground motion models that are consistent with those used to establish seismic safety guidelines in the National Building Code of Canada (NBCC, 2010).

Study outputs offer a capacity to explore thresholds of risk tolerance and opportunities for mitigation through ongoing emergency planning and land use decision-making activities in the community. Methodologies and insights gained through this study are transferrable to other communities who may face similar challenges of managing growth and development in areas exposed to earthquake hazards. Key findings and recommendations of the study contribute to broader efforts led by the Canadian Safety and Security Program to support disaster resilience planning at a community level in Canada.



A recent M3.2 tremor in the Georgia Strait (December 2014)— a reminder that we live in earthquake country.

PROJECT TEAM

A Profile of Earthquake Risk for the District of North Vancouver is the result of a five-year research and development effort led by the Earth Sciences Sector of Natural Resources Canada (ESS/NRCan). The study explores the realm of earthquake risk reduction at a municipal scale through collaborative partnerships with practitioners responsible for managing growth and development in areas exposed to earthquake hazards, and with researchers responsible for the development of methods and tools to support earthquake risk reduction and disaster resilience planning in Canada.

Case Study Partners

The District of North Vancouver (DNV) is the lead municipal case study partner and responsible for overall context and focus for the project. Primary roles included the sharing of detailed technical information about the community and critical assets, and the identification of policy goals and target criteria that have guided all aspects of the risk assessment process. Staff members from the Engineering department (Fiona Dercole, Michelle Weston and colleagues) have worked with research partners at each step of the process and have provided important new insights on the needs and operational requirements for earthquake risk reduction and disaster resilience planning at a municipal scale in Canada. They have worked with community members of the Natural Hazards Task Force to review study results and to help transform scientific and technical knowledge about the risk environment into a form that will support both day-to-day and longer-term strategic planning activities in the community.

The North Shore Emergency Management Office (NSEMO) coordinates cross-jurisdictional planning, preparedness, and the development of core operational capacities that are required to support emergency response and recovery efforts on behalf of the District of North Vancouver, the City of North Vancouver and the District of West Vancouver. As a member of the Integrated Partnership for Regional Emergency Management in the greater Metro Vancouver area, NSEMO also acts as a liaison between local and regional governments in the development of emergency plans and the coordination of disaster response and recovery efforts. Staff members at NSEMO (Dorit Mason and colleagues) have provided technical information on essential facilities and emergency service capacities in the region, and have contributed to the development of strategies for promoting the uptake and use of earthquake risk information by local governments, the business community, and members of the general public.

Research Partners

Natural Resources Canada (NRCan: Public Safety Geoscience Program) is the lead researcher for the project and one of several federal departments with a mandate to carry out fundamental research to help reduce the economic, social, and environmental impacts from natural hazards in Canada. NRCan contributes to the public safety mandate for Canada by generating knowledge about natural hazards (earthquakes, volcanoes, landslides, etc.) and developing integrated assessment methods to support risk reduction and disaster resilience planning in the public and private sector. Researchers with the Public Safety Geoscience Program (Murray Journeay, Nicky Hastings, Jorge Prieto, and Carol Wagner) have taken a lead role in the analysis and evaluation of earthquake risks for the District of North Vancouver through collaborative partnerships with case study partners, and with academic colleagues at the University of British Columbia and Simon Fraser University.

The UBC School of Community and Regional Planning (SCARP) is one of only a few research facilities in Canada that focuses on disaster management and urban sustainability at local and regional scales. Research is focused on issues of disaster recovery and the resilience of urban infrastructure systems, and includes both empirical studies of major urban disasters and computer-based modelling and analysis of risk reduction strategies. Researchers at SCARP (Stephanie Chang and Autumn Lotze) contributed to the analysis of business disruption and related income losses that are likely to be sustained in the District as a result of earthquake damages to buildings and related critical infrastructure systems that provide essential lifeline services to the community. In addition, they have provided key insights on earthquake risks within the business sector, and strategies to increase disaster resilience through strategic investments in both mitigation and adaptation.

The UBC Department of Civil Engineering is a leader in fundamental and applied research on seismic hazards and structural engineering in Canada. Researchers at the Earthquake Engineering Research Facility (EERF; Carlos Ventura and Liam Finn) worked with members of the NRCan team to assess local-scale seismic hazards using a combination of deterministic and probabilistic ground motion models, and contributed vital information on building assets to support a site-level analysis of earthquake risks for the District of North Vancouver. In addition, they have provided important insights and recommendations on seismic retrofit strategies that may be effective in reducing the vulnerabilities of older buildings that are susceptible to severe earthquake hazards in the District.

Peer Review

We are grateful to members of the DNV Natural Hazard Task Force for their guidance on this study and critical review of the final report. Their insights have helped to ensure that study outputs are relevant and will inform disaster resilience planing and policy development in the community. We also thank NRCan research scientists Trevor Allen and Heather Crow for critical review of study outputs and thoughtful contributions to the technical content of this report. Finally, we thank Shana Johnstone for reviewing analytical results and translating study outputs into a more accessible narrative form to help promote a broader awareness and understanding of earthquake risks in the DNV.

Project Sponsors

Defence Research and Development Canada (DRDC) is the project sponsor and the lead federal agency responsible for science and technology in support of public safety and socioeconomic security in Canada. Operational funding was provided to the Public Safety Geoscience program of NRCan through the Risk Assessment and Capability Integration Program of DRDC (Risk 09/10-0001SCP; Quantitative Risk Assessment Methods Project), Outputs of this study contribute to broader efforts led by DRDC and Public Safety Canada to develop an all-hazards risk assessment framework to support policy goals and operational requirements for a National Disaster Mitigation Program.

Federal Emergency Management Agency (FEMA) provided technical assistance and logistical support for the project through a Cooperative Activity Arrangement with Defence Research and Development Canada (DRDC) and Natural Resources Canada. The primary objective of this work was to establish a standardized methodology for quantitative damage and loss estimation that extends capabilities of Hazus to assist local and regional authorities in analyzing the impacts and consequences of natural hazards (floods, earthquakes and hurricanes), and in evaluating mitigation strategies that increase the disaster resilience of communities and regions. Secondary objectives were to help build a capability for quantitative risk assessment through a coordinated program of outreach and training that addresses the needs and requirements of emergency managers and land use planners in Canada.

EXECUTIVE SUMMARY

We live in a world where connections between natural and human systems are increasingly complex, and where decisions about how to manage societal risk are increasingly uncertain and ambiguous. As communities continue to grow and develop in areas exposed to the impacts of natural hazards, so too does the potential for increasingly severe and devastating events like the ones recently witnessed in Japan and New Zealand. Lessons learned from these and other global disasters underscore the need for a risk-based approach to community planning and emergency management — one that balances the risks of growth and development in hazardous terrain (constraints) with actions that can be taken in advance of a disaster to increase community resilience (opportunities; Figure 1).

Southwestern British Columbia is one of the most seismically active regions in Canada [Cassidy et al., 2010]. Smaller earthquakes occur daily and the region is known to have experienced some of the largest earthquakes ever recorded along the Pacific 'Ring of Fire.' Though infrequent, these larger earthquakes have the potential for catastrophic losses and pose an imminent and credible threat to settled areas in the Pacific northwest regions of British Columbia and Washington State.

A recent study commissioned by the Insurance Bureau of Canada reveals that losses associated with a major earthquake in southwestern British Columbia could exceed $75 billion [AIR Worldwide, 2013]. The Lower Mainland region of Metro Vancouver and the Fraser Valley are exposed to a wide range of seismic hazards including severe ground shaking, liquefaction, earthquake-triggered landslides and tsunami. All have the potential to cause catastrophic damage, loss of life and financial hardship. Areas at greatest risk include older neighbourhoods and commercial/industrial districts in downtown Vancouver, Richmond, Delta, Annacis Island and North Vancouver.

This study examines earthquake risks for the District of North Vancouver (DNV) — an urban municipality of approximately 83,000 people situated along the North Shore Mountains and marine waterfront areas of Burrard Inlet. It includes a detailed analysis of what to expect in terms of impacts and consequences should a major earthquake occur at some point in the near future, and provides insights on actions that might be considered to increase disaster resilience of the community over time.

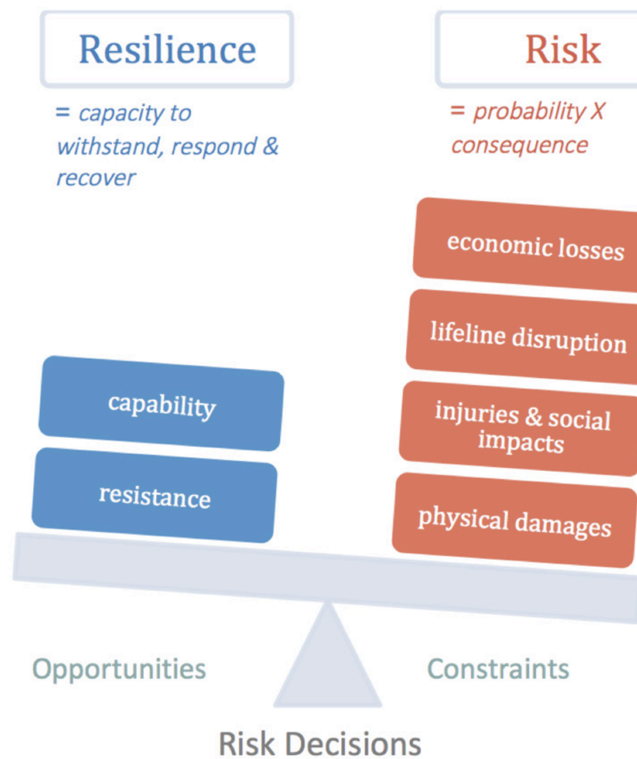


Figure 1: Balancing the risks of growth and development in hazardous terrain (constraints) with actions that can be taken in advance of a disaster to increase community resilience (opportunities)

Our Process at a Glance

Disaster resilience planning is a forward-looking process of analysis and deliberation through which knowledge about the risk environment is used to develop actionable strategies that increase the safety and security of a community and its capacity to respond and recover from hazard threats of concern.

We have adopted a framework for disaster resilience planning [J M Journeay, 2015] that utilizes methods of integrated assessment and scenario modelling to help bridge the gap between knowledge and action (Figure 2). Quantitative methods of integrated risk assessment are used to analyze cause-effect relationships and likely impacts and consequences for hazard threats of concern. Design-based methods of participatory planning and scenario modelling are used to establish decision protocols and to evaluate policy alternatives based on negotiated thresholds of risk tolerance.

The framework is aligned with national and international standards for risk management [Australia/New Zealand Standards, 2006; CAN/CSA-Z1600, 2008; ISO 31000, 2008], and incorporates best practices for risk governance and disaster resilience planning [International Risk Governance Council, 2008; Renn, 2006b]. Integrated risk assessment offers a structured and evidence-based approach to disaster resilience planning that is informed by

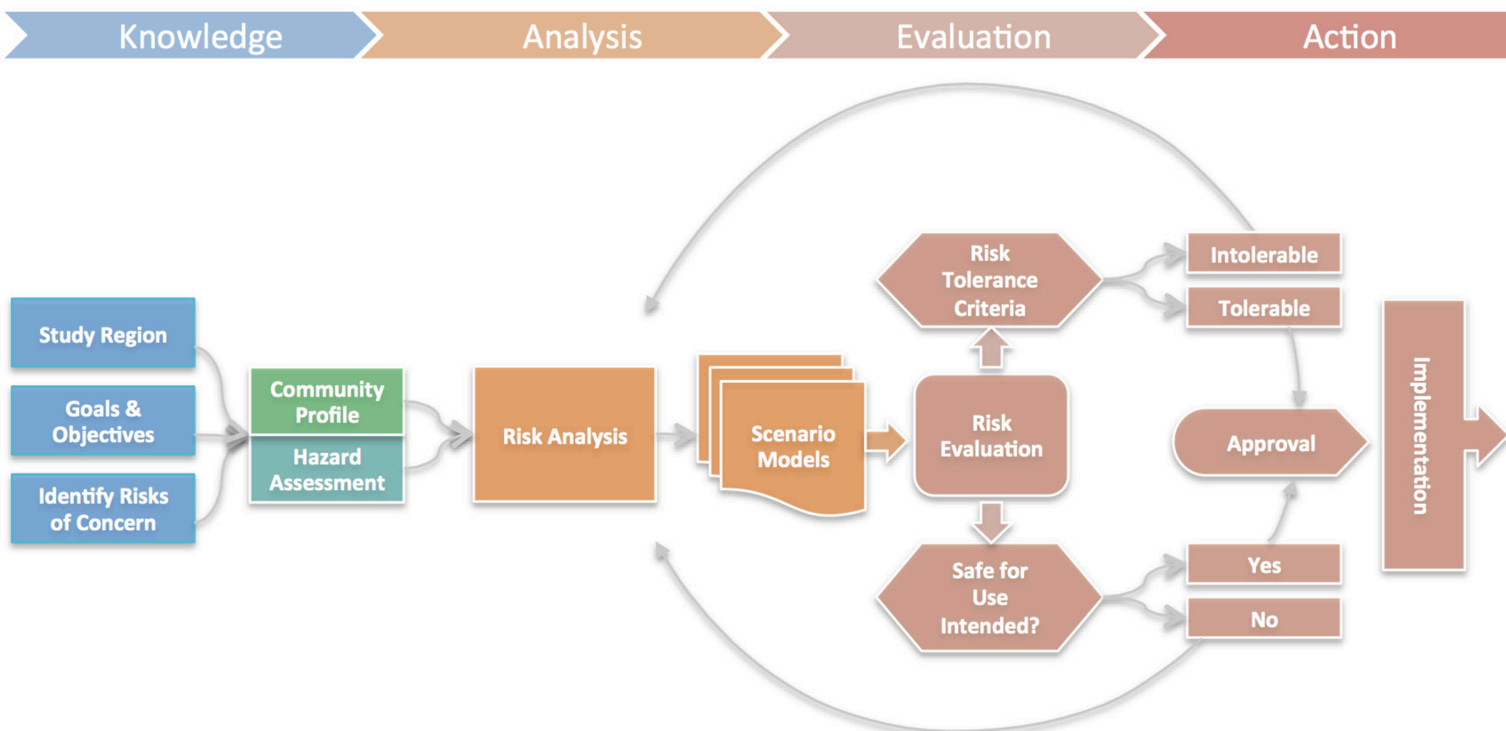


Figure 2: Elements of an integrated risk assessment framework for disaster resilience planning (Adapted from Journeay, 2015).

scientific analysis and predictive modelling, and governed by community values and preferences with respect to who and what are considered vulnerable and in need of safeguarding. Figure 3 is a summary of the process used to assess earthquake risks for the District of North Vancouver. Although described in terms of discrete steps, the process was iterative and evolved through ongoing deliberation, analysis and scenario modelling.

Deliberative components of the process are focused on subjective measures of risk, including the identification of community values and policy goals used to frame the risk assessment process (Step 1), and the establishment of target criteria used to evaluate mitigation alternatives in terms of building performance, public safety, lifeline resilience and socioeconomic security (Step 5). Deliberations were facilitated through a series of design-based workshops with planning staff from the District and North Shore Emergency Management Office (NSEMO), and with members of the Natural Hazards Task Force – a voluntary advisory group representing homeowners and the interests of commercial and industrial businesses in the community.

Analytic components of the process are focused on objective measures of risk, including factors that have contributed to the vulnerability of people and critical assets in the community (Steps 1 and 2), and what might be expected should a major earthquake strike at some point in the near future (Steps 3-5). Our assessment includes an analysis of damage potential and expected socioeconomic lesses for major earthquakes of concern, and an evaluation of risk reduction strategies based on target criteria established by the community (Step 5). Earthquake analysis and the evaluation of mitigation alternatives were facilitated using Hazus – a standardized loss estimation methodology developed for use in the public domain [FEMA, 2004; National Institute of Building Sciences, 2002].

Figure 3: Synopsis of risk assessment process used in this study.

What Can We Expect?

We explore the likely impacts of a significant earthquake through a system of performance measures (indicators) that offer a comprehensive profile of risk at the community level. The framework of indicators provides a capability to assess both current conditions of earthquake risk, and the effectiveness of risk reduction strategies that might be considered to increase longer-term disaster resilience of the community. Risk metrics include:

- Seismic Hazard Potential: The intensity of shaking and potential for ground failure at any given location as a result of seismic energy generated by an earthquake event.
- Building Performance: the likelihood of damage (resistance) and the estimated time to restore functionality to homes and businesses after a major earthquake (recovery).
- Public Safety: the likelihood of injury or death from earthquake damages, and the extent of social disruption caused by loss of habitation and business interruption.
- Social Vulnerability: intrinsic characteristics of a community (population & demographics) that may contribute to unsafe conditions and have the potential to amplify the negative impacts and consequences of a disaster event.
- Lifeline Resilience: the capacity of utility and transportation systems to withstand and recover from the impacts of a major earthquake.
- Economic Security: expected capital and income-related losses resulting from a major earthquake and the benefits of investing in mitigation and/or adaptation measures.

The focus of our study is the District of North Vancouver, one of 23 large urban centres within the broader Metro Vancouver region of southwest British Columbia (Figure 4). Our analysis does not include results for the City of North Vancouver. Nor does it include a full representation of critical lifeline systems (power, communication, etc) that are owned and/or operated in the

Figure 4: Study area location in southwest British Columbia, Canada.

private sector. While we have made every effort to use the best available information and methods of catastrophic loss modelling to assess likely impacts and consequences of a major earthquake at the community level, there are limits in our ability to fully represent the complexity of cause-effect relationships and the full range of scientific uncertainty. For this reason, the numbers reported in this study are considered estimates only, and do not reflect the full range of possibilities.

Seismic Hazard Potential

The Cascadia region of southwest British Columbia is one of the most seismically active regions in Canada. More than 400 felt earthquakes occur each year in a region extending from the north of Vancouver Island to Seattle. Most occur in offshore regions and do not pose an imminent threat to people or critical assets. Moderate-sized earthquakes capable of causing damage and socioeconomic losses occur every decade or so in the Cascadia region. Destructive earthquakes with a potential for catastrophic damage and losses occur on average every few hundred years and are among the World's greatest disaster threats [Cassidy et al., 2010]. With increased urbanization and expansion of global trade in the Pacific region, these rare but destructive earthquakes have the potential for socioeconomic losses and disruption that would challenge existing capacities for disaster resilience at all levels of government.

Our assessment of seismic risk for the District of North Vancouver is based on a catastrophic earthquake triggered by displacement along a shallow fault in the Strait of Georgia, ~50 kilometres west of Metro Vancouver (Figure 5). The fault is known to have ruptured in 1997, causing a M4.6 earthquake that rumbled throughout the Cascadia region causing minor damage. We use detailed ground motion models to explore what might be expected if this same fault were to rupture again at some point in the future with a displacement capable of generating a M7.3 earthquake.

The Georgia Strait scenario earthquake is similar in character to a M7.3 event that struck sparsely settled areas of eastern Vancouver Island in 1946. It is also representative of shallow crustal earthquakes of equivalent magnitude that are known to have occurred in the Georgia Basin region over the past ~500 years [Hyndman et al., 2003; Rogers, 1979]. Although credible, the Georgia Strait M7.3 event is not a prediction of what is most likely to happen, nor is it a worst-case scenario. Rather, it represents a

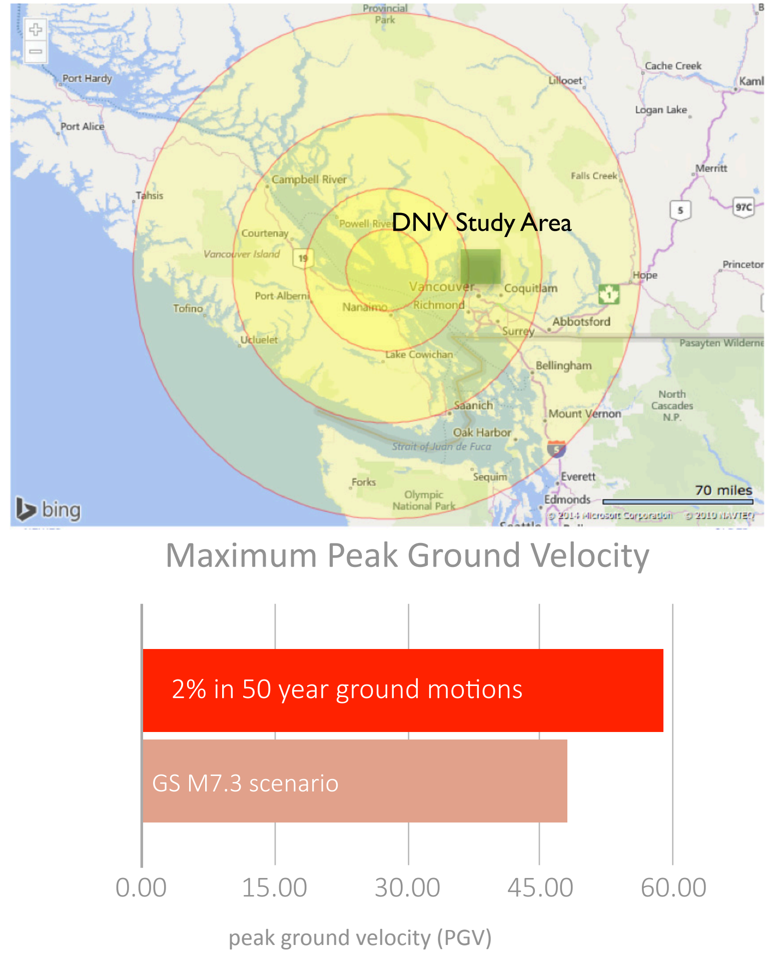


Figure 5: Comparative analysis of ground motions (PGV max) for the Georgia Strait M7.3 scenario earthquake with respect to all known seismic hazards with a return period of 2% in 50 year.

scientifically plausible ground motion model that helps makes evident cause-effect relationships and what might be expected if a near-source catastrophic earthquake were to occur at some point in the future.

In terms of ground shaking intensity, the Georgia Strait scenario is an example of what might be expected for a cumulative portfolio of earthquake hazards with a return period of ~1/500 years (p~12% in 50 years). With respect to shaking thresholds used for seismic safety guidelines in the 2010 National Building Code of Canada (1/2475 years; p =2% in 50 years), the Georgia Strait scenario ranks ~80% in terms of maximum peak ground velocity (PGV) and ~64% in terms of maximum lateral building displacement (Figure 5).

Because the earthquake epicentre is located close to the Earth's surface, it would be felt widely throughout the Georgia Basin region with very strong and locally severe ground shaking in the Metro Vancouver region (MMI VII-VIII). The main earthquake event would likely last only 20 and 30 seconds but would be felt as a combination of rumbling pressure waves causing violent push-pull motions, and rolling surface waves that would rock buildings and make it difficult to stand or drive a vehicle.

The initial quake would be followed by lesser magnitude but significant aftershock events that could last for several months. In addition to intense shaking, the Georgia Strait scenario earthquake would also cause liquefaction in low-lying areas and seismically triggered landslides in steeper terrain along valley walls. The intensity of shaking and related ground deformation hazards would be similar to those experienced during the powerful M6.3 earthquake that struck Christchurch, New Zealand in 2011.

Predicted ground motions vary considerably across the study area as a function of distance from the earthquake epicentre, geologic setting and the effects of local site amplification. Peak ground velocity (PGV) is a measure of instantaneous shaking at the surface and is often used as reference for assessing the relative intensity of an earthquake event at any given location. PGV values for the District are expected to range from 6.4 cm/second in highland areas underlain by solid bedrock — to a maximum of 48.1 cm/second in lowland areas where seismic waves are amplified by underlying layers of relatively soft sediment (Figure 5).

Building motions measure the lateral displacement of a building envelope with respect to a fixed point on the surface. Building displacements for the Georgia Strait scenario earthquake are expected to range from less than a centimetre to as much as 15.3 cm in areas of local site amplification (Figure 6). Though within the range of what is considered safe for recently constructed buildings, lateral displacements of this magnitude are sufficient to cause structural failure and/or collapse in older masonry and concretes buildings that do not conform to current seismic safety design guidelines.

Liquefaction is expected to occur in areas underlain by water-saturated soils that would loose cohesion during intense ground shaking. Of concern are low-lying waterfront areas underlain by saturated glacial outwash sediments and/or landfill deposits

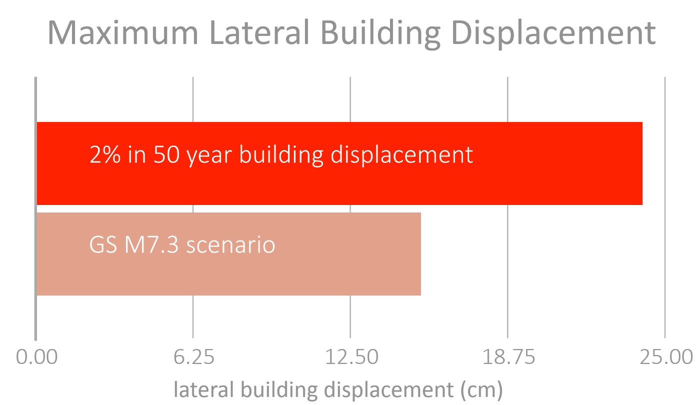


Figure 6: Comparative analysis of building displacement for the Georgia Strait M7.3 scenario earthquake with respect to all known seismic hazards with a return period of 2% in 50 years.

(sand, gravel, crushed rock). Lateral displacements in these areas are likely to be 60-90 cm, and in some places greater than 150 cm. Other areas of concern include delta and outwash terrace deposits of sand and gravel in the lower Capilano and Seymour valleys, where lateral displacements are likely to be 30-60 cm.

Earthquake-triggered landslides occur along steep unstable slopes where severe ground shaking results in forces that are strong enough to overwhelm the internal shear strength of surficial materials and the gravitational forces that hold them in place on the hillside. Hotspots of concern coincide with areas of previous landslides, and zones of high landslide potential identified through independent geotechnical studies commissioned by the District of North Vancouver [M Porter et al., 2007]. They include steep valley walls and preserved outwash terraces along the east shore of Capilano Reservoir, upper reaches of the Capilano River, Mackay Creek, Mosquito Creek, Lynn Creek and the Seymour River.

Building Performance

Building performance is a measure of physical vulnerability in the built environment— the capacity of a structure to withstand a wide spectrum of seismic forces that are experienced at a given site during an earthquake event. We have used the Hazus methodology to estimate damage state probabilities and corresponding levels of uncertainty for both individual structures and aggregate portfolios of buildings at the neighbourhood level [NIBS,FEMA, 2004; 2011; 2002; Schneider and Schauer, 2006].

Hazus uses fragility curves to assess the probability of exceeding minimum thresholds of damage for a given level of shaking and related ground failure. Damage probabilities are calculated for each of five states: None, Slight, Moderate, Extensive and Complete (See Figure 7). Overall building performance is reported on the basis of damage states with the highest probability of occurrence. Slight and moderate damage states describe physical impacts that exceed the yield point of a building but that do not compromise structural integrity. Extensive damage states are those in which load-bearing structural elements of a building are compromised beyond repair. Complete damage states are those in which there is a likelihood of structural failure by tilting and/or toppling with a potential for total collapse.

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

Figure 7: Building performance measured in terms of damage state probabilities. Estimates are based on Hazus loss estimation methodology.

Our analysis of building performance for the District includes an assessment of damage potential for current conditions and what might be expected if the most vulnerable buildings were seismically retrofitted according to modern seismic safety standards. Results are evaluated for the Georgia Strait scenario earthquake and for minimum thresholds of expected ground motion for all known seismic hazards over a return period of 1/2475 years (2% in 50 year design threshold). Differences between current and mitigated states provide a measure of effectiveness for investments in seismic retrofits.

General Building Stock

There are ~23,700 buildings spread across 45 neighbourhoods and commercial-industrial areas in the DNV. More than 60% of homes and businesses in the DNV were built before 1975, prior to the introduction of modern building code guidelines for seismic safety. Many of the older neighbourhoods and town centres in the District are located along the waterfront and valley escarpments—areas that have been significantly modified from their natural state to accommodate increasing demands for growth and development over the years.

The majority of buildings in the District (~92% of total) are expected to perform very well in the Georgia Strait scenario earthquake with little or no damage. These are either residential wood frame structures that are inherently resistant to ground shaking hazards, or concrete and steel frame buildings built after 1975. More than 1,000 buildings (4.4% of total) are expected to sustain slight or moderate levels of damage that would require inspection and repairs to restore full levels of functionality. These include older wood frame, concrete and masonry structures that predate modern safety codes and that are located in areas of very strong and severe shaking.

An additional ~840 buildings (3.6% of total) are expected to sustain extensive and/or complete levels of damage with varying levels of structural failure (Figure 8). These are primarily older unreinforced masonry and concrete structures in areas of severe ground shaking that are likely to be demolished and rebuilt during the recovery process. Seismic retrofits to the most vulnerable of these buildings would result in significant risk reduction with only ~20 structures expected to sustain damages that would require demolition during the recovery process.

Residential Sector

Most people in the District of North Vancouver (95%) live in single-family wood frame homes situated in well-established residential neighbourhoods. The remaining 5% live in multi-family

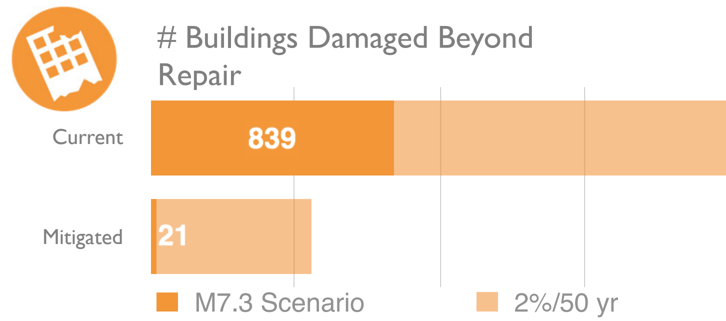


Figure 8: Estimates of building performance for ~22,700 structures in the DNV. Results are compared for the Georgia Strait M7.3 scenario earthquake and all known seismic hazards for a return period of 1/2475 years (2% in 50 years)

condominium, apartment and townhouse complexes made of wood, steel, concrete and masonry that are situated in or adjacent to multi-use residential/commercial town centres.

At least 640 pre-code wood frame houses are expected to sustain slight and moderate levels of damage from a major earthquake in low-lying areas of Norgate and in valley escarpments along the Capilano River. Concentrated pockets of extensive or complete damage are expected in the older residential neighbourhoods of Norgate, Pemberton Heights, Highlands, Edgemont, Lynnmour-South, and Riverside—areas that would be exposed to a combination of extreme shaking and ground failure during a major earthquake.

More than 215 residential buildings in these areas are likely to sustain permanent structural failure and would be in imminent danger of collapse (Figure 9). These include a mix of older wood frame single family buildings, and multi-family buildings made of concrete and/or masonry that do not conform to modern seismic safety standards. Results of our analysis indicate that nearly all of these structures could be preserved as a result of investments in seismic retrofits prior to a major earthquake.

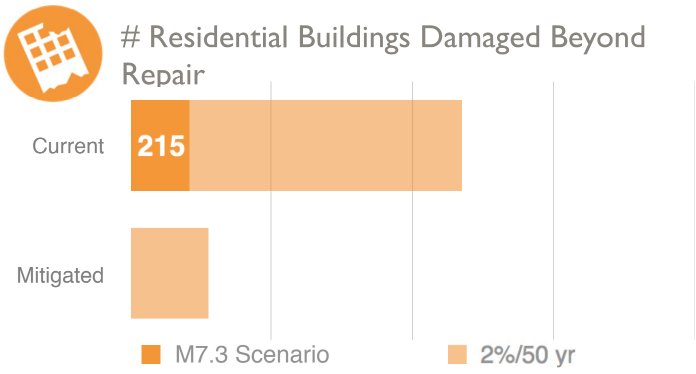


Figure 9: Comparative number of residential structures that are expected to sustain extensive and/or complete damage in the scenario earthquake.

Business Sector

Commercial and industrial businesses contribute 30% of the overall property tax revenue for the District and employ nearly 22,000 people. The majority are small home-based businesses (fewer than 50 employees) with approximately 1,300 buildings used for commercial purposes. Most of these buildings are wood-frame structures in residential neighbourhoods that are expected to sustain little or no damage in the scenario earthquake. However, at least 25 of these home-based businesses are likely to be damaged beyond repair. There are 1,200 larger commercial and industrial buildings in the District. Areas of highest business concentration (where five or more business share one building) occur along the waterfront where buildings are exposed to some of the highest levels of ground shaking and liquefaction.

At least half of all commercial and industrial buildings in the District (~600 structures) are expected to sustain extensive and/or complete levels of structural damage in the scenario earthquake (Figure 10). The most vulnerable of these are pre-code concrete and unreinforced masonry buildings located in the Lower Capilano-Marine, Edgemont, Lynnmour, and Maplewood areas.

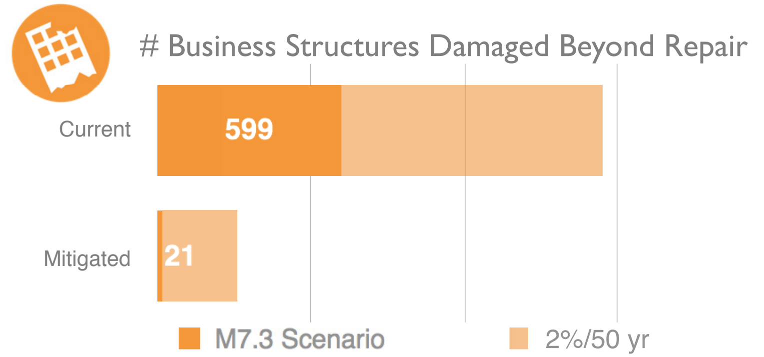


Figure 10: Comparative number of business structures that are likely to sustain extensive and/or complete damage in the scenario earthquake.

Investment in seismic retrofits prior to a major earthquake would likely preserve all but 21 of these structures.

Public Sector

There are ~350 community assets of concern in the District. These include more than 150 municipal buildings and related facilities used for government operations and essential services (police, fire), 115 school facilities owned and operated by the British Columbia Ministry of Education, and ~90 public/private care facilities for young children and the elderly. Of these, at least twenty-five structures are expected to sustain extensive and/or complete levels of damage in the scenario earthquake (Figure 11). Nearly all of these structures would survive the impacts of a major earthquake with seismic retrofit measures in place.

The majority of facilities under municipal jurisdiction (80%) are likely to perform well in the scenario earthquake with little or no significant damage. However, at least 30 buildings are expected to sustain significant levels of damage, and 20 of these are likely to be damaged beyond repair. Buildings of concern include the DNV's Operations Centre and related structures in Lower Lynn, and a variety of historic buildings and recreational facilities in Norgate, Edgemont, Delbrook, Maplewood and Dollarton.

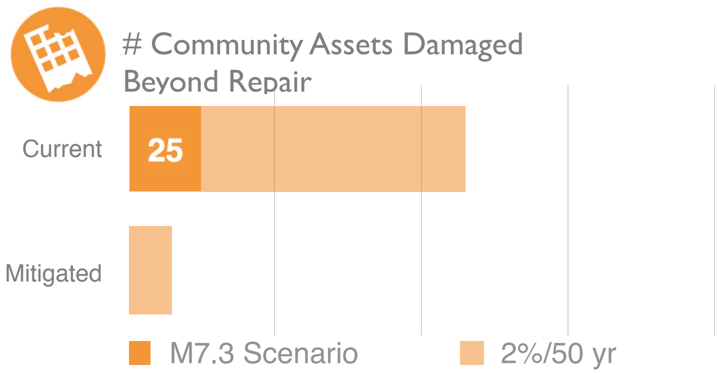


Figure 11: Comparative number of shared community assets (municipal buildings, schools, care facilities, etc) that are expected to sustain extensive and/or complete damage in the scenario earthquake.

Police services and the North Shore Emergency Management Office (NSEMO) are co-located in a newer building adjacent to the Lions Gate Hospital in the City of North Vancouver. All of these facilities are on firm ground and expected to perform well in a major earthquake. However, emergency fire and paramedic services within the DNV are likely to be impacted. Of concern are Fire Hall #2 and nearby emergency supply storage and training facilities in Lower Lynn, which are susceptible to damages caused by severe ground shaking and liquefaction. Facilities and emergency operation services in hardest hit areas are expected to be operating at less than 25% capacity in the days following a major earthquake.

The DNV has over 90 child and elder care facilities. They include a mix of public and private facilities in both commercial and residential buildings that are exposed to a wide range of seismic hazards. More than 95% of these buildings are expected to sustain little or no significant damage in the earthquake. However, a few facilities are located in older concrete and unreinforced masonry buildings located in low-lying neighbourhoods along the waterfront—areas that will experience severe ground shaking and liquefaction. Hotspots of concern include day care facilities in Lower Lynn and Norgate where at least three structures are expected to sustain extensive and/or complete damage.

There are 35 schools and a major university that collectively encompass more than 115 structures (buildings and related facilities) in the District of North Vancouver. Four elementary and secondary schools have been upgraded as part of the provincial seismic retrofit program and three more schools are in the process of being retrofitted to comply with current design guidelines for life safety. As a result of these mitigation efforts, approximately 80 of the 115 structures (70%) are expected to sustain little or no damage from the earthquake.

It is estimated that 25 structures (22%) are vulnerable to moderate levels of damage that will require extensive repairs during the recovery process. Most of these are older concrete buildings that support auxiliary functions (recreation, school operations, etc.) and temporary structures (portables) that are used as overflow classrooms. At least 9 of these structures (8%) are likely to sustain extensive and/or complete levels of damage. Only three of these are primary buildings. These rest are auxiliary buildings exposed to severe ground shaking and/or liquefaction hazards.

Public Safety and Social Disruption

Public safety is measured in terms of indicators that track the extent and severity of injuries, and levels of social disruption that may result from damaged homes and the displacement of business that sustain significant levels damage during a major earthquake. Although severe shaking and related ground deformation are expected to last for less than a minute, the impacts and consequences of a major earthquake like the Georgia Strait event would have consequences that will resonate in the community for many years.

More than 60,000 people make their way to work and school on any given day. Nearly half of those commuting from the DNV travel to jobs in downtown Vancouver and across the greater Metro Vancouver region by car, bus and ferry. The remaining population is at home or at jobs and activities within the community during the day.

Injuries

It is estimated that several thousand people would sustain injuries requiring immediate medical attention if the scenario earthquake occurred during the day. Several hundred individuals are expected to sustain life-threatening injuries that would result in hospitalization and/or death.

Areas of concern include the Lynnmour-Maplewood area where more than 1,000 people are expected to sustain injuries that would require immediate medical care, and the Norgate area where more than 650 people are expected to need paramedic services. The number of injuries requiring medical care would likely overwhelm the capacity of existing hospital resources that serve all of the north shore communities in the Vancouver Coastal Health District.

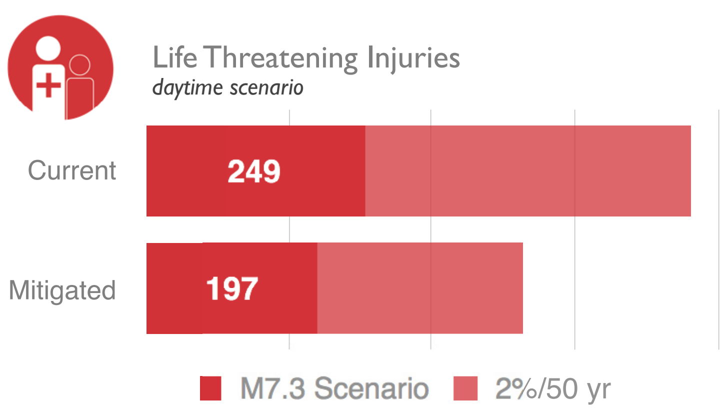


Figure 12: Comparative number of life threatening injuries that are expected for a daytime earthquake scenario.

At least ~250 people are likely to sustain life threatening injuries as a result of toppling and/or collapse of vulnerable buildings during a daytime earthquake scenario (Figure 12). Most of those with life-threatening injuries are employees working in vulnerable concrete and unreinforced masonry buildings in areas of severe ground shaking and liquefaction. By comparison, only ~30 people are expected to sustain life-threatening injures for a night-time earthquake scenario. While serious injuries are inevitable, more than 50 casualties could potentially be with avoided seismic retrofit measures in place.

Social Disruption

The majority of people in the District are likely to shelter in place following a major earthquake, but approximately 4,250 people are expected to seek shelter elsewhere as a result of damages to their homes. Most of those displaced from their homes will seek short-term shelter with family and friends while others will stay in motels or arrange rental accommodation in areas with little or no damage. Several hundred people will likely not have the means to provide for themselves and will seek public shelter and emergency services that are provided by relief organizations.

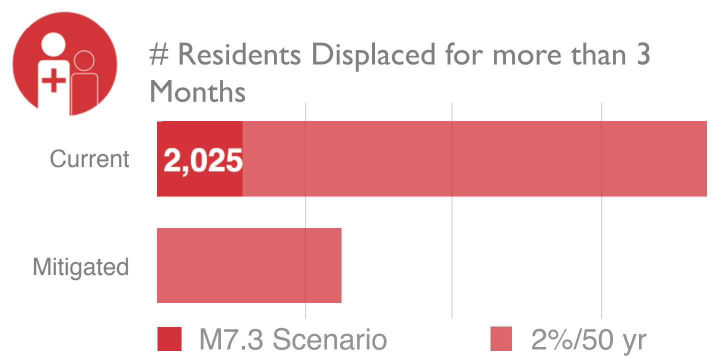


Figure 13: Estimated number of residents that are likely to be displaced from their homes for more than six months in the scenario earthquake.

Most people are expected to return home within a month after the earthquake. However, it is estimated that as many as 2,025 people will be displaced for more than three months and an additional 770 people will be displaced for up to a year, possibly longer (Figure 13). Those who have lost their homes may be forced to relocate. Investment in seismic retrofits would decrease recovery times with only a handful of residents being displaced from their homes for more than six months.

Damages to commercial and industrial businesses along the waterfront will result in a significant level of disruption to jobs and wages, the impacts of which will ripple through the community for a year or more. Hardest hit are employees in small retail and larger industrial businesses located in older buildings susceptible to higher levels of earthquake damage. Hotspots of damage are localized in business precincts along the waterfront and in the town centres of Lower Capilano-Marine, Edgemont, Lynnmour, and Maplewood areas. It is estimated that more than 17,850 employees will be displaced from their place of work for more than six months (Figure 14). The extent and concentration of damage in these areas will be significant and large parts of the business district are likely to be cordoned off for up to a year or more during the recovery and rebuilding process. The extent and level of disruption to the business sector would be similar to that experienced following the Christchurch earthquake of 2011.

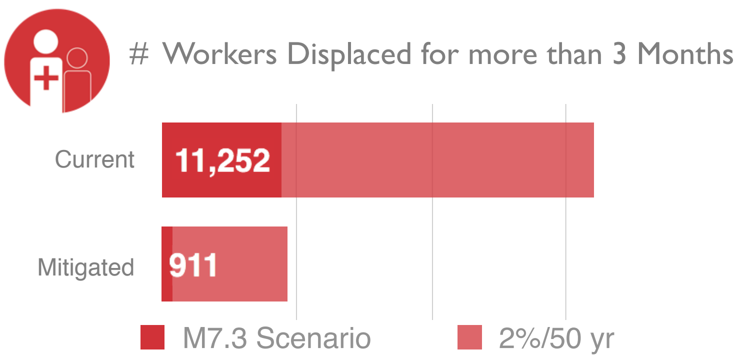


Figure 14: Estimated number of employees that are likely to be displaced from their place of work for more than six months in the scenario earthquake.

Social Vulnerability

Social vulnerability reflects the intrinsic characteristics of exposure and susceptibility that create unsafe conditions in a community, and that have the potential to amplify the negative impacts and consequences of a disaster event. Key factors include:

- Exposure: the location of homes and businesses and their susceptibility to earthquake damage;
- Agency: social and economic variables that will enable some to take actions that minimize the impacts of a major earthquake while forcing others to succumb; and
- Capacity: demographic variables that will influence capabilities to cope with and recover from the impacts of a disaster event.

Knowing who is most vulnerable and the underlying socioeconomic drivers provides insights on the types of emergency services that are likely to be needed in these areas during response and recovery operations. Our analysis of social vulnerability for the DNV is based on the well-known 'hazards of place' model, which utilizes geo-statistical methods to detect and rank patterns based on a wide range of demographic variables that reflect social and economic interactions at a neighbourhood level [Cox et al., 2006; Cutter et al., 2000; Dwyer et al., 2004].

As it turns out, the most vulnerable populations in the DNV are situated in areas exposed to some of the highest levels of shaking and ground failure during an earthquake.Areas of greatest concern include older neighbourhoods along the waterfront and isolated pockets throughout the community where the physical impacts of ground shaking and liquefaction are likely to be amplified by a more limited capacity of residents to respond and recover on their own. These are areas in which the demand for emergency social services is likely to be the greatest during and after a disaster event.

Lifeline Services

The District of North Vancouver relies on an extensive system of reservoirs, dams, pipes, pumps, roads, rails, bridges, and other engineering structures to provide essential lifeline services — failure of any one component as a result of natural and/or anthropogenic causes has the potential to disrupt water and power service to the community and the Metro Vancouver region as a whole. Lifeline systems are jointly owned and operated across several levels of government and by private sector utility companies. Critical infrastructure systems are inherently complex, interconnected and increasingly in need of upgrades to meet the needs of ongoing growth and development in the region.

Utilities

Utility systems are expected to sustain damage and loss of functionality in low-lying areas along the waterfront and in older residential neighbourhoods at higher elevations. These are areas in which there is a higher proportion of older non-ductile pipes and related facilities, and that are susceptible to damage from ground shaking and lateral displacement caused by liquefaction.

Of particular concern are water facilities adjacent to the Capilano Reservoir and pumping stations that service the neighbourhoods of Cleveland, Upper Lynn and Northlands. It is expected that nearly half of all homes and businesses in the DNV will be without access to potable water (~14,300), and as many as 3,250 buildings will be without electrical services seven days after a major earthquake (Figure 15).

Mean recovery times for areas hardest hit by the earthquake are estimated to be 30 days or more depending on the capacity of service crews to inspect and repair damages. These are considered conservative estimates as the recovery of lifeline services will likely be prioritized across the broader Metro Vancouver region depending on the extent of disruption and the criticality for emergency response and recovery operations.

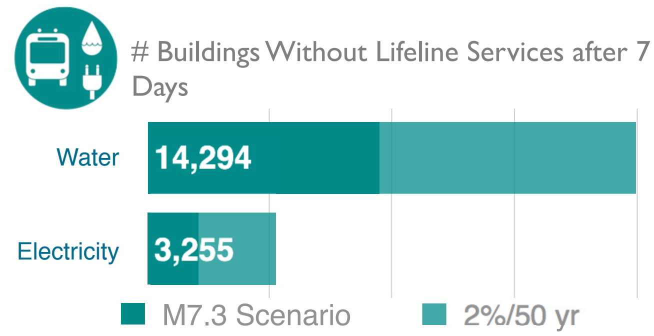


Figure 15: Estimated number of homes and businesses without access to essential lifeline services one week after the scenario earthquake.

Transportation Networks

Transportation hotspots for the scenario earthquake include designated disaster response routes along the waterfront and major east-west transportation corridors that cross the Capilano, Lynn and Seymour valleys (Figure 16). Of particular concern is the impedance of emergency response efforts and delays in the repair of water and electrical lines provided by repair service trucks and equipment.

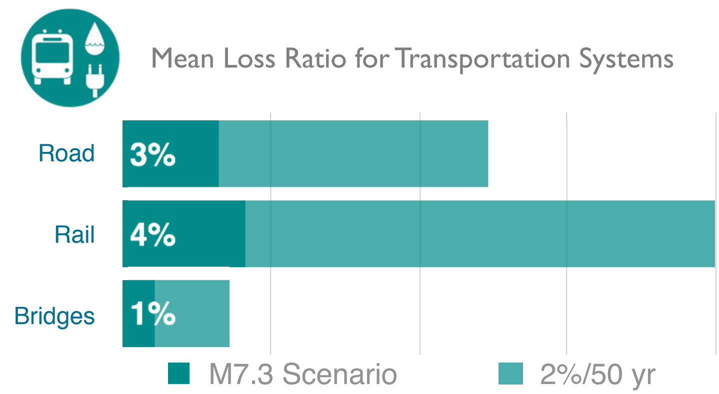


Figure 16: Mean loss ratios for transportation system components damaged as a result of the scenario earthquake.

Road and rail systems networks are vulnerable to damage from severe ground shaking, liquefaction and earthquake-triggered landslides. Second-order impacts include vehicle accidents and hazardous material spills, both of which can cause injury and loss of life. While it is expected that damages to highway and rail segments would be repaired in the days and weeks following the earthquake, loss of functionality immediately after the event would seriously compromise emergency response and recovery efforts.

Disaster Debris

Disaster debris poses a direct threat to individuals who are outside during an earthquake, and has the potential to burden recovery efforts for many months following the event. Areas with the most disaster debris will be found in higher-density town centres and in older neighbourhoods where a higher proportion of buildings are likely to sustain extensive or complete damage.

It is estimated that 280,000 tons of debris could be generated by scenario earthquake. This includes nearly 160,000 tons of steel and concrete and 120,000 tons of mixed wood, brick, glass and general building debris. The total amount of debris is equivalent to 11,200 truckloads of material that would need to be relocated either to infill sites within the community or transported to landfill sites outside the Metro Vancouver region.

Economic Security

Economic security is a measure of community wealth and the capacity of local and regional economies to withstand and recover from the consequences of a major disaster event. It is influenced by the location and exposure of monetary assets; the extent and duration of business disruption; and the degree to which any potential losses are covered by risk transfer through insurance markets.

Indicators of economic security track capital assets (stocks) and income generated by the exchange of goods and services (flows) before and after a disaster event. From a policy perspective, the goal is to maximize the security of community wealth and economic vitality through strategic investments in mitigation and/or adaptation measures that have a potential to reduce vulnerabilities and yield a positive rate of return over time horizons of interest to the planning process.

Community wealth for the District of North Vancouver is estimated to be in excess of $20.3 billion. This includes $18.4 billion of capital investments in buildings and critical infrastructure, and $1.9 billion in gross annual revenues generated by the flow of goods and services in the business sector.

Total economic losses for the scenario earthquake are estimated to be nearly $3 billion with an overall mean loss ratio of ~16.7% — comparable to that of the 2011 Christchurch earthquake [Daniell and Vervaeck, 2011]. Direct economic losses resulting from damages to buildings and contents are estimated to be $2.33 billion (~80% of total). Hardest hit are commercial and industrial businesses in major town centres along the waterfront where direct economic losses include both capital investments in buildings and contents (~$1.18 billion), and $645 million in lost revenue caused by service disruption in the weeks and months following the earthquake (Figure 17).

Capital Losses

The mean loss ratio for residential homes is ~13%, which translates into an average capital loss of ~$66,000 for a single-family residence and ~$345,000 for multi-family apartment and condominium complexes. The mean loss ratio for business assets is significantly higher with expected average capital losses of $360,000 for commercial buildings and up to $500,000 for industrial facilities. As expected the profile of loss is skewed by the vulnerability of older concrete and unreinforced masonry buildings in commercial/industrial zones along the waterfront.

Total capital losses for lifeline systems damaged in the scenario earthquake are estimated to be over $26 million (Figure 17).

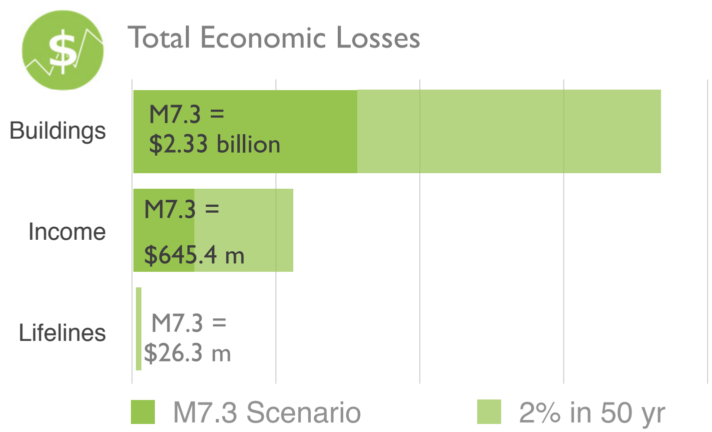


Figure 17: Estimated total economic losses from the scenario earthquake

About 78% of these losses are the costs of repairing roads damaged by ground failure. This includes $16.5 million to repair highways and secondary roads and an additional $3.2 million for rail lines and related facilities. Capital losses to water utility systems are estimated at $5 million. Losses specific to potable water systems are $2 million, with more than half of these caused by damage to treatment and pumping facilities and the balance shared between pipelines and water distribution lines. Losses specific to wastewater systems are $3 million and are evenly allocated between pipelines and distribution lines.

These are considered very conservative estimates as they do not account for losses to power and communication facilities (electricity, natural gas, telecommunications, etc.) that are privately owned and operated and for which we did not have access to information on asset vulnerability or replacement costs. Also not included in our analysis are direct economic losses to bus, ferry and port facilities in the DNV. Capital losses to port facilities are expected to be substantial as they are likely to sustain significant damage caused by severe shaking and liquefaction along the waterfront. Prolonged disruption of port operations will likely interrupt international trade and have a profound impact on both regional and national economies.

Business Disruption and Income-Related Losses

Businesses play an integral role in the functioning of a community — as revenue generators, employers, and providers of goods and service. DNV has more than 3,400 licensed businesses situated in 2,500 buildings across the District (District of North Vancouver, 2011). Commercial service providers represent more than 50% of the local business sector with the balance distributed across mining, construction and transportation industries (18%), wholesale and retail trade (15%), finance, insurance and real estate (8%), manufacturing (5%) and health services (3%). Extrapolating from provincial annual industry employment counts and gross domestic product (GDP) data, the DNV business community generates an estimated annual GDP of approximately $1.93 billion.

Income-related losses to the business sector are dependent on earthquake damage, interruptions to critical lifeline services (water & power), and the time required to restore baseline levels of functionality. Losses include reduced business revenue and the costs of relocation from areas that are cordoned off during the recovery process.

Because commercial and industrial assets are concentrated in areas of greatest vulnerability in the DNV, the business sector is expected to bear the largest burden of financial risk with a potential for up to 90% loss in gross daily revenue. This translates into nearly $645.4 million of total income-related losses for the duration of the recovery process. Prolonged business disruption at this level would have a substantial and lasting impact on the community and economic vitality in the broader Metro Vancouver region.

Financial Risk

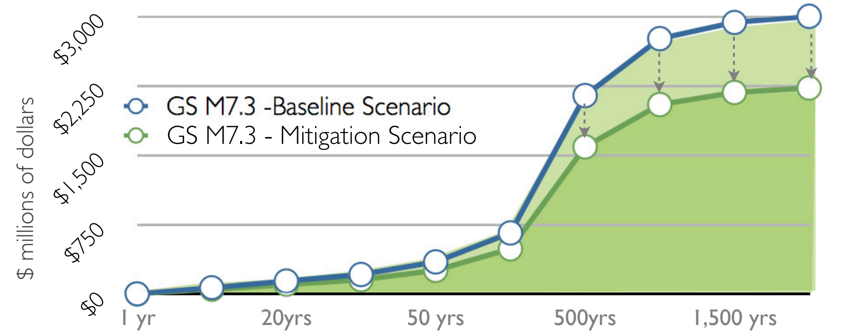
Financial risk is a function of total expected economic losses resulting from a disaster event (consequences), the likelihood of these losses occurring over a specified time horizon (probability), and the potential to reduce future losses through a combination of mitigation, business continuity planning and/or risk transfer (capacity). Since future patterns of economic risk are uncertain, investments in risk reduction measures need to be justified economically on the basis of losses that are avoided on average every year or over a specified planning horizon.

There are no specific guidelines on what constitutes a tolerable threshold of financial risk for municipal governments. However, the Canadian Office of the Superintendent for Financial Institutions (OSFI) does provide guidelines to secure collective investments in federally regulated institutions such as banks, pension plans and insurance companies that are exposed to earthquake risk (OSFI, 2013b). Minimum thresholds of economic risk are based on Probable Maximum Losses (PML) corresponding to earthquakes with a ~1/500 year likelihood of occurrence [CRESTA, 2003; Kovacs and Seweeting, 2004].

The Georgia Strait M7.3 earthquake is representative of large shallow crustal events that are known to occur in the upper plate of the Cascadia subduction region with a recurrence rate of ~1/500 years [Hyndman et al., 2003]. As such, it is a suitable scenario for exploring what might constitute a tolerable threshold of earthquake risk for the District of North Vancouver. A 30-year time horizon is often used as the financial planning context for managing individual and collective risks associated with capital investments in homes and businesses (mortgages, bank loans, etc.).

The 30-year probable maximum loss for the Georgia Strait scenario earthquake is estimated to be ~$220M for baseline conditions and ~$160M with structural mitigation measures in place (Figure 18). Probable maximum losses for longer time horizons that are relevant for strategic land use and infrastructure planning (100 years) are estimated to be ~$665M for baseline conditions and ~$490M with mitigation measures in place.

Risk Reduction Potential Through Investment in Seismic Retrofits



Probable Maximum Loss (PML) - $ millions of dollars over planning horizons of interest								
Hazard Event (of specified intensity)	Expected Loss PAA=1	1 yr	10 yrs	30 yrs	50 yrs	100 yrs	500yrs	1,000 yrs
GSM7.3 (B2)	$ 3,000.7	$7.5	$ 74.2	$217.1	$353.0	$ 664.5	$2,142.3	$ 2,755.2
GSM7.3 (M2)	$ 2,228.1	$5.6	$ 55.1	$161.2	$262.1	$ 493.4	$1,590.7	$ 2,045.7
Risk Reduction Potential	$ 772.6	$1.9	$ 19.1	$ 55.9	$ 90.9	$ 171.1	$ 551.6	$ 709.4

Figure 18: Risk profiles for the scenario earthquake without mitigation measures in place for planning horizons of interest.

From Knowledge to Action

Disaster resilience is a forward-looking process of planning through which knowledge about the risk environment is transformed into actions that have potential to reduce intrinsic vulnerabilities and increase the capacities of a community to withstand, respond to and recover from unexpected hazard events. The aim is to marshal the resources and capabilities needed to realize policy goals for growth and development (opportunities) while minimizing the potential negative impacts of hazards that can undermine the longer-term sustainability of a community or region (risks and liabilities).

Outputs of this study have been used to inform the development of an earthquake action ready plan for the District of North Vancouver (Figure 19). The plan was developed by District staff with input from the community Natural Hazard Task Force. It is aligned with risk reduction guidelines of the UN Disaster Resilience Cities Program [UNISDR, 2012], and is intended to help increase capacities of the District to reduce future losses and become more resilient to earthquake hazards through strategic investments in mitigation, emergency management and adaptation planning.

Mitigation

Mitigation is focused on measures that can be implemented before a disaster event to reduce the physical vulnerability of people and critical assets and the potential for socioeconomic losses. Structural mitigation involves retrofitting core elements of a building or engineered structure to increase physical resistance to seismic loads and lateral displacements caused by severe shaking and/or ground deformation. Non-structural mitigation includes measures that minimize the exposure of people and physical assets to known earthquake hazards through land use policies, development restrictions (permits, bylaws, etc.), early warning systems, and the physical retrofitting of non-skeletal building elements (facades, internal partitions, contents, machinery and utility systems).

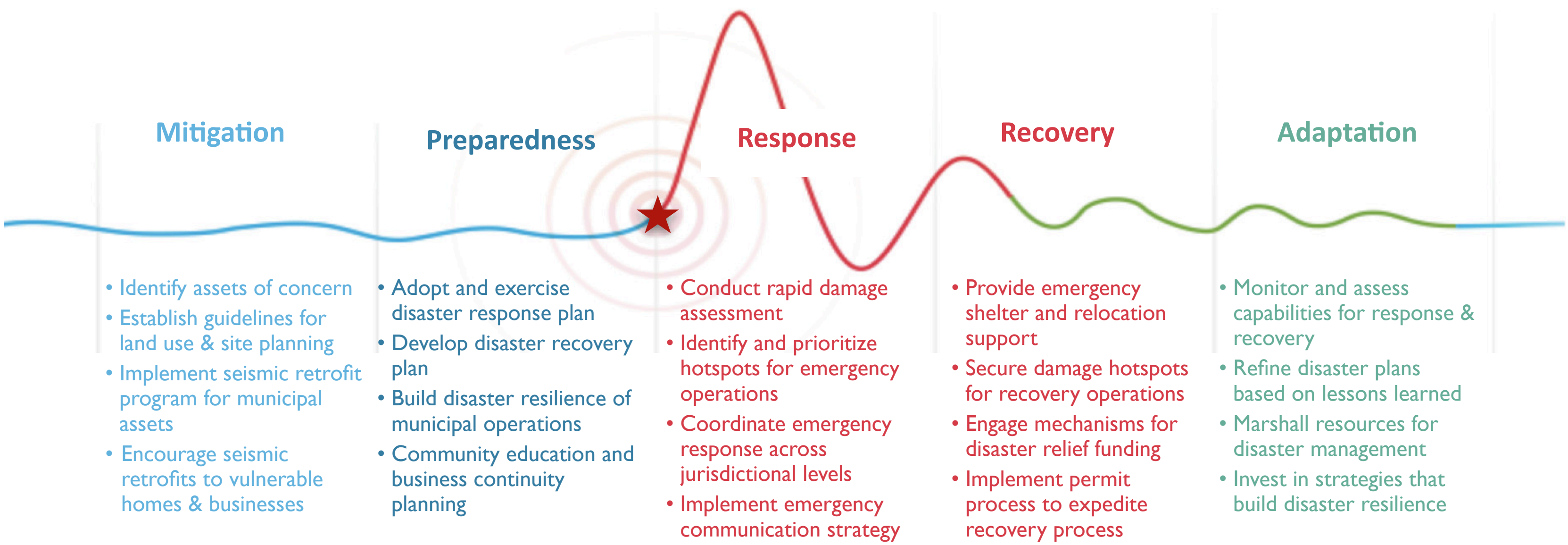


Figure 19: Elements of an earthquake action plan for the District of North Vancouver (Diagram modified from Keller and Schneider, 2014).

The DNV Earthquake Ready Action Plan includes a blend of structural and non-structural mitigation measures:

- Utilize scenario models and indicator framework to develop risk tolerance thresholds that will guide municipal planning and decision making. Risk tolerance criteria may be evaluated in terms of building performance, public safety, lifeline resilience and/or socioeconomic security.
- Establish land use policies and seismic safety guidelines to inform development in areas that exceed tolerable thresholds of earthquake risk. Investigate the feasibility of implementing development permit areas that reduce physical vulnerabilities, and encourage the establishment of professional practice guidelines to inform the work of Qualified Professionals in high-risk areas.
- Identify and prioritize municipal assets that exceed risk tolerance thresholds and develop seismic retrofit strategy that can be incorporated into the DNV asset management plan using principles of ALARP.
- Assess vulnerabilities and interdependencies of critical lifeline services (power, potable water, wastewater, etc.) in order to identify restoration priorities, and to develop an integrated recovery plan with Metro Vancouver and private owners/operators.
- Explore risk transfer strategies for municipal assets that exceed minimum thresholds, and that cannot be effectively mitigated using principles of ALARP.
- Research best practices and explore the potential of incentive programs that encourage private investment in seismic retrofits to homes and businesses in areas of high seismic risk.

We have utilized 'what-if' scenario models to evaluate the effectiveness of mitigation measures aimed at reducing the vulnerability of older buildings that are exposed to extreme seismic hazards. The analysis compares expected losses for the scenario earthquake to those of a mitigation scenario in which vulnerable buildings have been seismically retrofitted to current seismic design standards as part of the ongoing community development process (Figure 20). Mitigation costs are based on empirical data from seismic retrofit programs that have been implemented in California (Porter et al., 2006; City and County of San Francisco, 2010).

Risk reduction potential from seismic retrofits to vulnerable buildings

	Losses Avoided through Mitigation Investments					
	# Buildings Preserved	Reduced Recovery Time/Bldg (Days)	Reduced Social Disruption (People)	Total Injuries Avoided (People)	Losses Avoided/ Bldg	Benefit/ Cost Ratio
Construction Type						
Wood	211	718	3,019	24	$ 53,225	2.89
Concrete	322	308	11,644	168	$ 118,054	2.88
URM	260	295	9,448	349	$ 206,497	3.48
Steel	1	101	153	2	$ 48,395	3.19
Other Types (PC,RM,MH)	25	24	703	43	$ 560,712	4.85
Occupancy Class						
Single Family	160	131	163	4	$ 25,609	2.11
Multi-Family	55	565	73	18	$ 331,320	6.98
Commercial	214	238	10,724	274	$ 175,719	3.99
Industrial	365	282	10,629	241	$ 178,704	3.65
All Public facilities	25	153	3,378	49	$ 101,681	2.01
Municipal Assets Only	21	327	2,532	35	$ 129,362	3.65
Totals/Averages:	**819**	**274**	**24,967**	**586**	**$773 million**	**3.75**

Figure 20: A summary of risk reduction potential for the Georgia Strait M7.3 earthquake for baseline and mitigation scenarios

It is estimated that ~820 buildings would be preserved as a result of strategic investments in seismic retrofits. As expected, the most significant return on investment is for concrete and unreinforced masonry buildings in commercial/industrial centres along the waterfront, where the benefits of mitigation outweigh costs by ~4 to 1. Increased building performance through structural mitigation would also result in 585 fewer casualties (~50 fewer life-threatening injuries) and total economic savings of more than $770 million dollars. Ancillary benefits include shorter recovery times, reduced income-related losses and less social disruption — all of which translate into a higher level of disaster resilience for the community.

Emergency Management

Emergency management embraces the full spectrum of preparedness planning and operational activities that are taken both during and after a disaster to ensure the safety and security of people and critical assets. Emergency preparedness activities are designed to increase awareness, self-reliance, and response capabilities of individuals and communities. They include continuity planning for homes and businesses to minimize levels of disruption during the recovery process; risk transfer and disaster relief funding to minimize the longer-term socioeconomic consequences of a disaster; land use policies that direct the re-building and ongoing development of communities in ways that minimize exposure to earthquake hazards; and governance models that build on effective public-private partnerships to streamline the process of recovery and re-building.

Emergency preparedness recommendations developed as part of the DNV Earthquake Ready Plan include the following:

- Seek approval from municipal council to adopt and exercise the earthquake readiness action plan as part of ongoing emergency management operations in the District.
- Utilize scenario models to develop and refine post-earthquake response and recovery plans as new information becomes available.
- Build disaster resilience capacity of DNV staff through ongoing training and professional development in earthquake readiness.
- Integrate principles of earthquake readiness into sustainable community planning & DNV operations using risk tolerance criteria to help guide decision making.
- Promote an awareness and understanding of earthquake readiness through community outreach and business continuity planning.

Recommendations to increase emergency response capabilities for the District include:

- Utilize earthquake risk maps to identify and prioritize emergency response operations based on hotspots of concern (damages & casualties) and available resources.
- Increase capacity of rapid damage assessment unit to collect and catalogue earthquake impacts. Revise emergency response operations as new information and resources become available.
- Coordinate emergency response operations across all levels of government according to EMBC protocols and existing mutual assistance programs developed as part of the Integrated Partnership for Regional Emergency management in Metro Vancouver.
- Implement emergency communication strategy to ensure that information about the disaster event and evolving response/recovery operations is accessible and updated regularly.

Recommendations to increase the effectiveness of recovery operations in the District include:

- Provide short-term emergency shelter and relocation support based on initial damage assessment reports and updates from social assistance operations.
- Secure hotspots of concern for recovery operations and provide estimates for restoration of lifeline services (water, power, etc) and baseline functionality for homes and businesses that are damaged by the earthquake.
- Engage mechanisms of disaster relief funding for homes and businesses that sustain economic losses exceeding minimum thresholds established by Provincial and Federal agencies.
- Implement post-disaster permit guidelines and procedures to expedite recovery process for homes and businesses that are damaged in the earthquake.

Adaptation

Adaptation encompasses a wide range of actions that are planned in advance but implemented after a disaster event to increase the capacities of people, buildings, and engineered systems to respond and recover from the impacts and consequences of a major earthquake. Resilient systems experience relatively small levels of disruption and are likely to recover baseline levels of performance in a relatively short period of time. In some cases these systems may even increase overall performance due to adaptive design and reorganization during the recovery period. Systems characterized by low levels of resilience experience a relatively large drop in performance following a disaster, take a longer period of time to recover, and may never regain pre-event levels of functionality.

Adaptation measures identified in the DNV Earthquake Ready Action Plan are to:

- Monitor and assess capacities to withstand, respond and recover from earthquake event.
- Refine DNV guidelines and policies for disaster resilience planning based on lessons learned.
- Marshall the resources needed to meet community thresholds of risk tolerance for vulnerable populations and critical assets.
- Share lessons learned

The window of opportunity for implementing adaptation measures following a disaster event is often small and quickly crowded with diverse and often competing public policy issues. The key is to identify those actions with the greatest potential to effect change during the recovery process, and to marshal resources and capabilities that will be required to implement these measures when the time comes.

Outcomes

While we cannot predict when a devastating earthquake will strike, we do have the ability to anticipate what might happen, and to navigate an alternate path forward—one that is informed by scientific insights about potential impacts and consequences, and that is governed by what the community considers to be vulnerable and in need of safeguarding. Outputs of this study provide a foundation for ongoing disaster resilience planning and sustainable community development in the District of North Vancouver.

Insights and methodologies are transferrable to other communities who may face similar earthquake risks in Canada, and contribute to broader efforts by the Canadian Safety and Security Program to promote a culture of risk awareness in Canada, and to build capacities for an all-hazard approach to disaster resilience planning at a national scale.